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Accuracy of the FAMACHA system for on-farm use by sheep and goat producers in the southeastern United States

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Abstract

FAMACHA© is a practical on-farm system designed to provide small ruminant producers a tool for improving their management of *Haemonchus contortus* infections. Although this system has become very popular and widely accepted by small ruminant producers in many regions of the southern United States, there is very limited data reported on the effectiveness of the FAMACHA system when performed by farmers. The objective of this study was to evaluate the accuracy of the FAMACHA system for on-farm use by small ruminant producers during the summer season. Small ruminant producers from Georgia, Louisiana, Florida, and Puerto Rico were trained to use the FAMACHA system by veterinarians and scientists experienced with this method. FAMACHA scores were assigned at least every 2 weeks by producers to weaned and mature sheep ($n = 552$) and goats ($n = 676$) of various breeds and ages between April and September 2004. At intervals that varied among farms from 2 to 8 weeks, researchers determined body condition scores (BCS; 1 = thin and 5 = fat) and collected blood and feces from a group of animals selected randomly to determine packed cell volume (PCV) and fecal egg counts (FEC). Two separate anemia thresholds were evaluated; these were defined by either FAMACHA score ($\geq$3 versus $\geq$4) or PCV ($\leq$19 versus $\leq$15%). The correlation between FAMACHA scores and PCV or FEC was high for both sheep and goats ($P < 0.001$). Specificity was maximized when FAMACHA scores of 4 and 5 were considered anemic, but sensitivity was low. Sensitivity for detecting anemic animals was 50% for sheep and 89% for goats when eye score values of $\geq$3 were considered anemic and PCV cutoff was $\leq$15%. The percentage of false negatives (anemic animals not identified by FAMACHA evaluation) was less than 5% in sheep and less than 1% in goats when FAMACHA scores $\geq$3 were considered anemic and PCV cutoff was $\leq$15%. In both sheep and goats, predictive value of a negative was greater than 90% for all anemia and eye score categories. These data indicate that the FAMACHA method used by producers is a valuable tool for identifying anemic sheep and goats in the southern United States and Puerto Rico.
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Keywords: FAMACHA; Gastrointestinal nematode; Goats; *Haemonchus contortus*; Sheep

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1. Introduction

Sheep and goat numbers have increased in the southeastern United States in recent years, and in some states this increase has been dramatic (NASS, 2006). This change is being caused by numerous factors, among which are increased demands by ethnic consumers, availability of hair breeds of sheep that are easy to manage, and use of small ruminants for forage management and invasive vegetative control. However, the growth of the small ruminant industry is being increasingly hampered by the increasingly difficult problem of controlling anthelmintic-resistant gastrointestinal nematodes (GIN). The species of primary concern is *Haemonchus contortus*, a highly pathogenic blood-feeder that causes anemia and reduced productivity and can lead to death in heavily infected animals.

Typical management of GIN in small ruminants is based upon frequent treatments with anthelmintics, which has led to the development of drug-resistant worm populations throughout the world (Mortensen et al., 2003; Kaplan, 2004). The most important factor in reducing the selection pressure for the development of anthelmintic resistance is maintenance of adequate refugia, which is defined as the portion of the worm population that are not exposed to anthelmintics (VanWyk, 2001). Worms in refugia that remain unselected by drug treatment provide a pool of alleles sensitive to anthelmintics, thus diluting the frequency of resistant alleles in that population of worms. Consequently, a sustainable method of worm control that minimizes the use of anthelmintics should help to greatly reduce the development of resistance, and preserve the efficacy of the few drugs that remain effective. Recently, we have validated a system to manage *H. contortus*-infected small ruminants in the United States, the FAMACHA© system (Kaplan et al., 2004). This system was developed in South Africa for classifying animals into categories based upon level of anemia (Bath et al., 1996; Malan et al., 2001; Van Wyk and Bath, 2002; Vatta et al., 2001). We determined that the FAMACHA system is an extremely useful tool for identifying anemic sheep and goats in the southern US and US Virgin Islands and that use of dewormers could be vastly reduced with only an extremely small risk of missing animals that might die if not treated. However, in that study, all animals were scored for anemia by veterinarians or research scientists who were well trained and experienced in the FAMACHA system. The objective of the current study was to evaluate the accuracy of the FAMACHA system for on-farm use when scoring was performed by sheep and goat producers who were trained by scientists from the previous study.

