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Antimicrobial treatment of clinical mastitis in the eastern United States: The influence of dairy farmers' mastitis management and treatment behavior and attitudes

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ABSTRACT

To assess both the behaviors and social variables related to antimicrobial therapy for clinical mastitis, we sent a survey to 1,700 dairy farms in Michigan, Pennsylvania, and Florida in January and February 2013. The survey included questions related to 7 major areas: sociodemographic and farm characteristics, milking proficiency, milking systems, cow environment, infected cow monitoring and treatment, farm labor, and attitudes toward mastitis and related antimicrobial use. The overall response rate was 41% (21% in Florida, 39% in Michigan, and 45% in Pennsylvania). Herd size ranged from 9 to 5,800 cows. Only a small proportion of herds frequently or always cultured milk samples for bacteriology from cows with a high somatic cell count (17%), cows with clinical mastitis (18%), or bulk tank milk (13%). Likewise, only 56% of herds frequently or always maintained records of all treated cows and 49% reviewed records before administering mastitis treatments. Multivariate analysis determined that use of treatment records was associated with increased likelihood of frequent use for both intramammary (IMA) and systemic (SYA) administration of antimicrobial drugs for therapy of clinical mastitis. As would be expected, use of natural (organic) therapies was associated with decreased use of IMA, as was the respondent being a member of an Amish community. Lower levels of education and the use of bacterins to control *Staphylococcus aureus* mastitis were also associated with decreased IMA, whereas increased use of IMA at dry off and the belief that "bad luck" plays a role in mastitis problems were associated with increased IMA. Use of an internal teat sealant, the respondent being the sole proprietor, being from Michigan, use of conductivity to measure subclinical mastitis, the respondent placing increasing importance on decreasing antibiotic residues in cull cows, and having financial incentives for employees linked to somatic cell count were associated with increased use of SYA for the treatment of clinical mastitis. Use of sand or mattresses for bedding were associated with decreased SYA. These findings highlight the need to improve the acceptance of practices that are consistent with prudent antimicrobial use for the treatment of clinical mastitis on dairy farms. Additionally, the willingness of dairy farmers to administer antimicrobial drugs for the treatment of clinical mastitis is associated with other mastitis-related practices and attitudes.
Key words: clinical mastitis, antimicrobial treatment, behavior, attitudes

INTRODUCTION

Mastitis is the most common reason for antimicrobial drug therapy for cows on US dairy farms (Pol and Ruegg, 2007). In 2007, an estimated 16.4% of the approximately 9 million cows in the United States were treated for this disease (USDA-APHIS, 2008), equating to nearly 1.5 million mastitis cases treated annually. In a Wisconsin study, about 80% of all antimicrobial drugs used were for treatment or prevention of mastitis, which included dry-cow therapy (Pol and Ruegg, 2007). In a Canadian study, intramammary administration of antimicrobials (**IMA**) was estimated to account for 35% of all antimicrobial use on dairy farms, which was lower than use of antimicrobials administered systemically (**SYA**, 38%; Saini et al., 2012). However, the proportion of SYA that was administered for the treatment of mastitis was not identified. Although antimicrobial therapy improves animal health and well-being, the economic losses associated with additional labor costs and discarded milk are significant (Erskine et al., 2003). Culled dairy cows account for 67% of residue violations among all marketed livestock in the United States, and 83% of the residues in culled dairy cows resulted from antimicrobial drug use (USDA-FSIS, 2011).

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To date, the risk of emerging antimicrobial resistance among bovine mastitis pathogens has been low, particularly for drugs with high therapeutic value in human medicine (Erskine et al., 2004; Lindeman et al., 2013; McDougall et al., 2014). Nonetheless, prudent use of antimicrobials is needed on dairy farms, similar to the stewardship of antimicrobial resources advocated in human medicine (Weber, 2006). Microbial culture of milk is a practical tool to identify causative agents and target therapeutic regimens for effective mastitis treatment. A study conducted on a large Michigan dairy (Hess et al., 2003) demonstrated that on-farm bacteriologic culture of milk samples, when used as part of the therapeutic selection criteria for cows with clinical mastitis, reduced the number of treated cows by 80%. A recent multi-state study also found a reduction in antimicrobial use when culture-based treatments replaced empirical therapy (Lago et al., 2011a).

Standardized mastitis therapeutic protocols should diminish spontaneous "cow-side" biases and establish uniformity for therapeutic regimens (Wagner and Erskine, 2013). However, actual on-farm therapeutic decisions often differ from veterinary recommendations (Vaarst et al., 2002), which may result from mastitis therapy being administered without veterinary supervision. In a survey of Washington State dairy producers, most agreed that using written protocols for disease treatment could reduce therapeutic errors but fewer than one-third had protocols (Raymond et al., 2006). Additionally, Oliveira and Ruegg (2014) found that there was considerable extra-label drug use for the treatment of clinical mastitis and that over half of IMA for the treatment of clinical mastitis was for cases that were caused by *Escherichia coli* or for cases that did not yield any bacteria on culture.

Risk factors that decrease therapeutic efficacy include (1) increasing cow age, (2) high SCC before treatment, (3) long duration of infection, (4) multiple infected quarters, and (5) infections caused by *Staphylococcus aureus* (Deluyker et al., 2005; Barkema et al., 2006; Pinzón-Sánchez and Ruegg, 2011). Particularly, chronic infections are likely to have poor therapeutic outcomes and may require an extended duration of antimicrobial therapy (Owens and Nickerson, 1990; Erskine et al., 2003; Oliver et al., 2004).

Thus, for veterinarians and advisors who promote prudent antimicrobial use associated with mastitis treatment, it is important to understand the behaviors and attitudes of farm personnel with respect to (1) utilizing bacteriologic data, (2) applying standardized therapy protocols, and (3) identifying cow-level risk factors through the use of records for better assessment of potential therapeutic efficacy.

Swinkels et al. (2015) reported that extended treatment (defined as any therapeutic regimen beyond labeled dosing) was practiced on 37/38 dairy farms and was perceived as part of the social norm of "being a good farmer" and that mastitis was not treated "thoroughly" if clinical symptoms were still visible at the time of cessation of treatment. Interestingly, dairy farmers seemed to administer extended therapy based on wanting to comply with other farmers' and veterinarians' perceived norms that extended treatment is better, resulting in treatment protocols being driven by social approval among peers (Swinkels et al., 2015). In a study of dairy farms in the UK, intention to reduce antimicrobial use was strongly driven by the respondents' belief that their social and advisory network would approve of this behavior (Jones et al., 2015). Additionally, farms that were more likely to remain in milk production were significantly more likely to exhibit positive intentions to reduce antibiotic use.

To gain a better understanding of the attitudes and motivations that might affect decisions on the part of US dairy producers to use antimicrobial drugs for mastitis, this study collected information from a survey sent to dairy farms in Florida (**FL**), Michigan (**MI**), and Pennsylvania (**PA**). Additionally, we included variables that attempted to capture attitudes toward employee training and education. The objectives of this study were 2-fold: (1) to describe self-reported willingness for IMA and SYA for the therapy of clinical mastitis, and (2) to assess the relative and combined influences of management practices and farmer's attitudes and beliefs on frequency of IMA and SYA for the therapy of clinical mastitis. More specifically, 3 research questions guided the analysis in this study: To what extent are dairy farmers' management practices or behaviors associated with self-reported IMA and SYA? To what extent are dairy farmers' attitudes or beliefs associated with self-reported IMA and SYA? What specific dairy farmers' management practices/behaviors or attitudes/beliefs are the most important in explaining IMA and SYA?

MATERIALS AND METHODS

Dairy Farm Selection

Dairy farm selection protocols and survey questionnaire design were previously described in detail (Schewe et al., 2015). Briefly, a mail survey was sent to a stratified random sample of USDA grade A certified dairy farms (farms meeting requirements for interstate milk shipments set forth by the Pasteurized Milk Ordinance) in MI, PA, and FL. Addresses of 7,983 grade A certified dairy farms in FL, MI, and PA were obtained to serve as the total farm population from which to select our survey sample (full text of the survey is available at http://qualitymilkalliance.com/wp-content/uploads/2015/01/133813108-A-Survey-of-Mastitis-on-Dairy-Farms.pdf).

