THE ANTHELMINTIC EFFECT OF COPPER OXIDE WIRE PARTICLE (COWP) BOLUSES AGAINST *HAEMONCHUS CONTORTUS* IN INDIGENOUS GOATS IN SOUTH AFRICA

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DEDICATION

For Arthur, thank you.

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DECLARATION

Apart from the assistance received as acknowledged, this dissertation represents the original work of the author.

No part of this dissertation has been presented for any other degree at any other university.

Candidate:…………………………..……….

Date:……………….……………..………

The anthelmintic effect of copper oxide wire particle (COWP) boluses against *Haemonchus contortus* in indigenous goats in South Africa

by

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SUMMARY

A field trial was conducted to test the anthelmintic effect of a single dose of 4g of copper oxide wire particles (COWP) in bolus form in indigenous goats belonging to small scale communal farmers in three areas in the Bergville district of Kwa-Zulu Natal Province, South Africa namely Dukuza, Ogade and Hoffenthal. Faecal egg counts (FECs) determined by both the McMaster and Pitchford–Visser methods, FAMACHA© scores, haematocrits (PCV), body condition scores (BCS) and live weights (Wt) of 172 indigenous goats belonging to 15 farmers were monitored on a four-weekly basis for a period of 53 weeks. Faecal cultures were done to determine the generic composition of the gastro-intestinal nematodes in the experimental animals. Monitoring commenced in October 2007 and extended to October 2008. During November 2007, a pilot faecal egg count reduction test (FECRT), done on 75 goats not included in the trial, confirmed the efficacy of 12 mg/kg levamisole (Tramisol, Coopers, Afrivet, South Africa) in the area relative to three other anthelmintic groups. All trial goats were treated with 12 mg/kg levamisole when a FAMACHA© score of 3 – 5 was recorded. This allowed training of collaborating farmers in the FAMACHA© system and provided selective treatment of animals presumed to have high worm burdens. Trial animals were not dosed during December 2007 and January 2008 in order to allow normal seasonal worm burdens to develop unaffected by treatment intervention. In January 2008 (week 15 of the trial), when faecal egg counts were approaching peak numbers, the goats of each farmer were assigned to control and treated groups. The goats were ranked from highest to lowest according to faecal egg count obtained by the Pitchford-Visser method results for

week 13, i.e. the week of sampling of 7 January 2008. The goats were then sequentially paired and one of the two randomly assigned to the treated or the control group. The remaining one of the pair was then allocated to the group not allocated to the first of the pair. A bolus containing 4 g COWP was administered during the week of 21 January 2008 to each goat in the treated group. At the end of the trial (October 2008), the data were subjected to an analysis of variance (ANOVA) to compare the epidemiological variables between treated and control groups.

The Pitchford-Visser and McMaster faecal egg count methods, on comparison, showed similar results, with no statistical differences evident between the counts. The Pitchford-Visser method, however, generally yielded higher values and was thus used for the analyses. Faecal egg counts were similar in all three trial areas with higher burdens experienced in Dukuza, followed by Ogade and Hoffenthal. High faecal egg counts coincided with the higher environmental temperatures and precipitation associated with the summer months (December – March). Faecal egg counts decreased from April onwards to reach negligible numbers in mid-winter (June and July), increasing again during spring (October). A marked reduction in faecal egg counts was evident two weeks after COWP administration (week of 4 February 2008) in the treated groups of goats compared to those of the controls. The faecal egg counts of the treated groups of goats were significantly lower than those of the controls for all the groups analyzed, except for adult goats in the Hoffenthal area. The marked reduction in faecal egg counts was accompanied by a corresponding rise in PCV of the treated goats. This rise also proved to be significantly higher on analysis relative to those of the controls, except for the young group of goats in all three areas combined and for adult goats in the Hoffenthal area. In March 2008, six weeks after COWP administration, the faecal egg counts of the treated goats had returned to values comparable to those prior to COWP administration and similar to those of the control groups, with no statistical differences evident. The calculated percentage reduction in faecal egg count two weeks after COWP administration, for all areas combined was 89.5% for all goats, 87.7% for young goats and 89.8% for adults. The calculated efficacy for Hoffenthal was 91.5%, Ogade 95.3% and Dukuza 82.4%. Faecal cultures confirmed the predominance of *Haemonchus* in the trial areas. The administration of COWP therefore showed a marked, immediate effect in lowering faecal egg counts as determined two weeks after administration. The anthelmintic effect of COWP was of a relatively short duration, not being discernable six weeks after administration and the effect was mainly on *Haemonchus*. The reduction in faecal egg counts due to COWP also reduced the number of goats in the treated group that required dosing according to the FAMACHA© technique, from 46 during the week of sampling of 21 January 2008, week 15 to 38 in week 17, while that of the control group remained similar. Apart from this, the administration of COWP did not appear to have any discernable effect on the FAMACHA© and body condition scores. Further research on the effect of administering multiple COWP dosages to effectively control haemonchosis in indigenous goats farmed extensively is required. Communal use of available pastures under these conditions implies that almost all small ruminants that may contaminate these pastures with worm eggs be treated, for such an intervention to have the best effect.

Haematocrit values (PCV) compared with FAMACHA© categories show that FAMACHA© categories 4 and 5 are reliable indicators of increasing anaemia. The considerable overlap in PCV values between FAMACHA© categories, however, prevents the definitive relation of FAMACHA© category to PCV value. Other factors, such as nutrition, ectoparasite infection, extant diseases and general condition, may influence the anaemic state of an animal. It is therefore advisable that the FAMACHA© system be used as a general guide for anthelmintic treatment in goats but be supported by other criteria such as other clinical symptoms and body condition score. Also, the FAMACHA© system used was developed primarily for use in sheep and its application to goats may require further refinement.

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1. INTRODUCTION

Haemonchosis is a common and severe disease of small ruminants in many parts of the world, especially in tropical and sub-tropical areas. Haemonchosis is ranked among the most important diseases of small ruminants in the summer rainfall area of South Africa (Vatta, Letty, Van der Linde, Van Wijk, Hansen & Krecek 2001). It is caused by the blood-sucking abomasal nematode**,** *Haemonchus contortus*, which poses a threat from about November to April in South Africa when ambient temperature and rainfall are suitable for the nematode to complete its lifecycle on pasture. *Haemonchus contortus* may also cause problems in the winter and unseasonal rainfall areas and in the semi-arid interior of the country when suitable climatic conditions prevail (Vatta & Lindberg 2006).

The main clinical signs of haemonchosis are anaemia and bottle jaw. In the acute form of the disease, animals show anaemia, bottle jaw, and pasty faeces. Animals are weak and lethargic and may die. Ewes may suffer from agalactia, so that their lambs become emaciated and die from malnutrition. In the chronic form, animals lose weight and exhibit a chronic anaemia. Helminth infections result in lowered productivity and most of the economic losses are due to the sub-clinical effects of parasitism which are not immediately noticed by the owner (Soulsby 1982). Such losses may be aggravated by poor quality grazing as occurs in southern Africa and other tropical regions during the dry seasons.

The use of anthelmintics has become the most important method of control of the disease. Newton & Munn (1999) reported that the control of gastrointestinal nematodes cost the livestock industry worldwide about £1 000 million in 1994. For the sheep industry in Britain, the estimated annual cost for gastrointestinal parasite treatment is £84 million (Nieuwhof & Bishop 2005), and in Australia, between US$220 to 500 million (Jabbar, Iqbal, Kerboeuf, Muhammad, Khan & Afaq 2006). In South Africa, during the financial year 2003/2004, approximately R117 million was spent on anthelmintics for both sheep and cattle and endectocides for all animal species (Vatta & Lindberg 2006).

Unfortunately, populations of *H. contortus* have become resistant to anthelmintics. Anthelmintic resistance is generally accepted to be defined as the failure to reduce faecal egg counts (FECs) by at least 95% (Love, Neilson, Biddle & McKinnon 2003). Anthelmintic resistance of gastrointestinal nematodes has now become a global problem which is particularly serious in countries where the sheep and goat industries are well developed. A particular threat arises from nematode populations which have developed resistance against more than one anthelmintic class. In South Africa there are five main anthelmintic classes available which are effective against non-resistant populations of *H. contortus*. These are benzimidazoles and pro-benzimidazoles, imidazoles, macrocyclic lactones, halogenated salicylanilides and nitrophenols, and organophosphates. However, a recent survey in South Africa demonstrated that on 93% of the farms included in the study, *H. contortus* is resistant to at least one anthelmintic class, with 8% of the strains less than 40% susceptible to anthelmintics of four different activity groups (Van Wyk, Stenson, Van der Merwe, Vorster & Viljoen 1999). Resistance to benzimidazoles is common in *H. contortus* on a worldwide scale including on commercial farms in South Africa as well as in the small-scale sheep farming sector (Van Wyk *et al*. 1999). However, there are fewer records of resistance to levamisole in South Africa (Van Wyk *et al.* 1999) but in other parts of Africa such as Kenya levamisole resistance is widespread (Vatta & Lindberg 2006). Resistance to ivermectin is also widespread in South Africa and resistance to the salicylanilides and organophosphates has also been reported (Van Wyk *et al.* 1999). In Australia, Love *et al.* (2003) first reported resistance to moxidectin, the latest macrocyclic lactone to be released on the market, although it was still more than 95% effective on sheep farms against most strains of the parasite resistant to other macrocyclic lactone compounds.

Resistance to one or more of the broad-spectrum anthelmintics including the macrocyclic lactones has been reported for goat nematodes on numerous occasions from every continent (Schnyder, Torgerson, Schonmann, Kohler & Hertzberg 2005). Several reports of resistance have been made in Europe where the majority of these surveys were conducted on dairy goats. The resistance involved mainly benzimidazole drugs and several species of nematode were involved (Chartier, Soubirac, Pors, Silvestre, Hubert, Couquet & Cabaret 2001). Anthelmintic resistance appears to develop more quickly in goats than in sheep (Schnyder *et al*. 2005), and these nematodes can then easily be transferred to sheep (Escudero, Carceles, Diaz, Sutra, Galtier & Alvinerie 1999). This has probably already occurred for nematodes resistant to levamisole and the benzimidazoles (Conder & Campbell 1995) and possibly also for macrocyclic lactones (Escudero *et al.* 1999). It has also been reported from Yucatan, Mexico, that the control of gastrointestinal nematodes in goat herds is threatened by the emergence of anthelmintic resistance (Canto-Dorantes, Torres-Acosta, Calderon-Quintal, Perez-Garcia, Aguilar-Caballero, Vargas-Magana & Hoste 2004).

It appears that the most important issue in the rate at which resistance emerges is the number of worms that are left untreated (*in refugio*) (Van Wyk & Van Schalkwyk 1990; Coles, Rhodes & Wolstenholme 2005). These include the larval nematodes on pasture which are potentially able to propagate susceptible genes to the next generation. When there are a small number of helminths *in refugio* and anthelmintics are administered, the treatment will probably select strongly for resistance because there would be relatively few worms carrying genes coding for anthelmintic-susceptibility left in the population after treatment, with which to 'dilute out' the resistant genes (Vatta & Lindberg 2006).

Because of the extremely high costs associated with the development of new anthelmintic drugs, the development of new drugs is unlikely (Van Wyk, Hoste, Kaplan & Besier 2006) although the drug, monepantel, belonging to a new chemical class of anthelmintics, the amino acetonitrile derivatives, has recently appeared on the market (Jones, Hunter, Dobson, Reymond, Strehlau, Kubacki, Tranchard & Walters 2009). A variety of alternatives for worm management are also being researched.

One of the options that is aimed at reducing the number of anthelmintic treatments given to a flock is the FAMACHA© technique which enables quick detection of individual animals that may require drenching (Malan, Van Wyk & Wessels 2001). The FAMACHA© guide illustrates five colour variations of the ovine conjunctivae. Colour classification 1 represents a healthy red conjunctiva and colour classification 5 indicates a very pale anaemic conjunctiva. Only those animals that are considered anaemic are selectively drenched.

Supplementary feeding can improve resilience and resistance of kids against gastrointestinal nematodes and this has been exploited as a means of controlling helminths. Affordable supplements e.g. non-protein nitrogen in a liquid form for mixing with sub-standard roughages, or formulated into blocks or granules have been investigated (Sikosana, Smith, Mlambo, Owen, Mueller-Harvey, Mould & Maphosa 2004; Vatta & Lindberg 2006). The seed pods of local browse trees in Zimbabwe have been used as a supplement which increased milk yield in female goats, but it is unknown what the effect on helminth burdens would be (Sikosana *et al.* 2004; Vatta & Lindberg 2006). Supplementary feeding, however, does not fully defeat the negative effects of infection.

Research done by Heckendorn, Haring, Maurer, Senn & Hertzberg (2007) and Iqbal, Sarwar, Jabbar, Ahmed, Nisa, Sajid, Khan, Mufti & Yaseen (2007) showed that foods high in tannins, given to lambs, had an anthelmintic effect and showed a significant reduction of total daily faecal egg counts. In addition, Iqbal *et al.* (2007) found that sheep fed diets containing 3% condensed tannins had maximum weight gains. Max, Buttery, Wakelin, Kimambo, Kassuku & Mtenga (2004) tested the anthelmintic activity of leaf extracts from plants high in tannins and a commercial wattle tree tannin preparation *in vitro* against goat nematodes. Nematode survival was significantly reduced. The leaves of *Acacia* species are high in tannins and when fed to goats also reduced the faecal egg counts by 27% (Max *et al.* 2004).

A form of biological control used against *H contortus* are is the nematode-trapping fungus *Duddingtonia flagrans* (Terrill, Larsen, Samples, Husted, Miller, Kaplan & Gelaye 2004) and *Bacillus thuringiensis* toxin (Lopez, Flores, Mendoza, Vazquez, Liebano, Bravo, Herrera, Godines, Vargas & Zamudio 2006) as alternative methods of control against *Haemonchus contortus*. However, Terrill *et al.* (2004) advised that further evaluation of fungal technology under field conditions and assessment of its cost-efficacy would be required, while Waller (2006) considered it apparent that further research remained necessary before commercial products would become available.

Other options that may assist in reducing the reliance on anthelmintics include breeding sheep genetically resistant to worms (Waller 2006) and grazing management, including rotational grazing with cattle (Love *et al*. 2003).

Copper oxide wire particle (COWP) boluses consist of small pieces of copper oxide wire contained within a gelatin capsule. COWP boluses were developed to overcome copper deficiency in ruminants that graze on lands deficient of minerals (Dewey, 1977; Suttle, 1981). Once the gelatin capsule containing the copper particles has dissolved in the rumen, the particles pass to the abomasum where they lodge in the mucosal folds and, over an extended period of time, release ionic copper within the acidic environment of the abomasum. The ionic copper seems most likely to be responsible for anthelmintic activity. It is uncertain whether ingestion of copper by the nematodes or simple exposure to the copper is responsible for the anthelmintic effect. The high susceptibility of *H. contortus* to copper is unlikely to be associated with its haematophagous habit because plasma copper levels are not affected by COWP treatment (Bang, Familton & Sykes 1990). Bremner (1961) has suggested that soluble copper can penetrate the cuticle of the helminth.

Research has demonstrated the benefits of ultra-low-dose copper therapy in the reduction of certain parasite infections in grazing livestock (Knox 2002; Burke, Miller, Olcott, Olcott & Terrill 2004; Krecek & Waller 2006). A high level of anthelmintic activity and an extended period of protection of up to 3 months against new infections of *H. contortus* were shown when 2-5g COWP capsules were administered orally to sheep in New Zealand (Knox 2002).

Positive results concerning the use of copper wire particles in the control of *H. contortus* infections in goat kids have been forthcoming from Mexico (Canto-Dorantes *et al*. 2004) and in grazing sheep from Australia (Knox 2002). Canto-Dorantes *et al.* (2004) determined the effect of combining supplementary feeding of sorghum and soybean meal and COWP capsules. They concluded that this reduced the faecal egg counts in naturally infected Criollo kids browsing natural vegetation in Yucatan, Mexico, although total live weight gain was not significantly improved. Knox (2002) assessed the effect of COWP treatment at 2.5 g per sheep on worm burdens in Merino sheep, 3-4 and 11-12 months of age, receiving a weekly infection of 2 000 *H. contortus* larvae per animal for 8 weeks following COWP administration at the start of the experiment. The 11-12 month old group was additionally treated with either 2.5 g or 5.0 g after 8 weeks to gauge its therapeutic effect. In the 3-4 month old Merino lamb COWP treated group, faecal egg counts were reduced by 90% at 4 and 6 weeks and the remaining untreated lambs all had to be treated for haemonchosis after 6 weeks. In the 11-12 month old group of animals, total worm counts were reduced by 37% while both the 2.5 g and 5.0 g doses of COWP reduced faecal worm egg counts by 85%, the higher dose yielding an earlier response. The author concluded that COWP has the potential to reduce the establishment and fecundity of *Haemonchus* spp. and that COWP offer a supplementary means of control in areas experiencing anthelmintic resistance. Burke & Miller (2006) determined the efficacy of a sustained release multi-trace element/vitamin ruminal bolus containing copper on gastrointestinal nematodes of Spanish and Boer does during summer in the southeastern United States. Faecal egg counts were reduced within 7 days in the bolus-treated animals although control of gastrointestinal nematodes did not continue for more than 28 days, suggesting that additional control may be necessary. Chartier, Etter, Hoste, Pors, Koch & Dellac (2000) assessed the anthelmintic effect of copper wire needles on Saanen and Alpine dairy goats in France, both experimentally and under natural conditions. The effect of copper oxide needle application was found to clearly reduce *Haemonchus* burdens by 75% and to lower egg output in relation to the establishment of new infections over several weeks. In contrast, copper oxide needle treatment had no efficacy against *Teladorsagia, Trichostrongylus* and *Oesophagostomum* spp.

Recent pen trial research conducted in South Africa (Vatta, Waller, Githiori & Medley, 2009) supported the above findings. Vatta *et al* (2009) established that *H. contortus* infections were effectively reduced by 94% in the groups that were administered 2 g and 4 g COWP boluses. The 4 g COWP treatment was more effective (62%) than the 2 g COWP treatment against developing infections, but the differences were not significant.

COWP technology offers considerable promise as a means of control in the *H. contortus* endemic regions of Africa, but needs to be comprehensively assessed in South Africa.

This study aims to determine if the administration of COWP to indigenous goats belonging to small-scale farmers under natural communal grazing conditions would significantly reduce helminth, especially *H. contortus*, infection.

2. AIMS AND OBJECTIVES

The aims of this study were:

2.1 To monitor helminth infection levels in herds of indigenous goats kept on communal pastures by small scale farmers in KwaZulu-Natal Province over a period of at least 12 months.

2.2 To compare the relative accuracy of the Pitchford-Visser and McMaster faecal egg count methods.

2.3 To determine the effects of the administration of copper oxide wire particle (COWP) boluses to indigenous goats under natural grazing conditions on the epidemiological variables, faecal egg count (FEC), FAMACHA© score, haematocrit (PCV) and body condition score (BCS).

2.4 To assess the anthelmintic effect of copper oxide wire particles against *Haemonchus* infection in these goats.

2.5 To apply participatory rural appraisal methods and train the stock owners in goat management and the application of FAMACHA©.

3. MATERIALS AND METHODS

3.1 Study site and identification of participating farmers

The study site was in the Bergville area (Fig. 1) in KwaZulu-Natal Province, South Africa, where five of the trial farms were situated in the Hoffenthal area (Fig. 2.), six in the Ogade area (Fig. 3.) and four in the Dukuza area (Fig. 4.).

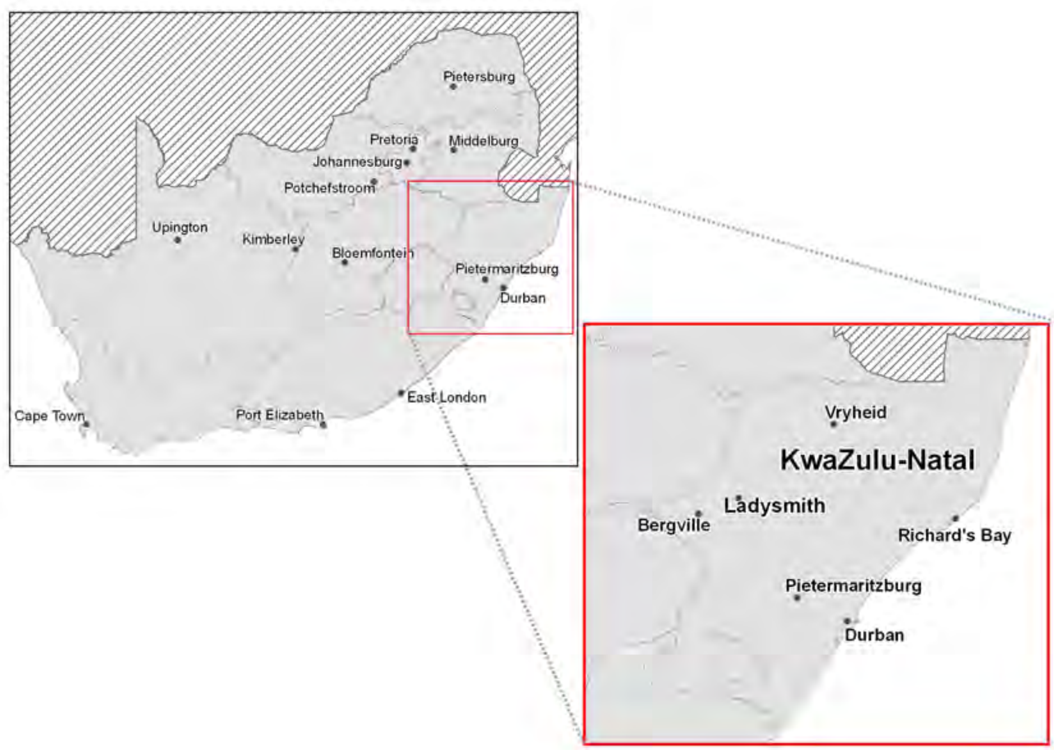


Fig. 1. Map of South Africa localizing KwaZulu-Natal Province and Bergville, in which area the trial was conducted.

Vatta, De Villiers, Gumede, Krecek, Mapeyi, Pearson, Smith, Stenson & Harrison (2007) and Vatta, Krecek, Pearson, Smith, Stenson, Van Wijk & Harrison (2008) conducted a project on the effect of supplementary feeding on goat helminth infection in the Bulwer area, KwaZulu-Natal. Following this study a cross-visit was carried out involving the participating farmers in that study visiting small-holder communal farmers in the Bergville area in order to exchange knowledge and experiences gained from the research done. As a result of this interaction the Bergville small-holder farming community was primed and receptive to participate in similar research projects which would be to their benefit.

Following the cross-visit, a Participatory Rural Appraisal meeting was conducted on 30 August 2007. This was organized by the Farming Systems Research and Extension Section, the Veterinary services and the extension services of KwaZulu-Natal Department of Agriculture and Environmental Affairs and the Onderstepoort Veterinary Institute. At this meeting, the attendees were requested to identify their constraints to livestock production. Diarrhoea and worm infections and a need for information on general goat management were mentioned in particular. Thereafter, a project proposal was broadly outlined to the group and a subsequent project planning meeting was requested of those interested in participating. At the subsequent project planning meeting (13 September 2007) it was put to the farmers that logistics and time constraints allowed sampling of at most 5 sites with a total of at most 75 goats per day for experimental purposes. The farmers were then asked to identify participants amongst themselves with due regard to these constraints. Fifteen participating farmers (Table 1) that complied with these experimental design prerequisites were selected from the nominees. Each farmer participating in the experiment undertook to reserve at least 8 female goats for the experiment as female goats were not likely to be sold or slaughtered as readily as males.

No formal agreements were entered into with participating farmers but the project undertook to provide training, specifically in the application of the FAMACHA© system, dosing and general veterinary care of livestock, including the provision of a "Goat Keepers' Animal Health Care Manual" (Vatta, Abbott, De Villiers, Gumede, Harrison, Krecek, Letty, Mapeyi & Pearson, 2007) in compensation for their participation. In return, verbal agreements were obtained from the farmers that they would make their animals available and provide labour for the experimental procedures on their goats.

In addition, regular feedback meetings of participating and other farmers in the community were scheduled in order to provide a forum to provide information, for discussion, to demonstrate techniques, to stimulate interest, to provide updates on the project results and progress, to maintain cooperation and for future planning.

The participating farmers were regarded as small scale, each owning from 14 – 150 goats as well as a variety of other livestock which were grazed on communal land. All livestock were housed in simple facilities at night. The experiment was conducted at 15 sites in the study area (Table 1; Fig. 5) and site localities and altitudes were determined using a GARMIN eTrex® Vista Cx Global Positioning System (GPS) device.

Table 1. Farmers, locality coordinates, altitudes (in metres above sea level) and areas in which the study was conducted.

Farmer	Area	Site coordinates South	Site coordinates East	Altitude (m)
Farmer 1	Hoffenthal	28° 47'37. 6"S	29 ° 14'28.9"E	1220
Farmer 2	Hoffenthal	28° 47'05. 6"S	29 ° 15'16.6"E	1152
Farmer 3	Hoffenthal	28° 47'07. 6"S	29 ° 15'16.6"E	1152
Farmer 4	Hoffenthal	28° 48'26. 4"S	29 ° 13'39.1"E	1276
Farmer 5	Maswazini*	28° 48'57. 6"S	29 ° 12'39.7"E	1205
Farmer 6	Ogade	28° 43'31. 6"S	29 ° 07'12.0"E	1275
Farmer 7	Ogade	28° 43'49. 7"S	29 ° 06'38.8"E	1304
Farmer 8	Ogade	28° 43'49. 7"S	29 ° 06'38.8"E	1304
Farmer 9	Ogade	28° 44'25. 7"S	29 ° 07'24.3"E	1267
Farmer 10	Ogade	28° 44'25. 7"S	29 ° 07'24.3"E	1267
Farmer 11	Ogade	28° 44'59. 6"S	29 ° 07'16.8"E	1285
Farmer 12	Dukuza	28° 45'31. 1"S	29° 12'52. 8"E	1203
Farmer 13	Dukuza	28° 46'45. 1"S	29° 11'32. 5"E	1238
Farmer 14	Dukuza	28° 45'54. 0"S	29 ° 11'03.5"E	1232
Farmer 15	Dukuza	28° 45'15. 7"S	29 ° 11'37.2"E	1191

*Maswazini is in close proximity to Hoffenthal and this farmer was thus included with the others in the Hoffenthal area.

Fig. 2. The Hoffenthal area where five of the trial farms were situated.

Fig. 3. The Ogade area where six of the trial farms were situated.

Fig. 4. The Dukuza area where four of the trial farms were situated.

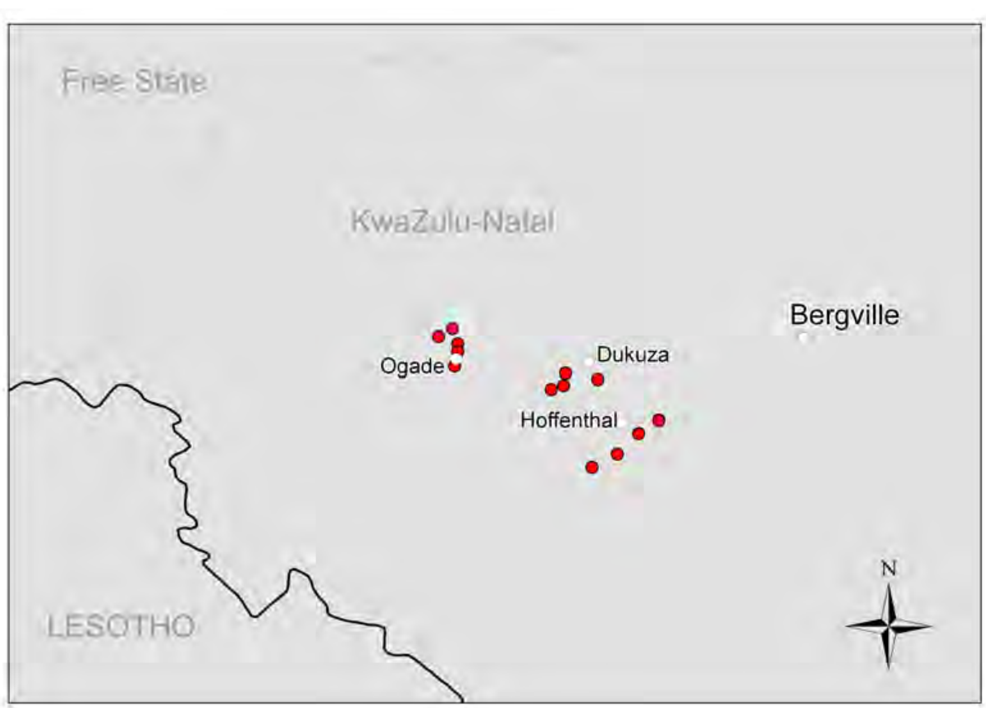


Fig. 5. Localities of the farms in the Hoffenthal, Ogade and Dukuza areas near Bergville, KwaZulu-Natal, where the field trials were done.

3.2 Questionnaire interviews

After the selection of the participating farmers had been agreed on, a structured questionnaire (Appendix 7.1) interview was conducted with each farmer with the aid of a translator. The aim was to establish base-line data on personal details and level of knowledge on internal parasites (known locally as *izikelemu*).

3.3 Climate and vegetation of the study area

The vegetation of the study area is classified by Acocks (1988) as Open Thornveld, which for the most part is found at altitudes ranging from 1 050 – 1 350m. Below an altitude of 1 050m the vegetation becomes transitional to the Valley Bushveld type but all localities contained in the experiment were situated above this altitude. The vegetation is described as an open savanna of *Acacia sieberiana* var. *woodii* in sourish mixed grassveld with plentiful patches of *Hyparrhenia hirta* and other species of *Hyparrhenia.* Soils have an erodible subsoil, with a very shallow (300-450mm) topsoil which may lead to severe erosion (Acocks 1988). Rainfall ranges from 650 – 900 mm per annum, with most of the rainfall occurring in the summer. The rainy season generally occurs from September to May with rainfall increasing to December, and then declining towards May. This assists to create conditions on pasture that are conducive for nematode infective larvae to survive. Temperatures range from 12 – 29 ^{o}C (mean 20.5 ^{o}C) in summer and 1 - 23 ^{o}C (mean 12 ^{o}C) in winter (Botes M, ARC-Agromet, Cedara, personal communication, 2008).

Data for rainfall and temperature during the 12 months of the study period were obtained from the Broad Acres (28.81865S; 29.40215E; Altitude 1 246m) weather station, Bergville.

3.4 Faecal egg count reduction test

A faecal egg count reduction test (FECRT) was conducted to assess the efficacy of levamisole relative to three other drugs for use in the symptomatic treatment of goats. Selective drenching was envisioned in order to contain gastrointestinal nematode infection in anaemic animals and as a means of farmer training in the FAMACHA© system (see section 3.8.2 below).

Seventy-five goats not included in the main monitoring experiment (see section 3.5 below) were selected for the FECRT which was conducted at the small holding of Farmer 12 (Table 1) (28°45'31.1"S; 29°12'52.8"E, 1 203m). In addition to 62 goats provided by Farmer 12, two other farmers, whose animals graze the same area, contributed 4 and 9 goats, respectively. The animals were randomly assigned to 5 groups of 15, ear-tagged and numbered. Four treated groups were drenched on 1 November 2007 using a syringe, according to their individual live weight, with 10 mg/kg fenbendazole (Panacur BS, Intervet, South Africa) (T1), 10 mg/kg closantel (Flukiver, Bayer AH, South Africa) (T2), 12 mg/kg levamisole (Tramisol, Coopers, Afrivet, South Africa) (T3), 400 µg/kg ivermectin (Ivomec, Merial, South Africa) (T4). The fifth group, control group (C), received 10 ml of water only. Pre-treatment faecal samples of all the animals in the FECRT trial were taken before treatment. Fourteen days after treatment all animals were again individually faecal sampled. Faecal egg counts were performed using the Pitchford-Visser method for all five groups on both pre- and post-treatment faecal samples. Larval cultures were made from pre-treatment faecal samples according to the method, *Faecal culture* (Agricultural Research Council (ARC), no date). Larvae were harvested after eight to twelve days and identified under a compound microscope according to the keys of Van Wyk, Cabaret & Michael, (2004).

Only goats with pre-treatment faecal egg counts of more than or equal to 200 epg were included in the analysis. Where a pre-treatment faecal egg count was more than or equal to 200 epg but no faecal sample was obtained post-treatment, the data were not included.

The percentage reduction in faecal egg counts were calculated as follows:

Percentage reduction = [1-(PoT/PrT)*(PrC/PoC)]*100 where

PoT = Post-treatment faecal egg count of treated group

PrT = Pre-treatment faecal egg count of treated group

PrC = Pre-treatment faecal egg count of the control group

PoC = Post-treatment faecal egg count of the control group

3.5 Epidemiological investigations

The field experiment was conducted from October 2007 until November 2008. A total of 189 animals were included in the experiment. The goats were aged by examining the incisor teeth (Mitchell 1982), assigned unique numbers and individually ear-tagged (Table 2). Young animals (0 permanent incisor teeth) and adults (≥2 permanent incisor teeth) were aged as such at the commencement of the trial (October 2008).

All animals included in the experiment were monitored on a four-weekly basis starting during the week of 15 October 2007 and continuing until the week of 13 October 2008 (Table 3). The animals were also monitored during week 15 for the purpose of the testing of the COWP (see section 3.6 **Testing of copper oxide wire particles**). The experimental animals were monitored for faecal egg count (FEC) in eggs per gram (epg) using both the McMaster and Pitchford-Visser methods, FAMACHA© score, packed cell volume (PCV), body condition score (BCS) and live-weight (Wt). In addition, all the goats belonging to each farmer but not included in the experiment were monitored by FAMACHA© score. Except for weeks 9 (December 2007) and 13 (January 2008) all animals with a FAMACHA© score of 3-5 were treated with levamisole at a dosage of 12 mg/kg. As an additional safeguard, all animals with a PCV of less than 20% and that had not been given a FAMACHA© score of 3, 4 or 5 and hence had not been treated, were also drenched with 12 mg/kg levamisole before the end of the week in question.

Table 2. Number of goats assigned to the project per farmer in each area in which the field experiments were conducted.

Area	Farmer	Number of animals
Hoffenthal	Farmer 1	11
	Farmer 2	9
	Farmer 3	14
	Farmer 4	15
	Farmer 5	15
Ogade	Farmer 6	14
	Farmer 7	2
	Farmer 8	7
	Farmer 9	4
	Farmer 10	8
	Farmer 11	15
Dukuza	Farmer 12	35
	Farmer 13	18
	Farmer 14	10
	Farmer 15	12
Total number of goats		**189**

Table 3. Experimental design - sampling and activity schedule for the 13 month project monitoring period.

