Use of copper oxide wire particles to control gastrointestinal nematodes in goats[1]

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ABSTRACT: The objectives of these experiments were to determine the optimal dose of copper oxide wire particles (COWP) necessary to reduce gastrointestinal nematode (GIN) infection in young and mature goats naturally infected with *Haemonchus contortus* or a mixed infection and to determine whether the effectiveness could be enhanced through feeding management. Two experiments were conducted during cooler months in Georgia, and 4 experiments were conducted during warmer spring or summer months in Arkansas. Meat goats received 0 up to 10 g of COWP under a variety of management conditions. In all experiments, blood and feces were collected every 3 or 7 d from 6 to 42 d to determine blood packed cell volume (PCV) and fecal egg counts (FEC) to estimate the degree of GIN infection. In mature goats grazing fall pasture, mean FEC of 0 g of COWP-treated goats increased, and those of 4 g of COWP-treated goats remained low on d 0, 7, and 14 (COWP × d, $P < 0.03$), and FEC decreased on these days ($P < 0.001$). In 5 and 10 g of COWP-treated goats, PCV increased ($P < 0.001$), but FEC and PCV remained unchanged over time in control goats. Fecal egg counts were similar among all low doses (0.5, 1, 2, 4 g) of COWP administered to weaned kids for all dates examined ($P > 0.10$), which were lower on d 7 through 21 (COWP × date, $P < 0.05$) but similar by d 28, compared with FEC of 0 g of COWP-treated kids. Packed cell volume was lower in 0 g compared with all COWP-treated kids by d 14 (COWP × date, $P < 0.05$). Feeding management in combination with COWP for GIN control had little effect compared with COWP alone for these short-term studies. In conclusion, a dose of COWP as low as 0.5 g, which was considered optimal to reduce the risk of copper toxicity, was effective in reducing FEC in young goats, and 5 g of COWP was effective in older goats. Copper oxide does not appear to be effective in controlling newly acquired L4 stage (preadult) larvae, which also feed on blood, leading to decreased PCV in newly infected goats.

Key words: copper oxide, goat, gastrointestinal parasite, sericea lespedeza

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INTRODUCTION

Past recommendations for gastrointestinal nematode (**GIN**) control in sheep and goats included frequent deworming and moving animals to clean pastures, which led to development of resistance to commercial dewormers available in the United States (Zajac and Gipson, 2000; Terrill et al., 2001; Mortensen et al., 2003; Kaplan et al., 2005). *Haemonchus contortus*, or barber pole worm, causes reduction in production and death losses during warm, humid months because of its voracious appetite for blood in the abomasum, where the adult lives and produces eggs. A highly prolific nematode, *H. contortus* has a short life cycle of approximately 3 wk, and severe outbreaks can occur during favorable weather conditions, which often coincide with weaning. This leaves the young goats particularly susceptible to infection while grazing summer pastures. Nematodes represent the most important health concern to sheep and goats in this region (USDA-APHIS-VS, 2003), thus alternatives to chemical control must be explored.

Copper oxide wire particles (**COWP**), initially used to treat copper deficiency in sheep (Dewey, 1977; Whitelaw et al., 1980; Suttle, 1981) and goats (Winter

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et al., 2004), have been determined to be an effective means of GIN control for lambs in the southeastern United States (Burke et al., 2004; Burke and Miller, 2006), and guidelines have been established for producers (Burke et al., 2006). Chartier et al. (2000) determined that COWP were effective in reducing the *H. contortus* worm burden in goats but not that of intestinal nematodes present. Little is known about the optimal dose of COWP as an anthelmintic in goats, agents that may enhance its use as an anthelmintic, and its use in combination with other novel approaches for GIN control.

The objectives of the following studies were to examine the use of COWP in mature and growing kids in summer or winter and under different management conditions to determine efficacy of reducing *H. contortus* infection at the lowest dose examined in growing kids.

MATERIALS AND METHODS

All experimental procedures were reviewed and accepted by the Institutional Animal Care and Use Committee at Fort Valley State University and ARS Animal Care and Use Committee.

Exp. 1: COWP Use in Pastured Mature Goats During Winter

The objective was to determine the effectiveness of COWP to reduce GIN in mature does grazing winter pasture. Twenty-two mature, naturally infected 4- to 5-yr-old Spanish does grazed 1.6 ha of Bermudagrass-dominant pasture in mid-October at the Fort Valley State University Agricultural Research Station, Fort Valley, Georgia. Does were assigned to treatment groups so that initial mean fecal egg counts (**FEC**) were similar to ensure that each group had relatively equal parasite burdens and then randomly allocated to receive an empty bolus or 4 g of COWP (Copasure, Animax Veterinary Technology, Suffolk, UK; n = 11/treatment). Copasure is available as a 12.5- or 25-g gelatin capsule for treatment of Cu deficiency in cattle. Repackaged gelatin capsules (size 13, Torpac Inc., Fairfield, NJ) were administered orally with a balling gun. Blood samples were collected via jugular venipuncture every 7 d for 42 d for determination of blood packed cell volume (**PCV**) to monitor the level of anemia. Fecal samples were collected directly from the rectum every 7 d to determine FEC using the modified McMaster technique, with a sensitivity of 50 eggs/g (Whitlock, 1948). Samples on d 0 were collected before treatment for this and subsequent experiments.