Before sample selection, dairy farms in both MI and PA were stratified into "large" or "small-to-medium" strata based on herd size distribution due to the small number of large herds in those states. In PA, large farms were defined as those with >250 cows and in MI, large farms were defined as those with >500 cows due to the larger mean and median herd size compared with PA. Because of the small number of dairy farms in FL, all 128 grade A farms in this state were included in the sample. Sample weighting procedures to account for differential probability of selection across herd size strata are described below in the statistical analysis section.

Survey questions covered 7 categories: (1) sociodemographic and farm characteristics (e.g., age, education, race, Mennonite or Amish, native English speaking, herd size); (2) milking proficiency (e.g., pre- and postmilking teat disinfection, wearing gloves during milking); (3) milking systems (e.g., parlor type, maintenance patterns); (4) cow environment (e.g., housing, grouping, bedding); (5) infected cow monitoring and treatment (e.g., record keeping, use of cultures); (6) farm labor (e.g., number of workers, employee management strategies); and (7) attitudes toward mastitis and related antimicrobial agent use (e.g., farm goals, belief in causes of mastitis, sources of information about mastitis). More details about herd selection and survey procedures have been described in a previous study (Schewe et al., 2015).

Measures

Dependent Variables. The dependent variables in this study were derived from self-reported frequency of antimicrobial drug use on dairy farms to treat clinical mastitis. Two types of antimicrobial drug use based on route of administration were considered: IMA and SYA. Respondents were asked (1) how often they used intramammary antimicrobial drugs to treat clinical mastitis, and (2) how often they used systemic antimicrobial drugs to treat clinical mastitis. The item responses for these questions were 1 = never, 2 = sometimes, 3 = frequently, and 4 = always. These 2 variables (IMA and SYA) were further each recoded into a dummy variable (1 = frequently or always, 0 = never or sometimes) for multivariate analysis.

Independent Variables. Independent variables were selected from a list of previously described variables (Schewe et al., 2015) including farm management practices, particularly monitoring and treatment practices of infected cows; social variables including knowledge, behaviors, beliefs about mastitis control and antimicrobial drug use; and labor management practices and attitudes, as well as controls for sociodemographic and farm characteristics. Variables were included in the logistic regression model only if they met the significance threshold ($P < 0.10$) in bivariate associations with the dependent variables (IMA and SYA; Appendix Table A1).

Statistical Analysis

Analysis proceeded through 3 stages: (1) factor analysis for dimension reduction among independent variables, (2) bivariate analysis to determine which independent variables to retain for multivariate analysis, and (3) multilevel mixed-effects logistic regression models to assess the relative and combined influences of dairy farmers' management and treatment behaviors and attitudes on antimicrobial drug use on dairy farms, including treatment practices for infected cows, dairy farmers' goals and attitudes, controlling for farmer's sociodemographic characteristics, farm structure, and cow environment.

All analyses were weighted to account for the sampling design in this study; weights were designed as probability weights to reflect the differential probability of each farm being sampled. Weighted analysis of complex survey data has been demonstrated to produce unbiased estimates and variances such that inference for a specified significance level can be achieved with correct probability coverage (McDowell and Pitblado, 2002). Farms in Michigan's small-to-medium strata had a probability of being selected of 0.39 and a sampling weight of 2.56 (pweight = 1/probability of being selected). Farms in Pennsylvania's small-to-medium strata had a probability of being selected of 0.12 and a sampling weight of 8.42. Statistical significance was defined as $P < 0.05$.

Factor Analysis. Principal component factor analysis with varimax rotation (Kim and Mueller, 1978) was performed to reduce the number of independent variables that were highly associated and loaded on the same factor. Factor analysis confirmed the retention of 4 scales, all with eigenvalues >1, Cronbach's α >0.60, and high factor loadings (>0.60) that confirm internal validity.

Bivariate Analysis. Bivariate associations with the dependent variables were tested to determine which independent variables were associated with IMA or SYA and thus included in multivariate regression ($P < 0.10$ threshold for inclusion). For binary (nominal) variables, we compared means of the dependent variables across the categories of the independent variables using an adjusted Wald test to test for significance of relationship. For ordinal and continuous variables, we performed Pearson correlations and used a 2-tailed significance test to test for significance with pairwise deletion of missing cases. In this second stage, the extent to which self-reported antimicrobial drug use differed by herd size was also determined.

Multilevel Mixed-Effects Logistic Regressions. We used multilevel mixed-effects logistic regression model to assess the relative and combined effects of dairy farmers' management practices or behaviors and attitudes or beliefs on IMA and SYA. The model uses information from 624 dairy herds nested within 5 clusters of farm size. Farm size is treated as a random effect. Farm size captures differences in the outcomes between states. Pennsylvania and Michigan have relatively smaller farm sizes as compared with Florida (Appendix Table A2). Of interest is the probability that a dairy farmer will use antimicrobial drugs on dairy farms (IMA or SYA = 1 if yes; 0 if no). The model controls for farmer's socio-demographic characteristics (e.g., educational attainment, language of respondent, being a member of an Amish community, and state), farm structure (e.g., herd size and primary position in the dairy-farm business), bulk tank SCC (**BTSCC**), and cow environment (e.g., bedding types). Mixed effects logistic regression models of IMA and SYA were performed in 3 steps.

First, we estimated a model with no predictors (unconditional model) to determine the magnitude of variation in the outcome between herds of different farm sizes. Given a Bernoulli sampling model and a logit link function, the level-1 model is expressed as

$$\eta_{ij} = \beta_{0j},$$

and the level-2 model as

$$\beta_{0j} = \Upsilon_{00} + \mu_{0j},\ \mu_{0j} \sim N(0, \tau_{00}).$$

In this model, Υ_{00} is the average log-odds of using IMA (or SYA); τ_{00} is the variance between herds of different sizes in average log-odds of using IMA (or SYA); and $\eta_{ij} = \log(\phi_{ij}/1 - \phi_{ij})$ is the log-odds of success, where ϕ_{ij} = the probability of success (e.g., using IMA or SYA); μ_{0j} is assumed to follow a normal distribution with mean 0 and variance τ_{00}.

Second, we estimated a full regression (conditional) model that included all independent variables that were significantly associated with the outcome(s) in the bivariate relationships ($P < 0.10$). The conditional model at level 1 is

$$\eta_{ij} = \beta_{0j} + \beta_{1j}X_{1j} + \beta_{2j}X_{2j} + \ldots + \beta_{pj}X_{pij},$$

where X_{ij} are herd-level predictors and β_{pj} the level-1 coefficients. In this model, the continuous or ordinal predictors are grand-mean centered whereas all other-level predictors are kept in their dummy variable metric. At level 2, we treated β_{0j} as random and considered other level-1 coefficients as fixed:

$$\beta_{0j} = Y_{00} + \mu_{0j},$$

$$\beta_{pj} = Y_{p0}, \text{ for } p > 0.$$

The random effects μ_{0j} are assumed to follow a normal distribution with mean zero and variance τ_{00}.

Third, we refined the model through backward stepwise regression, excluding any variables with $P > 0.10$. The state in which the farm was located and log-transformed geometric mean BTSCC were retained in both models as controls even if they were not significantly associated with the outcomes (Schewe et al., 2015). We also retained the culturing practices scale in the model for SYA even if it was not statistically significant.

The fits of the models of both outcomes to the data were assessed using the likelihood ratio test. The difference between −2 log-likelihood for the conditional model and −2 log-likelihood for the null model followed a chi-squared distribution (chi-squared deviance) with degrees of freedom equal to the difference in the number of estimated parameters between the 2 models. In both models, the chi-squared deviance statistics were statistically significant, suggesting that both models fit the data. To test for potential multicollinearity among independent variables, bivariate correlations among independent variables were first analyzed. Second, ordinary least square regression analysis of the dependent variables was performed before recoding (i.e., as ordinal scales) and estimated variance inflation factors (VIF) and tolerance values (models not shown). The results of these analyses revealed no highly correlated independent variables that would cause a multicollinearity issue (all VIF values were <10 and tolerance values were >0.1).