Week	Date	Activity
1	Tues 16 – Thurs 18 October 2007	Sampling/symptomatic treatment with 12 mg/kg levamisole where required
5	Tues 15 – Fri 18 November 2007	Sampling/symptomatic treatment with 12 mg/kg levamisole where required and feedback/discussion meeting
9	Tues 11 – Thurs 13 December 2007	Sampling/symptomatic treatment with 12 mg/kg levamisole where PCV was below 20%
13	Tues 8 – Thurs 10 January 2008	Sampling/symptomatic treatment with 12 mg/kg levamisole where PCV was below 20%
15	Tues 22 – Thurs 24 January 2008	Sampling/symptomatic treatment with 12 mg/kg levamisole where required excluding the COWP treated group/COWP administration
17	Tues 5 – Fri 8 February 2008	Sampling/symptomatic treatment with 12 mg/kg levamisole where required and feedback/discussion meeting
21	Tues 4 – Thurs 6 March 2008	Sampling/symptomatic treatment with 12 mg/kg levamisole where required
25	Tues 1 – Thurs 3 April 2008	Sampling/symptomatic treatment with 12 mg/kg levamisole where required
29	Tues 29 April – Thurs 1 May 2008	Sampling/symptomatic treatment with 12 mg/kg levamisole where required
33	Tues 28 – Fri 31 May 2008	Sampling/symptomatic treatment with 12 mg/kg levamisole where required and feedback/discussion meeting
37	Tues 24 – Thurs 26 June 2008	Sampling/symptomatic treatment with 12 mg/kg levamisole where required
41	Tues 22 – Thurs 24 July 2008	Sampling/ symptomatic treatment with 12 mg/kg levamisole where required
45	Tues 19 – Fri 22 August 2008	Sampling/ symptomatic treatment with 12 mg/kg levamisole where required and feedback/discussion meeting
49	Tues 16 – Thurs 18 September 2008	Sampling/symptomatic treatment with 12 mg/kg levamisole where required
53	Tues 14 – Thurs 16 October 2008	Sampling/symptomatic treatment with 12 mg/kg levamisole where required treatment

3.6 Testing of copper oxide wire particles

During Week 15 (the week of the sampling occasion of 21 January 2008), half the animals assigned to the experiment within each herd were selected and treated with 4g COWP (Copinox® Ewe/Calf, Animax Veterinary Technology, United Kingdom). The experimental goats of each of the 15 participating farmers were randomly allocated to a COWP treated and an untreated control group. They were ranked from highest to lowest according to faecal egg count obtained by the Pitchford-Visser method results for week 13, i.e. the week of 7 January 2008 sampling. The goats were then sequentially paired and one of the two randomly assigned to the treatment or the control group. The remaining one of the pair was then allocated to the group not allocated to the first of the pair.

Faecal samples from four animals were not collected in week 13 and insufficient faeces were collected from one animal to perform an egg count. These animals, plus an animal whose PCV was below 18% and had been treated with levamisole, during the week of 7 January 2008, were excluded from the pairing system and these six animals were randomly allocated to treatment or control groups. During week 15, the week of 21 January 2008 sampling occasion, COWP boluses were administered orally with an applicator, to those animals that had been allocated to the COWP treated group. Directly after the bolus had been given, 10 ml of water was administered to the animal using a syringe. The animals were carefully observed to ensure that the bolus had been swallowed. Animals assigned to the control group received 10 ml of water only, administered by syringe *per os.* The faecal egg counts (Pitchford-Visser method) for weeks 15 (the week of 21 January 2008, pre-COWP) and 17 (the week of 4 February 2008, post-COWP) were used to calculate the percentage reduction in egg counts (% efficacy) as a result of the COWP administration, using the same formula as for the FECRT described above. In the final calculations of efficacy, goats for which egg counts were not present at both sampling occasions, those with egg counts of less than 200 epg pre-COWP-treatment as well as those that received symptomatic treatment during weeks 15 were excluded from the calculations.

3.7 Analysis of data

Data for seventeen goats were absent at two or more sampling occasions and all the data for these goats were excluded for the analysis. A total of 172 goats were included in the final analyses, 55 from the Hoffenthal area (5 farmers), 45 from the Ogade area (6 farmers) and 72 from the Dukuza area (4 farmers) (Table 4).

Table 4. Number of young (0 permanent incisor teeth) and adult (≥2 permanent incisor teeth) goats from each area included in the analyses.

	Hoffenthal		Ogade		Dukuza		Total	
	COWP	**Control**	**COWP**	**Control**	**COWP**	**Control**	**COWP**	**Control**
Young	5	4	1	4	6	8	12	16
Adult	24	22	22	18	29	29	75	69
Total	55		45		72		172	

The data were entered into an MS-Excel spreadsheet and an analysis of variance (ANOVA) (using Genstat Statistical Software, version 10.1.0.72, VSN International Ltd.) was performed to test for differences between the control and treated groups of goats in mean faecal egg counts (McMaster and Pitchford–Visser methods), FAMACHA© score, packed cell volume (PCV) and body condition score (BCS). Faecal egg counts were transformed ($\log_{10}$) to stabilize variances for the analyses. Testing was done at the 5% confidence level and the means separated using Fisher's Protected Least Significant Difference (LSD) test**.** Correlation coefficients were calculated for the mean faecal egg counts as determined by the Pitchford-Visser versus the McMaster methods.

Live-weight data were used to determine drug dosage at the time of sampling and were not analyzed as to effect due to unreliability and inconsistency over the project period (e.g. single and multiple pregnancies, kidding). Data for young goats (0 permanent incisor teeth), adult goats (≥2 permanent incisor teeth) and all goats (young plus adult goats) were analyzed for all three trial areas combined (Hoffenthal, Ogade and Dukuza), while data for all goats (young goats and adults) and adult goats were analyzed for each of the three trial areas. Too few young goats were available per trial area for meaningful separate analysis (Table 4).

3.8 Laboratory techniques

3.8.1 Faecal egg counts (FECs)

At each sampling occasion a faecal sample was taken from the rectum of each animal in the experiment by an operator wearing latex examination gloves, lubricated with jelly (KY Lubricating Jelly, Johnson & Johnson, South Africa). The samples were placed in uniquely marked sealable bags, one bag per animal. The operator's hands were washed after each sampling. After collection the air was manually expressed from each bag, sealed and placed in a coolbox containing frozen ice bricks. Within six hours of collection the faecal samples were placed in a domestic refrigerator. After the three day sampling period, the faecal samples were transported to the ARC-Onderstepoort Veterinary Institute laboratories in a coolbox containing ice bricks and immediately on arrival placed in a refrigerator. In the week following the sampling procedure, at the laboratories of the ARC-Onderstepoort Veterinary Institute, the faecal samples of the animals in the experiment were individually subjected to faecal egg counts by both the Pitchford-Visser and McMaster methods as stipulated for goats by Reineke (1983) and as modified in the ARC-OVI Helminthology Manual (ARC, no date) to allow comparison between the two methods.

3.8.2 FAMACHA© (FCH) scores

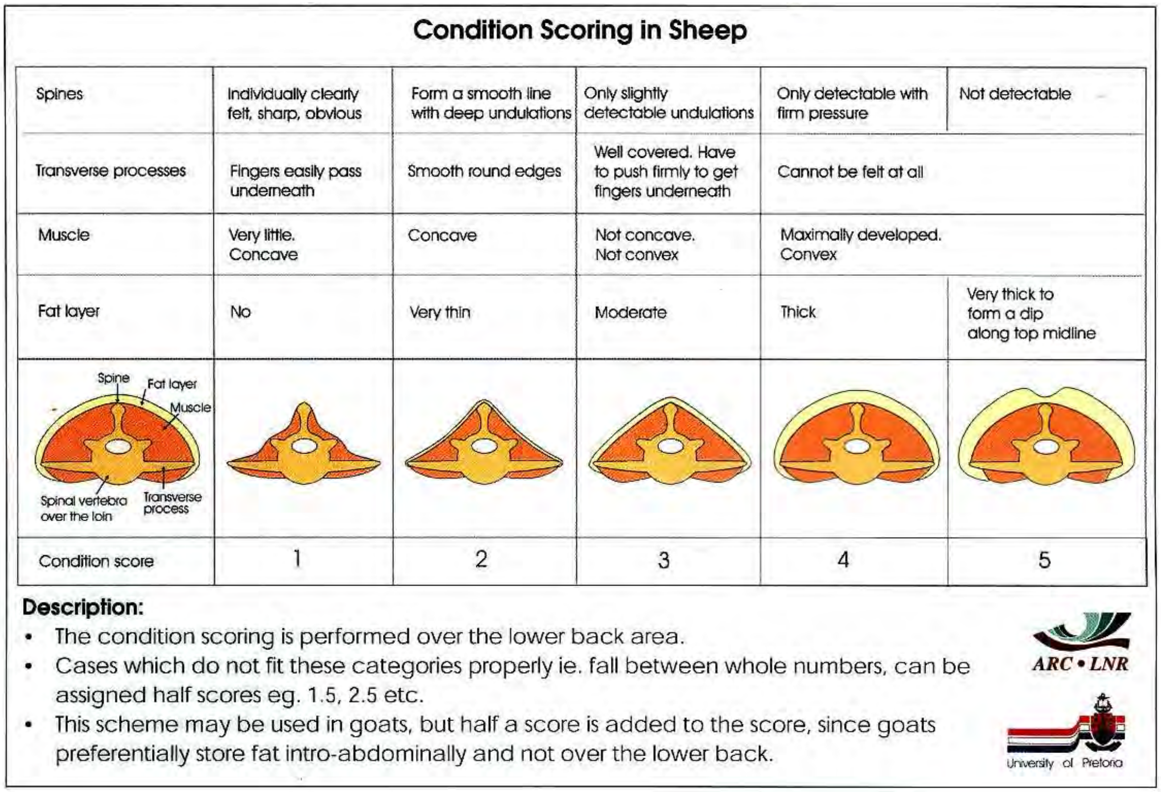
At each sampling occasion, the conjunctivae of all the goats in the herd were examined and a FAMACHA© score from 1-5 assigned according to the FAMACHA© anaemia guide using the technique as described in *FAMACHA©; Evaluating the colour of the ocular mucous membranes* (ARC, no date). The FAMACHA© guide (Appendix 7.2) illustrates stepwise colour variation of the ovine eye. It also contains information on the necessity to drench the animals according to the colour classification of their conjunctivae. In this study, animals that appeared anaemic with a FAMACHA© score of 3 - 5 were treated with levamisole at 12 mg/kg, except for all the experimental animals during the third (week of 10 December 2007; week 9 of trial) and fourth (week of 7 January 2008; week 13 of trial) (Table 3) sampling occasions. Experimental animals were not drenched on these two occasions to allow a realistic assessment of COWP efficacy by allowing helminth burdens to increase prior to treatment.

3.8.3 Haematocrits or packed cell volumes (PCVs)

At each sampling occasion each animal included in the experiment was bled from the jugular vein using a 21 G needle (Precision Glide ™ needles, Vacutainer systems Becton Dickinson, Plymouth, United Kingdom,) into sterile blood collection tubes (5ml BD Vacutainer®, Becton Dickinson, Plymouth, United Kingdom) containing the anticoagulant EDTA. Within 12 hours of bleeding, the blood was transferred to two capillary tubes per sample. One end of each tube was sealed off with clay (Haematocrit Sealing Compound, Brand, Germany) and the tubes were centrifuged in a microhaematocrit machine (Hermle, Germany) for eight minutes at 12 000 rpm. The PCV was determined using a microhaematocrit reader (Hermle, Germany).

3.8.4 Body condition scores (BCS)

At each sampling occasion, the muscle and fat covering in the lower lumber area was assessed and a subjective score on a scale of 1 to 5 was assigned, whereby a score of 1 has almost no fat and 5 has a very thick layer of fat (Fig. 6) (Russell 1984; Williams 1990).



Condition Scoring in Sheep

Spines	Individually clearly felt, sharp, obvious	Form a smooth line with deep undulations	Only slightly detectable undulations	Only detectable with firm pressure	Not detectable
Transverse processes	Fingers easily pass underneath	Smooth round edges	Well covered. Have to push firmly to get fingers underneath	Cannot be felt at all	
Muscle	Very little. Concave	Concave	Not concave. Not convex	Maximally developed. Convex	
Fat layer	No	Very thin	Moderate	Thick	Very thick to form a dip along top midline
Spine, Fat layer, Muscle, Spinal vertebra over the loin, Transverse process					
Condition score	1	2	3	4	5

Description:

- The condition scoring is performed over the lower back area.
- Cases which do not fit these categories properly ie. fall between whole numbers, can be assigned half scores eg. 1.5, 2.5 etc.
- This scheme may be used in goats, but half a score is added to the score, since goats preferentially store fat intro-abdominally and not over the lower back.

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Fig. 6. Body condition scoring chart used to assess the experimental animals.

3.8.5 Live-weight measurement

When presented, the live-weight of every animal in the experiment was determined and recorded at each sampling occasion using a Salter Model 235 (Capital Scales, Pretoria, South Africa spring balance) suspended from a tripod. The scale measured 200 kg in 500 g increments. The animal to be weighed was harnessed and suspended from the scale to be weighed. Goats that needed anthelmintic treatment as indicated by FAMACHA© score, but that were not included in the experiment, were also weighed in order to calculate the dose accurately.

3.8.6 Faecal cultures

Excess faeces not used for the faecal egg counts were pooled for each herd and a faecal culture was made after each sampling occasion in order to identify infective third stage larvae. Faeces were also collected from additional goats in each herd and added to the pooled faecal culture sample before culture. The infective third stage larvae (L3) can be differentiated to genus level while the eggs of most of the common nematode species cannot be differentiated. Faecal culture was done in order to assess the effect of COWP on *Haemonchus* as opposed to other nematode genera.

One hundred larvae harvested from each culture were identified under a standard compound microscope and the relative generic prevalence calculated. Where 100 larvae were not cultured, as many larvae were counted as possible.

4. RESULTS AND DISCUSSION

4.1 Questionnaire interviews

The average age of the farmers and a summary of the results relevant to gastrointestinal nematode infections in their animals are shown in Table 5.

Table 5. Average age (years as in 2007) of participating farmers (n = 15) and percentage answering "yes" to questions on gastrointestinal nematodes.

Average age in 2007 (range)	54 years (29-68 years)
Do you think that worms cause damage?	80%
Do you use commercial remedies?	100%
Do you recognize wireworm (*Haemonchus contortus*)?	87%
Do you recognize nodular worm (*Oesophagostamum spp)*?	67%
Do you recognize tapeworm (*Moniezia spp*)?	93%
Do you recognize liver fluke (*Fasciola hepatica*)?	0%
Have you seen any of these symptoms?	73%

The majority of those interviewed showed an acute awareness of worm problems and specific worm infections (especially tapeworm). All farmers in the Hoffenthal area recognized symptoms caused by worm infection contrary to only three of the six in the Ogade area and three in the Dukuza area. All the farmers make use of commercial remedies despite a poor resource base and could therefore benefit from cheaper alternative control methods.

4.2 Climate data

Mean average rainfall and minimum and maximum temperatures experienced throughout the study period are given in Fig. 7.

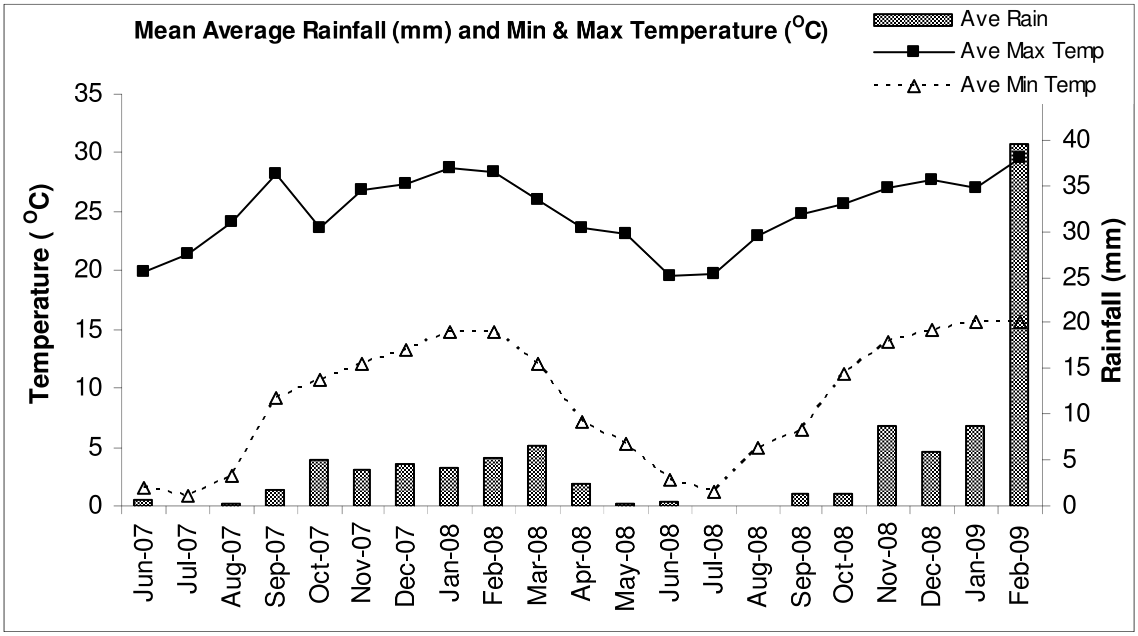


Fig. 7. Mean average rainfall, minimum and maximum temperatures in the Bergville area throughout the trial period.

Seasonal rainfall occurred from September 2007 to April 2008, and started again in September 2008. Maximum temperatures were seen in January and February 2007. Winter minimum temperatures occurred in July. The combination of high temperatures and high rainfall during January/February coincided with high nematode faecal egg counts (Fig. 8) which is indicative of peak pasture contamination. No long term climate data was available for comparison with prevailing conditions as the weather station was only functional from 2003 onwards.

4.3 Faecal egg count reduction test (FECRT)

The results of the pre- and post-treatment faecal egg counts for the FECRT are given in Table 6.

Table 6. Pre- and post-treatment faecal egg counts and percentage efficacy of the four anthelmintics tested in the faecal egg count reduction test.

Treated group (T)	Faecal egg count ± SD		% efficacy
	Pre-treatment 1 November 2007	Post-treatment 15 November 2007	
T1 Fenbendazole (10 mg/kg)	1 459 ± 118	404 ± 649	84.1
T2 Closantel (10 mg/kg)	1 608 ± 779	492 ± 461	82.4
T3 Levamisole (12 mg/kg)	873 ± 1182	23 ± 44	98.5
T4 Ivermectin (400 µg/kg)	967 ± 586	43 ± 83	97.4
T5 Control	471 ± 359	817 ± 824	

SD = Standard Deviation

The generic composition of the larvae identified from the pre-treatment faecal culture is given in Table 7. The most prevalent larvae identified were *Haemonchus* spp. Other larvae identified in the pre-treatment larval culture, in order of relative abundance, were *Teladorsagia* / *Trichostrongylus*, *Strongyloides* and *Oesophagostomum*.

Table 7. Relative abundance (%) of larvae identified from the pre-treatment faecal cultures for the faecal egg count reduction test.

Treated group (T)	***Haemonchus***	***Oesophagostomum***	***Teladorsagia* / *Trichostrongylus***	***Strongyloides***
Control	83		17	
T1	74		22	4
T2	73	2	12	13
T3	63		37	
T4	73	6	21	
Mean	73.2	1.6	21.8	3.4

Levamisole was the most effective anthelmintic treatment, with an efficacy of 98.5%. Of the four products used in the experiment, closantel was the least effective. However, this product is a narrow-spectrum product that is not effective against *Oesophagostomum*, *Teladorsagia*, *Trichostrongylus* or *Strongyloides* spp. As such, its efficacy was probably underestimated.

4.4 Comparison of Pitchford-Visser (FEC-P) and McMaster (FEC-McM) faecal egg count methods

The mean faecal egg counts obtained by the Pitchford-Visser and McMaster methods for both the control and COWP-treated goat groups in all three trial areas combined are illustrated in Fig. 8.

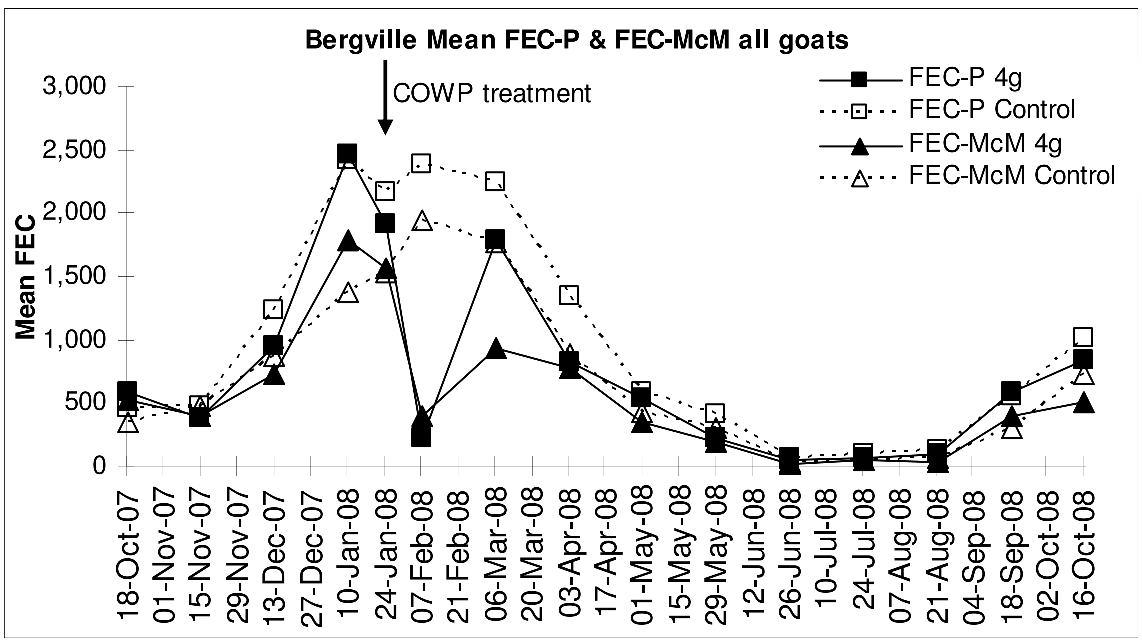


Fig. 8. Mean faecal egg counts (FECs) obtained for all three areas from the control and treated (4 g) groups of all goats by the Pitchford-Visser (FEC-P) and McMaster (FEC-McM) methods.

Both methods showed similar results. An increase in FEC was recorded from December 2007 to January 2008. Both the count methods showed a marked decrease in FEC for the COWP-treated group of goats (week of 4 February 2008), two weeks after COWP administration, followed by a recovery in egg counts during the next sampling event (week of 3 March 2008), four weeks after the COWP was given. Both methods showed statistically very significant differences ($P < 0.001$) in mean faecal egg count between the control (FEC-P = 2 382; FEC-McM = 1 945) and treated groups (FEC-P = 223; FEC-McM = 391) during the week of 4 February 2008 sampling, two weeks after COWP administration, while the Pitchford-Visser method detected significantly ($P = 0.042$) lower mean FEC in the treated group (214.7) compared to the control group (413.01) at the week of 27 May 2008 sampling, which was 14 weeks after COWP had been administered and thus probably not due to COWP. The McMaster method showed a significant ($P = 0.018$) difference at the week of 13 October 2008 sampling between mean FEC of the treated (513) and control groups (730). The latter two samplings were done when egg counts were at a seasonal low. Both methods showed that faecal egg counts for the control group of goats remained high two weeks after COWP was administered during the week of 4 February 2008 after which both methods showed a steady seasonal decline in mean FEC for both the control and COWP groups from April to May 2008, reaching negligible numbers in June and July 2008, after which numbers started to increase steadily again in October 2008.

As regards the controls, both methods in general showed that the mean FEC increased during the summer months from November - March, during the rainy summer season, thereafter decreasing steadily to negligible numbers during the winter months (June 2008 – August 2008), where after numbers increased again steadily in spring (October 2008).

Based on the means, the Pitchford-Visser and McMaster methods correlated well overall ($r = 0.9759$: $P < 0.0001$) as well as within the treated ($r = 0.9631$: $P < 0.0001$) and control ($r = 0.9914$: $P < 0.0001$) groups. Using the overall correlation analysis, an estimated $\log_{10}$FEC-P value may be calculated from an experimental $\log_{10}$FEC-McM value by the formula: $\log_{10}\text{FEC-P} = 1.0593 + 0.4106 \log_{10}\text{FEC-McM}$.

The correlation coefficient (based on individual values) for the two methods for Hoffenthal, was $r = 0.706$; for Ogade, it was $r = 0.567$ and for Dukuza, it was $r = 0.749$ ($P < 0.001$), the lowest correlation between the two methods being in the Ogade area.

The Pitchford-Visser method generally gave higher FEC values than the McMaster method, although these values were not statistically different. The Pitchford-Visser method was thus considered the method of choice for this study and used in all subsequent analyses.

4.5 Epidemiological investigations

4.5.1 Faecal egg counts (FECs)

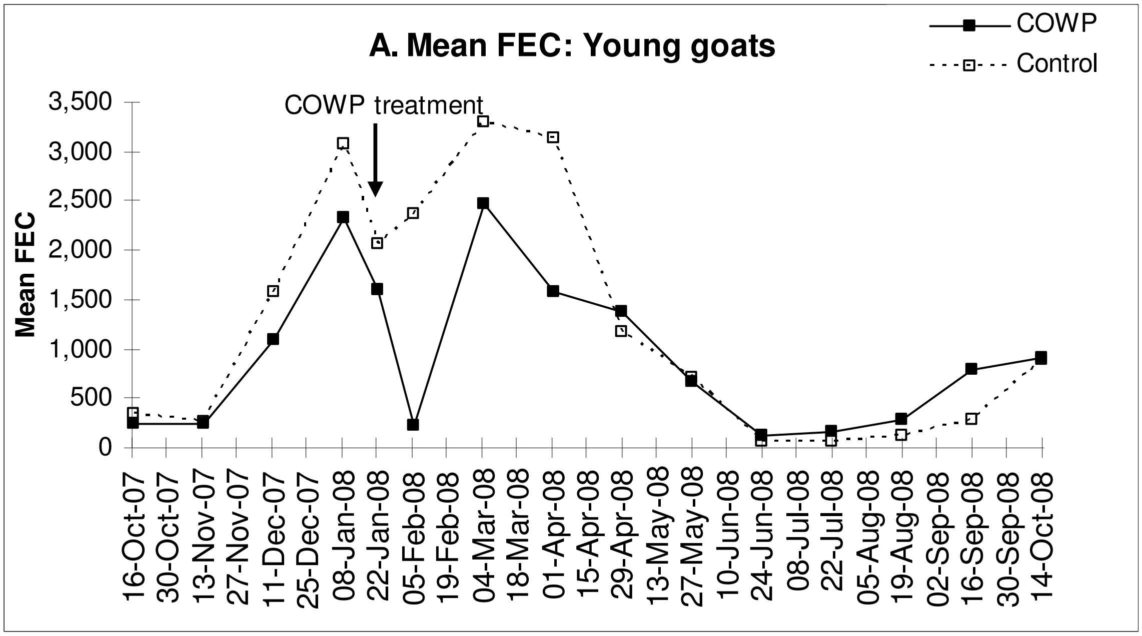
4.5.1.1 All goats in all three areas combined

The mean FEC as determined by the Pitchford-Visser method for young and adult goats combined in the control and treated groups in all three trial areas together (Fig. 8) are as discussed above (see 4.4). Results show that the timing of COWP administration was during the period of highest infection levels, the highest mean faecal egg count recorded at the beginning of January 2008, two weeks before COWP was administered. The results further show a very significant difference (Table 8) between the faecal egg counts observed two weeks after COWP administration during the week of 4 February 2008 for the treated group of goats and those of the controls. At four weeks post-COWP administration, the week of 3 March 2008, mean FEC of the treated group had increased to levels comparable to those of the control group and to pre-COWP treatment levels with no statistically significant differences being evident. This illustrates the short term effect of the COWP. Interestingly, mean FEC of the control and treated groups were significantly different during the week of 26 May 2008 sampling (Table 8). This is of little clinical significance as they were lower than 500 epg and were most probably low owing to a natural seasonal decline in infection, especially since they declined further in June 2008.

4.5.1.2 Young and adult goats in all three areas combined

Fluctuations in the mean FEC for young goats (Fig. 9A) in all three trial areas combined were similar to those of all goats combined (Fig. 8). A significant difference in mean FEC between the control and treated group of young goats was found at the week of 4

February 2008 sampling (Table 8), two weeks after COWP administration. No further differences in means were evident.



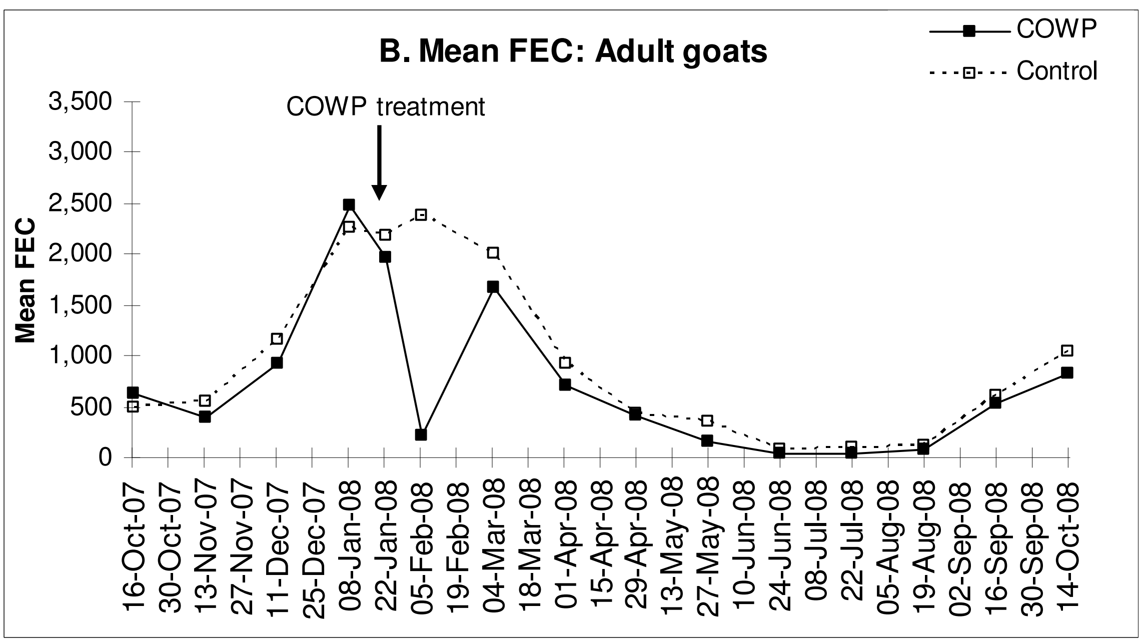


Fig. 9. Mean faecal egg counts (FECs) of the control and treated (COWP) groups of A. young goats and B. adult goats in the three trial areas combined.

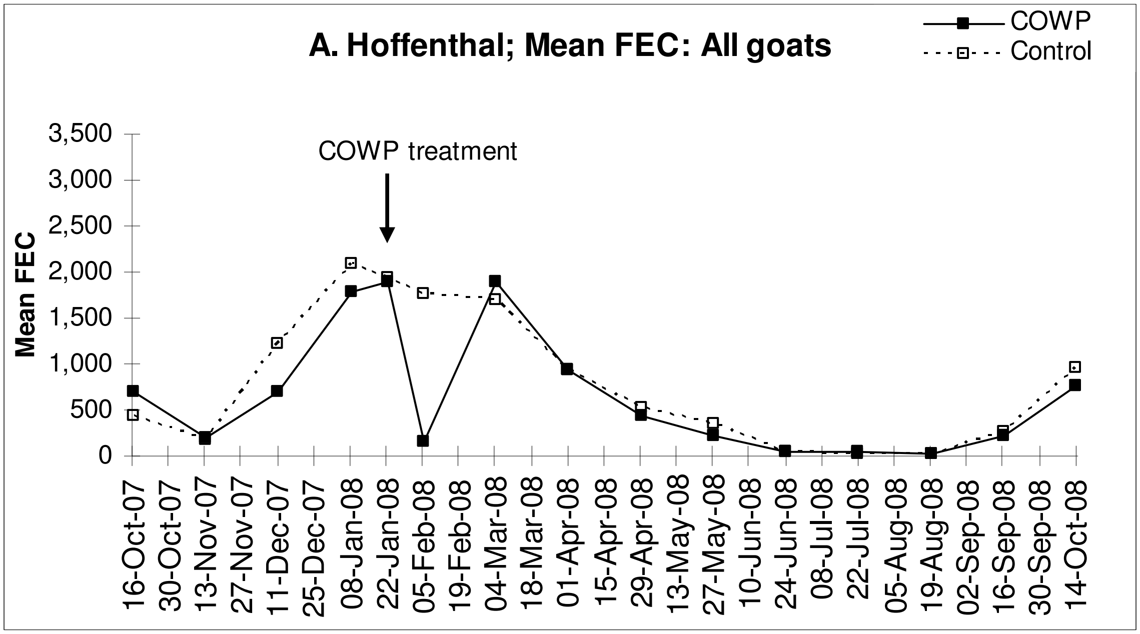
Young goats (Fig. 9A) had generally higher faecal egg counts than adults (Fig. 9B) from December 2007 – May 2008. This was not statistically tested as the small numbers of young goats in the trial did not allow meaningful analysis.

The mean FEC of adult goats from all three trial areas combined (Fig. 9B) showed similar seasonal fluctuations in egg counts and the COWP was as effective, as it had been used in the young and adult goats in all three areas combined (Fig. 8). Very significant differences ($P < 0.001$) between control and treated group FECs were evident at the week of 4 February 2008 (two weeks post-COWP administration). Significant differences ($P < 0.05$) were encountered at the week of 26 May 2008 and at the week of 21 July 2008 (Table 8), mean FECs at the latter two samplings being during a seasonal low (Fig. 9B).

4.5.1.3 Hoffenthal

At Hoffenthal, the young and adult goats combined (Fig. 10A) showed a significant difference in the mean FECs only at the week of 4 February 2008 sampling, two weeks after COWP administration, between the control and treated groups (Table 8).

The mean FECs of adult goats in the Hoffenthal area (Fig. 10B) displayed no significant differences at the week of 4 February 2008 sampling, two weeks after COWP administration, although a markedly lower count was evident in the treated group. A significant difference was, however, found for the week of 26 May 2008 sampling (Table 8), 18 weeks after COWP administration when infection was at a seasonal low.