2. Materials and methods

All experimental procedures were reviewed and accepted by the Institutional Animal Care and Use Committee at each institution or Agricultural Research Service Animal Care and Use Committee in accordance with the NIH *Guide for the Care and Use of Laboratory Animals*. Pain and stress to animals was minimized throughout the experimental period.

2.1. Animals and procedures

Small ruminant producers from each participating state were trained to use the FAMACHA system by the same group of researchers that validated the system in the US (Kaplan et al., 2004). Color of ocular mucous membranes of each animal was classified into five categories according to the FAMACHA eye color chart: 1 = red, non-anemic; 2 = red-pink, non-anemic; 3 = pink, mildly anemic; 4 = pink-white, anemic; 5 = white, severely anemic. FAMACHA scores were assigned by producers at least every 2 weeks for weaned and mature sheep ($n = 552$) and goats ($n = 676$) of various breeds and ages between April and September 2004 from 3 farms located in Georgia (sheep, $n = 196$; goats, $n = 272$), one farm each in Louisiana (goats, $n = 322$) and Florida (sheep, $n = 236$), and two farms in Puerto Rico (sheep, $n = 120$; goats, $n = 82$). Additionally, every 2–8 weeks, a group of animals from each farm was selected at random using a random numbers chart by researchers for collection of blood via jugular venipuncture and fecal samples directly from rectum to determine blood packed cell volume (PCV) and fecal egg counts (FEC), respectively, and to determine body condition scores (BCS; 1 = thin and 5 = fat). Fecal egg counts were performed using a modified McMaster's technique (Whitlock, 1948) with a sensitivity of 50 eggs/g of feces. The minimum, maximum, and mean numbers of animals from which samples were collected on a farm for each date were 12, 46, and 31.5, respectively. Period of sampling varied among farms from 3 to 8 months. For each farm, cultures of nematode larvae were prepared from a pooled fecal sample, and infective third-stage larvae (L_3) were recovered and identified to genus (M.A.F.F., 1977). In addition, DrenchRite® larval development assays (LDA; Horizon Technology, New South Wales, Australia) were performed to evaluate the resistance status of each farm, and to aid in the selection of a highly effective anthelmintic for use in treatments during the course of the study.

2.2. Statistical analysis

Data from sheep and goats were analyzed separately. Two-way frequency tables with PCV by eye score were created according to Vatta et al. (2001). Two anemia threshold levels (eye scores ≥ 3 versus ≥ 4 and PCV ≤ 19 versus $\leq 15\%$) were used to provide alternative views of the data, since no precise value for PCV has been clearly established at which anemia crosses a threshold of clinical importance. Sensitivity, specificity, predictive value of a negative and predictive value of a positive were calculated for the data according to Vatta et al. (2001). Sensitivity was defined by the proportion, true positives/(true positives + false negatives); specificity by true negatives/(true negatives + false positives); predictive value of a negative (PV_{neg}) by true negatives/(true negatives + false negatives); and predictive value of a positive (PV_{pos}) by true positives/(true positives + false positives). A true positive result was defined as animals that were anemic (PCV ≤ 15 or $\leq 19\%$) with pale eye scores (≥ 4 or ≥ 3). A false positive result was defined as animals that were not anemic (PCV > 15 or $> 19\%$) but with pale eye scores. A false negative result was defined as animals that were truly anemic but were assigned red or pink eye scores (≤ 2 or ≤ 3). A true negative result was defined as animals that were not anemic with pink or red eye scores (Vatta et al., 2001).