RESULTS

Survey Response Rate and Representative Sample

Of the 1,700 dairy farms in the initial sample, 79 (4.6%) had an incorrect address or were no longer a working farm. Thus, 1,621 valid farms were sampled, of which 660 farms (41%) responded to our survey. The response rate among valid farms was 21% in FL (25 of 119), 39% in MI (291 of 737), and 45% in PA (344 of

Table 1. Frequency distributions and means of self-reported antimicrobial drug use and farmers' mastitis management and treatment behavior on 628 dairy farms in Florida, Michigan, and Pennsylvania

Behavior variable	% of respondents indicating: Never	Sometimes	Frequently	Always	Not applicable	Mean ranking score[1]	SEM	n[2]
Use intramammary antibiotics	12.5	30.3	20.4	35.0	1.7	2.79	0.04	588
Use systemic antibiotics	22.5	45.9	12.3	12.3	6.9	2.15	0.04	537
Use of intramammary antibiotics at dry off (dry treatment)	9.5	10.0	3.8	76.8		3.48	0.04	613
Use of anti-inflammatory drugs	27.3	47.4	13.6	8.6	3.1	2.04	0.04	564
Use of oxytocin to treat clinical mastitis	45.5	36.7	8.8	6.5	2.5	1.76	0.04	585
Use of natural (organic) therapies to treat clinical mastitis	49.2	26.8	11.1	8.4	4.4	1.78	0.04	559
Use of alcohol pads before intramammary tube infusions	7.4	6.9	5.6	78.0	2.1	3.58	0.04	596
Keep written or computer records for all cows	29.1	13.5	11.1	44.0	2.4	2.72	0.05	581
Review treatment records before making treatment decisions	17.7	31.2	15.0	32.4	3.7	2.64	0.05	571
Treat mastitis cows for full course of antibiotic doses	8.5	18.0	15.4	55.5	2.6	3.21	0.04	595
Culture milk samples from high SCC or conductivity cows	33.3	47.1	9.9	6.4	3.2	1.89	0.03	575
Culture milk samples from clinical mastitis cases	31.5	49.1	8.6	8.8	2.0	1.94	0.04	581
Culture bulk tank milk samples	53.7	31.9	5.9	7.0	1.5	1.66	0.04	580
Use vaccines to control *Staphylococcus aureus* mastitis	74.3	10.2	2.2	9.7	3.5	1.45	0.04	575
Use gram-negative bacterins to control coliform mastitis	53.5	9.5	4.2	31.6	1.3	2.14	0.06	594
Use individual cow SCC to identify infected cows	18.4	29.4	20.8	28.6	2.8	2.61	0.05	588
Use conductivity in milk to identify infected cows	57.9	16.6	6.4	9.4	9.7	1.64	0.04	521
Train employees in mastitis protocols	10.2	12.5	15.1	42.3	20.0	3.12	0.05	456
Train employees in treatment protocols	13.7	13.9	12.5	40.5	19.5	2.99	0.05	459
Ensure strict compliance with milking protocols	6.3	12.2	22.3	55.4	3.7	3.32	0.04	566
Clean alleys/gutters after or during each milking	2.8	8.0	10.3	76.5	2.5	3.64	0.03	597
Milk mastitis and treated cows in a separate group	33.1	13.1	3.4	42.6	7.9	2.60	0.06	549
Use of oxytocin for milk letdown	36.4	52.2	7.0	3.0	1.5	1.76	0.03	593
Use of internal teat sealant (Orbeseal[3]) at dry off	49.9	6.0	1.8	40.9	1.3	2.34	0.06	591
Dock tails	68.1	7.7	3.3	19.9	1.0	1.75	0.05	602
Singe hair on the udders	58.9	19.1	10.0	11.6	0.5	1.74	0.04	600

[1]Excluding not applicable cases.

[2]Unweighted.

[3]Zoetis Animal Health, Parsippany, NJ.

765). Of the 660 responding farms, 32 respondents did not complete at least 50% of the survey and were excluded from analysis. Thus, an unweighted total of 628 cases were used in the analysis. Of the 660 responses, 41% of surveys were received after the first mailing, an additional 20% after one reminder postcard, an additional 25% after the third mailing, an additional 11% after the fourth mailing, and an additional 5% after the fifth mailing (Schewe et al., 2015). Previously, we had determined that our survey sample was largely representative of USDA-reported state averages for herd size, BTSCC, and production (Schewe et al., 2015).

Table 1 displays the prevalence and means of self-reported antimicrobial use, other types of treatment, treatment practices used to treat clinical mastitis, and mastitis management behavior. About 35 and 20% of the farms reported that they frequently or always treated cases of clinical mastitis with IMA, respectively. In contrast, only 12% indicated that they always or frequently (25% total) treated cases of clinical mastitis with SYA (Table 1). About 77% of dairy farmers in this study indicated that they always use IMA at dry off (blanket dry-cow therapy; Table 1).

In terms of other treatment practices, about 22, 15, and 20% of dairy farms indicated that they frequently or always treated cases of clinical mastitis with anti-inflammatory drugs, oxytocin, or natural and organic products, respectively (Table 1). Additionally, 55, 47, and 71% of farms indicated that they frequently or always kept written or computer treatment records, reviewed treatment records before making treatment decisions, and administered the full regimen of therapy when treating cases of clinical mastitis, respectively. The majority of farms (85%) reported that alcohol pads were always or frequently used before intramammary infusions (Table 1). Only a small proportion of herds frequently or always cultured milk samples for bacteriology from high-SCC or high-conductivity cows for bacteriology (16%), clinical mastitis cases (17%), or from bulk tank milk samples (13%) to aid in mastitis treatment decisions, or used vaccines to control for *Staphylococcus aureus* mastitis (12%). About 36% of herds frequently or always used gram-negative bacterins to control coliform mastitis (Table 1).

In terms of mastitis management, almost half of herds (49%) frequently or always used individual cow SCC to identify infected cows and 16% used conductivity in milk to identify infected cows. More than half of herds frequently or always trained employees in mastitis protocols (57%) and in treatment protocols (53%). The majority of herds frequently or always ensured strict compliance with milking protocols (78%) and cleaned alleys/gutters after or during each milking (87%). About 46% of herds frequently or always milked mastitis and treated cows in a separate group. About 43% of herds frequently or always used internal teat sealant (e.g., Orbeseal, Zoetis Animal Health, Parsippany, NJ) at dry off. The vast majority of herds never or sometimes used oxytocin for milk letdown (89%), docked tails (76%), or singed hairs on the udders (78%), respectively (Table 1).

Table 2 displays the prevalence and means of dairy farmers' attitudes (or beliefs) regarding antibiotic use, dairy farm business goals, and sources of information. The vast majority of dairy farmers indicated that it is important or very important to reduce antibiotics for mastitis (81%), antibiotic residues in milk (83%), and antibiotic residues in culled cows (81%), respectively. In terms of dairy farm business goals, over 90% of dairy farmers indicated that it is important or very important to improve milk quality (94%), receive financial incentives for milk quality (91%), increase income or profits (93%), improve herd health (96%), and reduce feeding costs (93%), respectively (Table 2). At least 85% of dairy farmers indicated that it is important or very important to stay in the dairy business (87%), improve the image of dairy products (86%), increase milk production (88%), recruit good employees (85%), retain good employees (89%), and motivate employees with positive feedback (88%), respectively (Table 2). Most dairy farmers also indicated that it is important or very important to set up the farm for the next generation (72%), prepare for retirement (64%), reduce labor costs (60%), closely supervise employees (72%), set goals for employees (64%), include employees in setting farm goals (62%), include employees in farm decisions (53%), evaluate employees' performance (73%), and provide training opportunities for employees (73%), respectively (Table 2). The vast majority of dairy farmers relied on veterinarians as their source of information regarding mastitis. About 85% of dairy farmers indicated that it is important or very important to go to veterinarians for mastitis information. Over half of dairy farmers also indicated that it is important or very important to get mastitis information from milk cooperatives (55%) or other dairy farm producers (55%), respectively.