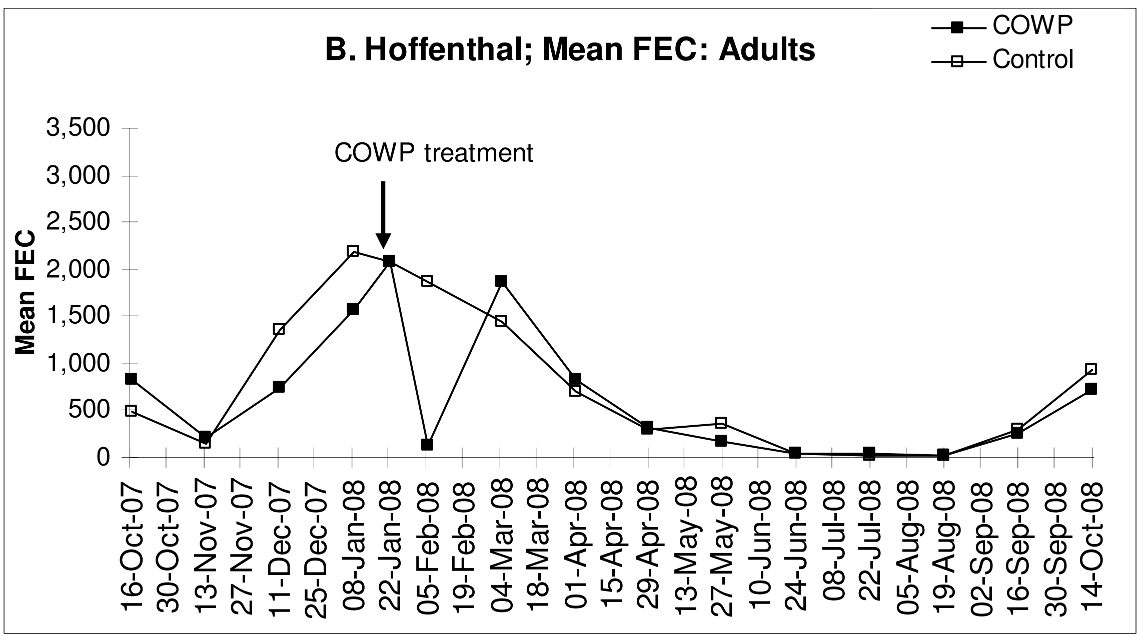
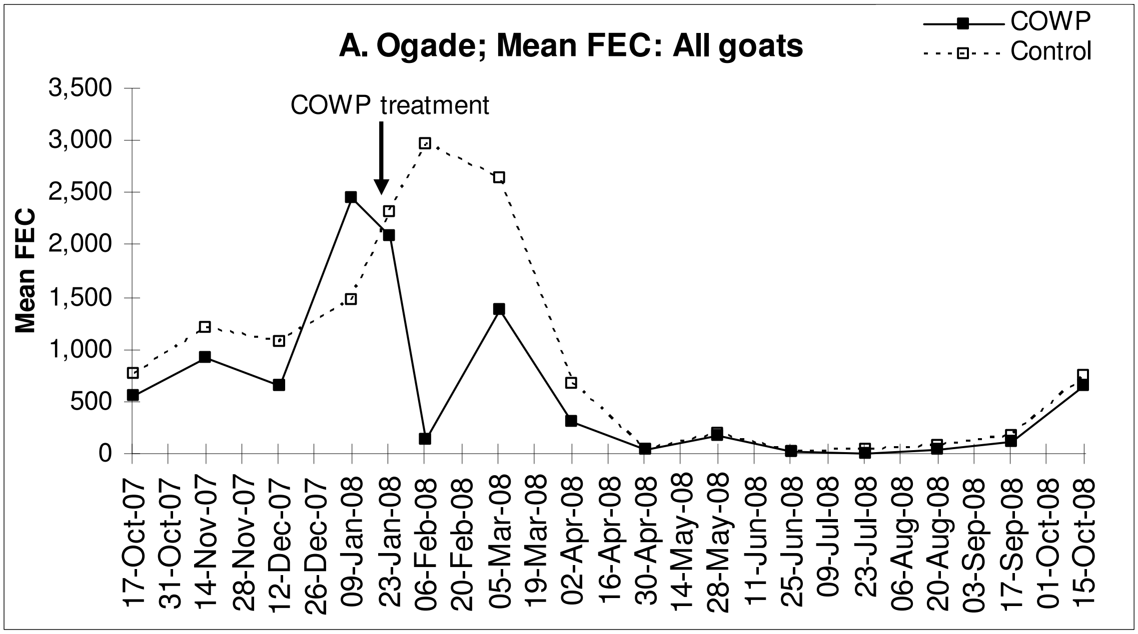


Fig. 10. Mean faecal egg counts (FECs) of the control and treated (COWP) groups of A. all goats (young and adults) and B. adult goats in the Hoffenthal area.

4.5.1.4 Ogade



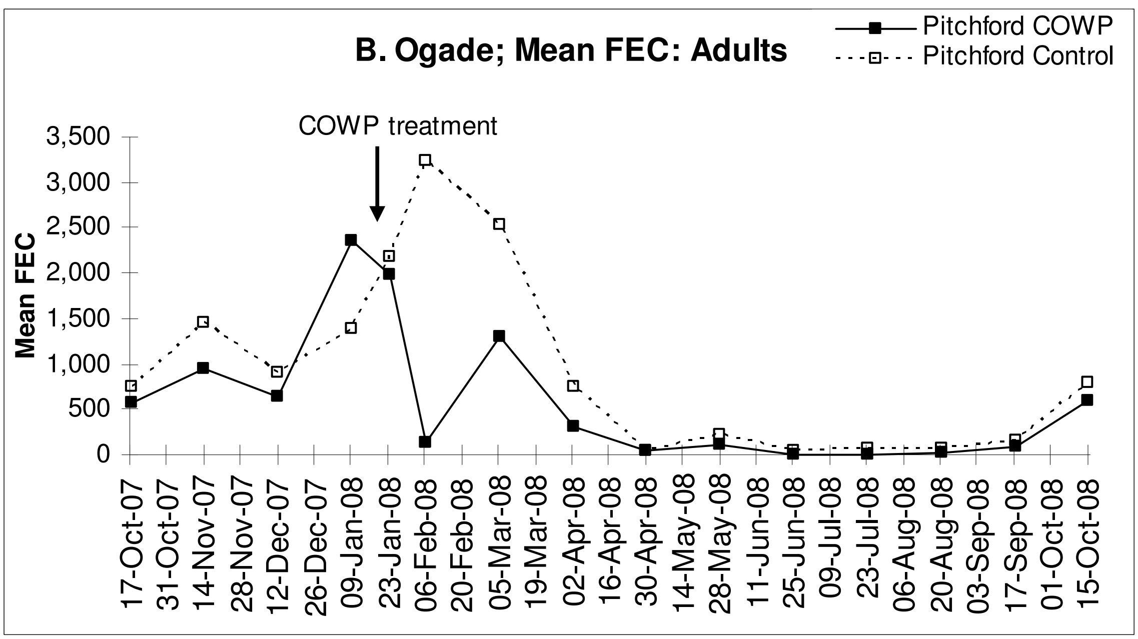


Fig. 11. Mean faecal egg counts (FECs) of the control and treated (COWP) groups of A. all goats (young and adults) and B. adult goats in the Ogade area.

The mean FECs of all goats (young and adults goats) in the Ogade area (Fig. 11A) displayed significant differences at the week of 4 February 2008, two weeks after COWP administration and again at the week of 21 July 2008 sampling (Table 8) during mid-winter when infection was at an extreme seasonal low.

The mean FECs of adult goats in the Ogade area (Fig. 11B) displayed significant differences at the week of 4 February 2008 sampling, two weeks after COWP administration and again at the week of 21 July 2008 sampling (Table 8) in mid-winter when the infection was particularly low.

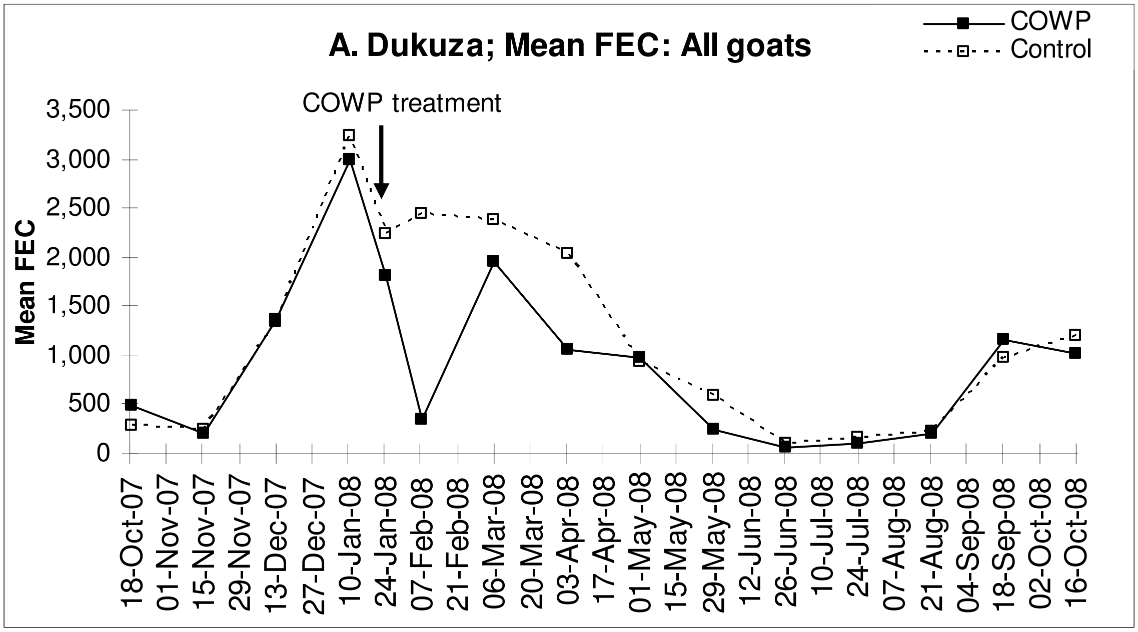
4.5.1.5 Dukuza

The mean FECs of all goats (young and adult goats) in the Dukuza area (Fig. 12A) displayed very significant differences only at the week of 4 February 2008 (Table 8), two weeks after COWP administration.

The mean FECs of adult goats in the Dukuza area (Fig. 12B) displayed very significant differences only at the week of 4 February 2008, two weeks after COWP administration (Table 8).

Based on data for all goats, the mean FECs shows that Dukuza had the highest peak (during the week of 7 January 2008) egg counts of the three areas, followed by Ogade and Hoffenthal. This suggests higher pasture contamination at Dukuza and probably accounts for the more marked rise in FECs recorded during September and October 2008 at Dukuza (Figs. 12A & B).

Also, peak numbers were recorded at all three areas (Figs. 10–12) during January 2008 except for the control group of goats at Ogade (Fig. 11) which showed peak numbers during February 2008.



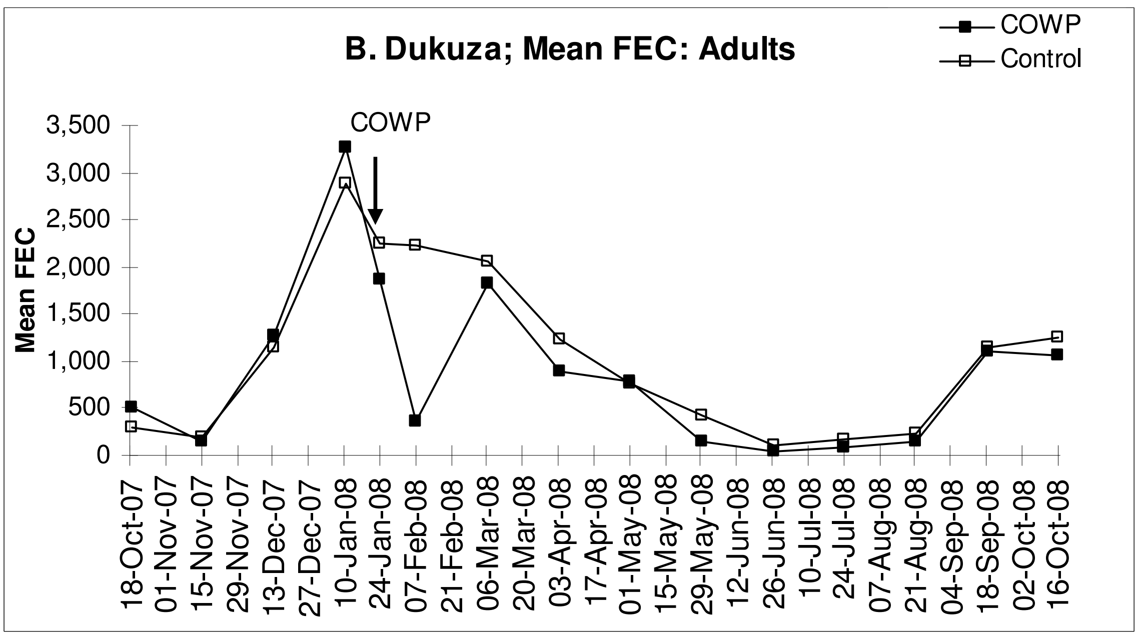


Fig. 12. Mean faecal egg counts (FECs) of the control and treated (COWP) groups of A. all goats (young and adults) and B. adult goats in the Dukuza area.

Table 8. Summary of significant differences (ANOVA) in mean faecal egg counts (FEC) between the control and treated (COWP) groups of goats included in the analyses (n = number of goats; s.e. = standard error; P = F probability).

Sampling week date	Trial week	Area	Age	Group	n	Mean FEC	log_{10}	s.e.	P
4 February 2008	17	All	All	Control	84	2382.00	2.73	0.12	<0.001
				COWP	84	223.00	1.79	0.12	
26 May 2008	33	All	All	Control	84	413.00	1.70	0.13	0.042
				COWP	86	214.20	1.33	0.13	
4 February 2008	17	All	Young	Control	16	2377.00	2.60	0.32	0.036
				COWP	11	245.00	1.50	0.38	
4 February 2008	17	All	Adults	Control	68	2382.00	2.76	0.13	<0.001
				COWP	73	220.00	1.83	0.13	
26 May 2008	33	All	Adults	Control	69	349.70	1.71	0.14	0.007
				COWP	75	148.30	1.19	0.13	
21 July 2008	41	All	Adults	Control	68	95.00	0.96	0.12	0.024
				COWP	75	47.95	0.58	0.58	
4 February 2008	17	Hoff	All	Control	25	1770.60	2.36	0.23	0.028
				COWP	28	146.40	1.64	0.22	
26 May 2008	33	Hoff	Adults	Control	22	362.00	1.94	0.24	0.021
				COWP	24	173.60	1.16	0.23	
4 February 2008	17	Ogade	All	Control	22	2971.00	2.62	0.27	0.007
				COWP	22	127.00	1.52	0.27	
21 July 2008	41	Ogade	All	Control	22	46.82	0.78	0.16	0.030
				COWP	23	5.74	0.27	0.16	
4 February 2008	17	Ogade	Adults	Control	18	3244.00	2.81	0.27	0.002
				COWP	21	133.00	1.59	0.25	
21 July 2008	41	Ogade	Adults	Control	18	57.22	0.96	0.18	0.009
				COWP	22	6.00	0.28	0.16	
4 February 2008	17	Dukuza	All	Control	37	2445.00	3.04	0.14	<0.001
				COWP	34	349.00	2.08	0.15	
4 February 2008	17	Dukuza	Adults	Control	29	2225.00	3.00	0.16	<0.001
				COWP	29	351.00	2.12	0.16	

Only the adult group of goats in the Hoffenthal area did not show statistically significantly lower FEC in the treated compared to the control group at the week of 4 February 2008 sampling occasion (Table 8). Significantly lower mean FECs were also evident in the treated group of goats during the week of 26 May 2008 (Hoffenthal adults) and the week of 21 July 2008 (Ogade adults) when FECs were at a seasonal low.

4.5.2 FAMACHA© scores (FCH)

4.5.2.1 All three areas combined

For all three areas combined, the mean FAMACHA© score (FCH) over the trial period of all goats (young goats and adults) (Fig. 13A) ranged from 2.12 - 3.10, for young goats (Fig. 13B) from 2.00 – 2.63, and for adult goats (Fig. 13C) from 2.13 – 3.13. The mean FCH fluctuated minimally during the trial period and displayed very little difference between the control and treated groups of goats. A significant difference in FCH means between the control and treated groups was evident only during the week of 28 April 2008 for all goats and adult goats (Table 9). Mean FECs were at a seasonal low during this period (Figs. 8 & 9) and the differences in FCH means could not be ascribed to COWP intervention.

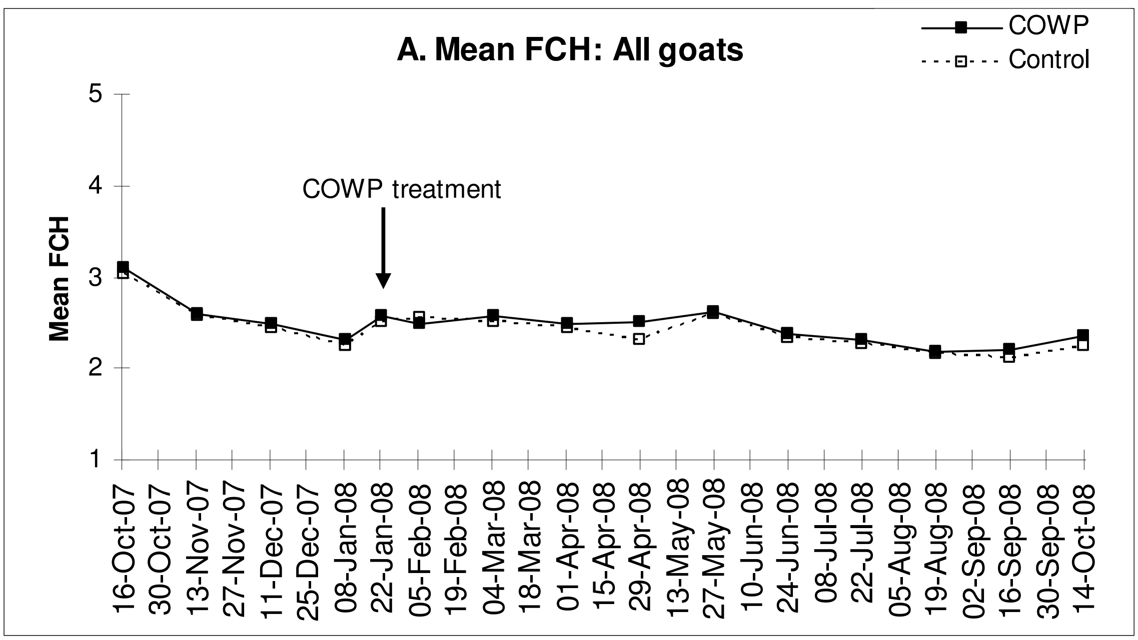
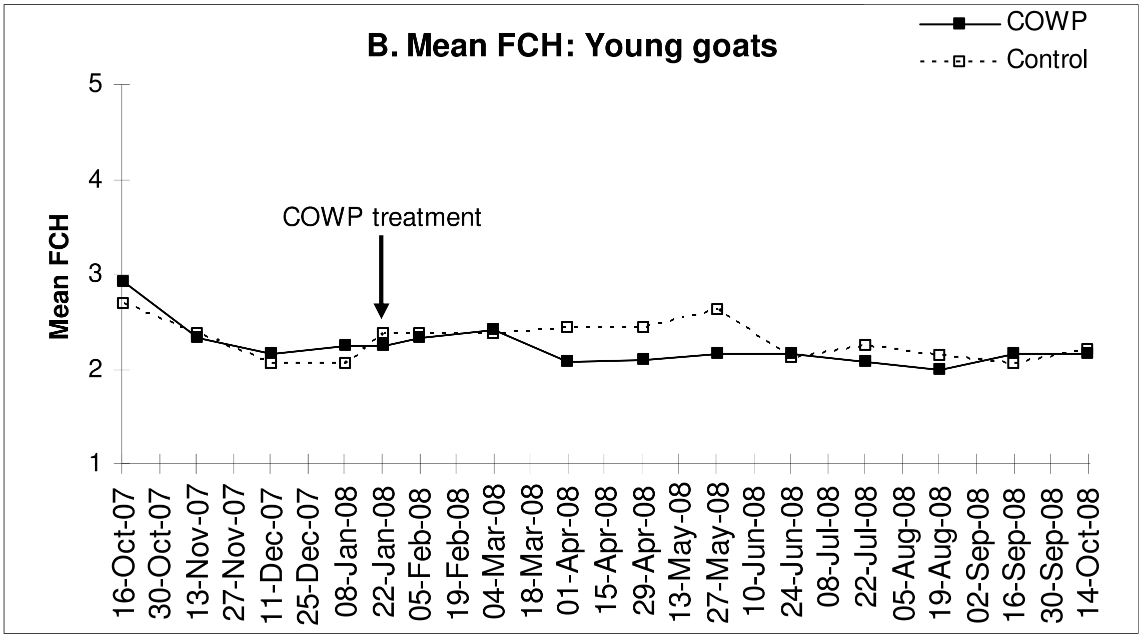


Fig. 13. Mean FAMACHA© score (FCH) over the trial period for all three areas combined of A. all goats (young and adults).



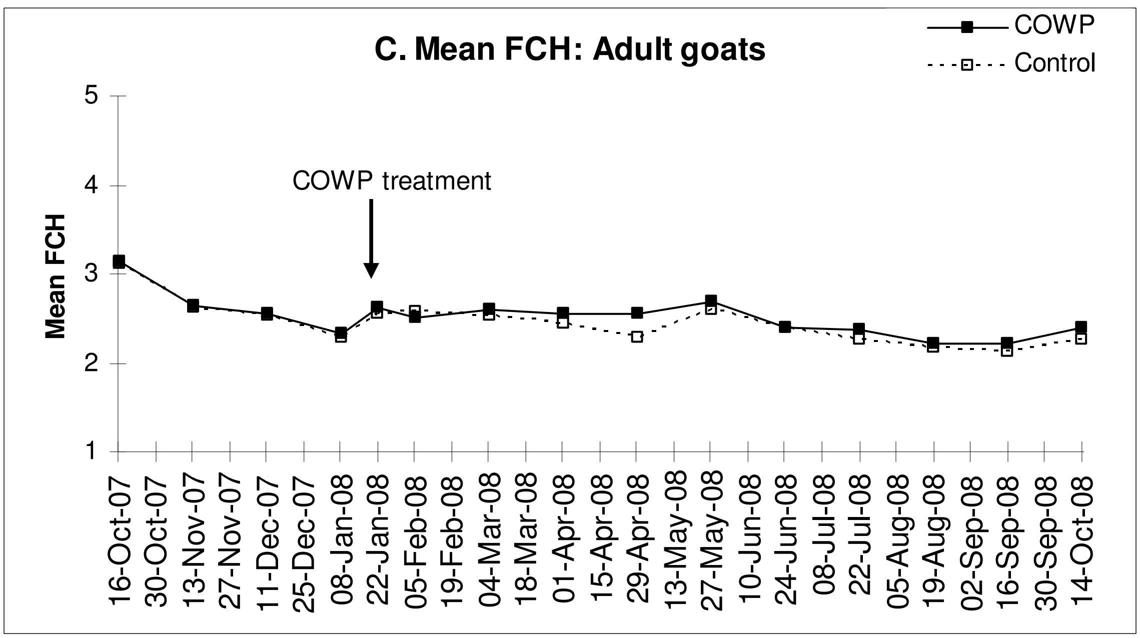


Fig. 13. Mean FAMACHA© score (FCH) over the trial period for all three areas combined of B. young goats and C. adult goats.

4.5.2.2 Hoffenthal

In the Hoffenthal area, the mean FCH of all goats (young goats and adults) (Fig. 14A) ranged from 2.04 – 3.41 and for adult goats (Fig. 14B), from 2.13 – 3.5 over the trial period. There were no significant differences between the control and treated groups.

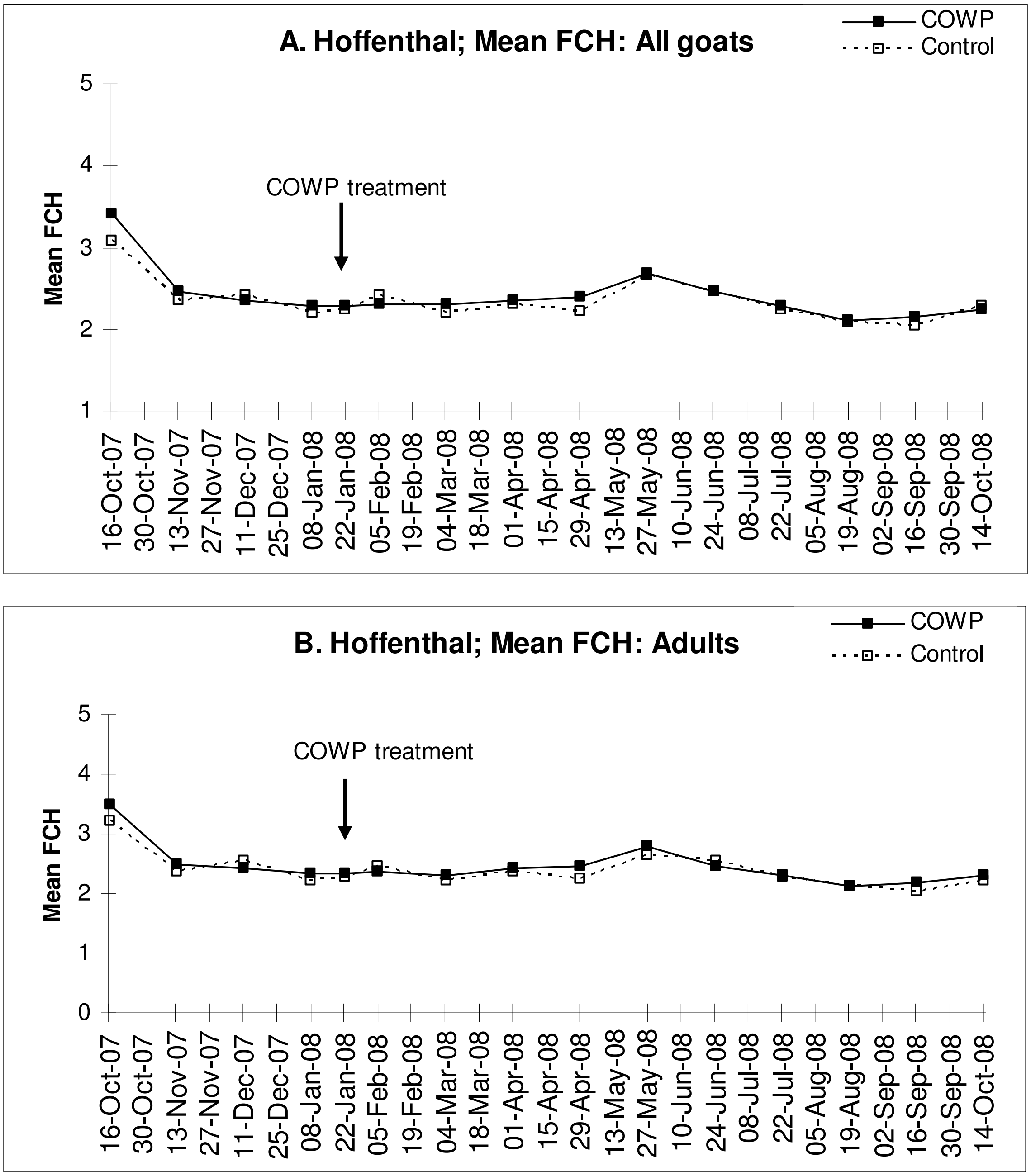
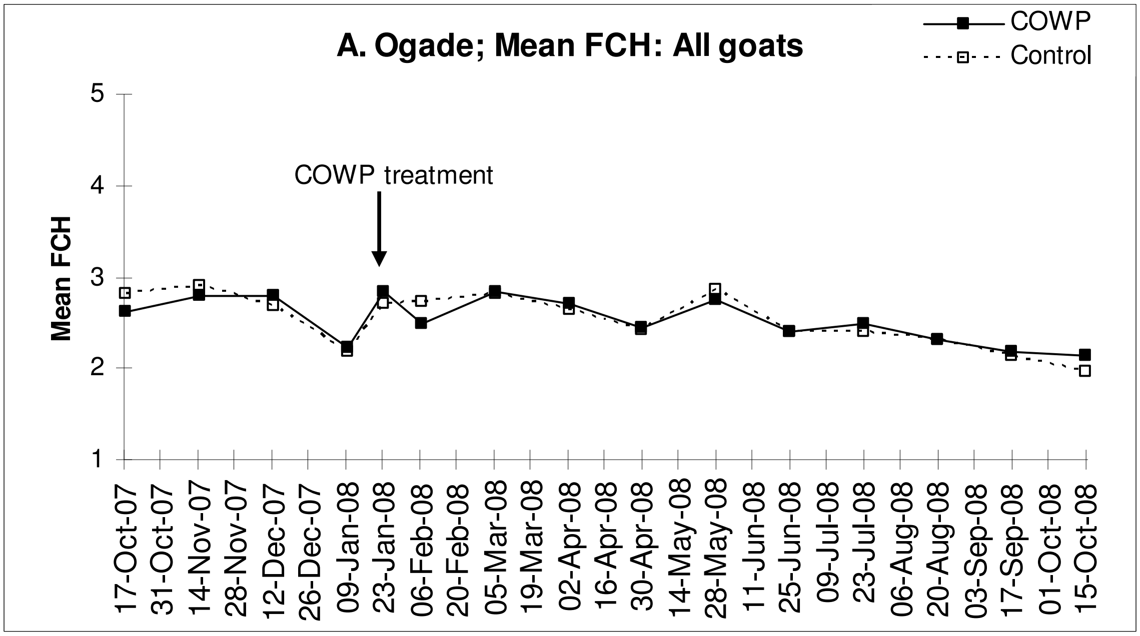


Fig. 14. Mean FAMACHA© score (FCH) over the trial period of A. all goats (young and adults) and B. adult goats in the Hoffenthal area.

4.5.2.3 Ogade

In the Ogade area, the mean FCH over the trial period of all goats (young goats and adults) (Fig. 15A) ranged from 1.96 – 2.91 and for adult goats (Fig. 15B) from 2.06 – 2.94 with no significant differences evident between the control and treated groups.



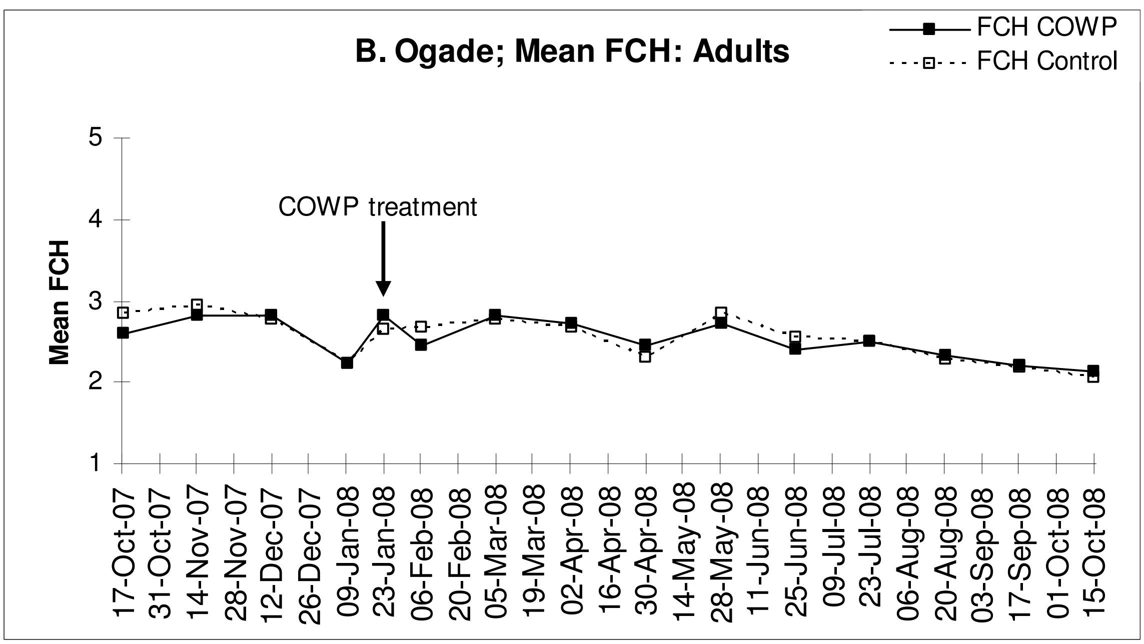


Fig. 15. Mean FAMACHA© score (FCH) over the trial period of A. all goats (young and adults) and B. adult goats in the Ogade area.

4.5.2.4 Dukuza

Over the trial period in the Dukuza area, the mean FCH for all goats (young goats and adults, Fig. 16A) ranged from 2.11 – 3.17 and for adult goats from 2.11 – 3.17. Significant differences between the control and treated groups were found during the week of 28 April 2008 for all goats and for adult goats. The mean FCH of the all goat group again showed significant differences during October 2008 (Table 9).