Exp. 2: 5 or 10 g of COWP in Mature Goats During Winter

The objective was to determine the effectiveness of 2 doses of COWP in reducing an established, mixed-GIN infection in mature goats grazing winter pasture. Twenty-one naturally infected, yearling Spanish × Boer crossbred bucks grazed mixed grasses before being transported to concrete-floor pens for a 28-d period to allow the GIN infection to mature. After the maturation period, treatments were administered, and goats were observed for a 35-d period. Once in their pens, the goats were fed a complete ration (50% alfalfa meal, 35% corn, 9% soybean meal, 0.5% trace mineralized salt, 0.5% vitamin premix, 5% poultry fat; 2.72 Mcal/kg of DE, 16% CP, 0.74% Ca, 0.26% P; DM basis) and Bermudagrass hay ad libitum. Goats were assigned to treatment groups so that the initial mean FEC were similar and then were randomly assigned to receive 0 (empty bolus; n = 6), 5, or 10 g of COWP (n = 7/group) as described in Exp. 1. Jugular venous blood and feces were collected every 7 d for 35 d to determine PCV and FEC.

Individual fecal samples were cultured according to Peña et al. (2002) and modified as follows. Feces were weighed, gently crushed, and placed in a 200-mL flexible plastic cup that was cut in half. Deionized water was added until the fecal material was moist but not saturated. The lower cup section with the feces was covered with 4 layers of cheesecloth, inverted, and placed into the upper section of the cup. Each culture cup was then placed in an intact cup containing 10 mL of deionized water and then incubated at 27°C for 14 d. The samples then were transferred to a larger cup, and the larvae were extracted from the culture material using a modified Baermann technique (Peña et al., 2002). Water was added to submerge the culture material, which was allowed to drain overnight so that the larvae could migrate through the culture material and collect in the larger cup. The cup was left undisturbed for 4 to 6 h to allow the larvae to settle, and then all but 45 mL was carefully removed from the top. The remaining solution was mixed thoroughly and placed in a 50-mL centrifuge tube for 3 to 4 h. This procedure was repeated, leaving 15 mL, which was transferred to an 18-mL centrifuge tube, allowed to settle again, and then reduced to 4 mL by carefully removing the upper 11 mL. One milliliter of 10% formalin was then added to preserve the larvae. Two 50-μL drops of well-mixed larval solution were placed on a microscope slide. The larvae were stained with a drop of Lugol's iodine solution, a cover slip was placed on top, and the L3 (infective stage) larvae were counted and identified as to species. Number of infective stage larvae was expressed as L3/g of cultured feces.

The goats were humanely slaughtered on d 35 by first using a captive bolt gun then exsanguination for collection of nematodes from the abomasum and small intestine. The organ contents were adjusted to 3 L with water, mixed well, and then a 150-mL aliquot was collected and preserved with 10% formalin. All worms were then recovered, counted, and identified as to species based on their morphological characteristics (Miller et al., 1987). In addition, a liver sample was collected at slaughter, and the liver copper concentration was determined at the Louisiana Veterinary Medical Diagnostic Laboratory, Baton Rouge.

Exp. 3: Determination of the Optimal Low Dose of COWP in Weaned Kids on Pasture

The objective was to examine a dose response of COWP to reduce GIN infection in growing goats. Kids and their dams grazed the same pasture of tall fescue at the Dale Bumpers Small Farms Research Center, Agricultural Research Service, USDA, in Booneville, Arkansas, before weaning at a stocking rate of 22 does/ha. In early May 2006, 40 Boer × Spanish doe (14.1 ± 0.6 kg) and wether (15.8 ± 0.6 kg) kids naturally infected with GIN were weaned (97 ± 2 d of age) and assigned randomly to 5 treatment groups: 0, 0.5, 1, 2, and 4 g of COWP (n = 8/treatment). After weaning, the kids grazed the same Bermudagrass pasture (33 kids/ha) that had been grazed previously by sheep or goats and were supplemented with 220 g of corn and soybean meal (**CSB**; 14% CP, DM basis; 78% corn, 18% soybean meal, 3.5% molasses, 0.007% calcium carbonate, on an as-fed basis) per kid daily. Trace mineralized salt (Sheep and Goat Mineral, Land O'Lakes, Shoreview, MN) and water were provided free choice. Body weight was recorded at 0 and 28 d after COWP administration, and feces and blood were collected every 7 d for FEC and PCV determination. Kids were dewormed with levamisole (Levasol, 12 mg/kg; Agri Laboratories Ltd., St. Joseph, MO) if the PCV fell below 20%, which occurred from 21 to 28 d after COWP administration for nearly all kids. Coprocultures were not performed, but *H. contortus* is typically the predominant GIN during summer months on this farm (Burke and Miller, 2006).

Exp. 4: Interaction Between COWP and Drenching with Apple Cider Vinegar in Wether Kids

In response to producer interest in alternative treatments, the objective was to determine whether drenching with vinegar would enhance the anthelmintic effect of COWP. In mid-July, Boer × Spanish wether kids (166 ± 2 d of age) naturally infected with GIN from grazing the Bermudagrass pastures described in Exp. 3 were assigned randomly to receive 0 g of COWP (n = 5), 5 g of COWP (n = 5), apple cider vinegar drench (34 g of vinegar powder in 120 mL of water; ACH Food Co., Memphis, TN; n = 4), or vinegar drench and 5 g of COWP (n = 6) in a 2 × 2 factorial arrangement. After the initial treatment, the vinegar drench was administered again 24 h later, at half the dose. The kids were maintained on concrete for observation for 6 d and were fed Bermudagrass hay free choice and 220 g of CSB (14% CP, DM basis) per animal daily. Trace mineralized salt (Land O'Lakes Sheep and Goat Mineral) and water were provided ad libitum. The kids weighed 21.0 ± 0.9 kg on the day of COWP administration (d 0). Feces and blood were collected on d 0, 3, and 6. One untreated kid died on d 2, likely from haemonchosis or secondary infection (PCV was 16%). One of 3 kids that responded negatively to vinegar treatment on the second day did not recover.