Table 3 displays the prevalence and means of dairy farmers' attitudes (or beliefs) regarding mastitis problems on their farms. About 45% of dairy farmers agreed or strongly agreed that mastitis is a problem on their farm. The majority of dairy farmers believed (i.e., they agreed or strongly agreed) that the weather (82%), milking equipment (85%), and employees (72%) play an important role in mastitis problems on their farm, respectively (Table 3). Most dairy farmers did not believe (i.e., they disagreed or strongly disagreed) that not following milking protocol (60%) or not following treatment protocol were problems on their farm, respectively. Surprisingly, some dairy farmers believed that stray voltage (47%) and bad luck (12%) play an important role in mastitis problems on their farms, respectively (Table 3).

Factor Analysis

Principal component factor analysis with varimax rotation confirmed the retention of 4 scales to be used as composite independent variables, 2 of which were used in our previous study (Schewe et al., 2015; Table 4). The first scale represents culturing practices and includes 3 behaviors related to milk culturing: culturing milk samples from high SCC or conductivity cows, culturing milk samples from clinical mastitis cases, and culturing bulk milk samples. The second scale represents treatment records practices, combining 2 items: keeping written or computer treatment records for all cows and reviewing treatment records before making treatment decisions. The third scale represents employee protocol compliance, combining 3 items: ensuring strict compliance with milking protocols, training employees in mastitis protocols, and training employees in treatment protocols. The fourth scale represents long-term farm goals, combining 6 components: the relative importance of staying in the dairy business, increasing income or profits, setting up the farm for the next generation, improving the image of dairy products, improving herd health, and reducing feed costs.

Bivariate Analysis

Table 5 displays the average frequency of various treatment practices for clinical mastitis on dairy farms by herd size. Large farms were more likely than small farms to use IMA during the dry off period. Large farms were also more likely to use IMA, SYA, oxytocin, and anti-inflammatory drugs to treat clinical mastitis than

Table 2. Frequency distributions and means of dairy farmers' attitudes or beliefs on 628 dairy farms in Florida, Michigan, and Pennsylvania

Attitudinal or belief variable	% of respondents indicating: Very unimportant	Unimportant	Neither important nor unimportant	Important	Very important	Mean ranking score	SEM	n[1]
Reducing use of antibiotics for mastitis	4.2	3.7	10.7	47.2	34.2	4.04	0.04	596
Reducing antibiotic residue in milk	5.4	1.5	10.5	26.8	55.8	4.26	0.04	593
Reducing antibiotic residue in culled cows	5.7	2.4	10.6	26.4	54.9	4.22	0.05	594
Improving milk quality	3.8	0.2	1.8	35.2	59.1	4.46	0.04	608
Receiving financial incentive for milk quality	4.0	0.8	4.6	31.5	59.1	4.41	0.04	607
Staying in the dairy business	3.9	3.1	6.1	33.6	53.4	4.29	0.04	611
Increasing income or profits	3.3	1.0	3.1	36.4	56.2	4.41	0.04	610
Setting-up the farm for the next generation	6.3	6.0	16.2	38.0	33.5	3.86	0.05	600
Improving the image of dairy products	3.5	2.0	8.8	49.0	36.7	4.13	0.04	600
Improving herd health	3.3	0.0	0.7	44.0	52.1	4.42	0.03	607
Reducing feed costs	3.6	0.3	2.8	41.2	52.1	4.38	0.03	611
Increasing off-farm income	13.5	27.8	34.2	18.8	5.8	2.75	0.04	591
Preparing for retirement	8.1	10.9	17.0	44.1	19.8	3.57	0.05	605
Reducing labor costs	4.3	6.7	29.5	35.8	23.8	3.68	0.04	584
Increasing herd size	10.8	23.6	36.2	20.3	9.1	2.9	0.05	602
Increasing milk production	3.0	2.0	6.6	40.1	47.6	4.28	0.04	603
Recruiting good employees	4.3	0.9	9.9	36.1	48.8	4.24	0.05	324
Retaining good employees	3.4	0.3	7.5	24.6	64.2	4.46	0.05	321
Motivating employees with positive feedback	3.7	0.6	7.8	44.1	43.8	4.24	0.05	322
Correcting employees with negative feedback	8.7	16.0	31.7	32.4	11.2	3.21	0.06	312
Closely supervising employees	2.5	5.6	19.6	52.7	19.6	3.81	0.05	321
Setting goals for employees	1.9	3.4	31.2	49.2	14.3	3.71	0.05	321
Including employees in setting farm goals	3.1	5.6	29.1	47.1	15.2	3.66	0.05	323
Including employees in setting farm decisions	5.6	11.0	30.1	46.1	7.2	3.38	0.05	319
Evaluating employee performance	1.9	2.8	22.7	59.5	13.1	3.79	0.04	321
Providing training opportunities for employees	2.8	3.1	21.4	54.4	18.3	3.82	0.05	322
Sources of information: veterinarian	6.6	2.4	6.0	36.6	48.5	4.18	0.05	588
Sources of information: milk cooperative	11.3	14.4	18.8	41.3	14.1	3.32	0.05	547
Sources of information: cooperative extension	12.1	15.5	44.9	24.8	2.7	2.91	0.04	628
Sources of information: farm journals	6.7	12.7	32.3	42.9	5.4	3.28	0.04	536
Sources of information: other dairy producers	5.4	7.1	22.6	52.9	12.0	3.59	0.04	552
Sources of information: Internet	23.4	17.5	39.7	16.7	3.3	2.59	0.05	509
Sources of information: drug company representatives	16.5	17.1	31.1	29.2	6.3	2.92	0.05	528

[1]Unweighted.

small farms. With respect to management practices, large herds tended to use alcohol pads before intramammary infusions, keep written treatment records for all cows, treat mastitis cows with a full therapeutic regimen, review treatment records before making treatment decisions, culture bulk tank milk samples,

Table 3. Frequency distributions and means of dairy farmers' attitudes or beliefs regarding mastitis problems on 628 dairy farms in Florida, Michigan, and Pennsylvania

Attitudinal variable	% of respondents indicating: Strongly disagree	Disagree	Neither agree nor disagree	Agree	Strongly agree	Mean ranking score	SEM	n[1]
Mastitis is a problem on my farm	9.5	26.3	19.4	38.3	6.4	3.06	0.05	608
Not following milking protocol is a problem on my farm	18.2	41.8	22.9	14.8	2.2	2.41	0.04	593
Not following treatment protocol is a problem on my farm	21.8	48.5	21.8	7.4	0.5	2.16	0.04	592
Bad luck plays an important role in mastitis problems	32.5	33.2	22.1	9.9	2.4	2.16	0.04	597
Weather plays an important role in mastitis problems	2.8	6.3	8.9	67.7	14.4	3.84	0.03	606
Milking equipment plays an important role in mastitis problems	2.0	5.1	8.2	56.0	28.8	4.05	0.04	611
Stray voltage plays an important role in mastitis problems	10.2	11.7	31.2	33.2	13.7	3.29	0.05	590
Employees play an important role in mastitis problems	4.5	5.2	18.2	43.8	28.5	3.87	0.04	562

[1]Unweighted.

and use vaccines to control *Staphylococcus aureus* and coliform mastitis more frequently than smaller herds. In contrast, small farms were more likely to rely on natural or organic therapies to treat clinical mastitis than large farms. Large farms were also more likely than small farms to use internal teat sealant at dry off, dock tails, singe hair on udders, clean alleys/gutters after or during each milking, and train employees in mastitis protocols (Table 5).

Table 6 displays the average frequency of dairy farmers' attitudes by farm size. Dairy farming business goals such as staying in the dairy business, increasing income or profits, improving the image of dairy products, improving herd health, reducing labor costs, increasing herd size, and increasing milk production varied by farm size. The means of these farming goals were significantly higher for larger farms than they were for smaller farms. Larger farms were more likely than small farms to rely on information from the Internet and drug companies and to believe that employees play an important role in mastitis problems on the farm. Small farms were more likely than large farms to believe that bad luck plays an important role in mastitis problems. Other dairy farmers' attitudes (or beliefs) such as setting up the farm for the next generation, increasing off-farm income, and preparing for retirement goals, the belief that mastitis is a problem on the farm, that not following milking and treatment protocols are problems on the farm, or that stray voltage play an important role in mastitis problems on the farm also significantly varied by farm size but in a nonlinear fashion (Table 6).