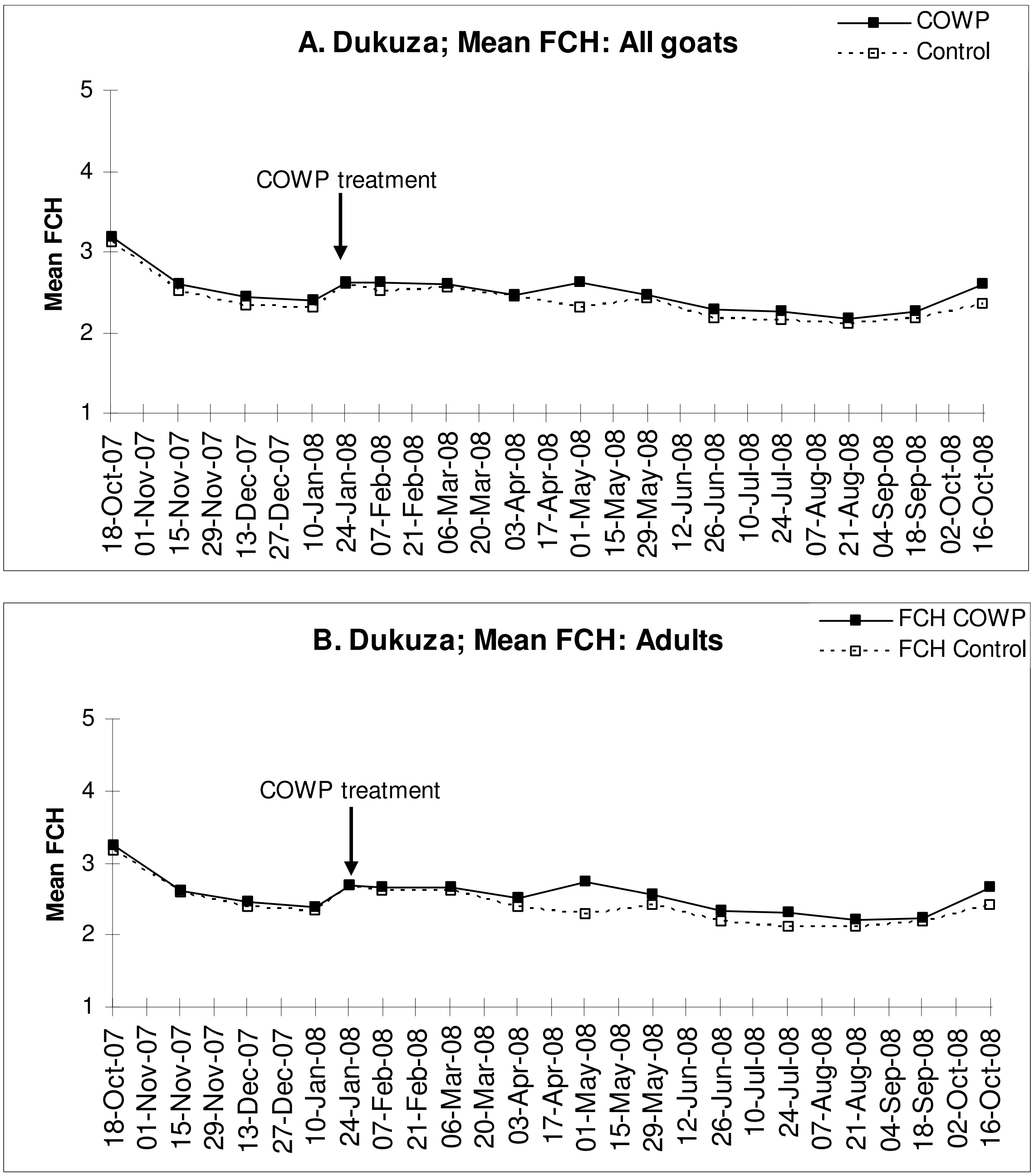


Fig. 16. Mean FAMACHA© score (FCH) over the trial period of A. all goats (young and adults) and B. adult goats in the Dukuza area.

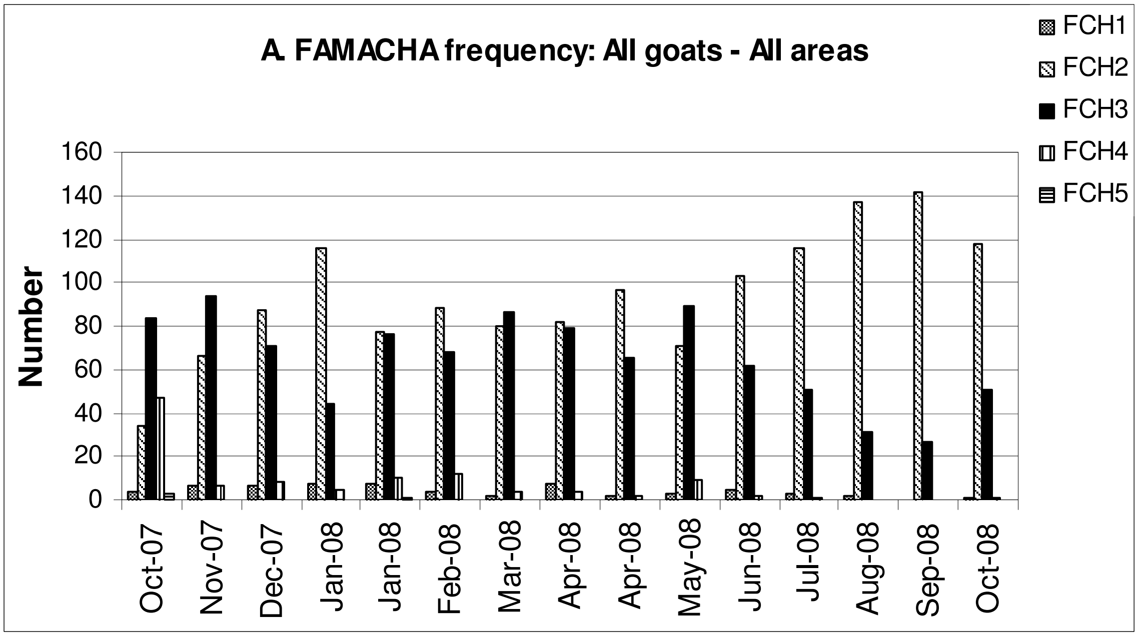
Table 9. Summary of significant differences (ANOVA) in mean FAMACHA© score (FCH) between the control and treated (COWP) groups of goats included in the analyses (n = number of goats; s.e. = standard error; P = F probability).

Sampling week date	Trial week	Area	Age	Group	n	Mean FCH	s.e.	P
28 April 2008	29	All	All	Control	82	2.305	0.059	0.019
				COWP	84	2.500	0.058	
28 April 2008	29	All	Adults	Control	66	2.273	0.066	0.002
				COWP	73	2.562	0.063	
28 April 2008	29	Dukuza	All	Control	37	2.297	0.088	0.010
				COWP	35	2.629	0.090	
28 April 2008	29	Dukuza	Adults	Control	29	2.276	0.098	0.002
				COWP	29	2.724	0.098	
13 October 2008	53	Dukuza	All	Control	37	2.311	0.085	0.046
				COWP	35	2.600	0.088	

The administration of COWP to the treated group of goats did not appear to have an effect on the mean FCH scores. A significantly higher mean FCH was evident only in the adult treated group when compared to the controls and only during the week of 28 April 2008 (Table 9), 14 weeks after COWP administration, when faecal egg counts were in a seasonal decline. A significantly higher mean FCH in the treated group of goats in the Dukuza area during the week of 13 October 2008 was, by elimination, due to a higher mean FCH in young goats in the treated group of goats during this sampling occasion when FECs were increasing with the commencement of the next summer season.

4.5.2.5 FAMACHA© score frequency: all three areas combined

The frequency of FAMACHA© category scores recorded over the trial period for all the animals included in the analyses is given in Fig. 17A, for all the control animals in Fig. 17B and for all the treated group of goats in Fig. 17C. Total FAMACHA© category scores assigned to the three groups are shown in Table 10.



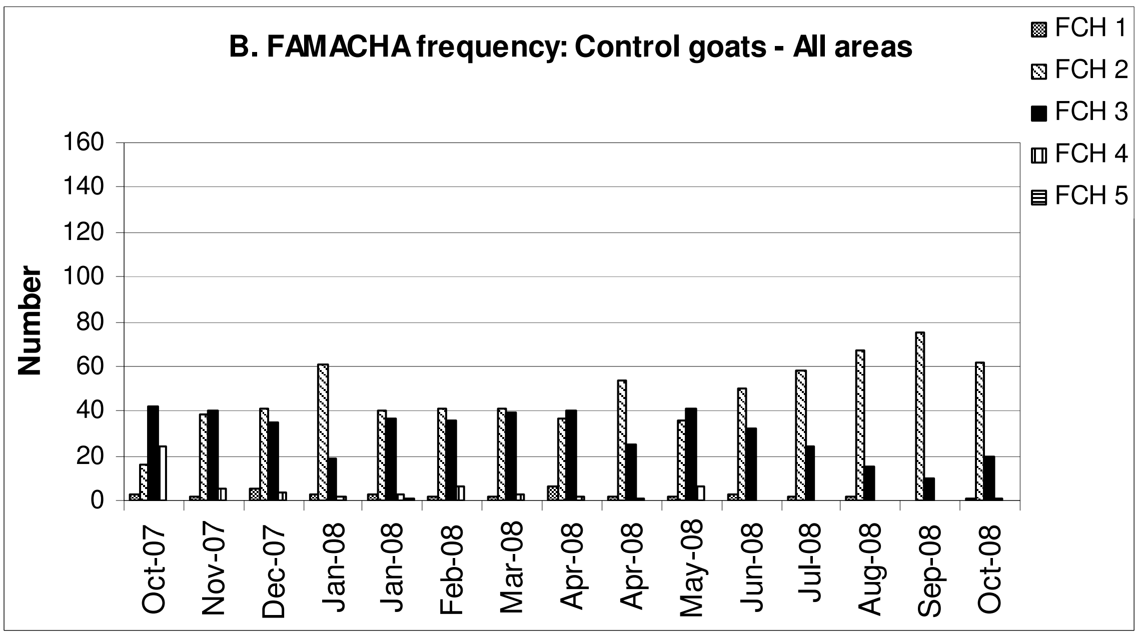


Fig. 17. Frequency of FAMACHA© scores per category (FCH 1 – FCH 5) for A. all animals and B. the control group of goats included in the analyses over the trial period.

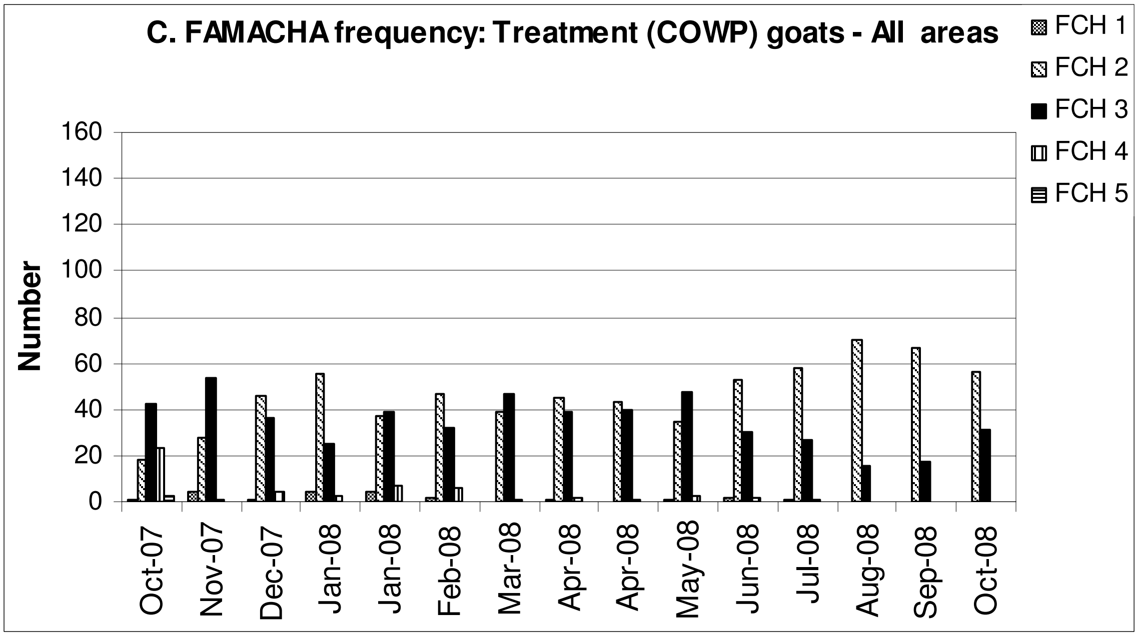


Fig. 17. Frequency of FAMACHA© scores per category (FCH 1 – FCH 5) for C. the treated (COWP) group of goats included in the analyses over the trial period.

FAMACHA© scores in category 2 were recorded the most over the trial period (1 414 in total), the most being recorded during the winter and autumn months (June – September 2008; Fig. 17A) when faecal egg counts were lowest (Fig. 8). Most FAMACHA© scores in category 3 (978 in total), were recorded at the start of the trial (week of 15 October 2007) and again from March – May, 2008 (Fig. 17A). Fewer FAMACHA© scores in categories 1 (59), 4 (111) and 5 (4) were recorded (Fig. 17A). Almost half (47) of the FAMACHA© category 4 scores were assigned at the first sampling occasion (October 2007) as were three of the four FAMACHA© category 5 scores.

Relative FAMACHA© scores in the five categories assigned to the control and treated groups of goats were very similar over the trial period (Fig. 17B and C), total accumulative scores being FCH1: 38, 21; FCH2: 717, 697; FCH3: 455, 523; FCH4: 57, 54 and FCH5: 1, 3, respectively. No statistical differences were evident.

The number of goats requiring drug treatment (FAMACHA© categories 3, 4 and 5) decreased from 87 in the week of 7 January 2008, pre-COWP administration, to 80 in the week of 4 February 2008, two weeks after COWP was given, increasing again to 90 at the following sampling occasion (week of 3 March 2008), six weeks post-COWP.

During the trial period, the FAMACHA© system as applied in this study, resulted in only 965 doses being drenched as opposed to 2 222 doses if blanket drenching of all the animals had been practised on the 13 sampling occasions when anthelmintic treatment was given. According to the FAMACHA© system as applied to goats in this study, animals required treatment on 42.6% of the occasions that the conjunctivae were examined (Table 10).

During the trial period that included 13 drenching occasions, anthelmintic treatment according to the FAMACHA© system, instead of blanket treatment, was dispensed in the control group to 453 as opposed to a total of 1 098 goats (41.3%) and in the treated group to 512 as opposed to a total of 1 124 goats (45.6%).

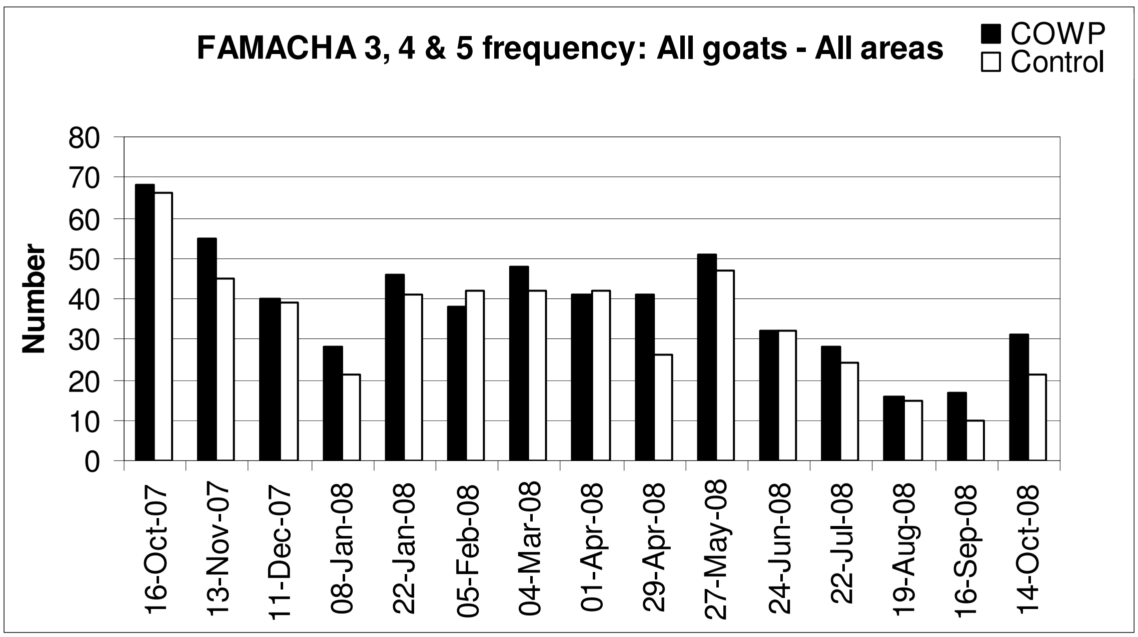


Fig. 18. Number of goats per sampling occasion in the treated (COWP) and control groups that required drenching (FAMACHA© categories 3, 4 & 5) over the trial period.

The number of goats that required drenching at the start of the trial (week of 15 October 2007) in the treated and control groups decreased from 68 to 31 and 66 to 21 respectively by the end of the trial period (week of 13 October 2008, Fig. 18). Before the administration of COWP, at the week of 21 January 2008 sampling, 46 of the treated group of goats and 41 of the controls required drenching. Two weeks post-COWP administration (week of 4 February 2008), 38 goats in the treated group and 42 in the control group required drenching. However, six weeks after COWP was given (week of 3 March 2008; Fig. 18). the number of treated group goats requiring drenching had increased to pre-COWP administration levels while those in the control group remained at 42. It appears that the general decrease over the trial period in the number of goats requiring anthelmintic treatment as applied through the FAMACHA© system in this trial was similar for both the treatment and control groups of goats and that the administration of COWP had an immediate but overall minimal effect in reducing drench applications. The consistent use of the FAMACHA© system in assigning drench applications over the trial period is probably the main reason for the decrease in drenching required at the end of the trial.

4.5.2.6 FAMACHA© score frequency: per area

The frequency of FAMACHA© scores per category for the control and treated groups of goats in each of the three areas in which the trial took place is given in Table 10.

Within both the control and treated groups combined, FAMACHA© category 2 scores were assigned the most number of times in all of the three areas in which the trial took place as well as in the total scores assigned over the trial period, followed by category 3 scores (Table 10). Hoffenthal recorded the most FAMACHA© category 1 and 5 scores of the three areas for the combined control and treated groups of goats (Table 10). Only four FAMACHA© category 5 scores were assigned during the trial, three to the treated group of goats at Hoffenthal and one to the control group of goats at Dukuza. FAMACHA© category 1 and 5 scores made up the least of the total scores assigned.

Despite a higher mean faecal egg count in goats from Dukuza (Fig. 12A) compared to Hoffenthal (Fig. 10A) and Ogade (Fig. 11A), the highest percentage of goats in FAMACHA© categories 3, 4 & 5 (and thus requiring anthelmintic treatment) was recorded in the Ogade area, which had the second highest peak mean epg (Fig. 11A), followed by Dukuza and Hoffenthal. The highest percentage of FAMACHA© category 1 & 2 scores (and thus not requiring anthelmintic treatment) was recorded in goats in the

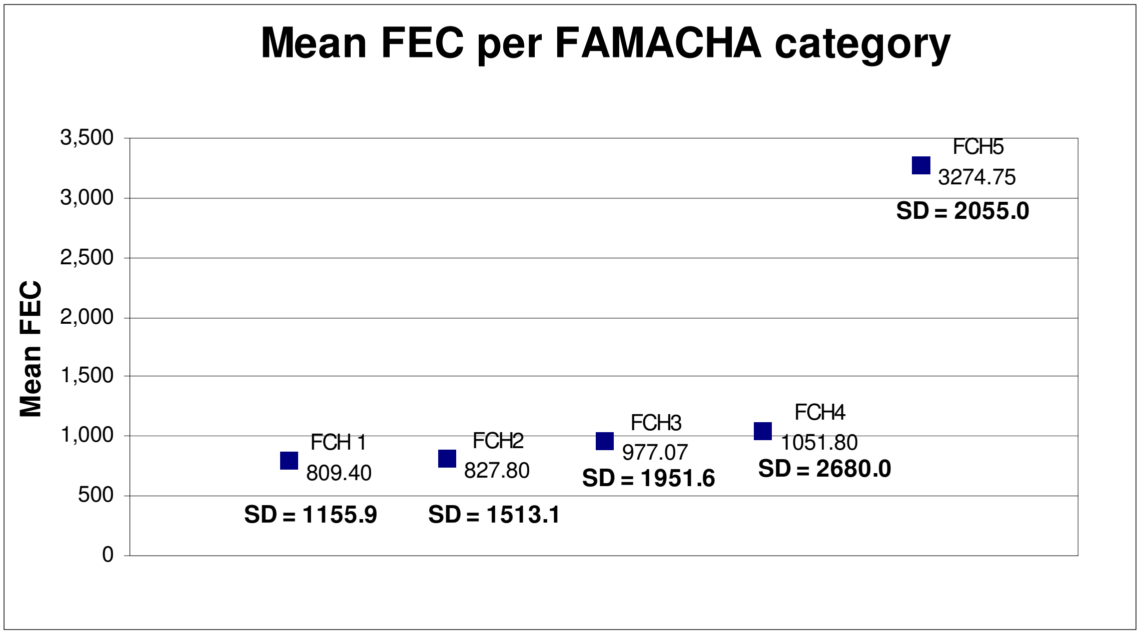
Hoffenthal area, which had the lowest mean FECs during periods of peak infection (Fig. 10A), followed by Dukuza and Ogade (Table 10).

Table 10. Accumulative number and percentage (%) of FAMACHA© scores per category assigned to control (C) and treated (COWP) groups of goats in each of the three trial areas.

FAMACHA© category	Accumulative numbers (%) of FAMACHA© scores						
	Hoffenthal		Ogade		Dukuza		Total overall
	C	COWP	C	COWP	C	COWP	
1	22 (5.7)	9 (2.1)	5 (1.7)	7 (2.0)	11 (1.98)	5 (0.95)	59 (2.3)
2	223 (57.8)	258 (60.1)	155 (47.3)	164 (47.7)	339 (61.2)	275 (52.4)	1414 (55.1)
3	127 (15.6)	145 (33.8)	150 (45.7)	158 (45.9)	178 (32.1)	220 (41.9)	978 (38.1)
4	14 (1.7)	14 (3.3)	18 (5.5)	15 (51.6)	25 (4.5)	25 (4.8)	111 (4.3)
5	0	3 (0.7)	0	0	1 (0.2)	0	4 (0.16)
Total	386	429	328	344	554	525	2566
Total (%) in FCH 1 & 2	512 (62.8)		331 (49.3)		630 (58.4)		1473 (57.4)
Total (%) in FCH 3, 4 & 5	303 (37.2)		341 (50.7)		448 (41.5)		1093 (42.6)

4.5.2.7 FAMACHA© category / FEC interface

The untransformed mean FEC per FAMACHA© category is given in Fig. 19 with the associated log_{10} transformed data given below as a box-whisker plot.



SD = Standard Deviation

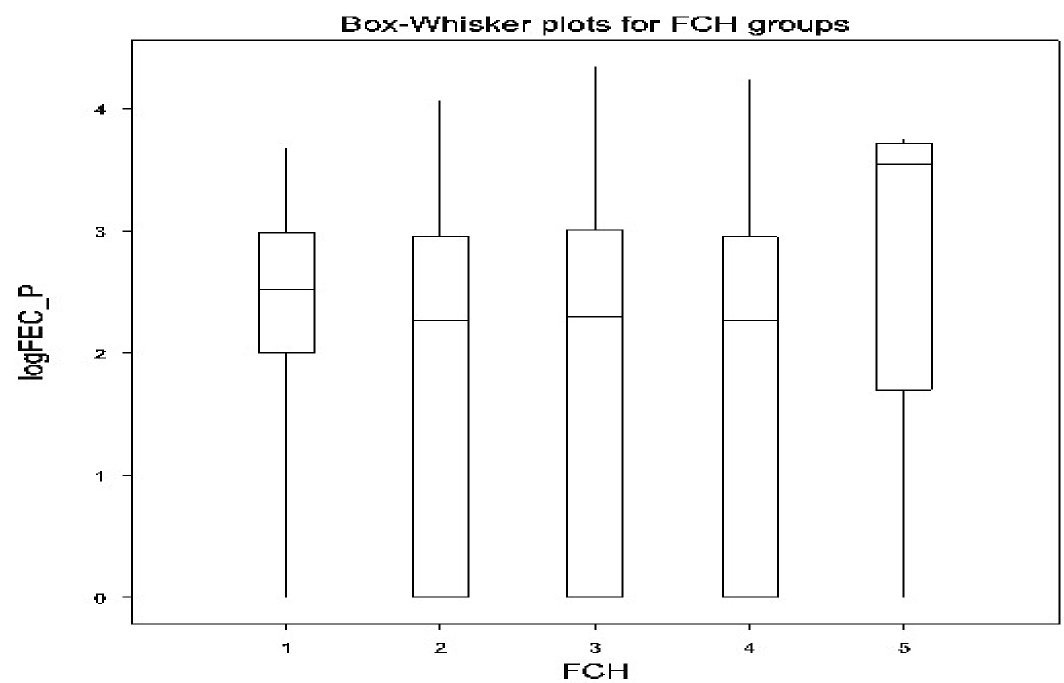


Fig. 19. Mean FEC per FAMACHA© category for all animals included in the analyses with associated box-whisker plot (log_{10}).

The mean arithmetic FEC increased marginally with higher FAMACHA© category from FCH1 to FCH4, while the mean FEC for FCH5 showed a major increment above that of the other categories. However, the box-whisker plot of the log-transformed egg counts indicates considerable overlap in FEC between the five FAMACHA© categories, especially FCH2 to FCH4. FCH5, while overlapping with the other FAMACHA© categories to a considerable extent still had a higher mean FEC value. Higher FAMACHA© categories are projected as indicative of increasing anaemia associated with higher nematode burdens. Faecal egg count, as a reflection of nematode burden, was therefore not clearly associated with the FAMACHA© category scores as assigned in this study, where higher FEC should be clearly associated with higher FAMACHA© category scores. Other factors, such as inadequate nutrition during the winter months which could affect the levels of anaemia, also probably influenced the assigning of FAMACHA© scores. The use of the FAMACHA© system to gauge nematode infection for drenching purposes in goats should therefore be supported by additional assessment criteria such as other clinical symptoms, condition scoring and consideration of nutritional status.

The mean FEC, SD and accumulated number of animals (n) monitored per FAMACHA© category in each of the two experimental groups in the three trial areas and for all three areas combined are given in Table 11. Table 11 clearly indicates that the control groups of goats within each of the FAMACHA© categories and in each of the three areas yielded higher FECs than the treated groups of goats. COWP was administered during January 2008 when FECs peaked (Figs. 10-12). The reduction in FECs due to COWP administration, albeit for a short period during peak infection (Feb-08, Figs. 10-12) was so marked as to account for the overall lower FECs in the treated groups of goats (Table 11).

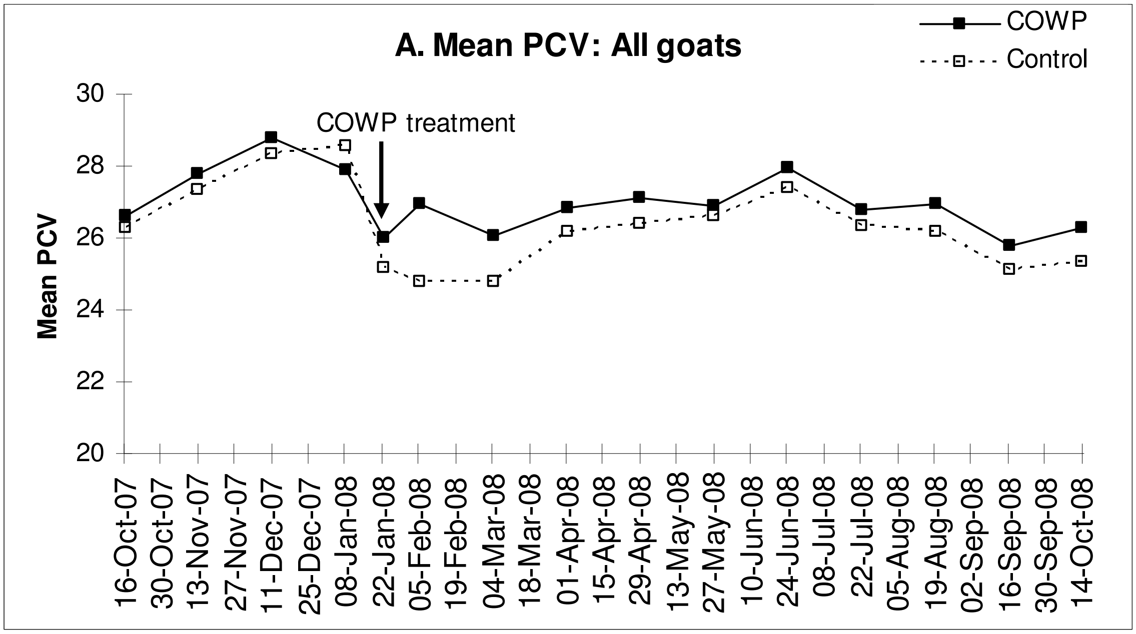
Although higher FECs were recorded with higher FAMACHA© category scores for both the control and treated groups of goats in all three areas combined, this was not the case with the FAMACHA© category and experimental groups in each separate area. Only the control and to some extent, the treated groups of goats in the Dukuza area displayed such an expected increase in FECs with increasing FAMACHA© score. Most of the groups within each of the FAMACHA© categories in the separate areas recorded a wide range in FEC values (with associated high SD values), most with a minimum of nil eggs counted, which had the effect of decreasing the relative mean FEC values. The control group of goats in FAMACHA© category FCH1 in the Ogade area recorded the highest mean FECs (Table 11) of all the groups in the separate areas in FAMACHA© categories FCH1 to FCH4, being surpassed only by the two groups in FCH5. These data accentuate the fact that FAMACHA© category scores do not always accurately reflect anaemia due to high FECs (Fig.19) and that the use of the FAMACHA© system alone, as used in this study for goats, is not a reliable indicator of FECs.

Table 11. Mean FEC, SD and accumulated number of animals (n) monitored per FAMACHA© category (FCH) in the control and COWP treated groups in the three trial areas and for all three areas combined.

FCH		Hoffenthal		Ogade		Dukuza		All 3 areas	
		COWP	Control	COWP	Control	COWP	Control	COWP	Control
1	FEC	369	737	894	2100	220	944	649	982
	SD	225.6	1 117.6	1 127.8	1 777.1	327.2	1 361.5	675.6	1 330.0
	n	9	21	6	5	5	11	20	37
2	FEC	653	741	452	677	951	1173	721	930
	SD	1 071.7	1 474.9	1 066.0	1 221.0	1 682.5	1 907.0	1 358.5	1 661.3
	n	248	219	163	155	268	333	680	707
3	FEC	649	1023	813	1216	910	1243	808	1173
	SD	1 353.4	1 755.8	2 257.4	2 489.6	1 497.4	2 196.5	1 726.9	2 187.1
	n	145	125	155	149	217	174	517	448
4	FEC	464	626	542	983	1171	2014	806	1297.4
	SD	586.0	782.7	798.9	1 409.7	3 495.9	4 568.4	2 403.4	3 032.0
	n	14	14	15	18	24	21	53	53
5	FEC	2722					4 933	2 722	4 933
	SD	2 839.5						2 839.5	
	n	3					1	3	1

4.5.3 Haematocrits or packed cell volumes (PCV)

4.5.3.1 All three areas combined



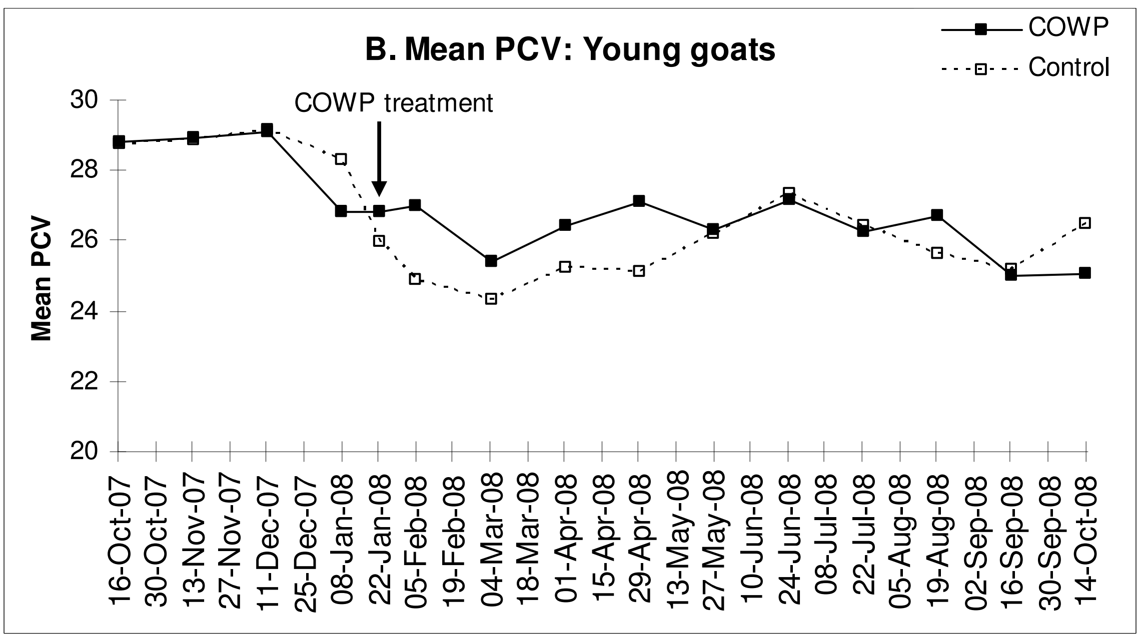


Fig. 20. Mean PCV over the trial period in all three areas combined for A. all animals and B. young goats.

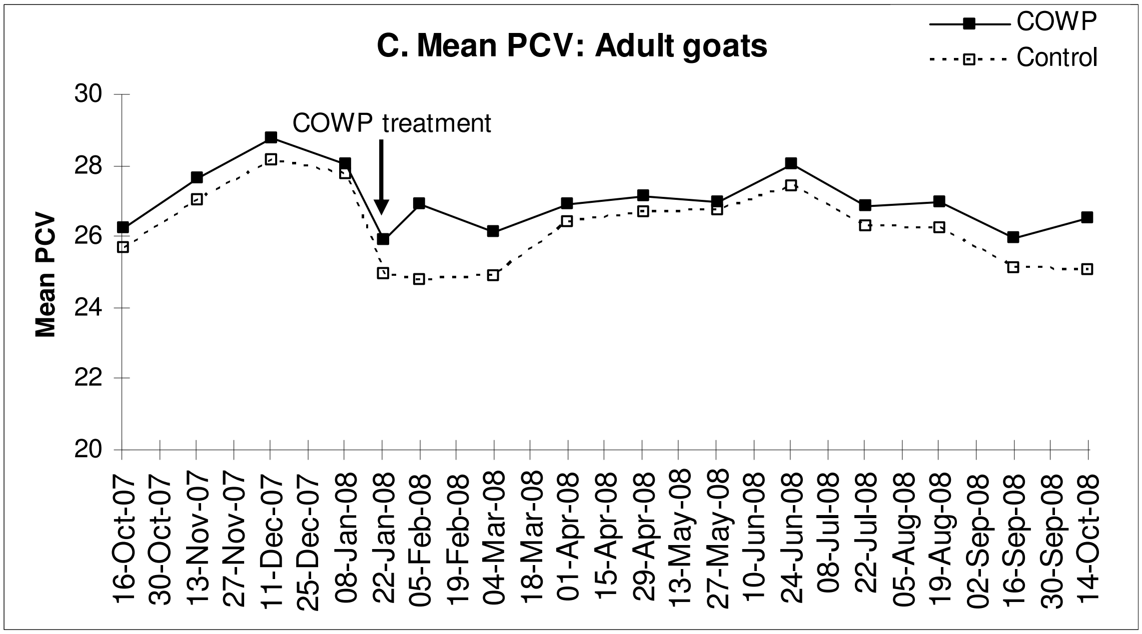


Fig. 20. Mean PCV over the trial period in all three areas combined for C. adult goats.