Spearman correlation coefficients were calculated for each species (SAS, 1996) to examine the relationship between eye scores, PCV, FEC, and BCS. Arithmetic means and standard errors of FEC were calculated.

3. Results

In sheep, there was a progressive increase in mean FEC as FAMACHA scores increased from 1 to 5, but in goats, mean FEC demonstrated two distinct groupings; one grouping for scores of 1–3 and a second grouping for goats with scores of 4 or 5 (Table 1). Respectively, the correlation and regression between eye scores and FEC were 43.5 and 18.9% ($P < 0.001$) for sheep and 14.9 and 2.2% ($P < 0.001$) for goats. In both sheep and goats, wide ranges in PCV were noted for FAMACHA scores between 1 and 4, but not for animals that scored as 5 (Fig. 1). Mean PCV was higher in sheep than in goats for FAMACHA scores of 1–4, but not in animals that scored as 5. Overall, values for PCV ranged from 8 to 47% for sheep and from 7 to 49% for goats (Fig. 1). The correlation and regression between eye scores and PCV were 23.8 and 5.7% ($P < 0.001$) in sheep and 19.9 and 3.9% ($P < 0.001$) in goats.

Table 1
Mean and standard error (S.E.) of fecal egg counts (eggs/g) by FAMACHA eye score category for sheep and goats

FAMACHA score	Sheep		Goats	
	n	Mean (S.E.)	*n*	Mean (S.E.)
1	106	312 (56)	152	975 (98)
2	208	602 (76)	244	870 (74)
3	136	1,524 (255)	203	969 (98)
4	34	3,204 (641)	39	2,534 (809)
5	11	10,690 (2834)	19	2,147 (417)

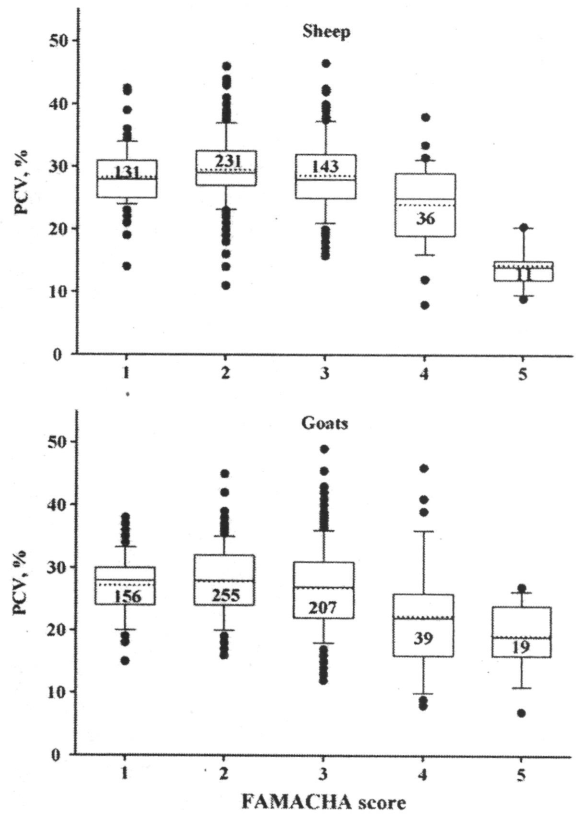

Fig. 1. Box plots demonstrating the relationship between PCV value and FAMACHA eye score category in sheep (top panel) and goats (bottom panel). Lower and upper borders of the box represent the 25th and 75th percentiles, respectively. Mean (dotted line) and median (solid line) values are presented within the box. Whiskers above and below the box indicate the 90th and 10th percentiles and the circles represent individual values outside of this range. Values within each box represent the number of animals that were scored within a particular FAMACHA category.