The bivariate analysis for selected independent variables that were associated with IMA at $P < 0.10$ and were used in logistic regression models to predict IMA are displayed in Table 7 (mean and SEM for binary variables) and Table 8 (Pearson correlations for continuous and ordinal variables). Those associated with SYA at $P < 0.10$ are displayed in Table 9 (mean and SEM for binary variables) and Table 10 (Pearson correlations for continuous and ordinal variables). Comparison of means and bivariate correlations indicated 19 binary variables and 29 continuous and ordinal variables that met the threshold for inclusion in the logistic regression model ($P < 0.10$) to predict IMA. For inclusion in the logistic regression model to predict SYA, 19 binary variables and 22 continuous and ordinal variables met the threshold for inclusion.

Multivariate Analysis

Table 11 displays the multilevel mixed-effects logistic regression model of IMA use on selected independent variables. Seven independent variables were significantly associated with IMA use ($P < 0.05$): being a member of an Amish community, having a high school education, believing that bad luck plays an important role in mastitis problems, use of IMA at dry off, use of vaccines to control *Staphylococcus aureus* mastitis, the treatment records scale, and use of natural (organic) therapies to treat clinical mastitis. The results show that the odds of IMA for the treatment of clinical mastitis were 1.6 times higher for dairy farmers who use IMA at dry off. The most significant factor related to IMA, in terms of relative odds, was the treatment records scale (an average scale that combines keeping written or computer treatment records for all cows and reviewing treatment

Table 4. Principal component factor analysis for independent variables from a survey of 628 dairy herds in Florida, Michigan, and Pennsylvania

Item	Factor loading	Eigenvalue	Cronbach's α
Culturing practices		1.93	0.74
Culture milk samples from high SCC or conductivity cows[1]	0.91		
Culture milk samples from clinical mastitis cases[1]	0.89		
Culture bulk tank milk samples[1]	0.55		
Treatment records		1.511	0.70
Keep written or computer treatment records for all cows[1]	0.869		
Review treatment records before treatment decisions[1]	0.869		
Employee protocols		1.910	0.73
Ensure strict compliance with milking protocols[1]	0.670		
Train employees in mastitis protocols[1]	0.884		
Train employees in treatment protocols[1]	0.824		
Long-term farm goals		3.82	0.89
Staying in the dairy business[2]	0.77		
Increasing income or profits[2]	0.85		
Setting up the farm for the next generation[2]	0.61		
Improving the image of dairy products[2]	0.79		
Improving herd health[2]	0.87		
Reducing feed costs[2]	0.85		

[1]Where 1 = never, 2 = sometimes, 3 = frequently, 4 = always.

[2]Where 1 = very unimportant, 2 = unimportant, 3 = neither, 4 = important, 5 = very important.

Table 5. Mean self-reported antimicrobial drug use and farmer's behavior by herd size from a survey of 628 dairy herds in Florida, Michigan, and Pennsylvania

	Herd size (number of milking cows)													
	<50		50–99		100–249		250–599		≥600		Total			
Variable	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	*P*-value[1]	n[2]
Use intramammary antibiotics to treat clinical mastitis[3]	2.35	0.08	2.88	0.08	2.94	0.09	3.32	0.11	3.33	0.10	2.79	0.04	<0.001	588
Use systemic antibiotics to treat clinical mastitis[3]	1.86	0.06	2.21	0.08	2.27	0.10	2.38	0.12	2.52	0.13	2.15	0.04	<0.001	537
Use intramammary antibiotics at dry off (dry treatment)[3]	3.01	0.08	3.62	0.07	3.79	0.07	3.84	0.08	3.95	0.05	3.48	0.04	<0.001	613
Use of anti-inflammatory drugs to treat clinical mastitis[3]	1.75	0.06	2.08	0.07	2.24	0.09	2.45	0.11	2.16	0.09	2.04	0.04	<0.001	564
Culture milk samples from high-SCC or high-conductivity cows[3]	1.83	0.05	1.94	0.08	1.94	0.08	1.89	0.11	1.92	0.12	1.89	0.03	0.710	575
Culture milk samples from clinical mastitis cases[3]	1.85	0.06	1.94	0.07	1.96	0.08	2.00	0.11	2.22	0.14	1.94	0.04	0.058	581
Culture bulk tank milk samples[3]	1.51	0.06	1.60	0.08	1.65	0.08	1.86	0.11	2.11	0.13	1.66	0.04	<0.001	580
Keep written or computer treatment records for all cows[3]	2.33	0.09	2.44	0.11	2.75	0.13	3.50	0.11	3.88	0.06	2.72	0.05	<0.001	581
Review treatment records before making treatment decisions[3]	2.36	0.08	2.50	0.09	2.69	0.11	3.00	0.14	3.46	0.09	2.64	0.05	0.001	571
Treat mastitis cows for full course of antibiotic doses[3]	2.85	0.08	3.25	0.08	3.36	0.09	3.58	0.11	3.76	0.07	3.21	0.04	<0.001	595
Use of oxytocin to treat clinical mastitis[3]	1.48	0.05	1.83	0.07	1.99	0.09	2.02	0.12	1.92	0.12	1.76	0.04	<0.001	585
Use of natural (organic) therapies to treat clinical mastitis[3]	2.20	0.08	1.77	0.07	1.51	0.07	1.34	0.09	1.21	0.07	1.78	0.04	<0.001	559
Use of alcohol pads before intramammary tube infusions[3]	3.46	0.07	3.60	0.07	3.52	0.10	3.69	0.10	3.88	0.06	3.58	0.04	0.021	596
Use vaccines to control S*taphylococcus aureus* mastitis[3]	1.33	0.05	1.36	0.07	1.61	0.11	1.68	0.16	1.72	0.15	1.45	0.04	0.004	575
Use vaccines to control coliform mastitis (e.g., J-5, J-VAC)	1.60	0.07	1.88	0.10	2.29	0.14	2.98	0.18	3.58	0.12	2.14	0.06	<0.001	594
Train employees in mastitis protocols[3]	3.61	0.12	3.10	0.10	3.29	0.10	3.46	0.10	3.58	0.08	3.12	0.05	<0.001	456
Train employees in treatment protocols[3]	2.46	0.11	2.94	0.11	3.12	0.12	3.46	0.11	3.59	0.09	2.99	0.05	<0.001	459
Ensure strict compliance with milking protocols[3]	3.15	0.08	3.35	0.07	3.32	0.09	3.53	0.09	3.57	0.08	3.32	0.04	0.007	566
Clean alleys/gutters after or during each milking[3]	3.40	0.06	3.68	0.06	3.83	0.06	3.88	0.07	3.95	0.03	3.64	0.03	<0.001	597
Milk mastitis and treated cows in a separate group[3]	2.49	0.09	2.29	0.12	2.00	0.13	3.23	0.16	3.89	0.07	2.60	0.06	<0.001	549
Use of oxytocin for milk letdown[3]	1.62	0.05	1.80	0.06	1.93	0.07	1.93	0.07	1.93	0.09	1.72	0.09	0.001	593
Use of internal teat sealant (Orbeseal[4]) at dry off[3]	1.71	0.08	2.45	0.12	2.59	0.15	2.93	0.19	3.33	0.15	2.34	0.06	<0.001	591
Dock tails[3]	1.24	0.05	1.63	0.09	2.05	0.13	2.39	0.19	2.78	0.18	1.75	0.05	<0.001	602
Singe hair on the udders[3]	1.45	0.06	1.54	0.08	1.90	0.10	2.33	0.15	2.51	0.16	1.74	0.04	<0.001	600

[1]Adjusted Wald test of significant difference between farm size categories.

[2]Unweighted.

[3]Where 1 = never, 2 = sometimes, 3 = frequently, and 4 = always.

[4]Zoetis Animal Health, Parsippany, NJ.