For all goats in all three areas combined (Fig. 20A), a very significantly lower mean PCV was found at the week of 4 February 2008 sampling in the control group of goats compared to that of the treated group of goats, two weeks after COWP administration. A significantly lower PCV for the controls than that of the treated group extended to the week of 3 March 2008 sampling and was again evident in the week of 13 October 2008 (Table 12). This last difference was recorded when FEC were increasing with the commencement of the summer season (Fig. 8).

Although the mean PCV of the control group of young goats in all three areas combined (Fig. 20B) was higher at the week of 7 January 2008 and the week of 13 October 2008 and lower from the week of 21 January 2008 to the week of 28 April 2008 and again at the week of 18 August 2008 than that of the treated group of goats, these differences were not statistically significant.

A very significantly lower mean PCV was found at the week of 4 February 2008 sampling in the control group of adult goats in all areas combined (Fig. 20C) compared to that of the treated group of goats, two weeks after COWP administration (Table 12). A significantly lower PCV for the controls than that of the treated group extended to the week of 3 March 2008 sampling and was again evident in the week of 13 October 2008 (Table 12). This last difference was recorded when FECs were increasing with the commencement of the summer season (fig. 9B). No significant differences between the controls and treated group in mean PCV was evident for young goats (Fig. 20B) and the differences recorded in the adults therefore account for the differences found for all animals (Fig. 20A) in the combined analysis.

4.5.3.2 Hoffenthal

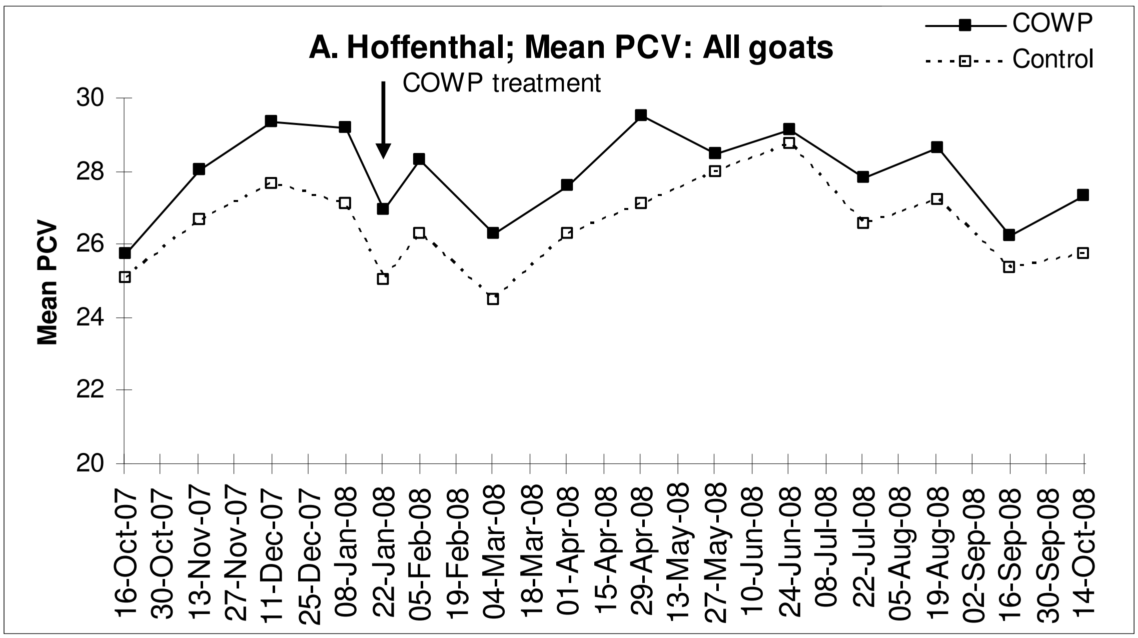


Fig. 21. Mean PCV over the trial period for A. all goats in the Hoffenthal area.

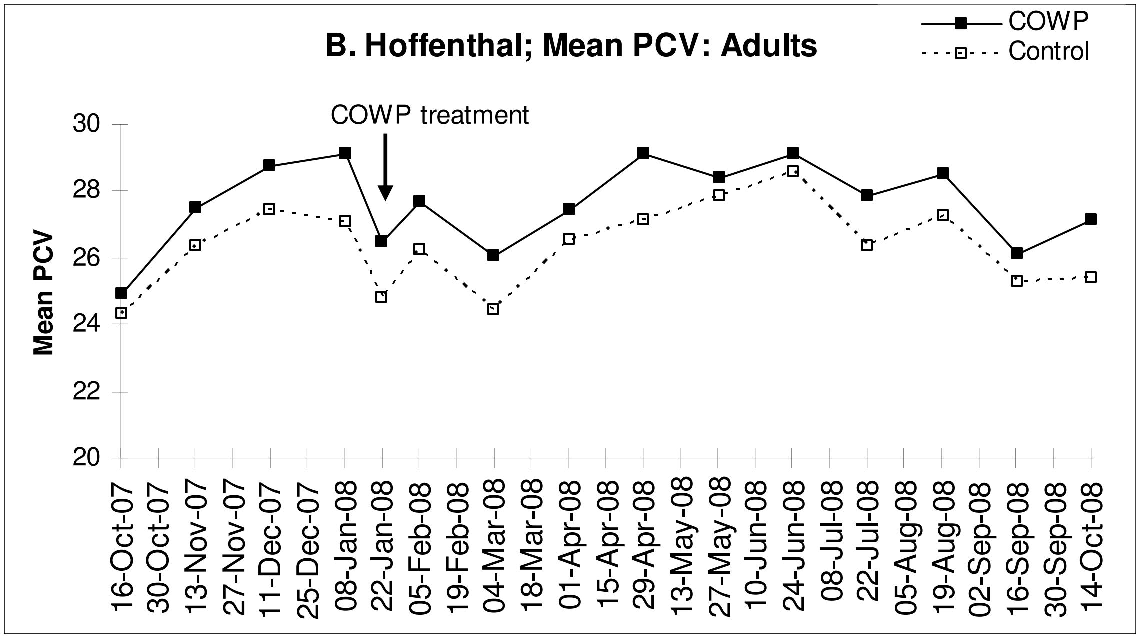


Fig. 21. Mean PCV over the trial period for B. adult goats in the Hoffenthal area.

For all goats (Fig. 21A) and adults (Fig. 21B) in the Hoffenthal area, the mean PCV of the controls was consistently lower than that of the treated group of goats over the trial period. However, for all goats (Fig. 21A), significant differences were evident at the weeks of 10 November 2007, 4 February 2008 and 28 April 2008 sampling occasions (Table 12). Adult goats (Fig. 21B) only showed a significant difference at the week of 28 April 2008 sampling (Table 12), which suggests that young goats (which were not included in the analyses per area) must have accounted for the differences recorded at the week of 10 November 2007 and 4 February 2008 samplings for all goats combined in the Hoffenthal area. The 4 February 2008 sampling was done two weeks after COWP administration further suggesting that the effect of COWP on PCV in this area was more marked in young goats than in adults.

4.5.3.3 Ogade

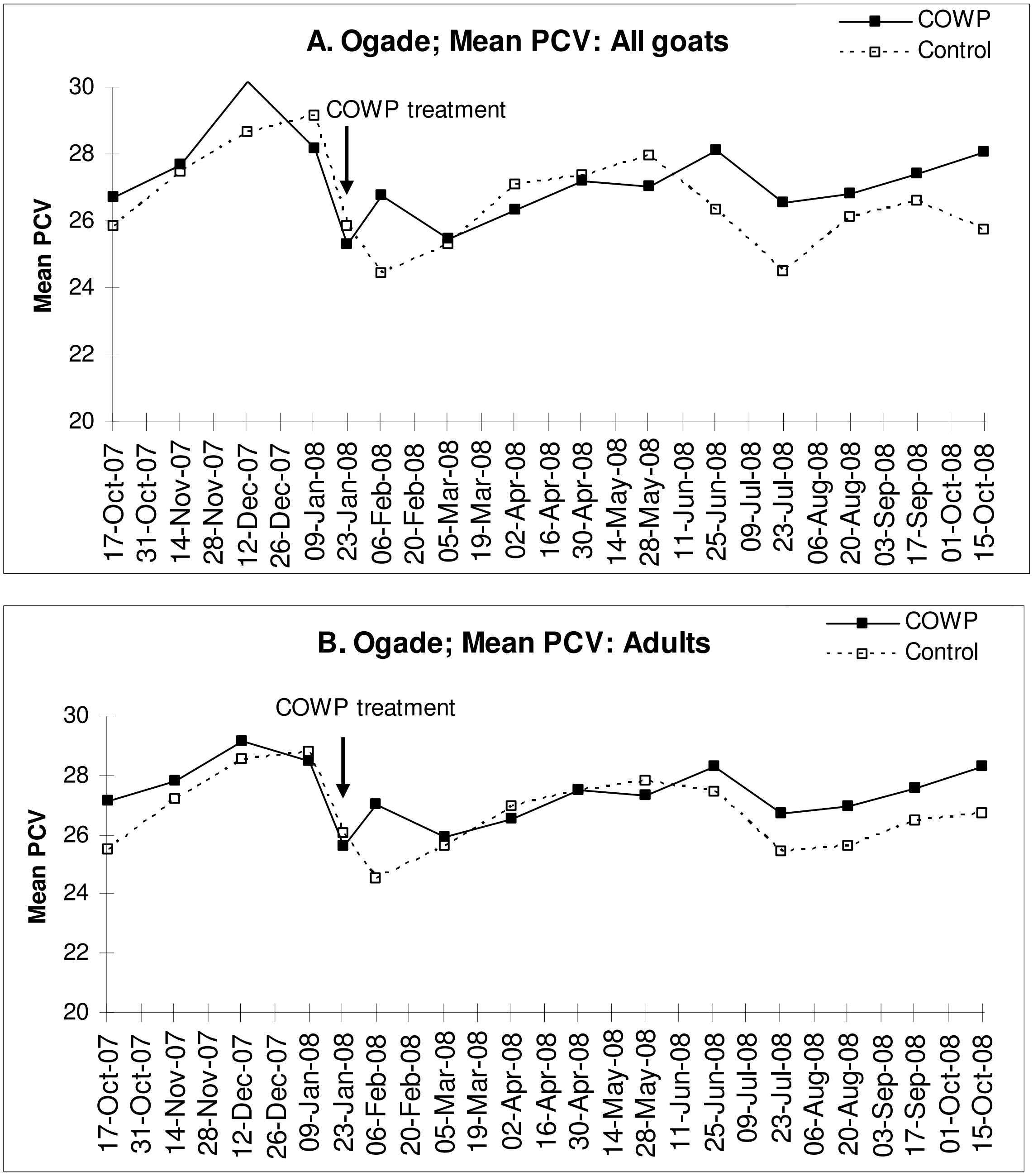
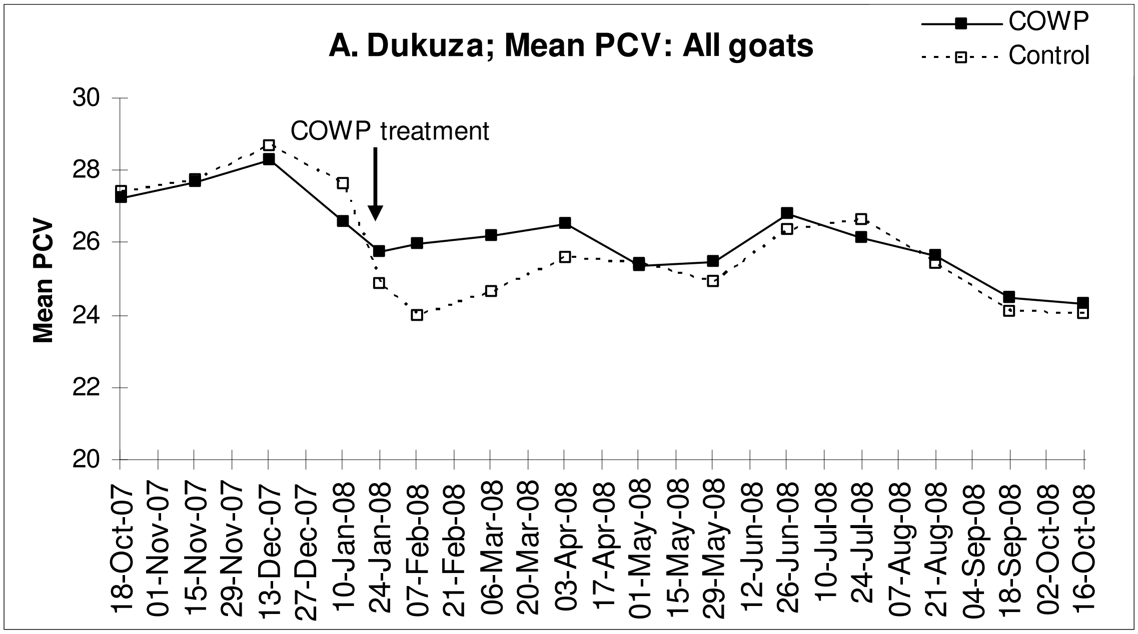


Fig. 22. Mean PCV over the trial period for A. all goats and B. adult goats in the Ogade area.

For all the goats combined (Fig. 22A) and for the adults (Fig. 22B) in the Ogade area, the mean PCV of both the control and treated groups fluctuated considerably over the trial period. For all the goats combined and for the adult goat groups, a significantly lower value for the control group compared to that of the treated group was only evident at the week of 4 February 2008 sampling occasion, two weeks after COWP administration (Table 12).

4.5.3.4 Dukuza



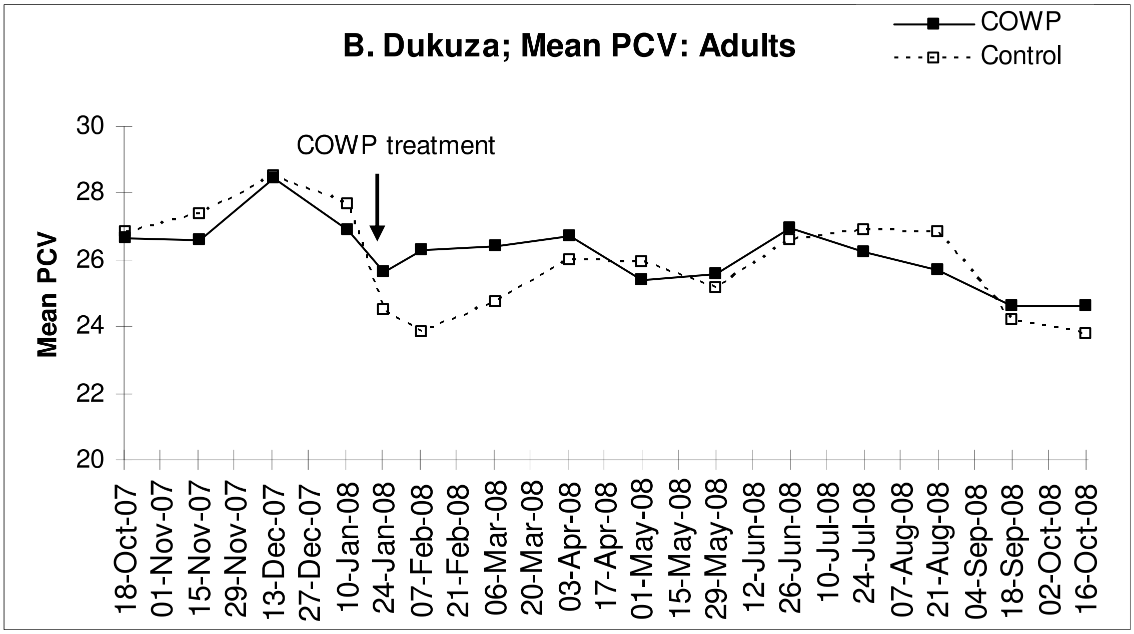


Fig. 23. Mean PCV over the trial period for A. all goats and B. adult goats in the Dukuza area.

For all goats combined (Fig. 23A) and adult goats (Fig. 23B) in the Dukuza area, a significantly lower PCV value for the control group compared to that of the treatment group was evident at the week of 4 February 2008 sampling occasion, two weeks after COWP administration (Table 12).

Table 12. Summary of significant differences (ANOVA) in mean PCV values between the control and treated (COWP) groups of goats included in the analyses (n = number of goats; s.e. = standard error; P = F probability).

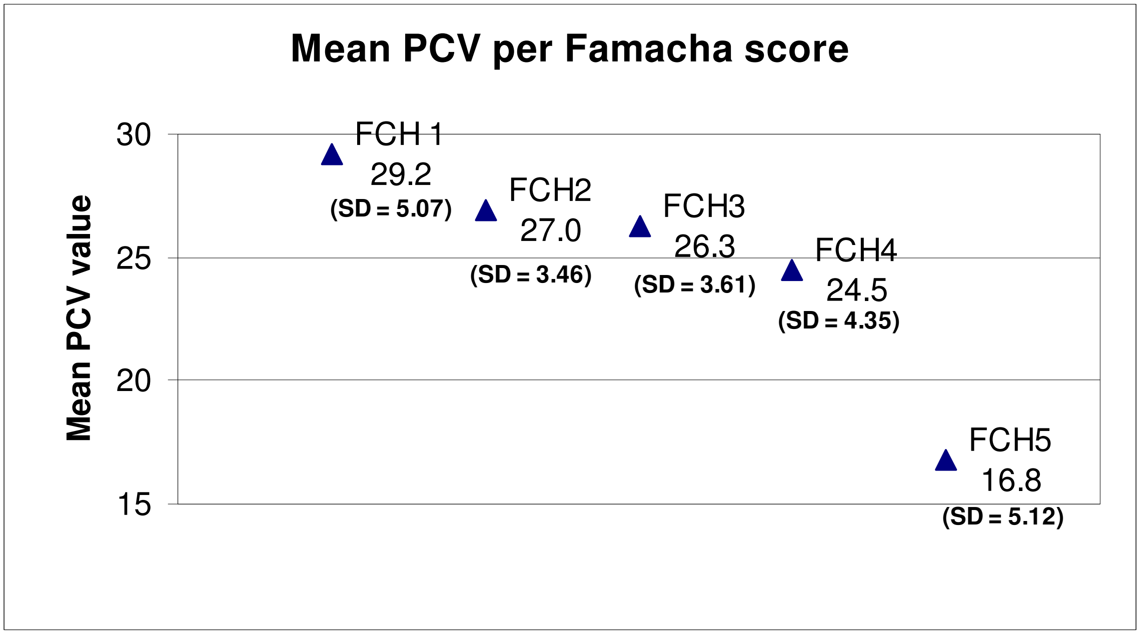
Sampling date	Trial week	Area	Age	Group	n	Mean PCV	s.e.	P
5-7 February 2008	17	All	All	Control	85	24.8	0.373	<0.001
				COWP	87	26.9	0.368	
4-6 March 2008	21	All	All	Control	85	24.8	0.411	0.028
				COWP	87	26.1	0.406	
14-16 October 2008	53	All	All	Control	84	25.3	0.357	0.050
				COWP	87	26.3	0.351	
5-7 February 2008	17	All	Adult	Control	69	24.8	0.383	<0.001
				COWP	75	26.9	0.368	
4-6 March 2008	21	All	Adult	Control	69	24.9	0.459	0.046
				COWP	75	26.2	0.440	
14-16 October 2008	53	All	Adult	Control	69	25.1	0.392	0.009
				COWP	75	26.5	0.376	
13-15 November 2007	5	Hoffenthal	All	Control	26	26.7	0.499	0.050
				COWP	29	28.0	0.472	
5-7 February 2008	17	Hoffenthal	All	Control	26	26.3	0.704	0.040
				COWP	29	28.3	0.667	
29 April – 1 May 2008	29	Hoffenthal	All	Control	24	27.1	0.572	0.004
				COWP	26	29.5	0.549	
29 April – 1 May 2008	29	Hoffenthal	Adult	Control	20	27.1	0.610	0.023
				COWP	22	29.1	0.582	
5-7 February 2008	17	Ogade	All	Control	22	24.5	0.647	0.015
				COWP	23	26.7	0.633	
5-7 February 2008	17	Ogade	Adult	Control	18	24.5	0.718	0.014
				COWP	22	27.0	0.649	
5-7 February 2008	17	Dukuza	All	Control	37	24.0	0.540	0.013
				COWP	35	25.9	0.555	
5-7 February 2008	17	Dukuza	Adult	Control	29	23.9	0.551	0.003
				COWP	29	26.3	0.551	

The mean PCV values of the control groups of all goats combined in all three of the areas in which the trial took place were lower than those of the treated groups of goats at the week of 4 February 2008 sampling occasion, two weeks after the administration of COWP. The administration of COWP resulted in a marked decrease in FEC in the treated groups of goats at the week of 4 February 2008 sampling (Table 8) which was mirrored by a corresponding increase in mean PCV value for the treated groups of goats. The mean FEC of the control groups of goats remained high at the week of 4 February 2008 sampling and their corresponding mean PCV values lower than those of the treated groups. The significantly higher PCV values obtained for the treated groups of goats at the week of 4 February 2008 sampling, were especially so for adults in the Ogade and Dukuza areas, while no significant difference was found for adults in the Hoffenthal area. However, all goats in the Hoffenthal area displayed a significantly higher mean PCV at the week of 4 February 2008 sampling which strongly suggests that the five young goats included in the treated group and the four in the control group in this area (Table 7) must have accounted for the significance of the difference observed.

4.5.3.5 FAMACHA© category / PCV interface

The mean PCV per FAMACHA© category for all animals included in the analyses is shown in Fig. 24 with associated box-whisker plot below.

The mean PCV decreased gradually by 1 to 2 percentage points between each category from FCH1 to FCH4 with a sharp 7 percentage point decrease for FCH5. The box-whisker plot shows overlaps in PCV values within FAMACHA© categories FCH1, FCH2, FCH3 and FCH4 and FCH2, FCH3, FCH4 and FCH5. FAMACHA© categories FCH1 and FCH5 appear relatively well defined and separated by relatively discrete PCV ranges. The overlap in PCV values between FAMACHA© categories FCH1 and FCH2 and again between FCH2, FCH3 and FCH4 prevents definitive assigning of FAMACHA© category to PCV value and renders these categories unreliable as definitive indicators of anaemia.



SD = Standard Deviation

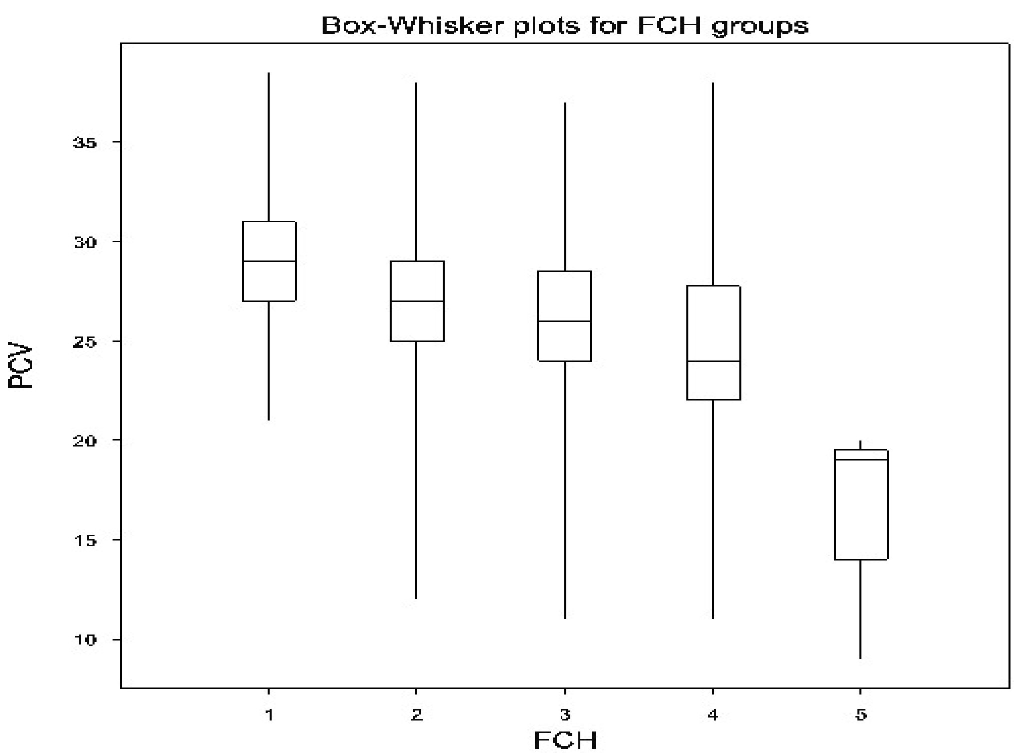


Fig. 24. Mean PCV per FAMACHA© (FCH) category for all animals included in the analyses with associated box-whisker plot.

However, the originators of FAMACHA© never intended the system to replace haematocrit determination and have always advised that it not be used by itself (Malan *et al*. 2001). Other factors, therefore, such as nutrition, ectoparasite infection, existing diseases and general condition, may influence the anaemic state of an animal and it is therefore advisable that the FAMACHA© system not be implemented alone as an indication of the need for anthelmintic treatment in goats. Other criteria such as seasonality, clinical symptoms, body condition score and the possible presence of other disease conditions should also be taken into consideration in establishing the necessity for drenching.

The mean PCV values, SD, range and accumulated number (n) of animals monitored in each of the five FAMACHA© categories for each of the three trial areas and for all three areas combined are given in Table 13.

Table 13. Mean PCV values, SD, range and accumulated number of animals (n) monitored in each of the five FAMACHA© categories (FCH) for each of the three trial areas and for all three areas combined.

FCH	Hoffenthal		Ogade		Dukuza		All 3 areas	
	COWP	C	COWP	C	COWP	C	COWP	C
1	29.0 SD= 2.24 (25 - 32) n = 9	30.9 SD = 3.25 (25 – 37) n = 21	30.5 SD = 3.73 (24 – 35) n = 6	26.0 SD = 4.30 (21 – 32) n = 5	29.1 SD = 6.41 (25 – 38.5) n = 4	29.6 SD = 2.38 (27 – 35) n = 11	29.4 SD = 3.66 (24 -38.5) n = 20	29.1 SD = 3.32 (21 -37) n = 37
2	29.4 SD = 3.31 (19 – 38) n = 248	27.3 SD = 3.52 (20 – 38) n = 219	27.8 SD = 3.20 (19 – 36) n = 163	26.8 SD = 3.31 (18 - 35) n = 155	27.0 SD = 3.16 (20 – 36) n = 268	26.6 SD = 3.24 (12 – 37) n = 333	27.4 SD = 3.30 (19 – 38) n = 680	26.5 SD = 3.35 (12 -38) n = 707
3	27.4 SD = 3.03 (21 - 35) n = 145	26.2 SD = 3.60 (17 – 35) n = 125	27.1 SD = 3.71 (11 – 35) n = 155	27.1 SD = 3.13 (18 – 37) n = 149	26.3 SD = 3.44 (19 – 36) n = 217	26.0 SD = 3.73 (12 – 36) n = 174	26.6 SD = 3.45 (11 – 36) n = 517	26.0 SD = 3.56 (12 -37) n = 448
4	25.1 SD = 3.64 (20 – 30) n = 14	23.6 SD = 3.08 (19 – 30) n = 14	25.3 SD = 3.61 (21 – 32) n = 15	26.1 SD = 3.37 (18.5 – 31) n = 18	25.7 SD = 4.30 (12 – 33) n = 24	27.3 SD = 5.88 (11 – 38) n = 21	24.9 SD = 3.90 (12 – 33) n = 53	24.1 SD = 4.73 (11 -38) n = 53
5	19.3 SD = 0.58 (19 – 20) n = 3	*	*	*	*	9.0 n = 1	19.3 SD = 0.58 (19 – 20) n = 3	9.0 n = 1

The overall range of PCV values recorded within the FAMACHA© categories (Table 13) confirms the overlap in PCV values between the different FAMACHA© categories as displayed in Fig. 24. FAMACHA© categories FCH1 and FCH5 are defined as representing distinct relatively high and low PCV ranges and may therefore be used as relatively reliable indicators of non-anaemic and severely anaemic status. However, despite generally recording a decrease in mean PCV value with higher FAMACHA© category in both experimental groups in the three separate areas, categories FCH2, FCH3 and FCH4 display almost identical ranges in PCV values. It is therefore suggested that FAMACHA© categories FCH2, FCH3 and FCH 4 may be used only as broad guidelines to anaemic status in goats, being unreliable as definitive indicators. The generally high standard deviations (SD) displayed by almost all except the FAMACHA© category FCH5 groups reflect the wide range of PCV values within the different groups and accentuate the unreliability of using FAMACHA© scores of 2 to 4 alone as definitive indicators of the necessity (or non-necessity) of drenching.

4.5.4 *Body condition scores*

4.5.4.1 All three areas combined

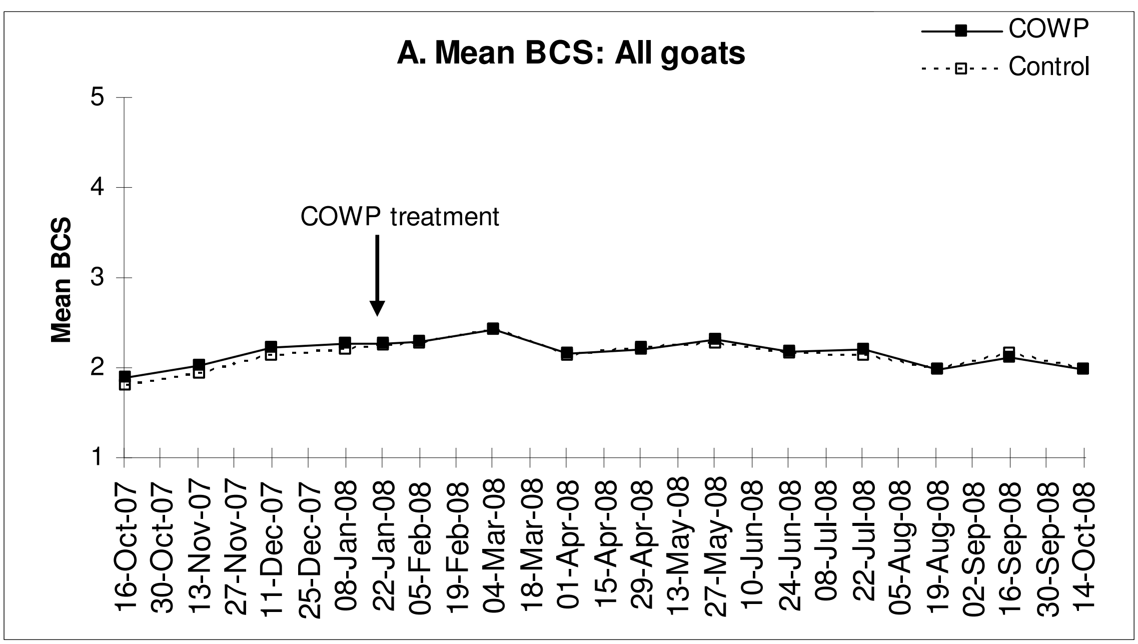
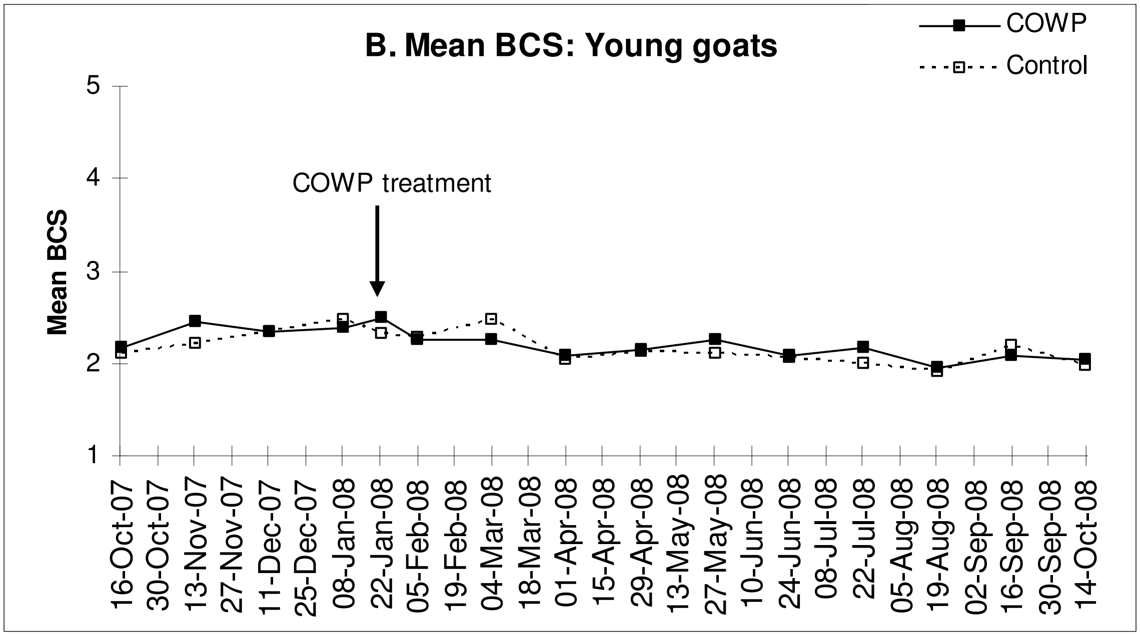


Fig. 25. Mean body condition score (BCS) over the trial period in all three areas combined for A. all goats.