Table 2
Frequency and percent (in parenthesis) of false negatives, false positives and correct treatment recommendations for assigned ranges in PCV values based on treatment of animals with FAMACHA eye scores ≥3

PCV value	False negative	False positive	Correct treatment	Total
Sheep				
≤19	31 (5.3)	–	45 (7.6)	76 (12.9)
20–29	–	91 (15.4)	193 (32.8)	284 (48.2)
>29	–	69 (11.7)	160 (27.2)	229 (38.9)
Total	31 (5.3)	160 (27.2)	398 (67.6)	589 (100)
Goats				
≤19	28 (4.1)	–	55 (8.1)	83 (12.2)
20–29	–	136 (20.0)	228 (33.5)	364 (53.5)
>29	–	76 (11.2)	157 (23.1)	233 (34.3)
Total	28 (4.1)	212 (31.2)	440 (64.7)	680 (100)

Incorrect treatment would have occurred if eye score was 3, 4 or 5 and PCV >19% (false positive) and if eye score was ≤2 and PCV ≤19% (false negative).

Eye score values were compared with PCV for sheep and goats (Tables 2–5) to determine rates of false negatives, false positives and correct treatment decisions as defined by the parameters established for anemia and need for treatment. Sixty-eight and 86% of sheep and 65 and 87% of goats (Tables 2 and 3) would have been correctly treated with eye scores ≥3 or ≥4, respectively, when a PCV value of ≤19% was considered anemic. Percentage correct was similar when a PCV value of ≤15% was considered anemic (Tables 4 and 5). Using the most conservative guidelines for need and assignment of treatment (PCV ≤19 and eye scores ≥4), less than 10 and 9% of anemic sheep and goats, respectively, would have failed to receive a required treatment (false negatives; Table 3). However, when more liberal criteria were used, in all cases, less than 7% of anemic sheep and 5% of anemic goats would have failed to receive a required treatment (Tables 2, 4 and 5). Using the most liberal criteria (PCV ≤15 and eye scores ≥3), 65 and 64% would have been correctly treated and less than 5 and 1% of sheep and goats, respectively, would have missed a necessary treatment (false negatives; Table 4).

Table 3
Frequency and percent (in parenthesis) of false negatives, false positives and correct treatment recommendations for assigned ranges in PCV values based on treatment of animals with FAMACHA eye scores ≥4

PCV value	False negative	False positive	Correct treatment	Total
Sheep				
≤19	53 (9.0)	–	23 (3.9)	76 (12.9)
20–29	–	20 (3.4)	264 (44.8)	284 (48.2)
>29	–	7 (1.2)	222 (37.7)	229 (38.9)
Total	53 (9.0)	27 (4.6)	509 (86.4)	589 (100)
Goats				
≤19	58 (8.5)	–	25 (3.7)	83 (12.2)
20–29	–	7 (1.0)	338 (49.7)	364 (53.5)
>29	–	26 (3.8)	226 (33.2)	233 (34.3)
Total	58 (8.5)	33 (4.8)	589 (86.6)	680 (100)

Incorrect treatment would have occurred if eye score was 4 or 5 and PCV >19% (false positive) and if eye score was ≤3 and PCV ≤19% (false negative).

Table 4
Frequency and percent (in parenthesis) of false negatives, false positives and correct treatment recommendations for assigned ranges in PCV values based on treatment of animals with FAMACHA eye scores ≥3

PCV value	False negative	False positive	Correct treatment	Total
Sheep				
≤15	26 (4.4)	–	26 (4.4)	52 (8.8)
16–29	–	110 (18.7)	198 (33.6)	308 (52.3)
>29	–	69 (11.7)	160 (27.2)	229 (38.9)
Total	26 (4.4)	179 (30.3)	384 (65.2)	589 (100)
Goats				
≤15	3 (0.4)	–	23 (3.4)	26 (3.8)
16–29	–	168 (24.7)	253 (37.2)	421 (61.9)
>29	–	76 (11.2)	157 (23.1)	233 (34.3)
Total	3 (0.4)	244 (35.9)	433 (63.7)	680 (100)

Incorrect treatment would have occurred if eye score was 3, 4 or 5 and PCV >15% (false positive) and if eye score was ≤2 and PCV ≤15% (false negative).