Table 6. Means of dairy farmers' attitudes or beliefs by herd size on 628 dairy farms in Florida, Michigan, and Pennsylvania

	Herd size (number of milking cows)													
	<50		50–99		100–249		250–599		≥600		Total			
Attitudinal variables	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	*P*-value[1]	n[2]
Reducing use of antibiotics for mastitis[3]	4.02	0.07	3.94	0.08	4.10	0.09	4.05	0.13	4.21	0.11	4.04	0.04	0.414	596
Reducing antibiotic residue in milk[3]	4.25	0.07	4.15	0.09	4.26	0.11	4.37	0.15	4.48	0.12	4.26	0.04	0.306	593
Reducing antibiotic residue in culled cows[3]	4.21	0.08	4.08	0.09	4.23	0.11	4.34	0.15	4.51	0.12	4.22	0.05	0.110	594
Improving milk quality[3]	4.45	0.06	4.35	0.08	4.45	0.09	4.52	0.11	4.70	0.08	4.46	0.04	0.106	608
Receiving financial incentive for milk quality[3]	4.35	0.06	4.37	0.08	4.46	0.09	4.47	0.13	4.60	0.09	4.41	0.04	0.345	607
Staying in the dairy business[3]	4.16	0.07	4.20	0.08	4.31	0.10	4.52	0.11	4.76	0.08	4.29	0.04	<0.001	611
Increasing income or profits[3]	4.28	0.06	4.34	0.07	4.44	0.09	4.69	0.10	4.78	0.08	4.41	0.04	<0.001	610
Setting up the farm for the next generation[3]	3.81	0.08	3.73	0.09	3.87	0.12	4.17	0.14	4.11	0.14	3.86	0.05	0.042	600
Improving the image of dairy products[3]	3.99	0.06	4.09	0.07	4.14	0.10	4.40	0.11	4.50	0.09	4.13	0.04	<0.001	600
Improving herd health[3]	4.35	0.05	4.32	0.07	4.45	0.08	4.52	0.11	4.74	0.08	4.42	0.03	0.005	607
Reducing feed costs[3]	4.32	0.06	4.31	0.07	4.40	0.09	4.47	0.11	4.66	0.09	4.38	0.03	0.054	611
Increasing off-farm income[3]	2.95	0.08	2.70	0.08	2.58	0.10	2.50	0.14	2.71	0.14	2.75	0.04	0.011	591
Preparing for retirement[3]	3.41	0.08	3.55	0.09	3.77	0.10	3.72	0.15	3.71	0.13	3.57	0.05	0.063	605
Reducing labor costs[3]	2.33	0.05	2.45	0.06	2.57	0.07	2.74	0.07	2.73	0.06	2.49	0.03	<0.001	584
Increasing herd size[3]	2.72	0.07	2.75	0.09	2.98	0.11	3.31	0.14	3.71	0.12	2.93	0.05	<0.001	602
Increasing milk production[3]	4.14	0.06	4.18	0.08	4.39	0.08	4.55	0.11	4.60	0.09	4.28	0.04	<0.001	603
Recruiting good employees[3]	3.86	0.11	4.13	0.14	4.35	0.10	4.41	0.13	4.39	0.11	4.24	0.05	0.012	324
Retaining good employees[3]	4.00	0.12	4.34	0.11	4.48	0.09	4.64	0.12	4.76	0.10	4.46	0.05	<0.001	321
Motivating employees with positive feedback[3]	3.94	0.12	4.15	0.12	4.24	0.09	4.30	0.13	4.50	0.10	4.24	0.05	0.022	322
Correcting employees with negative feedback[3]	3.15	0.14	3.29	0.13	3.21	0.12	3.23	0.17	3.16	0.16	3.21	0.06	0.961	312
Closely supervising employees[3]	3.65	0.11	3.86	0.11	3.79	0.10	3.77	0.11	3.94	0.12	3.81	0.05	0.554	321
Setting goals for employees[3]	3.51	0.10	3.50	0.11	3.55	0.09	3.86	0.11	4.15	0.08	3.71	0.05	<0.001	321
Including employees in setting farm goals[3]	3.78	0.13	3.59	0.11	3.54	0.09	3.58	0.13	3.84	0.12	3.66	0.05	0.249	323
Including employees in setting farm decisions[3]	3.48	0.12	3.25	0.12	3.33	0.12	3.33	0.14	3.56	0.12	3.38	0.05	0.374	319
Evaluating employee performance[3]	3.73	0.12	3.62	0.10	3.78	0.08	3.89	0.11	3.95	0.08	3.79	0.04	0.109	321
Providing training opportunities for employees[3]	3.47	0.12	3.69	0.10	3.78	0.09	4.03	0.10	4.11	0.11	3.82	0.05	<0.001	322
Sources of information: veterinarian[3]	4.06	0.07	4.13	0.09	4.23	0.12	4.50	0.12	4.30	0.14	4.18	0.05	0.072	588
Sources of information: milk cooperative[3]	3.31	0.09	3.16	0.11	3.46	0.13	3.48	0.14	3.36	0.13	3.32	0.05	0.308	547
Sources of information: cooperative extension[3]	1.93	0.06	2.02	0.07	2.05	0.08	2.09	0.12	2.02	0.10	2.00	0.04	0.617	527
Sources of information: farm journals[3]	3.26	0.08	3.30	0.08	3.31	0.10	3.28	0.13	3.19	0.12	3.28	0.04	0.945	536
Sources of information: other dairy producers[3]	3.62	0.07	3.67	0.08	3.58	0.09	3.51	0.14	3.37	0.12	3.59	0.04	0.300	552
Sources of information: Internet[3]	2.25	0.08	2.59	0.10	2.82	0.12	2.80	0.15	2.98	0.13	2.59	0.05	<0.001	509
Sources of information: drug company[3] representatives	2.49	0.08	2.87	0.10	3.08	0.11	3.36	0.15	3.61	0.13	2.92	0.05	<0.001	528
Mastitis is a problem on my farm[4]	3.04	0.07	2.91	0.09	3.09	0.11	3.46	0.15	3.09	0.15	3.06	0.05	0.042	608
Not following milking protocol is a problem on my farm[4]	2.36	0.07	2.21	0.08	2.36	0.10	2.83	0.14	2.72	0.15	2.41	0.04	<0.001	593
Not following treatment protocol is a problem on my farm[4]	2.27	0.06	2.05	0.07	2.27	0.09	2.11	0.11	1.97	0.10	2.16	0.04	0.026	592
Bud luck plays an important role in mastitis problems[4]	1.62	0.05	1.46	0.06	1.35	0.06	1.26	0.06	1.31	0.07	1.47	0.03	<0.001	597
Weather plays an important role in mastitis problems[4]	3.88	0.05	3.88	0.07	3.86	0.08	3.74	0.11	3.69	0.13	3.84	0.03	0.415	606
Milking equipment plays an important role in mastitis problems[4]	2.78	0.04	2.77	0.05	2.77	0.06	2.83	0.06	2.77	0.07	2.78	0.02	0.967	611

Continued

Table 6 (Continued). Means of dairy farmers' attitudes or beliefs by herd size on 628 dairy farms in Florida, Michigan, and Pennsylvania

Attitudinal variables	Herd size (number of milking cows)													
	<50		50–99		100–249		250–599		≥600		Total			
	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	Mean	SEM	*P*-value[1]	n[2]
Stray voltage plays an important role in mastitis problems[4]	2.23	0.05	2.36	0.06	2.30	0.08	2.25	0.10	1.98	0.10	2.25	0.03	0.032	589
Employees play an important role in mastitis problems[4]	2.42	0.05	2.64	0.05	2.69	0.06	2.84	0.06	2.92	0.05	2.63	0.03	<0.001	562

[1]Adjusted Wald test of significant difference between farm size categories.

[2]Unweighted.

[3]Where 1 = very unimportant, 2 = unimportant, 3 = neither, 4 = important, and 5 = very important.