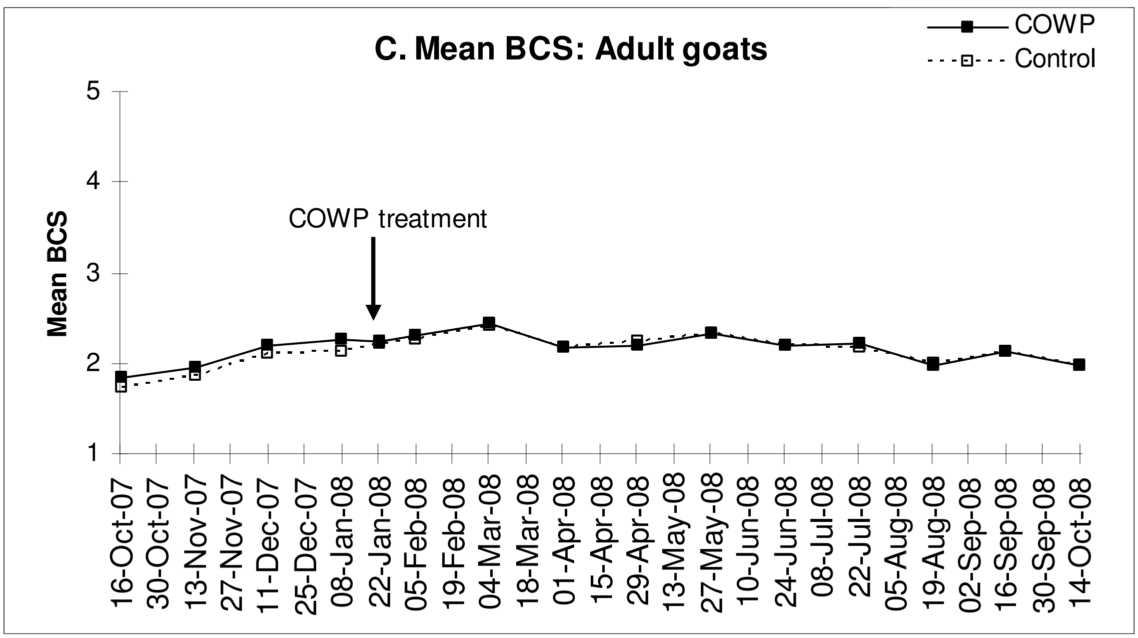
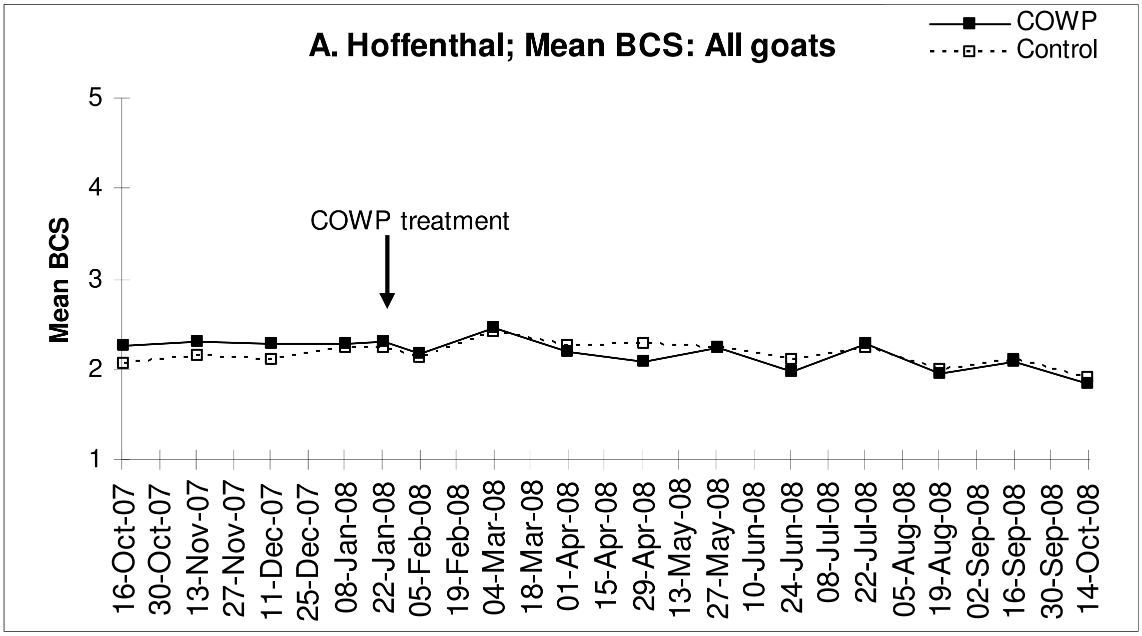


Fig. 25. Mean body condition score (BCS) over the trial period in all three areas combined for B. young goats and C. adult goats.

The mean BCS for all goats (Fig. 25A), young goats (Fig. 25B) and adult goats (Fig. 25C) in all three trial areas combined fluctuated minimally over the trial period with no significant differences between the control and treated groups of goats being evident. The BCS of the young goats ranged between 1.79 to 2.42 for the controls and 1.89 to

2.42 for the treated group of goats. The BCS of the adults ranged between 1.73 to 2.41 for the controls and 1.85 to 2.45 for the treated group of goats.

4.5.4.2 Hoffenthal



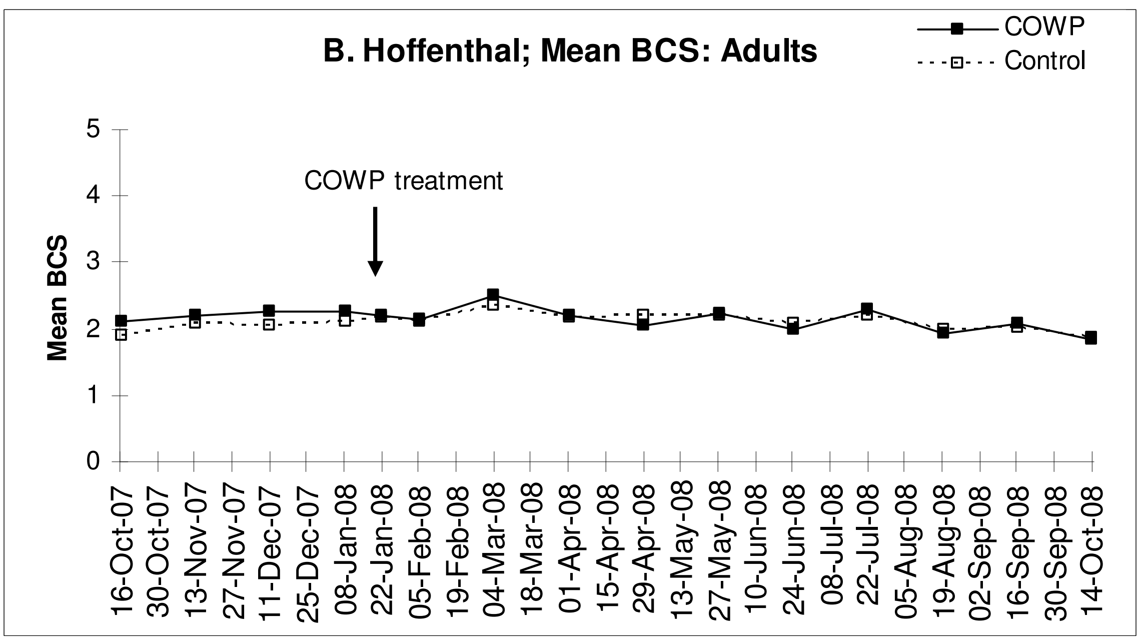


Fig. 26. Mean body condition score (BCS) for A. all goats and B. adult goats over the trial period in the Hoffenthal area.

The mean BCS for all goats (Fig. 26A) in the Hoffenthal area ranged from 1.84 to 2.31 and 2.04 to 3.08 for the control and treated groups respectively. The treated group had a significantly lower BCS than the control group at the week of 28 April 2008 sampling (Table 14).

The mean BCS for adult goats (Fig. 26B) in the Hoffenthal area ranged from 1.86 to 2.34 and 1.94 to 2.5 for the control and treated groups respectively with no statistical differences being evident.

4.5.4.3 Ogade

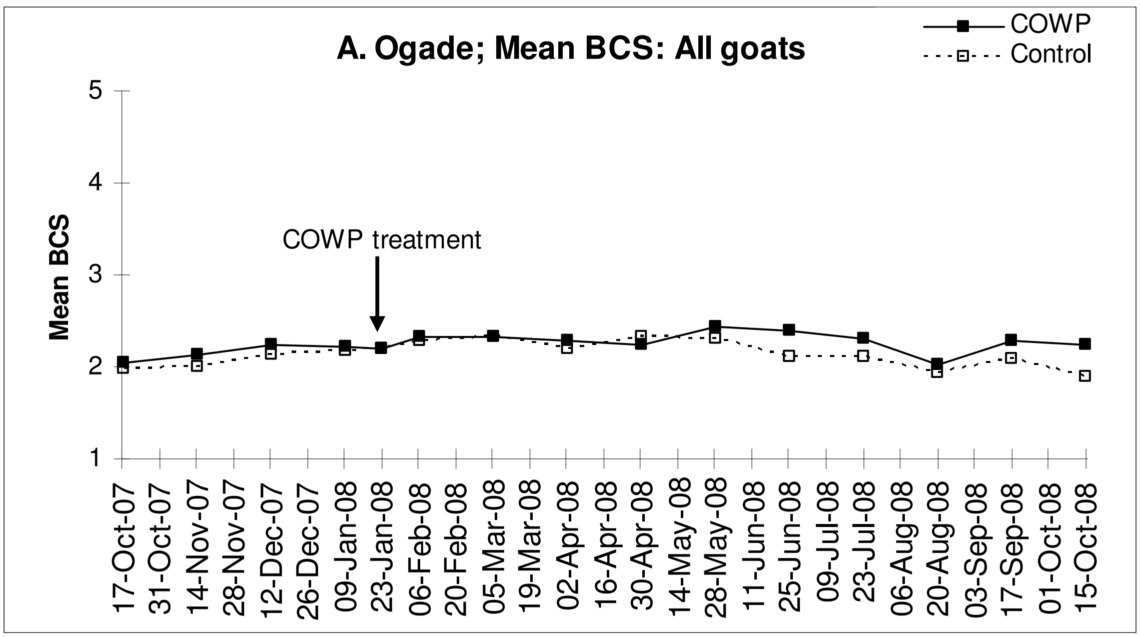


Fig. 27. Mean body condition score (BCS) for A. all goats in the Ogade area over the trial period.

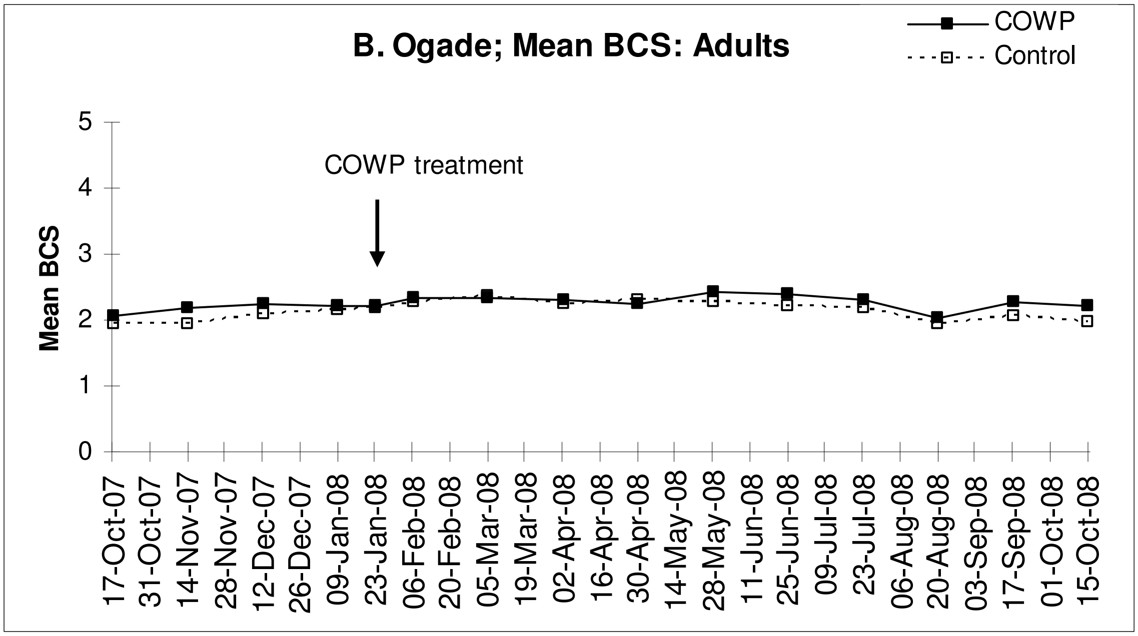


Fig. 27. Mean body condition score (BCS) for B. adult goats in the Ogade area over the trial period.

For all goats in the Ogade area (Fig. 27A), the mean BCS ranged from 1.9 to 2.3 for the control and from 2.02 to 2.43 for the treated group of goats over the trial period. Significantly higher BCS values for the treated group of goats were recorded in the week of 15 September 2008 and again in the week of 13 October 2008 (Table 14).

For adult goats in the Ogade area (Fig. 27B), the mean BCS ranged from 1.94 – 2.36 for the control and from 2.02 – 2.43 for the treated group of goats over the trial period. As for all goats, significantly higher BCS values for the treated group of adult goats were recorded in the week of 15 September 2008 and again in the week of 13 October 2008 (Table 14).

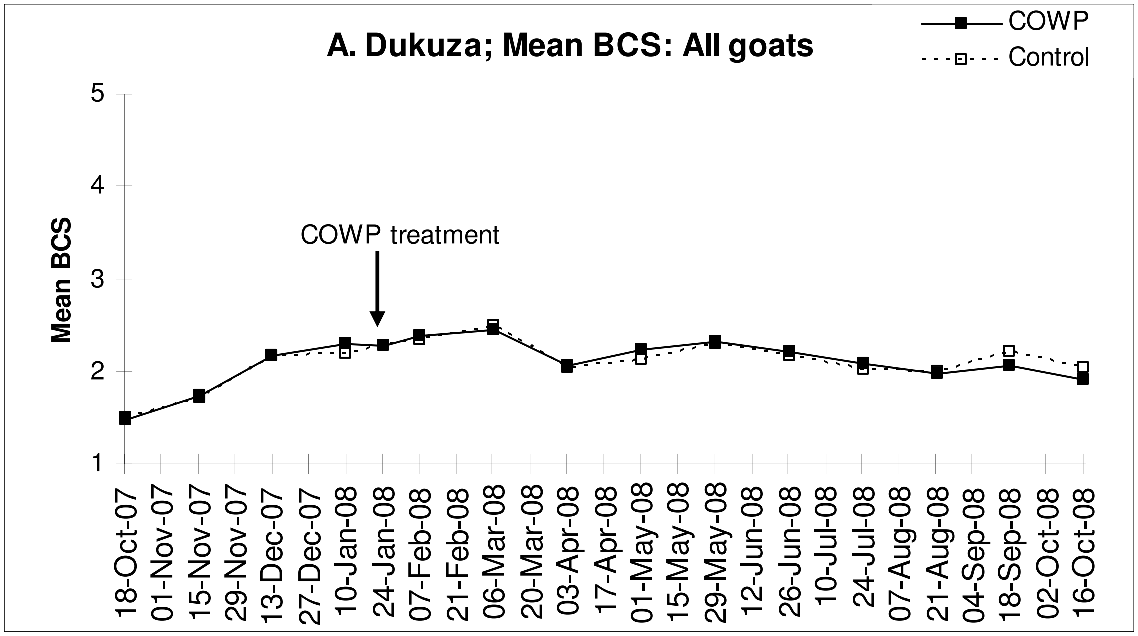
4.5.4.4 Dukuza

The mean BCS for all goats in the Dukuza area (Fig. 28A) ranged from 1.49 to 2.44 for the control goats and 1.50 to 2.50 for the treated group of goats over the trial period. No statistical differences were evident between the control and treated groups.

Adult goats in the Dukuza area (Fig. 28B), had a mean BCS that ranged between 1.47 to 2.48 for the control goats and 1.45 to 2.50 for the treated group over the trial period. In the week of 13 October 2008, the treated group of adult goats had a significantly lower BCS than the control group (Table 14).

Overall, the lowest BCS recorded was 1.47 (in Dukuza) during the week of 15 October 2007 and the highest 3.08 (at Hoffenthal) during the week of 3 March 2008 with average scores of 2.5 being more common. The relatively low scores assigned are indicative of the relatively poor condition of the goats kept under the trial conditions in the Bergville area. Body condition score did not appear to be affected to any extent by the administration of COWP, significant differences in BCS between the control and treated groups of goats only being evident in the weeks of 28 April 2008, 15 September 2008 and 13 October 2008, respectively 14, 34 and 38 weeks after COWP administration.

The statistical differences in BCS (Table 14) were observed when FECs were at a seasonal low (Fig. 8), and may have been due to nutritional factors but were most probably coincidental in nature.



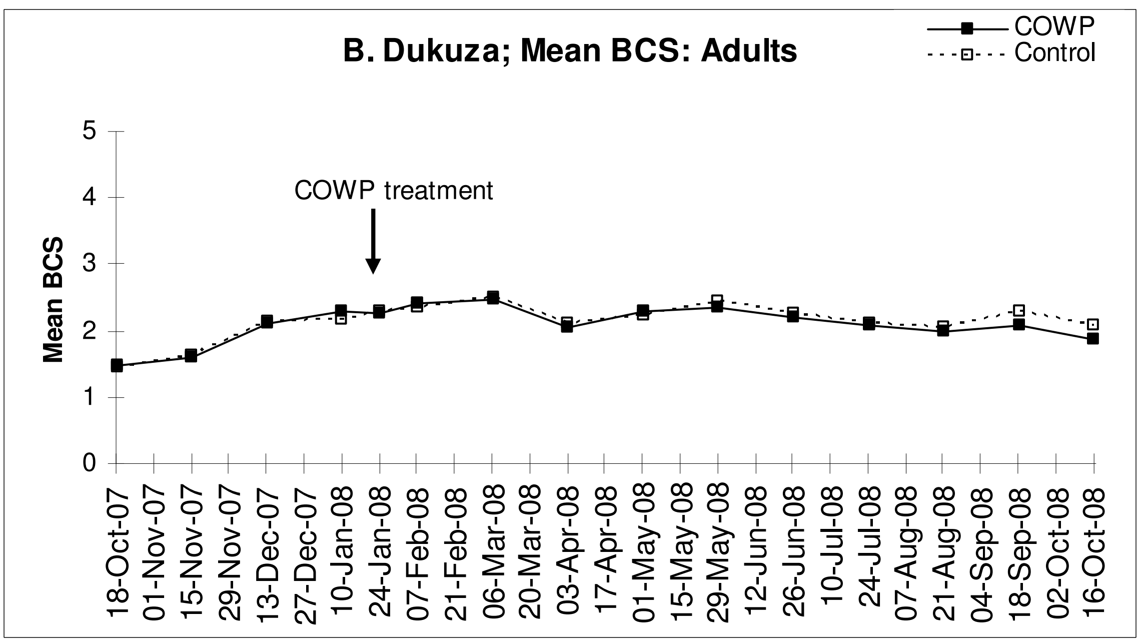


Fig. 28. Mean body condition score (BCS) for A. all goats and B. adult goats in the Dukuza area over the trial period.

Table 14. Summary of significant differences (ANOVA) in mean BCS values between the control and treated (COWP) groups of goats included in the analyses (n = number of goats; s.e. = standard error; P = F probability).

Sampling date	Trial week	Area	Age	Group	n	Mean BCS	s.e.	P
29 April - 1 May 2008	29	Hoffenthal	All	Control	24	2.279	0.0707	0.045
				COWP	26	2.077	0.0680	
16-18 September 2008	49	Ogade	All	Control	22	2.091	0.0587	0.034
				COWP	22	2.273	0.0587	
14-16 October 2008	53	Ogade	All	Control	22	1.977	0.0703	0.011
				COWP	23	2.239	0.0687	
16-18 September 2008	49	Ogade	Adult	Control	18	2.056	0.0643	0.024
				COWP	21	2.262	0,0595	
14-16 October 2008	53	Ogade	Adult	Control	18	1.972	0.0820	0.027
				COWP	22	2.227	0.0742	
14-16 October 2008	53	Dukuza	Adult	Control	29	2.069	0.0617	0.034
				COWP	29	1.879	0.0617	

4.5.4.5 BCS / FEC / PCV / FCH interface

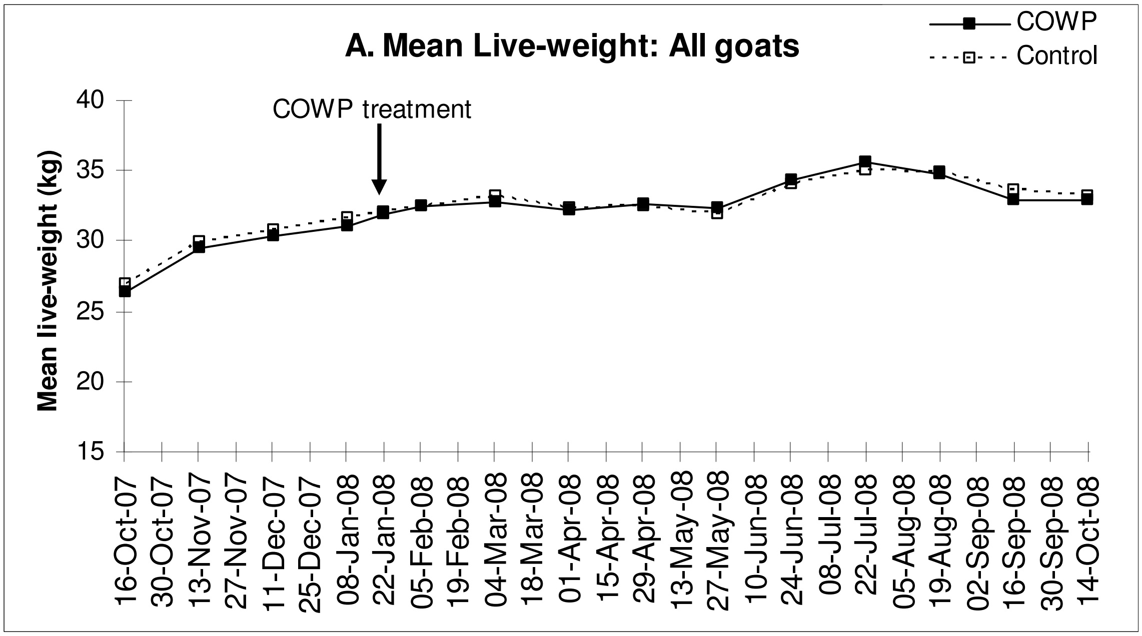
Table 15 gives the mean BCS, FEC and PCV and the accumulated number of animals monitored (n) for the control and treated groups of goats in each of the FAMACHA© categories assigned.

Table 15. Mean BCS, FEC and PCV and the accumulated number of animals monitored (n) for the control and treated (COWP) groups of goats in each of the FAMACHA© categories assigned.

FCH	Mean BCS		Mean FEC		Mean PCV	
	Control	COWP	Control	COWP	Control	COWP
1	2.18 n=38	2.24 n=21	982.43 n=37	489.30 n=20	29.08 n=38	29.38 n=20
2	2.20 n=717	2.22 n=696	930.15 n=707	721.40 n=680	26.51 n=716	27.41 n=697
3	2.06 n=455	2.12 n=523	1172.58 n=448	807.66 n=517	25.98 n=455	26.57 n=522
4	1.90 n=57	2.00 n=54	1297.40 n=53	806.21 n=53	24.07 n=57	24.93 n=54
5	1.00 n=1	1.50 n=3	4933.00 n=1	2722.00 n=3	9.00 n=1	19.33 n=3

The highest mean BCS recorded was for the treated group of goats in FAMACHA© category 1 and the lowest mean BCS was recorded for the control group in FAMACHA© category 5. BCS scores were assigned on a scale of 1 to 5 and the relatively low BCS scores recorded in this trial are reflective of the poor diet on which these animals were maintained. The goats were grazed under extensive conditions on lands that were in parts eroded and which required the goats often to make substantial journeys to find sufficient food. Added to this was the additional challenge of gastrointestinal nematode infection. Despite the adverse environmental and nutritional conditions, FECs, FAMACHA© score and PCV seemed to be associated with BCS. The mean BCS decreased with higher FAMACHA© category (Table 15) for both the control and treated groups of goats, as did the mean PCV, while the inverse was true for the mean FEC. This suggests that, although the interrelationships between FAMACHA© category, FEC, PCV and BCS are not definitive enough to be used singly to determine the necessity for drenching, the combined use of especially FAMACHA© and BCS could and should be used in deciding on treatment where relatively large numbers of animals are involved.

4.5.5 *Live-weights*



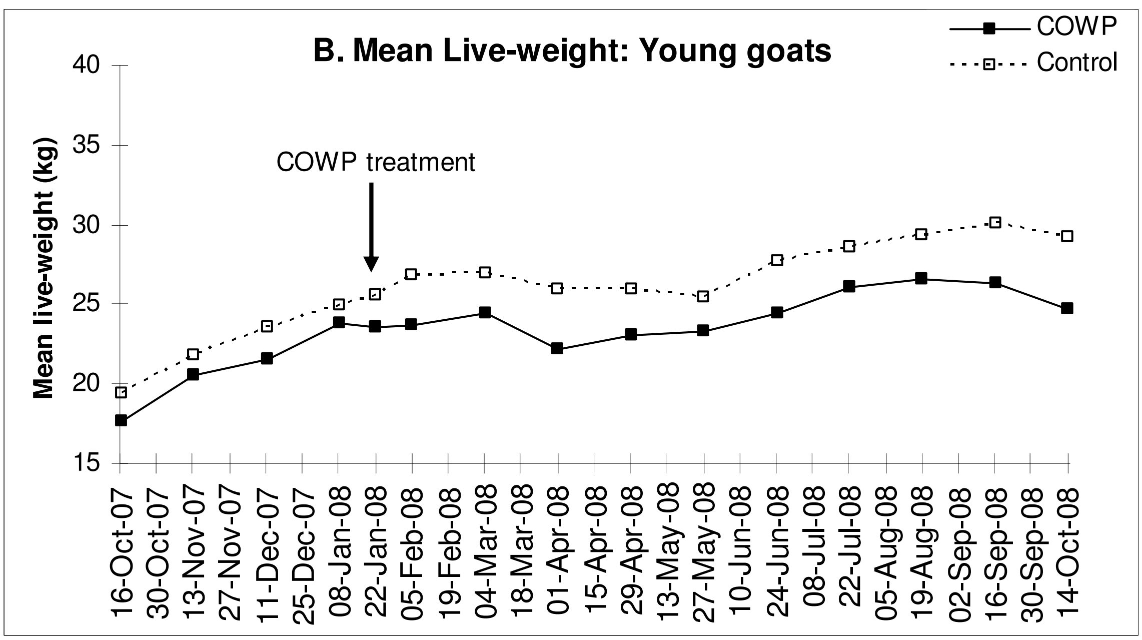


Fig. 29. Mean live-weight (kg) of the control and treated (COWP) groups of A. all goats and B. young goats for all three areas combined over the trial period.

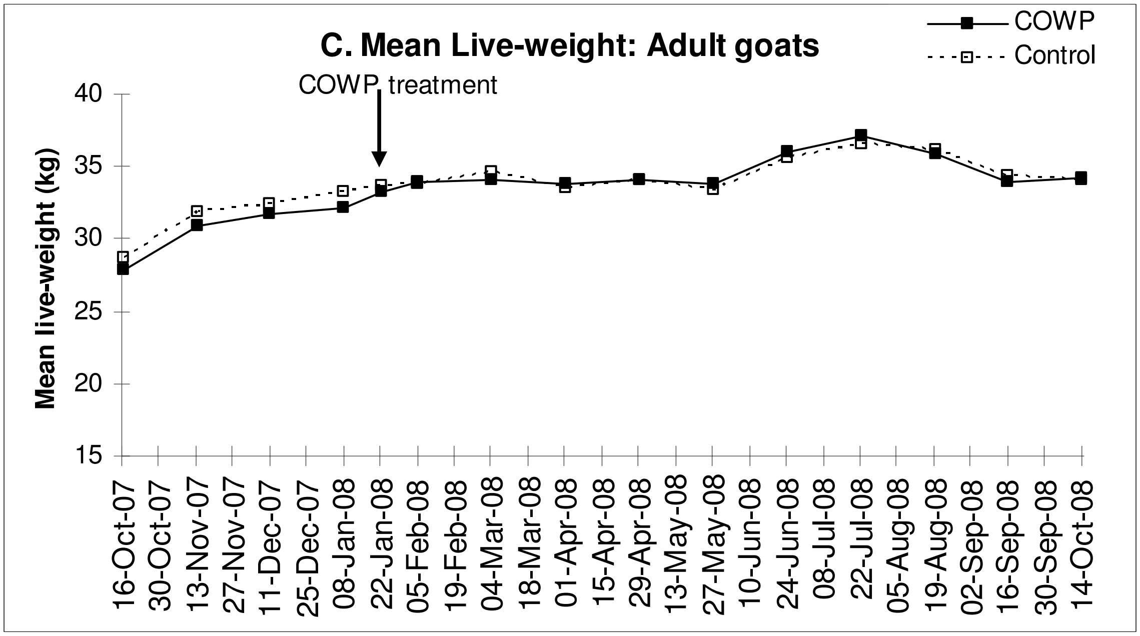


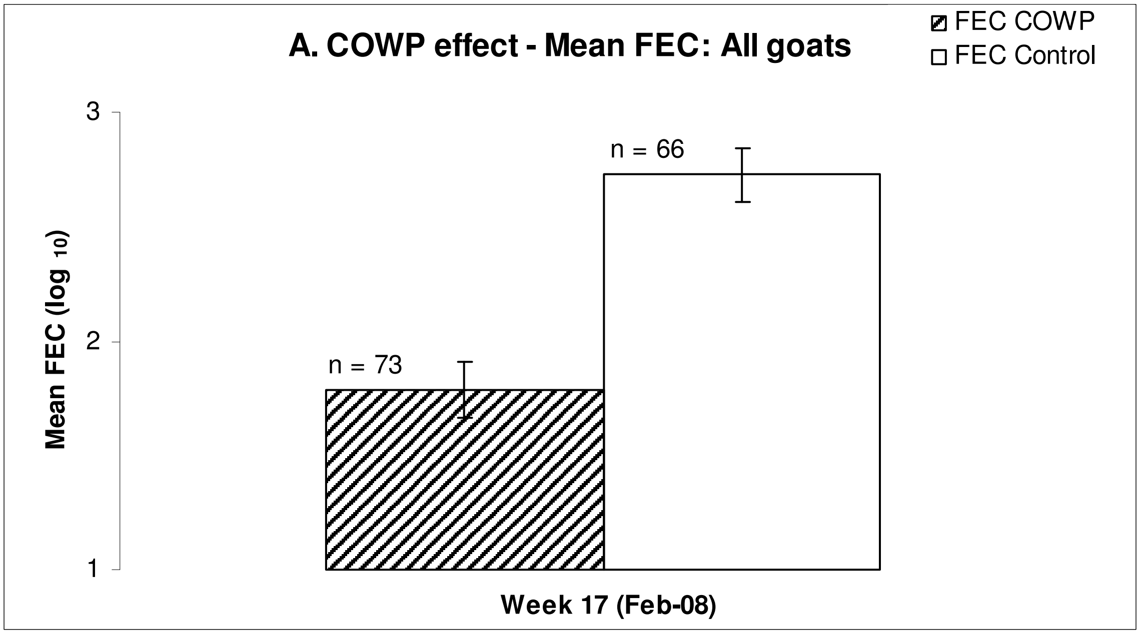
Fig. 29. Mean live-weight (kg) of the control and treated (COWP) groups of C. adult goats for all three areas combined over the trial period.

The mean live-weight (kg) of the control and treated groups of goats are given for all goats in all three areas combined in Fig. 29A, for young goats in Fig 29B and for adult goats in Fig 29C. The mean live-weight (kg) for all goats ranged from 26.4 kg to 35.6 kg for the control and from 27.0 kg to 35.0 kg for the treated group of goats. For young goats the mean live-weight (kg) of the controls varied from 17.7 kg to 26.6 kg and of the treated group from 19.4 kg to 30.1 kg. Young goats were assessed as such at the commencement of the trial and were 12 months older and quite possibly adult, but not subsequently assessed as such, at its conclusion. The mean live-weight of young goats in the control group was consistently higher than that of the treated group of goats. However, young goats in the control group showed a mean live-weight gain of 7.0 kg at the conclusion of the trial compared to the 9.7 kg gained by the treated group. Adult goats weighed from 27.8 kg to 37.1 kg (control group) and 28.7 kg to 36.5 kg (treated group), the control group gaining a mean of 6.3 kg over the trial period compared to the mean 5.4 kg gain of the treated group. These differences in weight gains were not statistically analyzed due to the unreliable nature of individual weight data.

4.6 Testing of copper oxide wire particles

The main discernable effect of COWP was on FEC (Fig. 8 – 12B; Table 8) and PCV (Fig. 20A – 23B; Table 12) during the week of 4 February 2008 which was two weeks after COWP administration. The administration of COWP (week of 21 January 2008) significantly reduced FEC in the treated groups of goats at the week of 4 February 2008 sampling, causing a corresponding increase in the relative mean PCV values, both variables returning to values comparable to pre-COWP levels at the next sampling occasion (week of 3 March 2008), which occurred six weeks after COWP administration. The effect of COWP was thus directly on the nematode responsible for FEC, which in turn affected PCV. The effect of the COWP was of short duration, being evident only two weeks after its administration. The effect of COWP on mean FEC (log_{10}-transformed) for the different groups and the reaction displayed by mean PCV during the week of 4 February 2008, two weeks after COWP administration are discussed in more detail hereunder.