Exp. 5: Interaction Between COWP and Supplementary Cottonseed Meal in Mature Doe Kids on Pasture

The objective was to investigate use of COWP for GIN control in goats consuming a moderate- or high-protein supplement. In early August, Boer and Spanish × Boer does (193 ± 2 d of age) were assigned randomly in a 2 × 2 factorial arrangement to receive 0 or 2 g of COWP while being supplemented daily as a group with 220 g of CSB (14% CP, as described above; 9 untreated and 8 COWP-treated does/supplement) or 220 g of cottonseed meal (**CSM**; 41% CP; 8 untreated and 9 COWP-treated does/supplement) per head while grazing 1 of 2 Bermudagrass pastures at a stocking rate of 14 does/ha. Does were offered trace mineralized salt free choice (Land O'Lakes Sheep and Goat Mineral) and water. To minimize differences in forage quality between pastures, does were rotated between the 2 pastures every 7 d for 49 d, and supplement was withdrawn on d 42 (d 0 = day of COWP administration). A second 2-g bolus of COWP was administered to all kids on d 42 to assess its value as an anthelmintic regardless of previous treatment. Body weight was determined every 28 d, and feces and blood were collected every 7 d for FEC and PCV analyses.

Exp. 6: Interaction Between COWP and Grazing Sericea Lespedeza in Yearling Does

The objective was to investigate use of 5 g of COWP to control GIN in goats grazing stockpiled tall fescue or sericea lespedeza (*Lespedeza cuneata*). In mid-June, Boer yearling does that weighed 35 ± 2 kg were assigned randomly in a 2 × 2 factorial arrangement to receive 0 or 5 g of COWP (4 untreated and 6 COWP-treated does/tall fescue; 6 untreated and 4 COWP-treated does/sericea lespedeza) at a stocking rate of 25 does/ha. Sericea lespedeza pasture was approximately 75% sericea lespedeza, 20% tall fescue, 5% forbs and other grasses. Does were offered trace mineralized salt free choice (Land O'Lakes Sheep and Goat Mineral) and water. Does grazed their respective pastures for 21 d and then were all returned to tall fescue. Feces and blood were collected every 7 d for 28 d for FEC and PCV analyses. Does were dewormed with moxidectin if their PCV declined below 19% and were removed from the data set.

Statistical Analyses

For all experiments, PCV, FEC, larval cultures, and BW were analyzed as a repeated measures design (Littell et al., 1996) using the MIXED procedure with an autoregressive covariance structure (SAS Inst. Inc., Cary, NC). In Exp. 1, 2, and 3, completely randomized design models included treatment, time, and their interaction. Exp. 4, 5, and 6 were analyzed as a completely randomized design arranged in as a factorial, and the models included COWP and diet supplement or forage, time, and all possible interactions. Because it is biologically relevant to examine the initial response of COWP as if it were an anthelmintic, when the COWP × time interactions were not significant for the entire experimental period (up to 42 d) after administration of COWP, the initial response to COWP was examined by analyzing the COWP × day interactions for d 0, 7, and 14.

The GLM (SAS) and a completely randomized design were used for analysis of worm counts and concentrations of copper in the liver in Exp. 2, and the model included treatment. For all experiments, goat was the experimental unit. Means separation was done using preplanned pairwise comparisons with a Student's *t*-test when the treatment effect was significant at $P < 0.05$. Trends were reported at $P < 0.10$. Fecal egg count data were log-transformed: ln(FEC + 1). Statistical inferences were made on transformed data, and untransformed least significant means were presented.

RESULTS

Exp. 1

In mature goats grazing winter pasture, mean FEC were similar between 0 and 4 g of COWP groups throughout the experiment (COWP × d, $P = 0.12$; Figure 1), but when considering only d 0, 7, and 14 (in a separate analysis as described in the statistical analyses section), FEC of untreated goats increased and those of COWP-treated goats remained low (COWP × d, $P < 0.03$). Packed cell volume declined slightly over time in control and COWP-treated goats (d 0, 30.5; d 42, 27.0 ± 1.1%; $P < 0.001$) but was similar between groups.

Exp. 2

Mean FEC were similar in 0, 5, or 10 g of COWP-treated goats throughout the experiment and decreased from d 0 to 35 (d, $P < 0.001$). Mean PCV was not different among groups ($P = 0.11$).

Proportion of *H. contortus* L3 larvae cultured from feces collected from untreated goats was more than 4-fold greater on d 7 ($P < 0.001$) but was not different than that of COWP-treated goats on d 21 and 35 (COWP × d, $P = 0.01$; Figure 2). Similarly, the proportion of *Trichostrongylus* cultured was greater in COWP-treated goats on d 7 ($P < 0.001$) compared with untreated goats but was similar on d 21 and 35 (COWP × d, $P = 0.01$; Figure 2). There was less than 4% of *Oesophagostomum* cultured in feces collected from each group, and LS means were not different among groups ($P = 0.87$).

All small intestinal worms were identified as *Trichostrongylus colubriformis*. Total worm numbers in abomasal and small intestinal samples were not different among groups of goats (abomasum: 716 ± 440, 1,606 ± 401, 390 ± 401; intestine: 10,104 ± 2,560, 13,653 ± 2,337, and 6,596 ± 2,337 for 0, 5, and 10 g of COWP-treated goats, respectively; $P > 0.10$). Concentrations of copper in the liver were greater in COWP-treated goats (5 g: 153; 10 g: 149 ± 34 mg/kg of DM) than untreated goats (56 ± 34 mg/kg of DM; $P < 0.001$).