[4]Where 1 = strongly disagree, 2 = disagree, 3 = neither, 4 = agree, and 5 = strongly agree.

records before making treatment decisions). The odds of IMA use were 3.3 times higher for each unit increase in that scale. The odds of IMA were 1.3 times higher for dairy farmers who believe that bad luck plays an important role in mastitis problems. The odds of IMA use were 0.8 times lower for dairy farmers who indicated that they use vaccines to control *Staphylococcus aureus* mastitis, 0.5 times lower for Amish dairy farmers, and 0.6 times lower for dairy farmers who indicated that they use natural (or organic) therapies to treat clinical mastitis, respectively. The odds of IMA were 1.4 times higher for respondents with a high school diploma (or equivalent) than those of respondents with other levels of education (Table 11).

Table 12 displays the multilevel mixed-effects logistic regression model of self-reported SYA for the treatment of clinical mastitis on selected characteristics. The final model includes 9 independent variables that were significantly associated with SYA use ($P < 0.05$). The results showed that the odds of SYA use were 2.0 times higher for herds in Michigan compared with those in Pennsylvania and Florida. Also, the odds of SYA use were 1.2 times higher for dairy farms that use internal teat sealant at dry off. The most important factors of SYA for the treatment of clinical mastitis, in terms of relative odds, were the treatment records scale and employees receiving a financial or other penalty if SCC increase; the odds of SYA use were 2.4 times higher for each unit increase in the treatment records scale and 2.3 times higher if employees are sanctioned or penalized if SCC increases. The odds of SYA use were 1.6 times higher for dairy farms that use conductivity in milk to identify infected cows. The odds of SYA were 1.3 times higher for dairy farmers who reported that reducing antibiotic residue in culled cows is important. The culturing practices scale was negatively associated with the odds of SYA but not statistically significant. Among the control variables, education and bedding types were also significantly related to SYA. Specifically, the odds of SYA were 1.7 times higher for respondents with less than high school education compared with those of respondents with other levels of education. The odds of SYA were 0.5 times lower for dairy farms that use mattress with straw, sawdust, or wood shavings and for those that use sand compared with dairy farms that use other bedding types, including platforms with straw, sawdust, or wood shavings; loose pack straw, sawdust, or wood shavings; or other bedding types and combinations (Table 12).

DISCUSSION

The objectives of this study were 2-fold: to describe the likelihood that dairy farmers will use antimicrobial

Table 7. Comparison of mean intramammary administration of antimicrobial drugs (IMA) for intramammary drug use for the treatment of clinical mastitis from a survey of 628 dairy herds in Florida, Michigan, and Pennsylvania by selected binary characteristics with $P < 0.10$

	IMA[1]					
	Yes		No			
Variable	Mean	SEM	Mean	SEM	*P*-value[2]	n[3]
Respondent is sole proprietor[4]	2.70	0.07	2.88	0.06	0.005	607
Respondent is Amish[4]	1.92	0.09	2.97	0.05	<0.001	616
Herd in Pennsylvania[4]	2.71	0.06	2.87	0.06	0.070	627
Herd in Florida[4]	3.56	0.15	2.76	0.05	<0.001	627
English is first language of respondent[4]	2.96	0.05	2.05	0.10	<0.001	616
Respondent has less than high school education[4]	2.22	0.08	3.01	0.05	<0.001	612
Respondent has high school education[4]	2.98	0.08	2.67	0.06	<0.001	612
Respondent has college education or higher[4]	3.01	0.05	2.22	0.08	<0.001	612
Use of post-milking teat disinfection[4]	2.83	0.04	2.21	0.22	<0.001	605
Gloves worn during milking[4]	2.96	0.05	2.51	0.08	<0.001	608
Teats stripped before milking[4]	2.89	0.05	2.55	0.09	<0.001	608
Entire milking system is evaluated at least twice per year[4]	3.10	0.09	2.72	0.05	<0.001	584
Liners replaced >5 times per year[4]	2.96	0.06	2.59	0.07	<0.001	628
Tie-stall barn[4]	2.47	0.06	3.05	0.06	<0.001	624
Milking parlor[4,5]	3.02	0.06	2.56	0.06	<0.001	616
Sand bedding[4]	2.98	0.08	2.72	0.05	0.009	613
Presence of non-family employees[4]	3.08	0.06	2.56	0.07	<0.001	559
Employees received a financial or other incentive based on milk quality[4]	3.02	0.10	2.78	0.05	0.048	544
My mastitis treatment plan was designed with or by my veterinarian[4]	3.09	0.07	2.62	0.06	<0.001	588

[1]Where 1 = never, 2 = sometimes, 3 = frequently, and 4 = always.

[2]*P*-values for *t*-tests.

[3]Unweighted.

[4]Where 1 = yes and 0 = no.

[5]Including side opening (tandem) parlors (weighted n = 21), herringbone parlors (weighted n = 574), parallel parlors (weighted n = 220), rotary parlors (weighted n = 3), and swingline parlors (weighted n = 51).

drugs for the therapy of clinical mastitis on dairy farms and to determine the relative and combined influences of management practices and dairy farmers' behaviors and attitudes on self-reported antimicrobial use while controlling for other herd-level factors. Thus, the measure of antimicrobial drug use in the present study was an assessment of the willingness of dairy producers to use antimicrobials for the treatment of clinical mastitis, however they may define the disease.

Considerable research has established the best practices to reduce nonprudent antimicrobial drug use for clinical mastitis, particularly for mild to moderate cases. Cows that are older, had high SCC before treatment, a long duration of infection, multiple infected quarters, or infection with pathogens such as *Staph. aureus* or noncoliform gram-negative organisms are likely to be poor candidates for therapy (Erskine et al., 2003; Deluyker et al., 2005; Barkema et al., 2006; Pinzón-Sánchez and Ruegg, 2011). In particular, chronic infections are likely to have poor therapeutic outcomes and may require an extended duration of antimicrobial therapy (Owens and Nickerson, 1990; Erskine et al., 2003; Oliver et al., 2004). Additionally, investigators have demonstrated that culture-based therapy, when used as part of therapeutic selection criteria for cows with clinical mastitis, reduced antimicrobial use for mastitis treatments compared with empirical therapy and did not result in any long-term effects on recurrence of clinical mastitis, SCC, milk production, or cow survival in the herd (Hess et al., 2003; Lago et al., 2011a,b). Finally, standardized mastitis therapeutic protocols should diminish spontaneous "cow-side" biases and establish uniformity for therapeutic regimens (Wagner and Erskine, 2013). Thus, 3 best practices that should be part of a mastitis therapy protocol on dairy farms should be (1) use of records to determine cows at risk for poor therapeutic outcomes, (2) use of bacteriology to determine if the causative organisms are likely to respond to therapy, and (3) development and compliance of herd-specific mastitis therapy protocols.

About half of the herds in this study typically recorded treatments and reviewed records before treatments were administered. This is similar to a previous Pennsylvania study, which also found that 50% of dairy farms maintained antibiotic treatment records (Sawant et al., 2005). Thus, 10 yr after the Pennsylvania study, we found that the same proportion of farmers might be unaware if treatment of a case of clinical mastitis is likely to result in failure due to unheeded risk factors; for example, chronic duration of infection or a history

Table 8. Correlations with intramammary administration of antimicrobial drugs (IMA) for the treatment of clinical mastitis from a survey of 628 dairy herds in Florida, Michigan, and Pennsylvania and selected characteristics with $P < 0.10$

Variable	IMA		n[1]
	Pearson r	*P*-value (2-tailed)	
Herd size (log-transformed)	0.34	<0.001	624
Age of respondent (yr)	0.12	0.003	615
Number of years of respondent on the farm	0.10	0.013	614
Bad luck plays an important role in mastitis problems[2]	−0.12	0.004	597
Milk mastitis and treated cows in separate group[3]	0.15	<0.001	549
Use oxytocin for milk letdown[3]	0.14	0.001	593
Use of intramammary antibiotics at dry off (dry treatment)[3]	0.41	<0.001	613
Use internal teat sealant at dry off[3]	0.23	<0.001	591
Dock tails[3]	0.19	<0.001	602
Singe hairs on the udders[3]	0.17	<0.001	596
Use vaccine to control coliform mastitis[3]	0.24	<0.001	594
Use vaccine to control *Staphylococcus aureus* mastitis[3]	0.12	0.006	575
Clean alleys/gutters after or during each milking[3]	0.14	<0.001	597
Use individual cow SCC to identify infected cows[3]	0.08	0.047	588
Use conductivity in milk to identify infected cows[3]	0.12	0.006	521
Use of natural (organic) therapies to treat clinical mastitis[3]	−0.43	<0.001	559
Use alcohol pads before intramammary tube infusions[3]	0.26	<0.001	596
Use of oxytocin to treat clinical mastitis[3]	0.20	<0.001	585
Reducing antimicrobial drug residue in culled cows[4]	0.09	0.085	594
Increasing milk production[4]	0.16	<0.001	603
Preparing for retirement[4]	0.07	0.096	605
Veterinarian important source of information[4]	0.13	0.002	588
Drug company representatives important source of information[4]	0.17	<0.001	528
Internet important source of information[4]	0.14	0.002	509
Not following treatment protocols is a problem on my farm[2]	−0.20	<0.001	592
Culturing practices (scale)[3, 5]	0.13	0.002	554
Treatment records (scale)[3, 6]	0.54	<0.001	544
Employee protocols (scale)[3, 7]	0.29	<0.001	566
Long-term farm goals (scale)[4, 8]	0.09	0.025	584

[1]Unweighted.