4.6.1 *All goats: all three areas combined*



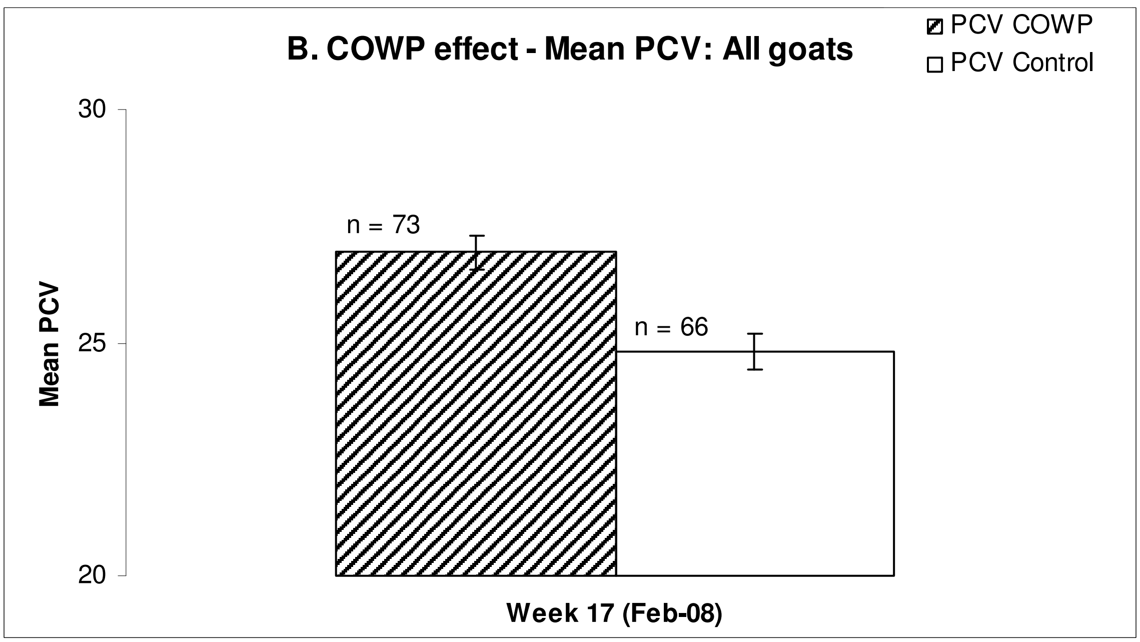
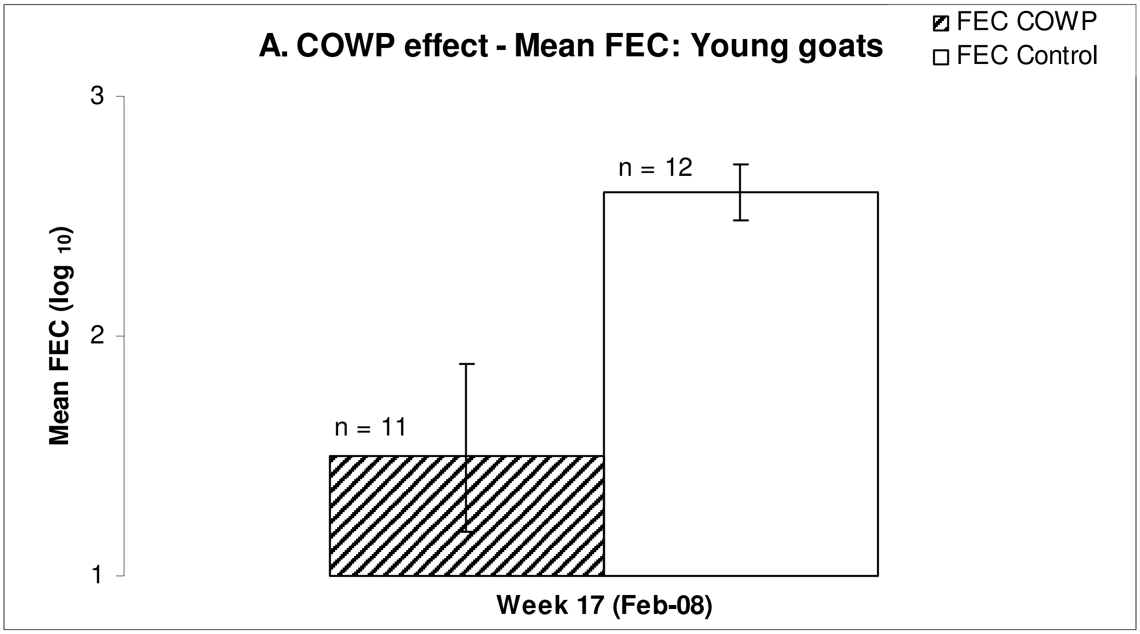


Fig. 30. A. Mean faecal egg counts (FEC) (log_{10} - transformed) and B. the mean PCV values two weeks post-COWP-administration for the treated (COWP) and control groups of all goats in all three areas combined.

For all goats in all three areas combined (Fig. 30A), the mean FEC of the treated group of goats was very significantly lower than that of the control group of goats two weeks after COWP administration (Table 8). The untransformed pre- (week of 21 January 2008) and post- (week of 4 February 2008) COWP administration mean FECs for the control group were 2 157.71 and 2 382.12 respectively and the corresponding values for the treated group were 1 910.29 and 223.39.

For all goats in all three areas combined (Fig. 30B), the mean PCV of the treated group of all goats was very significantly higher than that of the control group, two weeks after COWP administration, reflecting the decreased FEC in the treated group (Fig. 30A).

4.6.2 Young goats: all three areas combined



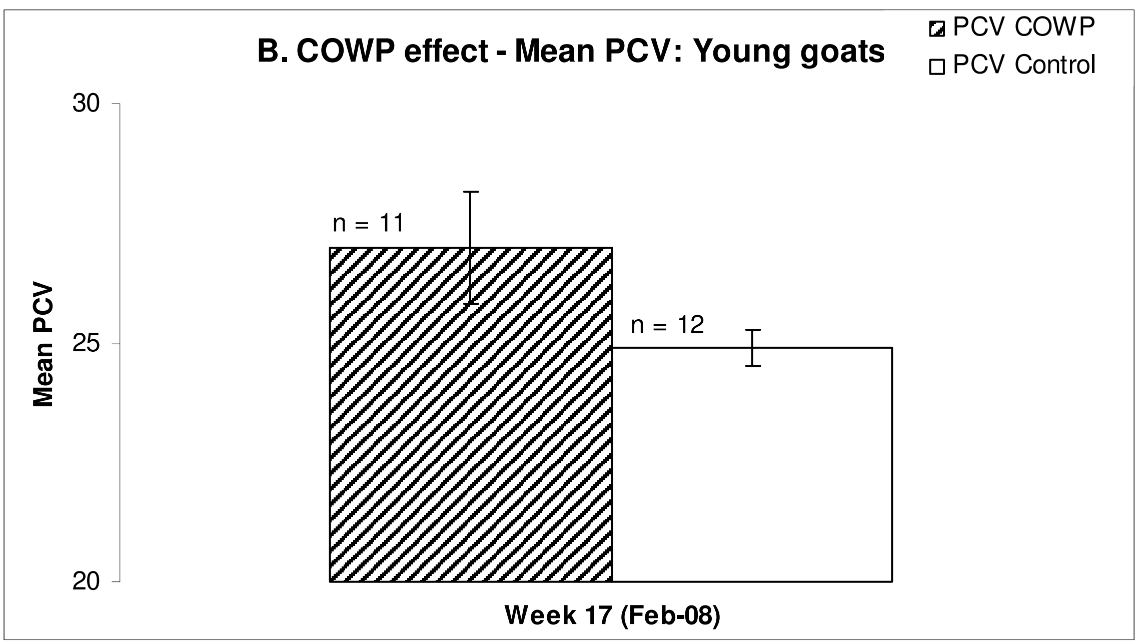
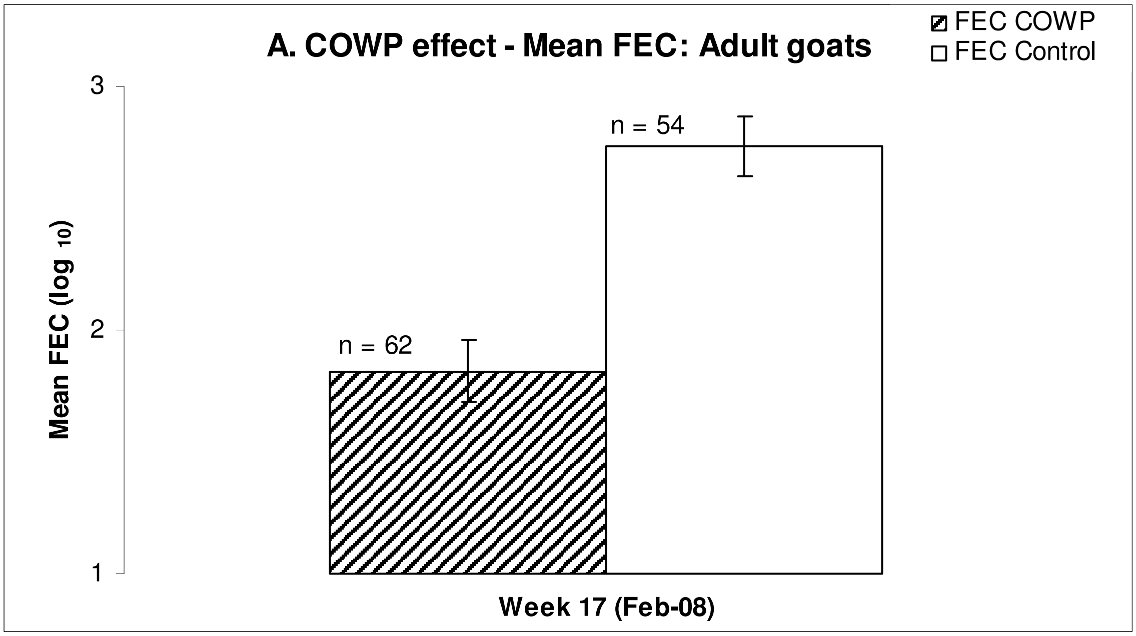


Fig. 31. A. Mean faecal egg counts (FEC) (log_{10} - transformed) and B. the mean PCV values two weeks post-COWP-administration for the treated (COWP) and control groups of young goats in all three areas combined.

For young goats in all three areas combined (Fig. 31A), the mean FEC of the treated group of young goats was significantly lower than that of the control group of young goats two weeks after COWP administration (Table 8). The untransformed pre- (week of 21 January 2008) and post- (week of 4 February 2008) COWP administration mean faecal egg counts for the control group were 2 071.2 and 2 377.1 respectively and the corresponding values for the treated group were 1 588.7 and 225.

Despite the significantly lower FEC in the treated group of young goats in all three areas combined, compared to that of the controls (Fig. 31A; Table 8), the relative PCV values (Fig. 31B) were not statistically different (P = 0.244), albeit higher for the treated group (27.0; s.e. = 1.35) compared to those of the controls (24.88; s.e. = 1.17) two weeks after COWP administration. The relatively high standard errors encountered are indicative of high variance which may account for the non-significant difference in the PCV values obtained.

4.6.3 Adult goats: all three areas combined



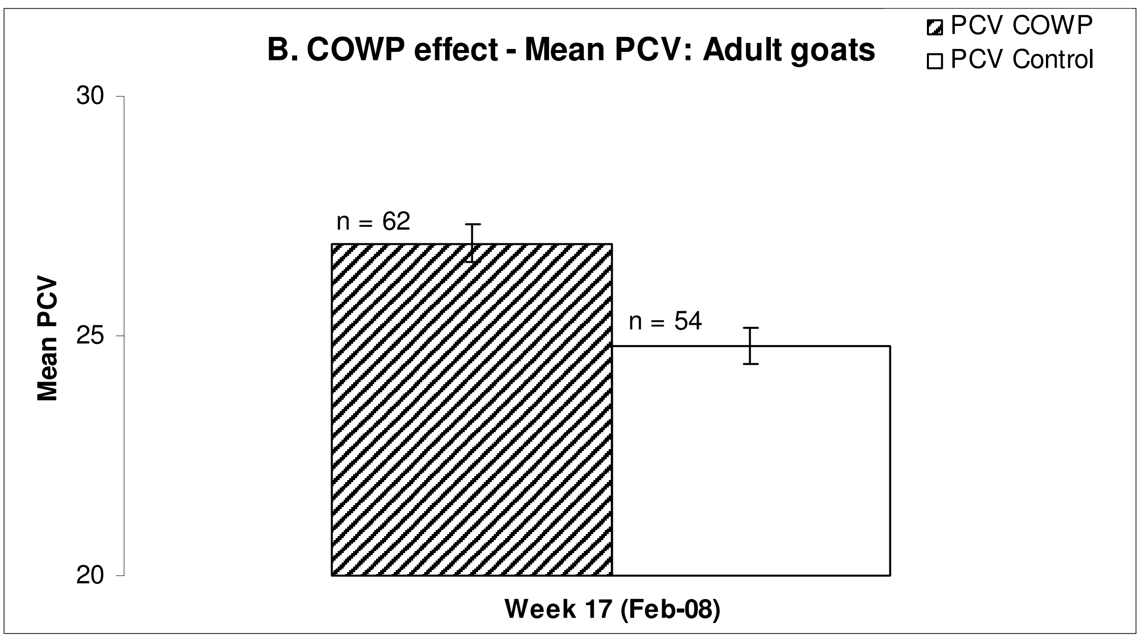


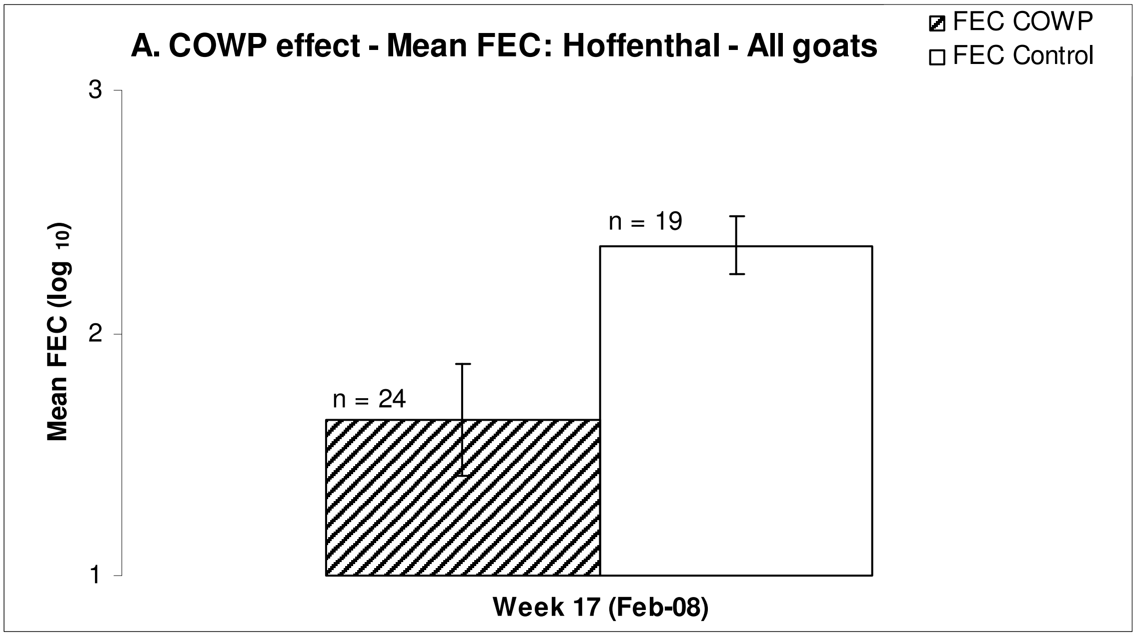
Fig. 32. A. Mean faecal egg counts (FEC) (log_{10} - transformed) and B. the mean PCV values two weeks post-COWP-administration for the treated (COWP) and control groups of adult goats in all three areas combined.

The mean FEC of the treated group of adult goats in all three areas combined (Fig. 32A) was very significantly lower than that of the control group of goats two weeks after

COWP administration (Table 8). The untransformed pre- (week of 21 January 2008) and post- (week of 4 February 2008) COWP administration mean FEC for the control group were 2 177.1 and 2 383.3 respectively and the corresponding values for the treated group were 1 963.9 and 220.1.

For adult goats in all three areas combined, the mean PCV (Fig. 32B) of the treated group of adult goats was very significantly higher than that of the control group (Table 12), two weeks after COWP administration, reflecting the decreased FEC in the treated group (Fig. 32A).

4.6.4 Hoffenthal: all goats



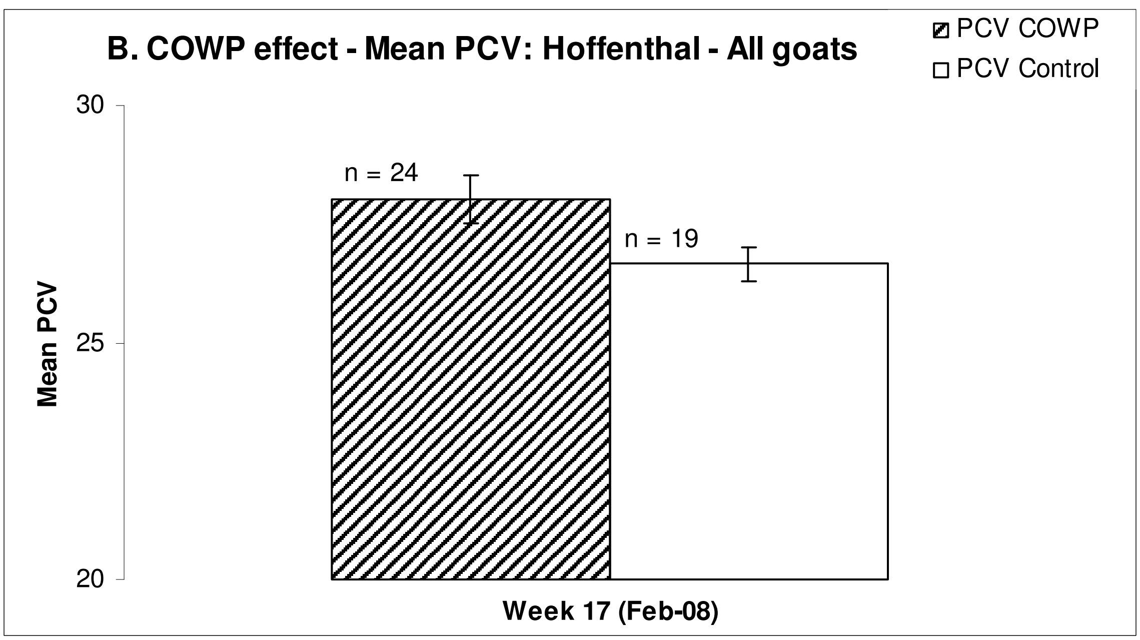


Fig. 33. A. Mean faecal egg counts (FEC) (log_{10} - transformed) and B. the mean PCV values two weeks post-COWP-administration for the treated (COWP) and control groups of all goats in the Hoffenthal area.

The mean FEC of the treated group of all goats in the Hoffenthal area (Fig. 33A) was significantly lower than that of the control group of goats two weeks after COWP administration (Table 8). The untransformed pre- (week of 21 January 2008) and post- (4 February 2008) COWP administration mean FEC for the control group were 1 934.6 and 1 770.6 respectively and the corresponding values for the treated group were 1 887.7 and 146.4.

The mean PCV of the treated group of adult goats in the Hoffenthal area (Fig. 33B) was significantly higher than that of the control group (Table 12), two weeks after COWP administration, reflecting the decreased FEC in the treated group (Fig. 33A).

4.6.5 Hoffenthal: adult goats

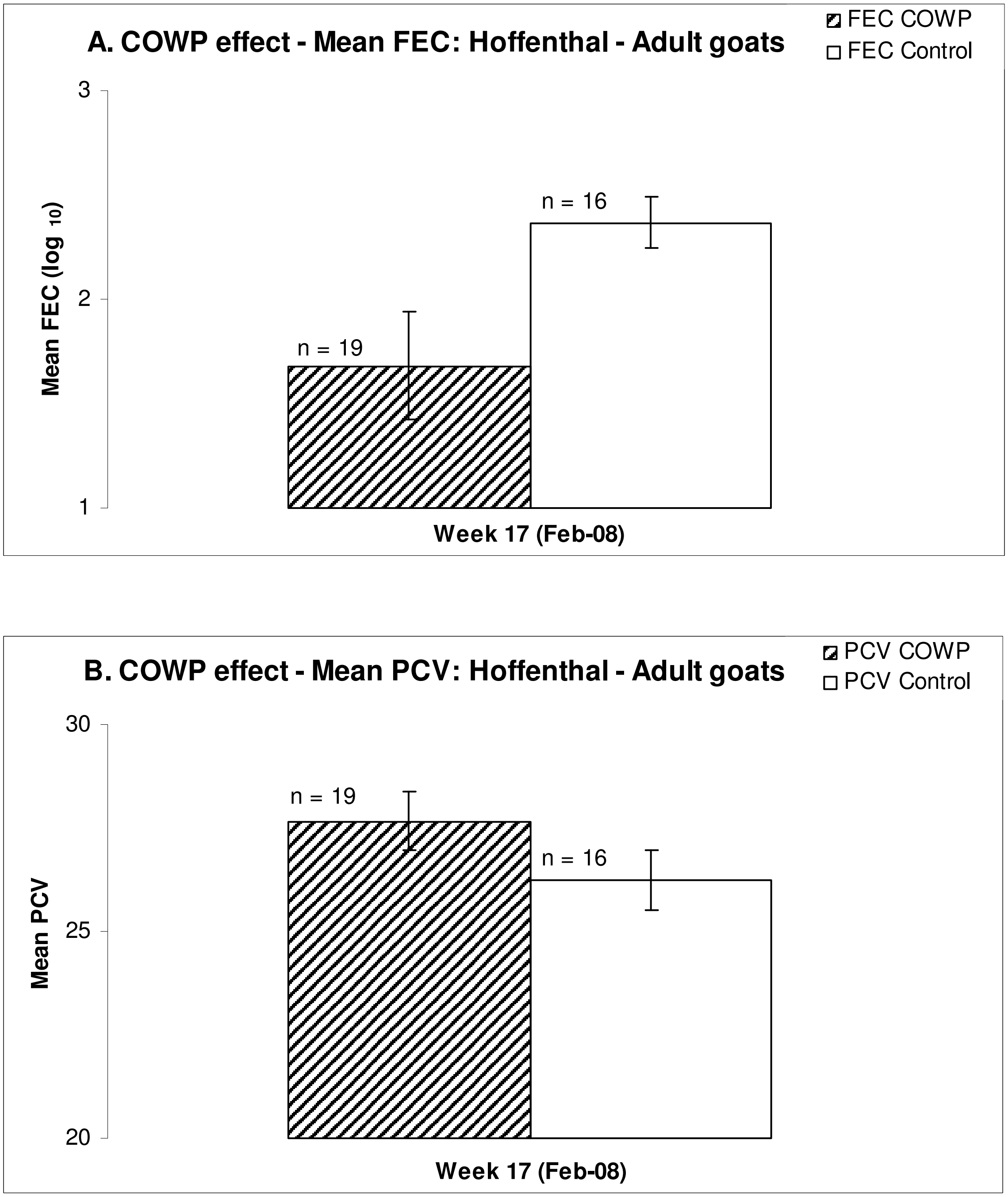


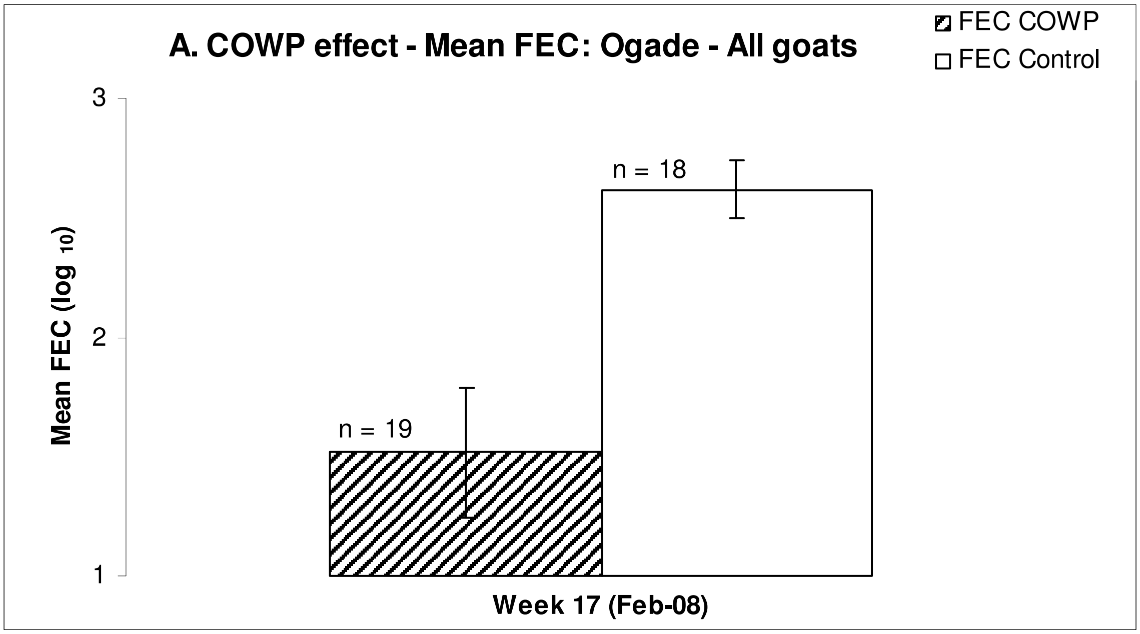
Fig. 34. A. Mean faecal egg counts (FEC)($\log_{10}$ - transformed) and B. the mean PCV values two weeks post-COWP-administration for the treated (COWP) and control groups of adult goats in the Hoffenthal area.

Although the mean FEC of the treated group of adult goats in the Hoffenthal area (Fig. 34A) was lower (1.682; s.e. = 0.243) than that of the control group of adult goats (2.368;

s.e. = 0.255), these means were not statistically different (P = 0.058). The untransformed pre- (week of 21 January 2008) and post- (4 February 2008) COWP administration mean FEC for the control group were 2 077.2 and 1 863.4 respectively and the corresponding values for the treated group were 2 068.3 and 134.7.

Similarly, although the mean PCV of the treated group of adult goats in the Hoffenthal area (Fig. 34B) was higher (27.67; s.e. = 0.686) than that of the control group of adult goats (26.23; s.e.= 0.717), these means were not statistically different (P = 0.154) reflecting the non-significant difference of the mean FEC found for this group. However, the group of all goats in the Hoffenthal area did display a significant difference in mean FEC between the treatment and control groups (Table 8, Fig. 33A) which strongly suggests that the respective FEC of young goats at Hoffenthal accounted for the apparent difference found.

4.6.6 Ogade: all goats



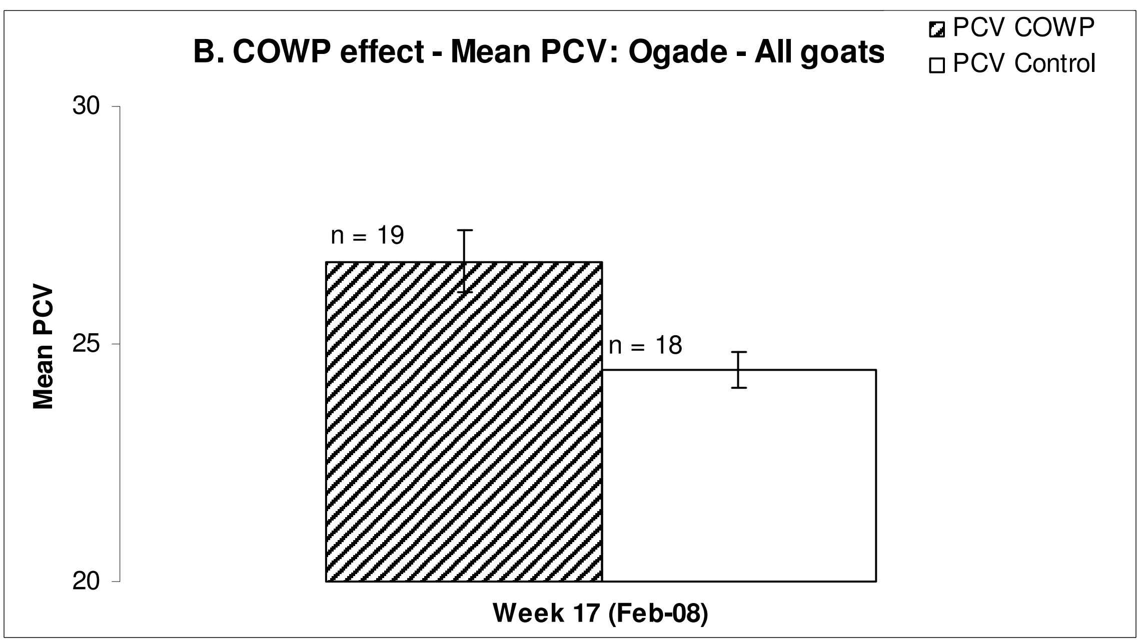
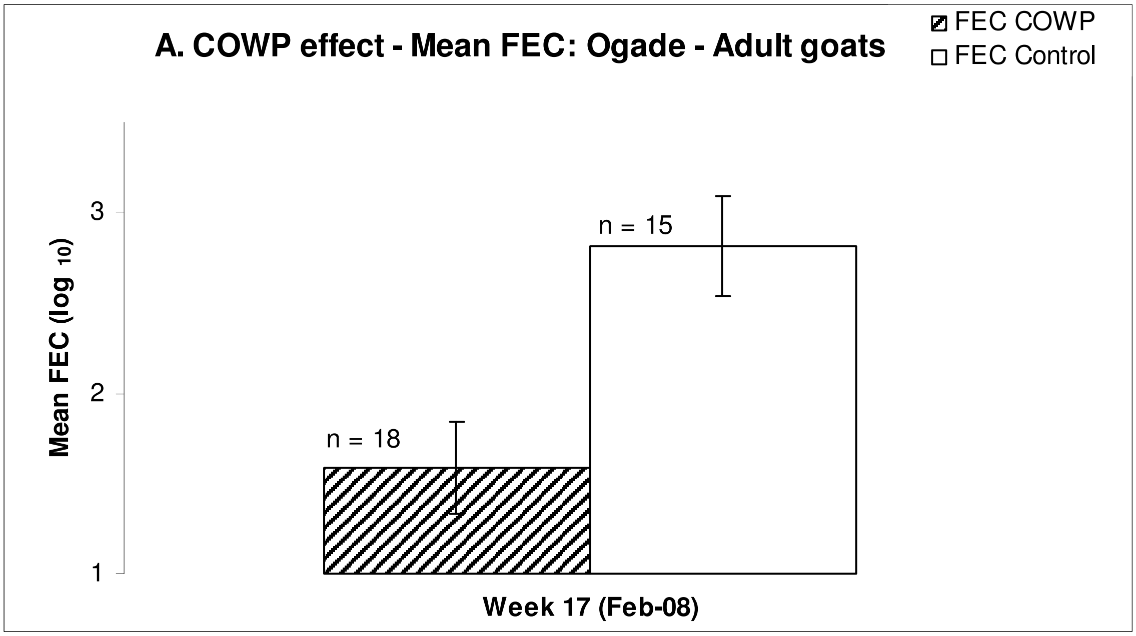


Fig. 35. A. Mean faecal egg counts (FEC) (log_{10} - transformed) and B. the mean PCV values two weeks post-COWP-administration for the treated (COWP) and control groups of all goats in the Ogade area.

The mean FEC of the treated group of all goats in the Ogade area (Fig. 35A) was significantly lower than that of the control group of goats two weeks after COWP administration (Table 8). The untransformed pre- (week of 21 January 2008) and post- (4 February 2008) COWP administration mean FEC for the control group were 2 315.9 and 2 971.3 respectively and the corresponding values for the treated group were 2 093.9 and 127.2.

The mean PCV of the treated group of all goats in the Ogade area (Fig. 35B) was significantly higher than that of the control group (Table 12), two weeks after COWP administration, reflecting the decreased FEC in the treated group (Fig. 35A).

4.6.7 Ogade: adult goats



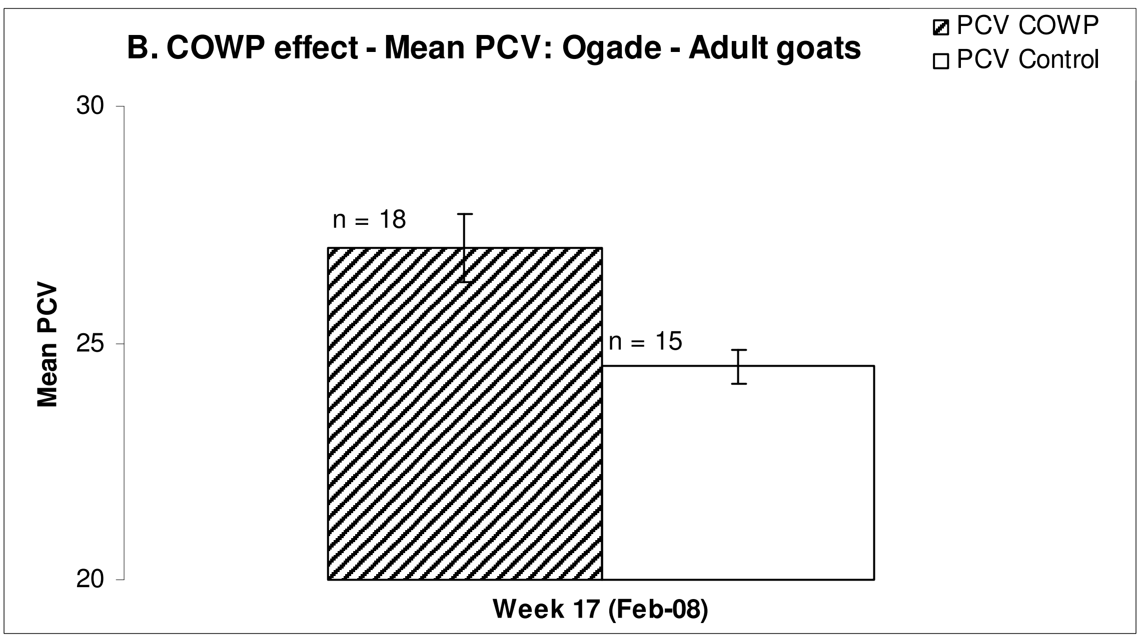


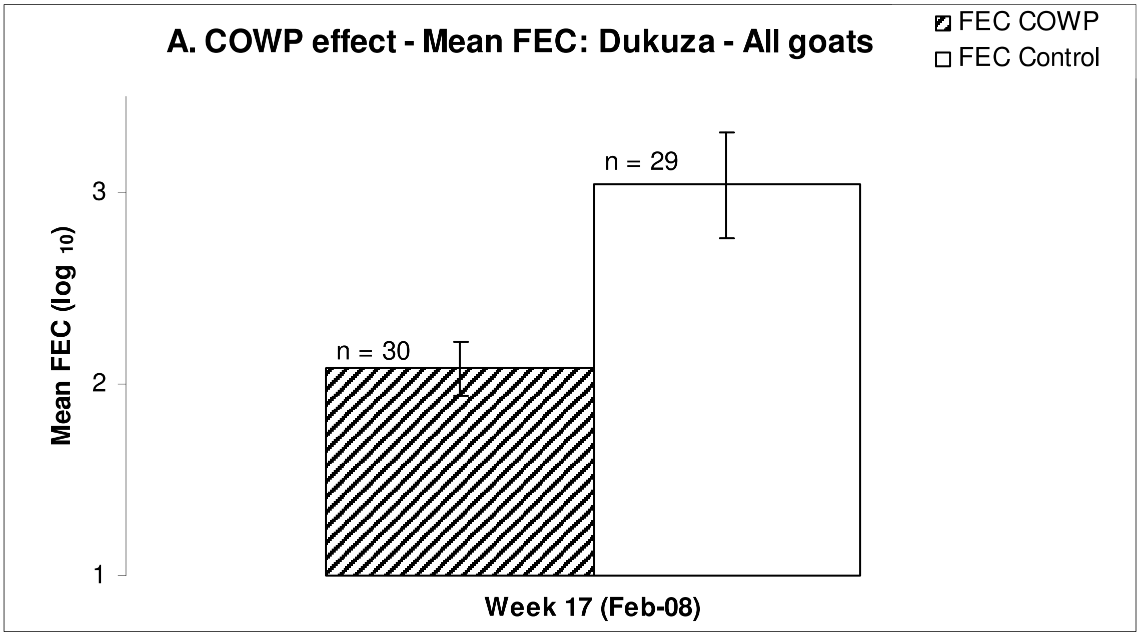
Fig. 36. A. Mean faecal egg counts (FEC) (log_{10} - transformed) and B. the mean PCV values two weeks post-COWP-administration for the treated (COWP) and control groups of adult goats in the Ogade area.