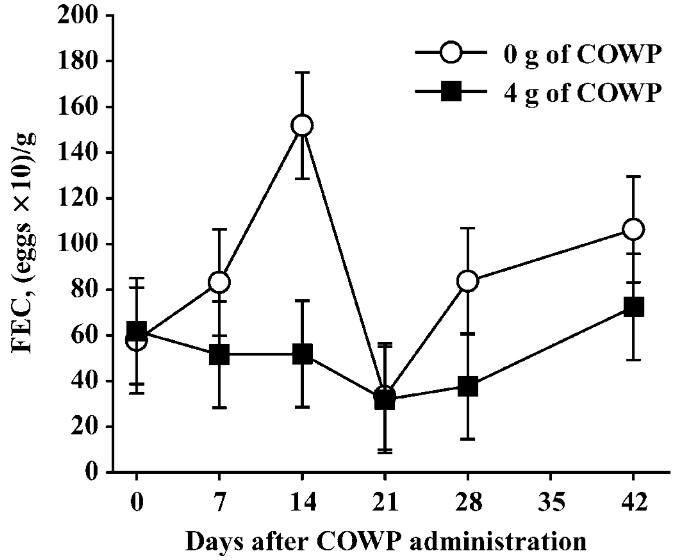

Figure 1. Effect of administration of 0 or 4 g of copper oxide wire particles (COWP; n = 11/group) on fecal egg counts (FEC) in mature goats (Exp. 1) from d 0 through 42 after administration of COWP. Least squares means and SE are presented, and statistical analysis of FEC was performed on logarithm-transformed values. The COWP in gelatin capsules was administered orally with a balling gun on d 0. Considering d 0 through 14 (a period of biological relevance for an anthelmintic), FEC of untreated goats increased and those of COWP-treated goats remained low (COWP × d, $P < 0.03$). However, for the entire observation period, FEC was similar between groups ($P = 0.12$).

Exp. 3

In weaned goats grazing spring pasture, FEC ranged between 440 (0.5-g group) and 2,050 eggs/g (1-g group) on d 0 (day of COWP administration), but logarithm-transformed means were not different among untreated and groups treated with low doses of COWP on that day. Fecal egg counts were similar among all doses of COWP for all dates ($P > 0.10$). Because there was no dose response with quantities administered in this study, COWP-treated groups were pooled and compared with control on each day. Fecal egg counts were lower (COWP × date, $P = 0.04$; Figure 3A) on d 7 ($P < 0.002$), 14 ($P < 0.004$), and 21 ($P < 0.05$) compared with untreated kids but were similar by d 28. Packed cell volume was similar between untreated and COWP-treated kids on d 0 and 7 but was lower in untreated

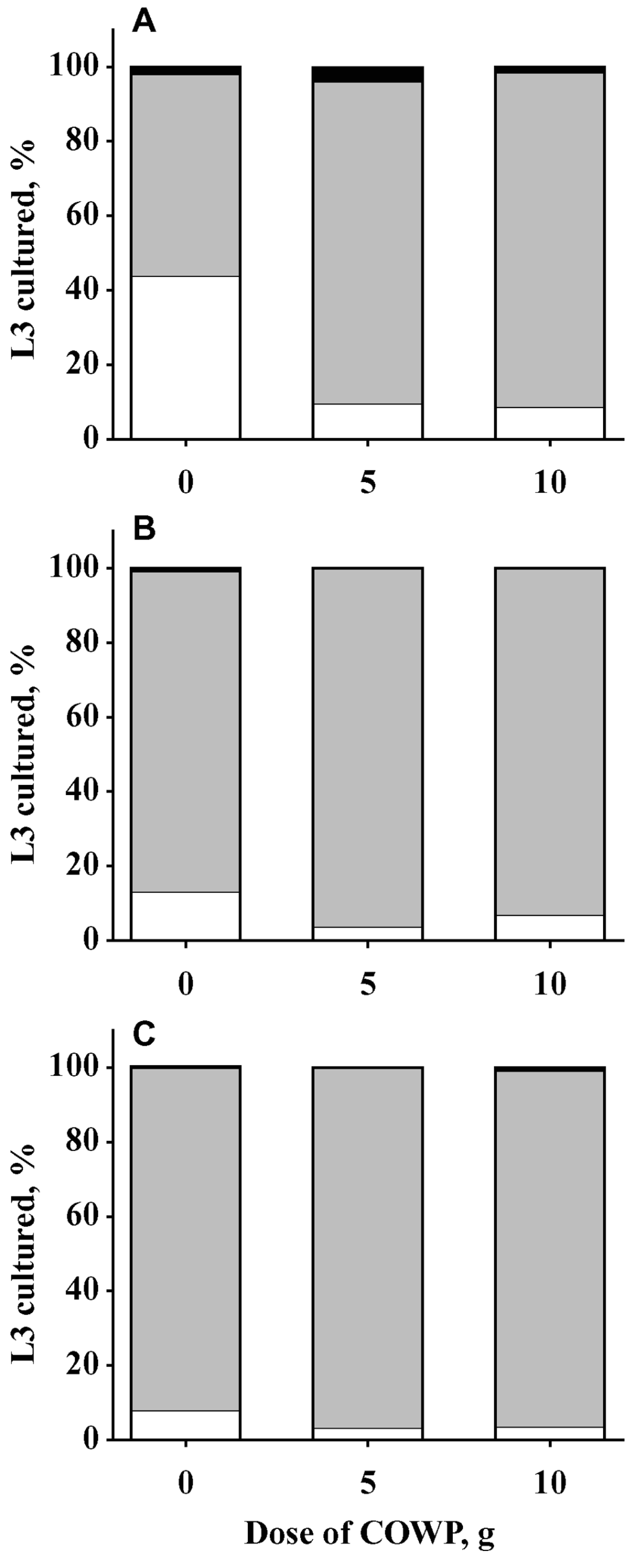

Figure 2. Effect of increasing doses of copper oxide wire particles (COWP; n = 6/dose) on the proportion of *Haemonchus contortus* (white), *Trichostrongylus* (gray), or *Oesophagostomum* (black) L3 larvae cultured from feces collected on d 7 (A), 21 (B), and 35 (C) after administration of COWP to mature goats (Exp. 2). Least squares means (SE were 4.5, 9.2, and 1.0 for *H. contortus*, *Trichostrongylus*, and *Oesophagostomum*, respectively) are presented for each treatment group and day.