Table 5
Frequency and percent (in parenthesis) of false negatives, false positives and correct treatment recommendations for assigned ranges in PCV values based on treatment of animals with FAMACHA eye scores ≥4

PCV value	False negative	False positive	Correct treatment	Total
Sheep				
≤15	38 (6.4)	–	14 (2.4)	52 (8.8)
16–29	–	29 (4.9)	279 (47.4)	308 (52.3)
>29	–	7 (1.2)	222 (37.7)	229 (38.9)
Total	38 (6.4)	36 (6.1)	515 (87.4)	589 (100)
Goats				
≤15	15 (2.2)	–	11 (1.6)	26 (3.8)
16–29	–	40 (5.9)	381 (56.0)	421 (61.9)
>29	–	7 (1.0)	226 (33.2)	233 (34.3)
Total	15 (2.2)	47 (6.9)	618 (90.9)	680 (100)

Incorrect treatment would have occurred if eye score was 4 or 5 and PCV >15% (false positive) and if eye score was ≤3 and PCV ≤15% (false negative).

Table 6
Comparison of sensitivity, specificity, and predictive values for positive and negative tests in sheep and goats using differing FAMACHA and packed cell volume (PCV) criteria for positive test results and anemia

	Sensitivity[a]	Specificity[b]	(a + b)/2	PV_{neg}[c]	PV_{pos}[d]
Sheep					
FAMACHA values 3–5 considered positive test results					
PCV cutoff ≤19%	59.2	68.8	64.0	91.9	22.0
PCV cutoff ≤15%	50.0	66.7	58.4	93.2	12.7
FAMACHA values 4 and 5 considered positive test results					
PCV cutoff ≤19%	30.3	94.7	62.5	90.2	46.0
PCV cutoff ≤15%	26.9	93.3	60.1	92.9	28.0
Goats					
FAMACHA values 3–5 considered positive test results					
PCV cutoff ≤19%	66.3	64.5	65.4	93.2	20.6
PCV cutoff ≤15%	88.5	62.7	75.6	99.3	8.6
FAMACHA values 4 and 5 considered positive test results					
PCV cutoff ≤19%	30.1	94.5	62.3	90.7	43.1
PCV cutoff ≤15%	42.3	92.8	67.6	97.6	19.0

[a] Sensitivity = (true positives/(true positives + false negatives)) × 100.
[b] Specificity = (true negatives/(true negatives + false positives)) × 100.
[c] Predictive value of a negative (PV_{neg}) = (true negatives/(true negatives + false negatives)) × 100.
[d] Predictive value of a positive (PV_{pos}) = (true positives/(true positives + false positives)) × 100.

The percentage of sheep and goats that would be recommended for treatment [(true positive + false positive)/total number of animals × 100] differed greatly depending on whether FAMACHA scores of ≥3 or ≥4 were used for making this decision. Percentage of sheep and goats recommended for treatment with eye scores of ≥3 were 34.8 and 39.3% (Tables 2 and 4), respectively, whereas this value was reduced to 8.5% (Tables 3 and 5) when eye scores of ≥4 were used. For goats, sensitivity was maximized when eye score values ≥3 were considered anemic and PCV cutoff value was ≤15%. However, for sheep, a PCV cutoff value of ≤19% maximized sensitivity (Table 6). Specificity was maximized for both sheep and goats when eye score values ≥4 were considered anemic and PCV cutoff was ≤19% (Table 6). In both sheep and goats, the predictive value of a negative was greater than 90% for all anemia and eye score categories, and was greater than 92% for both eye score categories when an anemia cutoff of ≤15% was used. However, because of a large number of false positives, the predictive value of a positive was less than 50% for all categories.