The mean FEC of the treated group of adult goats in the Ogade area was significantly lower than that of the control group of goats two weeks after COWP administration (Fig.

36A; Table 8). The untransformed pre- (week of 21 January 2008) and post- (week of 4 February 2008) COWP administration mean FEC for the control group were 2 174.5 and 3 244.5 respectively and the corresponding values for the treated group were 1 990.4 and 133.2.

The mean PCV of the treated group of adult goats in the Ogade area (Fig. 36B) was significantly higher than that of the control group (Table 12), two weeks after COWP administration, reflecting the decreased FEC in the treated group (Fig. 36A).

4.6.8 Dukuza: all goats



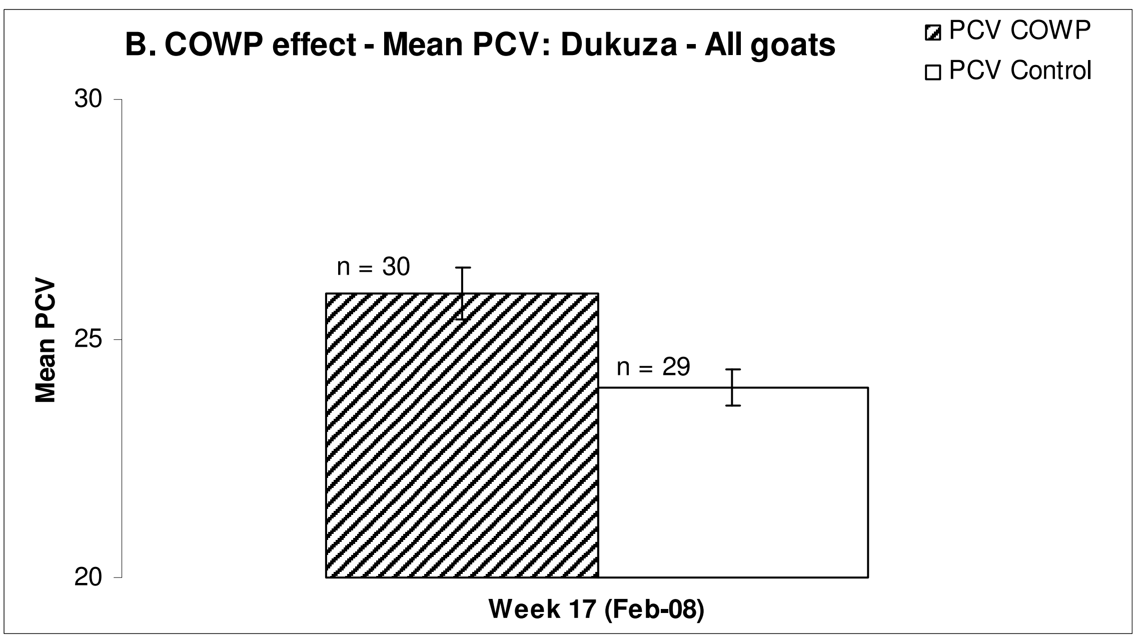
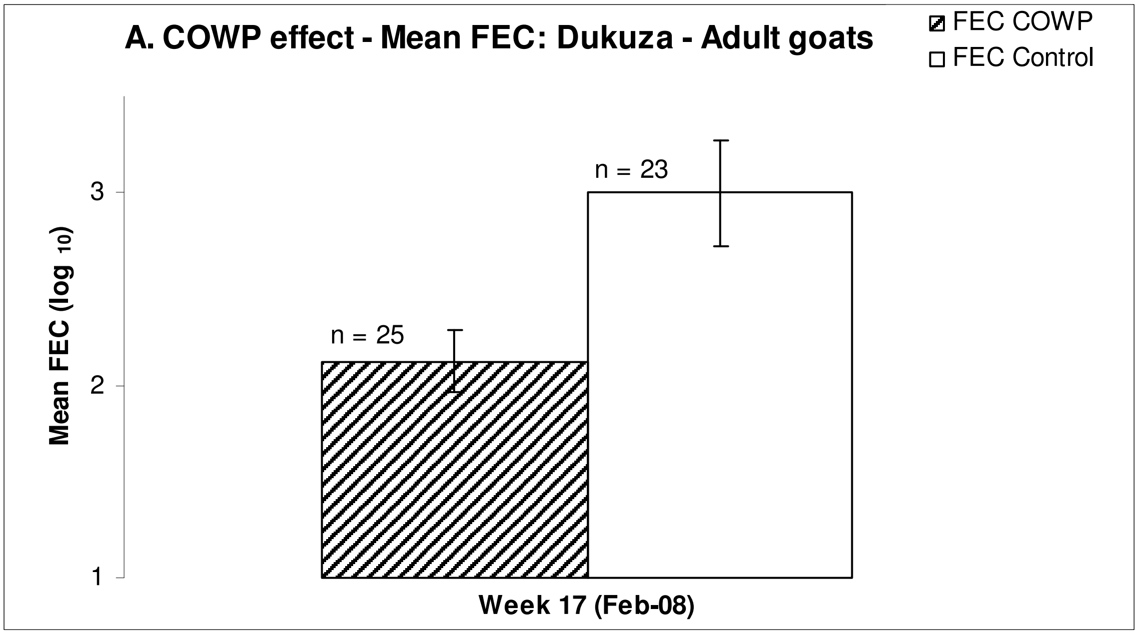


Fig. 37. A. Mean faecal egg counts (FEC) (log_{10} - transformed) and B. the mean PCV values two weeks post-COWP-administration for the treated (COWP) and control groups of all goats in the Dukuza area.

The mean FEC of the treated group of all goats in the Dukuza area was very significantly lower than that of the control group of goats two weeks after COWP administration (Fig. 37A; Table 8). The untransformed pre- (week of 21 January 2008) and post- (4 February 2008) COWP administration mean FEC for the control group were 2 228.5 and 2 445.0 respectively and the corresponding values for the treated group were 1 812.3 and 349.1.

The mean PCV of the treated group of all goats in the Dukuza area was significantly higher than that of the control group (Table 12), two weeks after COWP administration, reflecting the decreased FEC in the treated group (Fig. 37A).

4.6.9 Dukuza: adult goats



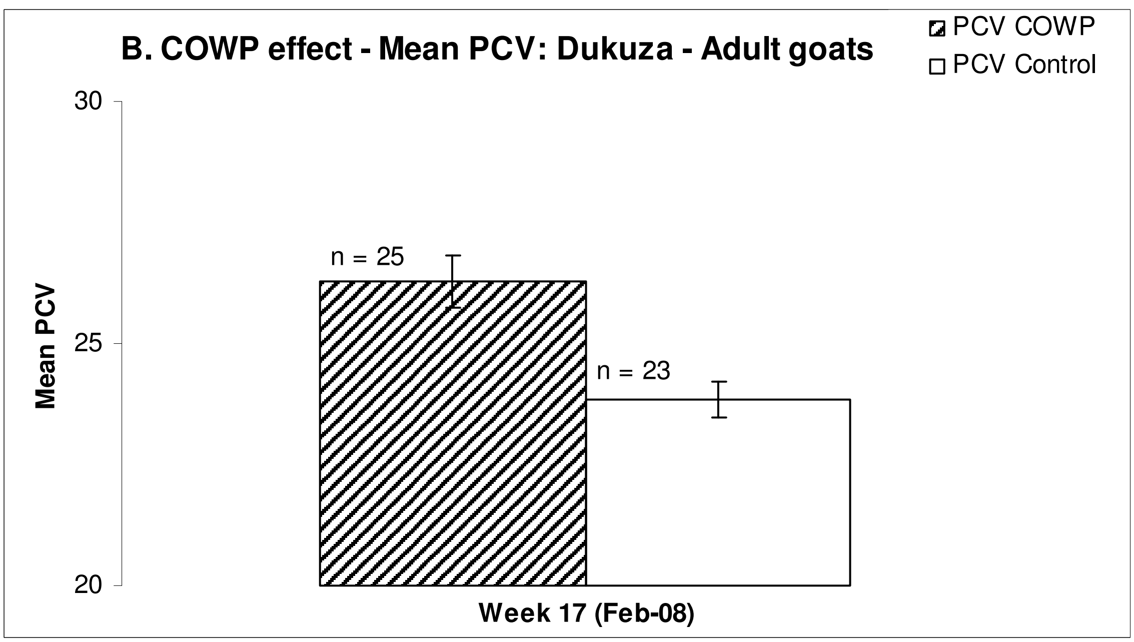


Fig. 38. A. Mean faecal egg counts (FEC) (log_{10} - transformed) and B. the mean PCV values two weeks post-COWP-administration for the treated (COWP) and control groups of adult goats in the Dukuza area.

The mean FEC of the treated group of adult goats in the Dukuza area was very significantly lower than that of the control group of goats two weeks after COWP administration (Fig. 38A; Table 8). The untransformed pre- (week of 21 January 2008) and post- (week of 4 February 2008) COWP administration mean FEC for the control group were 2 257.1 and 2 225.2 respectively and the corresponding values for the treated group were 1 865.5 and 350.7.

The mean PCV of the treated group of adult goats in the Dukuza area was significantly higher than that of the control group (Table 12), two weeks after COWP administration, reflecting the decreased FEC in the treated group (Fig. 38A).

Overall, based on all animals in the two groups, COWP intervention at peak FEC resulted in the mean FEC of all goats in all three trial areas being reduced by 89.54% two weeks after COWP administration. The effect of COWP intervention was of short duration, mean FEC returning to values comparable to pre-COWP administration levels when monitored six weeks later (Fig. 8).

Goats in the Ogade area displayed the highest calculated percentage reduction in faecal egg counts, based on all animals in the two groups, due to COWP intervention followed by Hoffenthal and Dukuza. Goats in the Dukuza area had the highest mean FEC during periods of peak infection (Jan-08) (Fig. 12) and yet showed the lowest percentage reduction due to COWP intervention. A possible explanation may be that the Dukuza area has relatively more goats than the other trial areas, all kept on communal grazing with resultantly higher concentrations of nematode eggs being shed on the vegetation than is the case in the other trial areas.

4.6.10 Calculation of reduction in FEC (% efficacy) due to COWP

In the calculation of the percentage reduction in FEC due to COWP, data for animals not present at both sampling occasions (i.e. on the day of treatment and two weeks post-treatment) as well as those yielding less that 200 epg pre-COWP (on the day of treatment) were excluded in the definitive calculation of percentage efficacy due to COWP intervention (Table 16).

Table 16. The calculated percentage efficacy, pre- and post-COWP administration, mean FEC, (range) and number of animals sampled (n) for the control (C) and treated (COWP) groups of goats per area and age group.

Area	Goat age group	Mean FEC pre-COWP		Mean FEC post-COWP		Calculated % efficacy
		C	COWP	C	COWP	
All	All	2 652 (200 - 11533) n =66	2 347 (200 - 13300) n = 73	2 709 (0 - 14433) n = 66	264 (0 - 1800) n = 73	89.0
All	Young	2 572 (200 – 8433) n = 12	1 591 (237 – 5133) n = 11	2 736 (0 – 9167) n = 12	246 (0 – 867) n = 11	85.5
All	Adult	2 669 (267 – 11533) n = 54	2 482 (200 – 13300) n = 62	2 703 (0 – 14433) n = 54	267 (0 – 1800) n = 62	89.4
Hoffenthal	All	2 512 (267 - 10833) n = 19	2 114 (200 - 2233) n = 24	2 221 (0 - 14433) n = 19	165 (0 - 567) n = 24	91.2
Hoffenthal	Young	1 478 (367 - 3467) n = 3	1 093 (267 – 2233) n = 5	1 689 (33 – 4867) n = 3	200 (0 – 567) n = 5	84.0
Hoffenthal	Adults	2 706 (267 – 10833) n = 16	2 383 (200 – 533) n = 19	2 321 (0 – 14433) n = 16	156 (0 – 100) n = 19	92.4
Ogade	All	2 737 (200 - 6667) n = 18	2 419 (567 - 4267) n = 19	3 489 (0 - 7133) n = 18	130 (0 - 167) n = 19	95.8
Ogade	Young	3 878 (200 – 6467) n = 3	4 267 (4267) n = 1	1 756 (0 – 5267) n = 3	0 (0) n = 1	100
Ogade	Adults	2 509 (633 – 6667) n = 15	2 317 (567 – 1867) n = 18	3 836 (0 – 7133) n = 15	137 (100 – 167) n = 18	96.1
Dukuza	All	2 690 (333 - 11533 n = 29	2 489 (237 – 13300) n = 30	2 545 (0 – 11667) n = 29	428 (0 – 1800) n = 30	81.8
Dukuza	Young	2 467 (600 – 8433) n = 6	1 553 (237 – 5133) n = 5	3 750 (167 – 9167) n = 6	340 (0 – 867) n = 5	85.6
Dukuza	Adults	2 748 (333 – 11533) n = 23	2 676 (1967 – 13300) n = 25	2 230 (0 – 11667) n = 23	445 (167 – 1800) n = 25	79.5

The highest calculated percentage efficacy due to COWP was seen in the Ogade area. There were only 4 young goats in the Ogade area and for calculation purposes only the one COWP-treated goat had a sufficiently high FEC to be included in the calculation. This resulted in a calculated 100% efficacy for young goats in this area. The overall calculated efficacy in the Hoffenthal area amounted to 91.2% where the reduction in the adults was 92.4% and in the young goats it was 84%. Overall efficacy in the Dukuza area was 81.8% (young goats 85.6% and adults, 79.5%). Hoffenthal displayed the lowest FEC of the three trial areas (Fig. 10) while Dukuza had the highest (Fig. 12). This, combined with the fact that Dukuza had the most goats that could contaminate pastures, was the probable reason for the relative efficacies in these two trial areas.

4.7 Faecal cultures

The mean number of helminth larvae identified from faecal cultures pooled for all three trial areas are shown in Fig. 39 for each sampling occasion of the trial period. Only four genera were identified in faecal culture, i.e. *Haemonchus, Oesophagostomum, Teladorsagia / Trichostrongylus* and *Strongyloides. Haemonchus* larvae were predominant during the rainy summer season from November 2007 – March 2008 with *Teladorsagia / Trichostrongylus* second in abundance during this period (Fig. 39). From April 2008 – October 2008, during the drier, autumn and winter months, this predominance was reversed. *Oesophagostomum* and *Strongyloides* larvae were present in low numbers throughout the trial period at most sampling occasions (Fig. 39). COWP was administered when peak faecal egg counts were recorded (Fig. 8) in January 2008, corresponding to peak *Haemonchus* spp. larval abundance which was almost 3-fold higher than that of the second most abundant group (*Teladorsagia / Trichostrongylus* (Fig. 39).

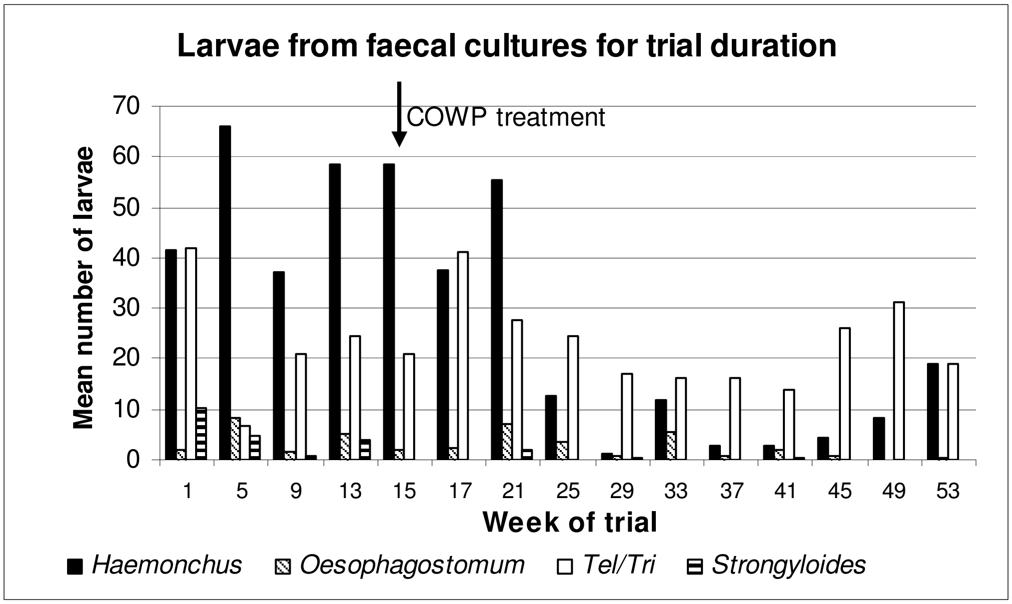


Fig. 39. Mean number of *Haemonchus*, *Oesophagostomum*, *Teladorsagia/ Trichostrongylus* (*Tel/Tri*) and *Strongyloides* third-stage larvae identified from pooled faecal cultures, for all three trial areas, for each sampling occasion of the trial period.

The calculated reduction (89.54%) in FEC in February 2008, week 17 of trial (Fig. 30A) due to COWP administration two weeks previously, occurred after *Haemonchus* spp. larvae were by far the most abundant (71.9%) (January 2008, week 15 of trial) compared to 25.7% for *Teladorsagia/Trichostrongylus*) (Fig. 39), strongly implying that the anthelmintic effect of COWP was primarily on *Haemonchus* spp. Even though the faecal cultures were done from pooled faeces and not only from the faeces of COWP treated goats, a reduction is evident in *Haemonchus* spp. larvae (mean = 37.5 larvae = 46.1% of total larvae) identified in faecal cultures in the week of 4 February 2008, week 17 of trial, (Fig. 39), two weeks after COWP was administered, while *Teladorsagia/ Trichostrongylus* counts in the week of 4 February 2008, week 17 of trial, doubled (mean = 41.3 larvae = 50.9% of total larvae) compared to those of the week of 21 January 2008, week 15 of trial, (pre-COWP administration). This data confirms that the COWP effect was primarily on the *Haemonchus* spp. present at the time of administration.

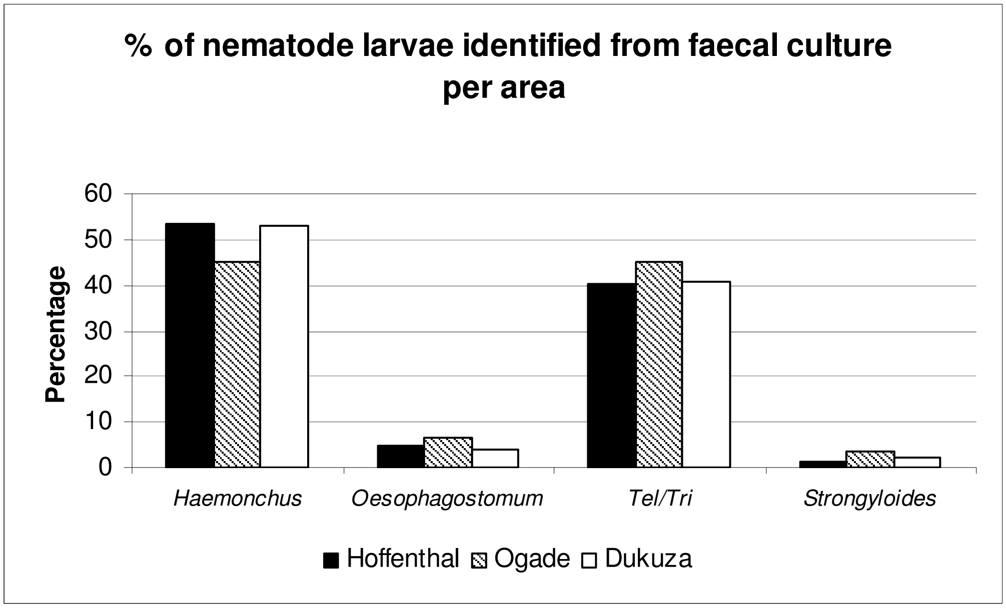


Fig. 40. Percentage of *Haemonchus*, *Oesophagostomum*, *Teladorsagia/Trichostrongylus (Tel/Tri)* and *Strongyloides* larvae identified from pooled faecal cultures per trial area.

In the Hoffenthal area 53.5% of the helminth larvae identified in faecal culture were *Haemonchus*, 40.3% were *Teladorsagia/Trichostrongylus* while *Oesophagostomum* (6.5%) and *Strongyloides* (1.2%) were present in relatively low numbers (Fig. 40). The faecal cultures from Dukuza yielded similar results while the relative abundance of *Haemonchus* and *Teladorsagia/Trichostrongylus* in the Ogade area was the same (45%).

Table 17 confirms the predominance of *Haemonchus* in the Dukuza area from where the relative majority of this genus was identified in faecal cultures, whereas the relative majority of *Oesophagostomum, Teladorsagia/Trichostrongylus*, and *Strongyloides* were identified in faecal samples from the Ogade area.

Table 17. The relative abundance (%) per area of *Haemonchus, Oesophagostomum, Teladorsagia/Trichostrongylus* (*Tel/Tri*) and *Strongyloides* larvae identified in faecal cultures.

	Haemonchus	*Oesophagostomum*	*Tel/Tri*	*Strongyloides*
Hoffenthal	32.92	29.79	29.62	15.61
Ogade	31.12	43.64	37.28	54.85
Dukuza	35.96	26.57	33.10	29.54
Total	100	100	100	100

5. GENERAL DISCUSSION

5.1 Monitoring helminth infection levels

Nematode infection levels in herds of indigenous goats raised on communal pasture by small scale farmers near Bergville in KwaZulu-Natal Province of South Africa, as measured by faecal egg counts for a period of 13 months commencing at the start of the rainy summer season in October 2007, were high from November to March. This was as expected in the summer rainfall area of South Africa (Vatta *et al.* 2001). Peak egg counts occurred during January and faecal egg counts decreased from March to May with negligible numbers recorded during mid-winter (June and July) when ambient temperatures and rainfall were lowest. Faecal egg counts started to increase again during spring (October 2008).

5.2 Comparing the relative efficacy of the Pitchford-Visser and McMaster faecal egg count methods

Both the Pitchford-Visser and McMaster faecal egg count methods showed similar results and correlated well overall, both for the treated and the control groups. However, the Pitchford-Visser method generally gave higher FEC values than the McMaster method, although these differences were not statistically significant. The higher FEC values with the Pitchford-Visser method may have been obtained because of the clearer samples obtained by this method. The Pitchford-Visser method was thus considered the method of choice in this study and was used in all statistical analyses. The close correlation of results displayed by the two methods, however, suggests that the less labour intensive and less time-consuming McMaster method would be quite suitable for field studies of an epidemiological nature and that definitive results required from such a diagnostic test would not be compromised.

5.3 The effect of copper oxide wire particle (COWP) boluses administered to indigenous goats on faecal egg count and packed cell volume

The main discernable effect of COWP administered as a 4 g bolus was on FEC and PCV measured two weeks after COWP administration. The administration of COWP when FECs were at a peak subsequently significantly reduced FECs in the treated groups of goats, mirrored by a corresponding increase in the relative mean PCV values. The values of both variables returned to levels comparable to those recorded pre-COWP administration at the next sampling occasion, six weeks after COWP administration. A single administration of 4 g of COWP during peak faecal egg counts thus caused an immediate and marked reduction in FECs, which resulted in a corresponding increase in PCV similar to the results found by other authors (Burke *et al*. 2004).

5.4 Assessing the anthelmintic effect of copper oxide wire particles (COWP) against *Haemonchus* infection

An assessment of the anthelmintic effect of COWP was made by calculating the percentage reduction in faecal egg count using FEC values pre- and post-COWP administration.

For the three trial areas combined, the overall effect of COWP dosed as a 4 g bolus was to reduce FECs in indigenous South African goats on communal pasture by 85.5 % in young goats, 89.4 % in adult goats and 89.0 % in all animals combined. For young and adult goats combined, the greatest efficacy was in the Ogade area (95.8 %) followed by Hoffenthal (91.2 %) and Dukuza (81.8 %). FEC reduction varied between 84.0 – 100 % in young animals and by 79.5 – 96.1 % for the adult animals for the three trial areas.

Faecal culture analysis supports the theory that COWP efficacy is mainly, if not totally, on *Haemonchus* sp. The reduction in FECs due to COWP occurred primarily on *Haemonchus* sp. as these larvae were by far the most abundant (71.9%).

The results of this trial are in accordance with those of other workers. Burke *et al.* (2004), using 2 g, 4 g and 6 g COWP, dosed to lambs with four-week old *H. contortus* infections obtained reductions of 90 %, 94 % and 93 % respectively. Chartier *et al.* (2000) administered COWP at 2 – 4 g doses to dairy goats and obtained a 75 % reduction in FEC of four-week-old established *H. contortus* infections. Waller, Bernes, Rudby-Martin, Ljungström & Rydzik (2004) obtained 97 % and 56 % reductions in six-week-old burdens of adult and fourth stage larvae, respectively, of *H. contortus* in sheep treated with a 4 g COWP bolus. In pen trials conducted as a precursor to this study, Vatta *et al.* (2009) obtained 95 % and 93 % reductions in mean worm counts in 2 g and 4 g COWP treated goats respectively. The studies cited above were all done on artificially established infections, whereas the present study confirms that 4 g COWP administered to goats is effective in reducing FECs under field conditions on communal pasture.

Stewart (1950) established that the maximum concentration of COWP in the abomasum occurs for the first five to six days after administration which should therefore be the time of highest anthelmintic efficacy. In the present study, the effect of COWP intervention was of short duration. A marked reduction in FECs was evident two weeks after COWP administration and mean FECs returned to values comparable to pre-COWP administration levels when monitored two weeks after that. The anthelmintic effect of COWP can thus be deduced to be for a period of approximately two weeks only. Vatta *et al.* (2009) also speculate that soluble copper levels in the abomasum are raised sufficiently high to kill abomasum nematodes for only two weeks after COWP administration.

The administration of COWP to sheep and goats is associated with the risk of copper toxicity, although goats are regarded as less susceptible (Burke & Miller 2006). Burke *et al.* (2004) recommended that the use of COWP in sheep should not exceed one dose per annum due to the accumulation of copper in the liver. However, there appears to be less chance of copper toxicity due to the use of COWP in goats than in sheep as shown by Vatta *et al.* (2009) who found that tissue copper levels in 4 g COWP treated animals did not differ significantly to those that were not treated. It remains, however, to be determined whether additional follow-up COWP treatments are desirable.

The present trial, as conducted, does have the inherent disadvantage that the control goats, as well as others owned by all farmers in the community, shared the same pasture as the COWP treated goats. This would theoretically have the effect of a large number of non-COWP-treated animals potentially re-infesting the same pastures. Had all the experimental animals, or even, most of the small ruminants sharing the same communal pastures received COWP at the same time as the treated goats, this tactical intervention could have potentially decreased FECs for the rest of the season.

These studies also show that COWP, as used under conditions where indigenous goats are raised extensively on communal pastures, has excellent efficacy as a tactical intervention to control *H. contortus*. The product is, however, not commercially available in South Africa as yet and its eventual cost-efficacy when made available would determine its use and acceptance as an alternative to chemical anthelmintics.

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7. APPENDICES

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7.1 Survey questionnaire

Questionnaire: Bergville project (OV21/10/C131)

Date: ______________ Translator/Staff: ________________________

Area: Hoffenthal: ☐ Ogade: ☐ Dukuza: ☐

Farmer: ____________________ Gender: M ☐ F ☐

Age of farmer

Years / or date of birth (dd/mm/yyyy)	

Family details (number in the household):_____________________________________

1). What is your level of education?

No formal education	
Grade 1 – Grade 3	
Grade 4 – Grade 7	
Grade 8 – Grade 10	
Grade 11 - Grade 12	
Post matric - specify...	
Other – specify ….....................................	

2). How long have you lived in Hoffenthal, Ogade, Dukuza?

Years	

3). Name of the head of your household: _____________________________________

4). How old is the head of your household?

Years / or date of birth	

5). What is your relationship to the head of your household?

Head of household	
Husband/Wife	
Son/Daughter	
Other relation	
No direct relation	
Other – specify...……..........	

6). What are your main sources of income – how do you make ends meet? Indicate three to five of your main sources of income. Rank these from 1 to 5, with 1 being the most important source and 5 the least important.

Pension and other grants (child support, disability, etc.)	
Crops	
Vegetables	
Livestock	
Money sent back from family in town/city	
Temporary employment off farm	
Permanent employment off farm	
Other – specify	

7). Do you have electricity?

Yes	No

8). Where do you get water from as your regular source? Indicate one to three of your most important sources of water if you use more than one source. Rank these from 1 to 5, with 1 being the most important source and 5 the least important.

Tap inside dwelling	
Tap outside dwelling but on plot	
Tap in the area	
Collection of rainwater	
Tanker	
River/stream/dam	
Borehole	
Bought from private person	
Other – specify	
No regular source	

9). Have you seen any worms – what do they look like?

10). Where have you seen them (inside the goat when slaughtered or in the dung)?

11). Are these worms important? What damage do they cause, if any?

12). What do you do when your goats have worms?

a) Do you use commercial remedies? State which if possible.
b) Do you use traditional remedies? State which if possible.

13). How easy is it to buy remedies? Where are they obtained from? (Availability / cost)

Photos / Specimens: What do you recognize in each of the photos?

A) *Haemonchus* (3 photos and 1 specimen)
Do you know what this is? (Person conducting the interview to point at the abomasum)
Can you see the worms?
What is the name of the worm?
Do you treat for this worm?

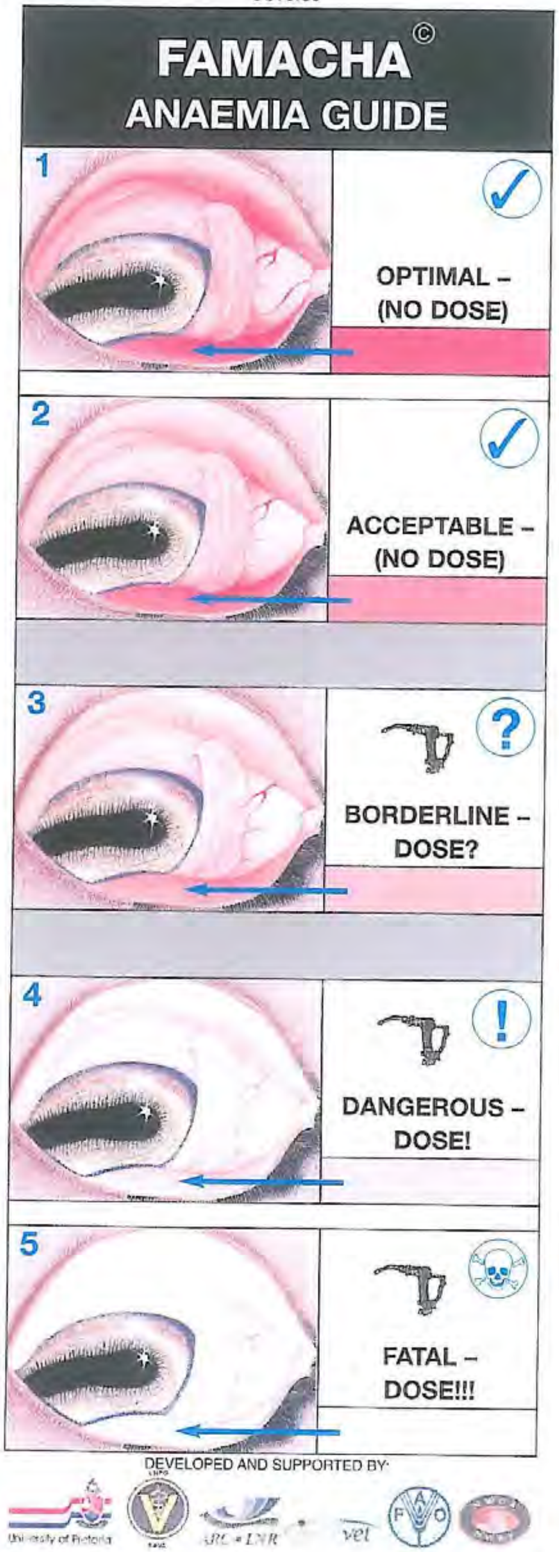
B) *Oesophagostomum* (2 photos)
Do you know what this is? (Person conducting the interview to point at the infected intestine)
Can you see the worms and the lesions/knobs?
What is the name of the worm?
Do you treat for this worm?

C) Tapeworm (3 photos and 1 specimen)
Have you seen this in the dung? Have you seen this in the intestine?
Can you see the worms?
What is the name of the worm?
Do you treat for this?

D) *Fasciola hepatica* (4 photos and 1 specimen)
Do you know what this is? (Person conducting the interview to point at the damaged liver)
Can you see the worms?
What is the name of the worm?
Do you treat for this worm?

E) Symptoms (Each farmer was asked the following questions regarding each of the clinical signs shown in each picture):
Do you know what this is? What is it called? Do you treat for this condition?
E1: Bottle jaw
E2: Anaemia
E3: Diarrhoea

7.2 FAMACHA© chart

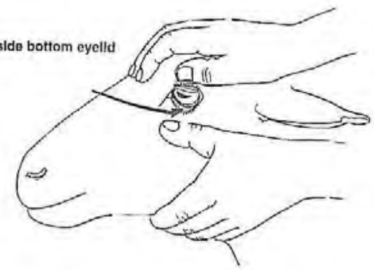


Reverse

INSTRUCTIONS FOR USE

Examination

- Examine sheep in good, natural light
- Open the eyelid as shown in the sketch
- Push the upper eyelid down with the upper thumb, while the lower thumb gently pulls the lower lid downward
- Look especially at the colour inside the lower eyelid
- Open the eyelid for a short time only, or else the mucous membrane may become redder
- Compare the colours seen to those on the reverse side of this card
- Score the sheep 1 to 5 and proceed as explained in the pamphlet
- If in doubt, score the sheep at the lower (paler) category
- Examine weekly and no less than every 2 to 3 weeks
- Contact your veterinarian if you have any questions



Precautions

- Only properly trained persons should use this card
- Read the full information pamphlet before using the guide and follow instructions carefully
- This guide is intended for sheep only
- If used for goats, all those in category 3 should also be treated
- This card is an aid in the control of wireworm only
- Paleness or reddening of the eyes may have other causes
- Maintain standard worm control measures
- The colours of this card will fade with time, especially if exposed to the sun
- Replace the card after 12 months use
- As the system is used in conditions outside their control, no organisation involved in its development or distribution accepts liabilty for losses or problems associated with its use

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