kids by d 14 (COWP × date, $P = 0.04$; Figure 3B). Because PCV dropped below 20%, nearly one-third of all kids were dewormed on d 21, and 88% were dewormed by d 28, independent of COWP treatment. Average daily gain tended to increase with dose of COWP up to 2 g then decreased at 4 g ($y = 93.2 + 26.3x - 6.2x^2$, where y = ADG in g and x = COWP dose; $R^2 = 0.13$; $P < 0.07$). Body weights on d 0 were 14.7 ± 0.4 kg and were 18.4 ± 0.4 kg for all kids on d 28 (d, $P < 0.001$; COWP × date, $P = 0.06$).

Exp. 4

There was no effect of vinegar drenching on FEC in 0 or 5 g of COWP-treated kids ($P = 0.36$). Copper oxide wire particle-treated kids experienced a reduction in FEC within 3 d ($P = 0.02$) and even greater by 6 d ($P < 0.001$) compared with d 0 (Figure 4A) and compared with untreated kids on d 6 (COWP × d, $P < 0.001$). Although PCV was not expected to change within a 6-d period, this measure of anemia tended to decrease in untreated goats by d 6 compared with COWP-treated goats (COWP × d, $P = 0.06$; Figure 4B).

Exp. 5

Supplementation with CSM and administration of COWP influenced GIN measurements. There was a marked reduction in FEC in COWP-treated goats within 7 d, which remained lower than untreated does until d 21 for CSB-supplemented does and d 28 in CSM-supplemented does; however, the COWP × supplement × day interaction was not significant ($P = 0.57$; COWP × d, $P < 0.001$; supplement × d, $P = 0.07$; Figure 5A). Although FEC were similar in does that did not receive COWP in both feed groups, FEC were lower in CSM than CSB-supplemented does that received COWP (COWP × supplement, $P = 0.02$). Packed cell volume values tended to increase over time in COWP-treated compared with untreated does ($P < 0.06$), and PCV values were reduced in CSM-fed does that did not receive COWP compared with other groups (COWP × supplement, $P = 0.04$; Figure 5B). Body weight was similar among treatment groups throughout the experiment (d 0: 21.1 ± 0.5 kg; d 28: 25.0 ± 0.5 kg). At the completion of the study (d 42), 2 g of COWP was administered to all goats and resulted in a 79% reduction in FEC 7 d later (d 42: 1,484 ± 147; d 49: 309 ± 152).

Exp. 6

Administration of 5 g of COWP decreased FEC (COWP × d, $P = 0.01$; Figure 6A), and sericea lespedeza grazing tended to decrease FEC ($P < 0.07$). Packed cell volume peaked by d 21 in does receiving both novel treatments compared with other groups (COWP × forage × d, $P < 0.02$; Figure 6B). There was no interaction between COWP and sericea lespedeza for overall means. There were 3 tall fescue and 2 sericea lespedeza goats that did not receive COWP that were dewormed

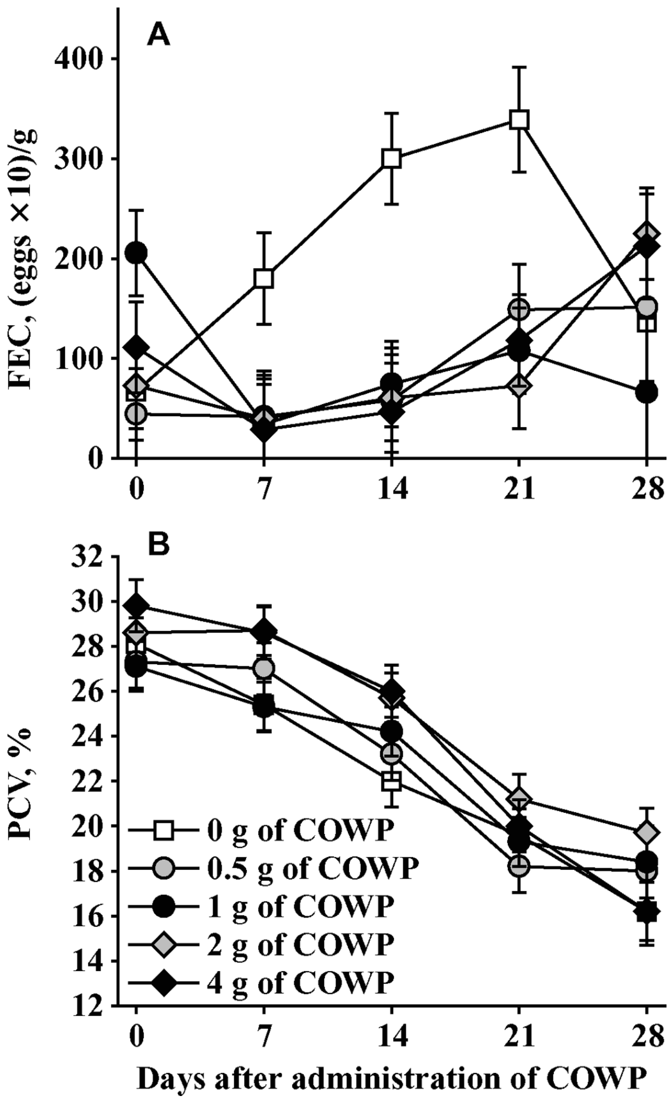

Figure 3. Effect of increasing dose of copper oxide wire particles (COWP; n = 8/dose) on fecal egg counts (FEC; A) and blood packed cell volume (PCV; B) from d 0 through 21 after administration of COWP in weaned kids on pasture (Exp. 3). Least squares means and SE are presented, and statistical analysis of FEC was performed on logarithm-transformed values. The COWP in gelatin capsules was administered orally with a balling gun on d 0. When all COWP treatments were pooled, FEC was reduced (COWP × date, $P < 0.05$) in COWP-treated kids compared with controls on d 7, 14, and 21.