The successful identification of animals that needed treatment varied considerably by farm and time. When correct treatment was considered as PCV ≤19%, one goat farm had a consistently high incidence (>10%) of false negatives when PCV ≤19% was considered anemic, but when PCV ≤15% was considered anemic, most goat farms had no false negatives and in no instances were false negatives more than 3% (Table 7). In contrast, the incidence of false negatives on sheep farms was generally higher (Table 7). Because random animals from each farm were sampled at each collection period and collection periods for each farm did not occur at the same time, analyses over time were not conducted. However, individual farms did not appear to

Table 7
Percentage of false negatives and correct treatment recommendations based on treatment of sheep and goats with FAMACHA eye scores ≥3 using PCV value cutoffs of ≤19 or 15%

Collection period	False negative (%)			Correct treatment (%)		
	First	Second	Last	First	Second	Last
Sheep						
Farm 1 PCV ≤19%	15.0	12.5	2.5	72.5	87.5	92.5
PCV ≤15%	7.5	5.0	0	75.0	92.5	92.5
Farm 2 PCV ≤19%	5.0	0	0	50.0	55.0	55.0
PCV ≤15%	0	0	0	45.0	55.0	55.0
Farm 3 PCV ≤19%	5.0	40.0	5.1	52.5	37.1	35.9
PCV ≤15%	2.5	22.9	0	52.5	54.3	28.2
Goats						
Farm 1 PCV ≤19%	0	0	0	25.0	28.6	0
PCV ≤15%	0	0	0	8.3	21.4	0
Farm 2 PCV ≤19%	14.3	13.5	17.4	80.0	56.8	76.1
PCV ≤15%	2.9	0	0	88.6	64.9	87.0
Farm 3 PCV ≤19%	0	0	2.5	47.4	58.6	85.0
PCV ≤15%	0	0	0	44.7	58.5	85.0
Farm 4 PCV ≤19%	0	9.1	8.3	50.0	54.6	41.7
PCV ≤15%	0	0	0	50.0	54.6	37.5

improve their accuracy in identifying anemic animals over time. There were a high percentage of false positives on some farms, which reduced the percentage of correctly treated animals (Table 7).

Body condition scores ranged between 1 and 4.5 in sheep and 1.5 and 4.5 in goats. The relationship between BCS and indicators of GIN infection were significant for sheep (FEC: $R = -15.6\%$, $R^2 = 2.4\%$, $P < 0.003$; PCV: $R = 31.9\%$, $R^2 = 10.1\%$, $P < 0.001$; eye score: $R = -18.1\%$, $R^2 = 3.3\%$, $P < 0.001$) and goats (FEC: $R = -20.9\%$, $R^2 = 4.4\%$, $P < 0.001$; PCV: $R = 25.3\%$, $R^2 = 6.4\%$, $P < 0.001$; eye score: $R = -15.2\%$, $R^2 = 2.3\%$, $P < 0.02$). The regression equation for PCV versus BCS, $y_{\text{PCV}} = 22.5 + 2.1x_{\text{BCS}}$ for sheep and goats (pooled because curves were similar), indicates that for every 1 unit increase in BCS, PCV increases by 2.1%.

4. Discussion

In this study, the relationships between eye scores and FEC or PCV were significant, but this relationship was not as close-fitting as when scores were assigned by more experienced scientists in a previous study (Kaplan et al., 2004). Considering eye scores of three or greater as anemic, sensitivity of the FAMACHA system for producers in this study was lower and specificity was higher than reported in earlier studies (Vatta et al., 2001; Van Wyk and Bath, 2002; Kaplan et al., 2004). High sensitivity is much more important than high specificity, since not treating a false negative may mean that an animal dies, whereas no harm is done by treating a false positive. A lower sensitivity occurred in the current study because of the increased number of false negatives (undetected anemic animals) on approximately half of these farms (Table 7) and a higher specificity because the number of false positives detected in the current study was lower than the two previous studies. Perhaps with time and experience, the number of false negative animals would decrease on these farms, as occurred in the second year of the Vatta et al. (2001) study. An additional factor differing in the current study was the high number of non-anemic animals. Less than 4% of sheep and goats had a PCV of ≤15 and 8% of sheep and 12% of goats had a PCV of ≤19%. The task of assigning the correct eye score becomes more difficult when there are a disproportionate number of animals that are non-anemic.