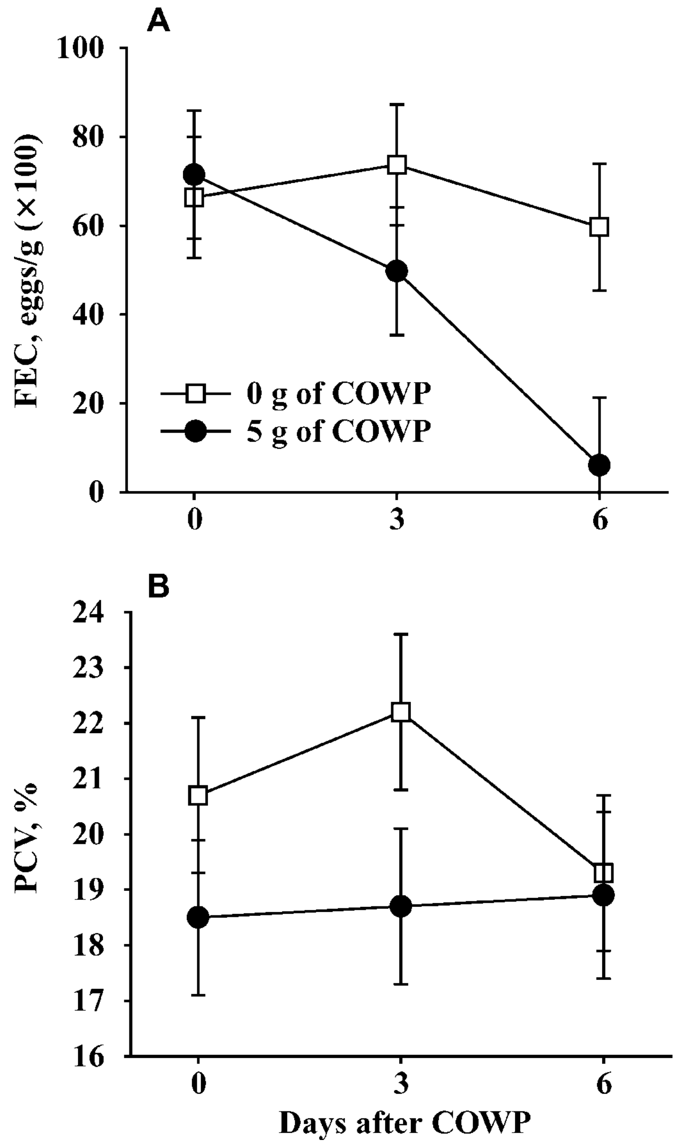

Figure 4. Effect of 0 (n = 10) or 5 g of copper oxide wire particles (COWP; n = 9) on fecal egg counts (FEC; A) and blood packed cell volume (PCV; B) from d 0 through 6 after administration of COWP in wether kids (Exp. 4). Least squares means and SE are presented, and statistical analysis of FEC was performed on logarithm-transformed values. The COWP in gelatin capsules was administered orally with a balling gun on d 0. The FEC was reduced (COWP × date, $P < 0.001$) in COWP-treated kids compared with controls on d 3 and 6.

on d 21 and were removed from the data set on d 28. None of the COWP-treated does required deworming by d 28, but 54 ± 11.6% of untreated does required deworming by this time ($P < 0.005$).

DISCUSSION

Use of COWP during cooler months (Exp. 1 and 2) may have reduced FEC, but PCV continued to decline (Exp. 1) or increased (Exp. 2) compared with untreated goats on pasture. Fecal cultures from goats in the confinement study indicated a reduction in *H. contortus* larvae 7 d after COWP administration compared with cultures from untreated goats and a greater proportion of other nematode species compared with those typically found in summer months in warm, humid climates. There was also a greater proportion of intestinal than abomasal worms recovered 35 d after treatment in all groups of goats in Exp. 2. Chartier et al. (2000)