By treating eye scores of 3 or higher rather than scores of 4 and 5 only, producers reduced the number of anemic animals that would have missed treatment. However, the percentage of correctly treated animals decreased, because the number of false positives or non-anemic animals that were treated increased. Although this increases dewormer usage, treating animals that do not need treatment is not nearly as big of a problem as not treating animals that are truly anemic. Based on a FAMACHA threshold score for treatment of 3, fewer than 6% of sheep and goats would have missed treatment if cutoff level for anemia or PCV was considered ≤19%. These data reinforce the precaution that is emphasized during training that the FAMACHA system should not be the sole basis for making treatment decisions. To reduce the chances of having false negatives left untreated, consideration of other signs of gastrointestinal parasitism should be made while observing animals during handling. The differences in false negatives observed when scores ≥4 or ≥3 are considered anemic is of more importance where young animals or female animals in late pregnancy and lactation are concerned. When scoring these groups and making decisions on treatment, it is more critical for these animals that more caution is exercised and, as previously recommended, 3s should be treated (Kaplan et al., 2004). Additionally, frequent examination of animals (7–14 day intervals) during periods of heavy worm infection may be crucial to minimize losses and maximize the success of the system.

Although producers can benefit from reduced anthelmintic costs by using the FAMACHA system, the most significant benefit is in its ability as a tool to maintain a population of *H. contortus* in refugia. Anthelmintic resistance will develop slowly if the number of *H. contortus* that are not exposed to anthelmintic and maintained in refugia is high. In the current study, had eye scores of ≥3 been used for making treatment decisions, 65% of sheep and 61% of goats would have remained untreated. With these untreated animals, sufficiently large refugia should be maintained that is expected to greatly reduce the rate with which anthelmintic resistance will develop.

Although there was a significant relationship between BCS and PCV or FEC, BCS by itself is not a good indicator of infection with *H. contortus*. The small regression values in this study indicate that there were many other factors that contributed to changes in BCS. Because haemonchosis can develop so rapidly, a reduction in body condition or body weight will likely not be apparent during an acute infection. Others have found no relationship between BCS and FEC (Vatta et al., 2002), nor body weight and worm counts (Roberts and Swan, 1982) when *H. contortus* was the predominant nematode. Noting changes in BCS may be more applicable in environments where *Teladorsagia* or *Trichstrongylus* are predominant (Van Wyk et al., 2006).

The FAMACHA system has proven to be a valuable tool that producers can use to identify animals in need of treatment, to reduce the number of animals to be treated, thereby saving dewormer and contributing to more worms in refugia. Because worms are over-dispersed among animals in a herd/flock, a relatively small number of animals are infected with most of the worms (Barger, 1985; Hoste et al., 2001). Furthermore, within a herd/flock it tends to be the same animals that are consistently infected with high worm burdens over time. Using the FAMACHA system, animals that repeatedly require treatment can be identified and culled to reduce the herd/flock worm load. In addition, selection of resilient (the ability to withstand worm infection) animals occurs by using FAMACHA. Some animals may harbor worms without becoming anemic, but typically susceptible animals with a high number of worms become anemic. Genetic progress can be made toward selection of a more resilient group of animals (Bisset and Morris, 1996; Bisset et al., 2001). The FAMACHA system should continue to be used in consultation with technical assistance to develop individualized GIN control programs.

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Mention of trade names or commercial products in this manuscript is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

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