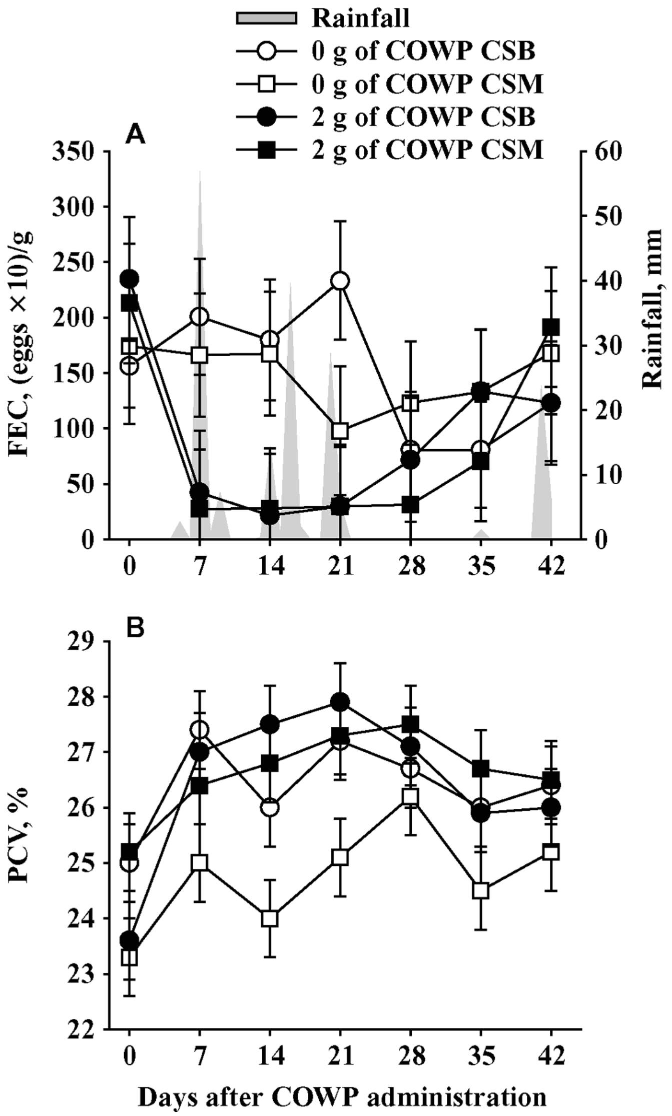

Figure 5. Effect of 0 or 2 g of copper oxide wire particles (COWP; n = 17/treatment) in kids supplemented with corn and soybean meal (CSB) or cottonseed meal (CSM; n = 17/supplement) on fecal egg counts (FEC; A) and blood packed cell volume (PCV; B) from d 0 through 42 after administration of COWP (Exp. 5). Least squares means and SE are presented, and statistical analysis of FEC was performed on logarithm-transformed values. The COWP in gelatin capsules was administered orally with balling gun on d 0 and does were supplemented with CSB or CSM from d 0 to 42. The FEC were reduced in COWP-treated kids (COWP × d, $P < 0.001$).

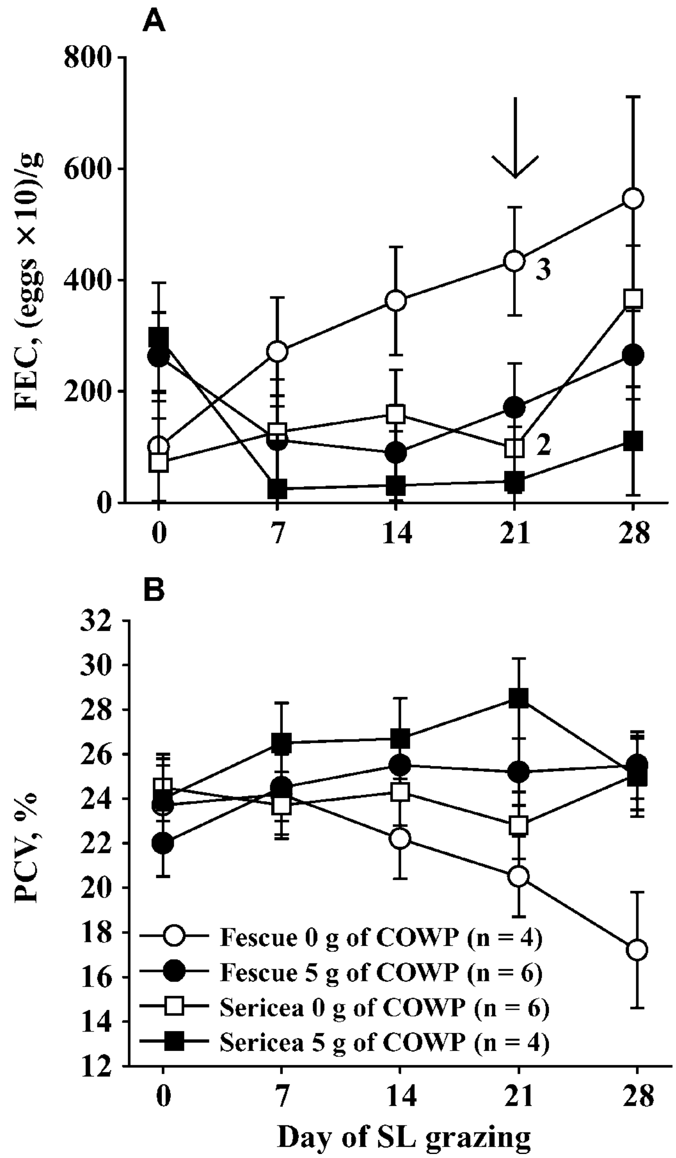

Figure 6. Effect of 0 or 5 g of copper oxide wire particles (COWP; n = 10/treatment) in yearling does grazing tall fescue or sericea lespedeza (SL; n = 10/forage) on fecal egg counts (FEC; A) and blood packed cell volume (PCV; B) from d 0 through 28 after administration of COWP (Exp. 6). Arrow indicates day goats were removed from SL. A number to the right of a symbol indicates number of does that were dewormed with moxidectin on that day, which were removed from the data set the following week. Least squares means and SE are presented, and statistical analysis of FEC was performed on logarithm-transformed values. The COWP in gelatin capsules was administered orally with a balling gun on d 0. The COWP decreased FEC (COWP × d, $P = 0.01$) on d 7, 14, and 21 in treated compared with control goats.

indicated a reduction in *H. contortus* but not other GIN species, as observed in the current study.

During warmer months (Exp. 3 through 6), all doses of COWP clearly reduced FEC but did not necessarily alleviate anemia. The primary GIN species in these experiments was likely *H. contortus* according to previous studies at this location (Burke et al., 2004; Burke and Miller, 2006). In Exp. 3, weaned goats were overstocked, which resulted in a high level of pasture contamination of infective larvae. Nematode infection quickly reestablished after an initial reduction in FEC, and the presumably high number of blood-feeding *H. contortus* L4 larvae led to anemia in 88% of goats within 28 d after administration of COWP. Other investigators have indicated that COWP appears to act most effectively on established GIN while copper is being solubilized from the COWP bolus, which may last up to 14 d depending on abomasal pH (Bang et al., 1990). Interestingly, abomasal copper may be elevated for up to 44 d (Langlands et al., 1989). Copper oxide wire particles were determined to be about 40% effective against incoming larvae in a previous study with dairy goats (Chartier et al., 2000), but the low doses used in the current study were not effective against incoming larvae in the face of an overwhelming GIN challenge. A relatively low dose (2 g) of COWP was more effective against GIN in older doe kids in Exp. 5, which was completed in August, when the reinfection challenge may have been lower. There may also be species differences in effectiveness of COWP against GIN. Burke and Miller (2006) observed effective GIN control with multiple treatments in lambs administered COWP every 42 d at 4 dose levels similar to those used in Exp. 3 with kids. Adult worms appeared to produce eggs, though at a reduced output, 3 d after COWP administration, but egg production was minimal 3 d later (Exp. 4).

Copper oxide wire particles may be less effective in reducing GIN infection in mature sheep or goats compared with growing animals. The reduction in FEC in mature ewes was only 58% seven days after COWP administration (Burke et al., 2005) compared with 98% in lambs (Burke et al., 2004), even though the proportion of *H. contortus* was thought to be relatively high. Similarly, there was only a 45% reduction in FEC in mature goats grazing tall fescue (Exp. 6) compared with kids grazing Bermudagrass (Exp. 3 and 5) that were administered COWP. Chartier et al. (2000) reported a 67% reduction in response to COWP 7 d later compared with untreated lactating dairy goats with a mixed-GIN infection. A lack of a reduction in GIN in response to COWP could be associated with increased abomasal pH so that the copper is insoluble (Bang et al., 1990).

Increased dietary protein has been successful in control of GIN by acting to improve immune response to parasites (Datta et al., 1999; Strain and Stear, 2001). In Exp. 5 of the current study, in those goats that did not receive COWP, there were few differences between goats fed a moderate or high level of protein. The CSB group may have experienced a self-cure phenomenon after d 21 in response to significant rainfall around d 7. An influx of new L3 may lead to expulsion of the adult nematodes (Gordon, 1950) and may have led to reinfection or a second increase in FEC by d 42. Infection level of the other groups of does was less critical based on the greater PCV and lower FEC at that time. There appeared to be no benefit to increased dietary protein. The critical nutrients or protein level may have been met in the CSB group of goats so that no benefit of added protein was apparent in reducing existing GIN infection or the feeding period was too short to observe any benefit. In this experiment, the combination of COWP and increased protein did not appear to be additive.

Human nematode pathogens such as *Angiostrongylus costaricensis* or *Anisakis* have been deterred by soaking larvae-infected food with solutions of vinegar (Zanini and Graeff-Teixeira, 1995; Sanchez-Monsalvez et al., 2005). In the current experiment (Exp. 4), there was no apparent reduction of the existing GIN infection, because FEC were similar to undrenched goats, but effects on larvae were not examined. It was not determined whether abomasal pH was reduced by vinegar, but COWP led to a 90% reduction in FEC, suggesting adequate copper solubility for adult nematode reduction. Considering the risk of upsetting rumen function, as was apparent in a few of the goats, treatment with vinegar is not recommended.

Bioavailability of copper oxide is considerably less than that of copper salts (Ledoux et al., 1995). However, there was a greater concentration of copper in the liver in COWP-treated compared with untreated goats in Exp. 2, and values were in the lower range of adequate values, which were 83 to 500 mg/kg of DM according to Puls (1988). No signs of copper toxicity were apparent in any animals used in these experiments. Goats are less susceptible to copper toxicity than sheep (Ademosum and Munyabantu, 1982; Economides, 1986). Dietary copper requirements of goats have not been well established. Complex mineral interactions with molybdenum, sulfur, selenium, and iron can bind copper, creating a copper deficiency. When the level of these minerals is insufficient to interfere with copper availability, there may be an increased potential for copper toxicity. In some areas of the United States, copper oxide should not be used because of the high levels of copper in the environment or in forages. Further, copper toxicity levels vary among breeds of goats. Copper oxide wire particles should not be administered to animals of unknown copper status or those supplemented with other forms of copper. Copper oxide wire particles should not be used in animals suffering from jaundice or any other liver disorder. Risk to copper toxicity has not been examined in goats administered multiple doses of COWP.

Use of COWP should be combined with other worm control strategies. Selective treatment is advised to minimize development of nematode resistance to COWP. Burke et al. (2004) reported survival of worms from COWP-treated lambs in confinement 56 d after administration and in the current study (Exp. 2) 35 d later. Because not all worms are killed, resistance of surviving worms could occur. Therefore, selective deworming is recommended, similar to that recommended for chemical dewormers (Kaplan et al., 2004). Selective treatment can be implemented using the FAMACHA system of anemia detection (Van Wyk and Bath, 2002). Only animals with anemic FAMACHA scores should be treated.

In summary, COWP reduced FEC during warmer months, but changes in FEC were variable during winter months. However, indicators of anemia were less affected by the use of COWP during either period. Mature goats did not benefit as much as young animals from the use of COWP. More research is necessary on the use of COWP with other nonchemical means of parasite control.

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