[2]Where 1 = strongly disagree, 2 = disagree, 3 = neither, 4 = agree, 5 = strongly agree.

[3]Where 1 = never, 2 = sometimes, 3 = frequently, 4 = always.

[4]Where 1 = very unimportant, 2 = unimportant, 3 = neither, 4 = important, 5 = very important.

[5]Average scale of 3 items: culture milk samples from high SCC or conductivity cows, culture milk samples from clinical mastitis cases, and culture bulk tank milk samples.

[6]Average scale of 2 items: keep written or computer treatment records for all cows and review treatment records before making treatment decisions.

[7]Average scale of 3 items: ensure strict compliance with milk protocols, train employees in mastitis protocols, and train employees in treatment protocols.

[8]Average scale of 6 items: staying in the dairy business, increasing income or profits, setting up the farm for the next generation, improving the image of dairy products, improving herd health, and reducing feed costs.

of high SCC (Pinzón-Sánchez and Ruegg, 2011). In part, the high proportion of herds that do not maintain or review treatment records might be explained by the data in Table 5, which suggests that smaller herds are less likely to maintain and review treatment records compared with larger herds. This may reflect a “comfort level” on the part of dairy producers with fewer cows to recognize and remember therapeutic histories of their cattle on the farm, compared with herds with hundreds or even thousands of cattle that may also have numerous personnel, including employees, responsible for the treatment of animals. Nonetheless, relapses of clinical mastitis can occur more than 60 d after the original onset or multiple quarters can be affected, which may lend itself to confusion regarding previous treatments if not recorded.

Multivariate analysis from our study revealed that more frequent review and maintenance of treatment records was one of the variables most strongly associated with the willingness of farmers to use both IMA and SYA for the treatment of clinical mastitis, even when controlling for herd size. This might reflect that producers who maintain and review treatment records can more easily validate the need for therapy. However, record keeping is also an indicator of better management and when this variable is coupled with our findings that use of IMA at dry off and use of internal teat sealants were also associated with higher likelihood of

Table 9. Comparison of mean systemic administration of antimicrobial drugs (SYA) for the treatment of clinical mastitis from a survey of 628 dairy herds in Florida, Michigan, and Pennsylvania by selected binary characteristics with $P < 0.10$

	SYA					
	Yes		No			
Variable	Mean[3]	SEM	Mean[3]	SEM	*P*-value[1]	n[2]
Respondent is sole proprietor[4]	2.09	0.06	2.24	0.06	0.063	607
Respondent is Amish[4]	1.66	0.08	2.26	0.05	<0.001	616
Herd in Pennsylvania[4]	2.05	0.05	2.26	0.06	0.009	627
Herd in Florida[4]	2.89	0.21	2.13	0.04	<0.001	627
English is first language of respondent[4]	2.23	0.04	1.84	0.09	<0.001	616
Respondent has less than high school education[4]	1.91	0.007	2.25	0.005	<0.001	312
Respondent has college education or higher[4]	2.48	0.10	2.09	0.04	0.001	612
Use of post-milking teat disinfection[4]	2.17	0.04	1.86	0.19	0.087	605
Gloves worn during milking[4]	2.26	0.05	1.97	0.07	<0.001	608
Entire milking system is evaluated at least twice per year[4]	2.37	0.09	2.11	0.05	0.007	584
Liners replaced >5 times per year[4]	2.24	0.05	2.04	0.06	0.013	628
Tie-stall barn[4]	1.97	0.06	2.30	0.06	<0.001	624
Milking parlor[4, 5]	2.27	0.06	2.02	0.05	0.002	616
Other bedding[4, 6]	2.31	0.08	2.07	0.05	0.008	613
Presence of non-family employees[4]	2.30	0.06	1.97	0.06	<0.001	559
Employees received a financial or other incentives based on milk quality[4]	2.43	0.10	2.11	0.05	0.004	544
Employees received a financial or other penalty if SCC increases[4]	2.61	0.24	2.15	0.04	0.043	544
Bulk tank SCC (BTSCC) of concern is >300,000 cells/mL[4, 7]	2.47	0.10	2.71	0.06	0.055	613
My mastitis treatment plan was designed with or by my veterinarian[4]	2.34	0.07	2.03	0.06	<0.001	537

[1]*P*-values for *t*-tests.

[2]Unweighted.

[3]Where 1 = never, 2 = sometimes, 3 = frequently, and 4 = always.

[4]Where 1 = yes, 0 = no.

[5]Including side in–side out parlors (weighted n = 21), herringbone parlors (weighted n = 574), parallel parlors (weighted n = 220), rotary parlors (weighted n = 3), and swingline parlors (weighted n = 51).

[6]Yes = not mattress; platform with straw, sawdust, or wood shavings; recycled manure; sand; straw, sawdust, or wood shavings with loose housing; or pasture.

[7]Binary coding of answer to the question: "I get concerned when the BTSCC in my herd reaches…" yes = threshold of concern is BTSCC >300,000 cells/mL.

antimicrobial therapy of clinical mastitis, it appears that herds with some higher degree of management may be more likely to use IMA and SYA for the treatment of clinical mastitis. Likewise, we determined that use of sand or mattresses for bedding, rather than older styles of housing, were associated with decreased SYA.

Whether derived from cows with high SCC, clinical cases, or bulk tanks, less than 20% of the herds responded that they typically (frequently or always) collected milk samples for bacterial culture and about one-third of the herds responded that they never used milk bacteriology. Seemingly, across many herds, treatment decisions for clinical mastitis are often made with little or no knowledge of causative agents in the herd. As with the lack of treatment records, misunderstanding of bacterial pathogens can result in greater risk of treatment failure and inefficient antimicrobial therapy of clinical mastitis (Hess et al., 2003; Barkema et al., 2006; Lago et al., 2011a). Evidence for this was supported by Oliveira and Ruegg (2014), who found that over half of IMA for the treatment of clinical mastitis was for cases caused by *Escherichia coli* or cases where no organism was isolated. Yet, these important variables regarding milk culture were not significant in our model to describe the willingness to treat clinical mastitis. Once again, this may reflect a bias toward treatment of clinical cases for which bacteriology may have limited value (e.g., treatment of severe clinical mastitis) or might indicate that despite collection of milk samples, therapy with IMA or SYA may proceed empirically and the culture results are used for general herd information, not individual case decision-making. Moreover, the association between culture of milk and therapy of mastitis was confounded by our finding of significant positive correlations between more frequent use of bacteriologic culture of milk and use of IMA and SYA. Interpretation of this data is limited because it was part of our bivariate analysis and not our final multivariate model. Nonetheless, it raises questions as to how some farms use milk bacteriology information; for example, are culture results used to select drugs for the treatment of clinical mastitis or to decide if the case should be treated? It is also possible that herds with a higher incidence of clinical mastitis (data that were not

Table 10. Correlations with systemic administration of antimicrobial drugs (SYA) for treatment of clinical mastitis from a survey of 628 dairy herds in Florida, Michigan, and Pennsylvania by selected characteristics with $P < 0.10$

Variable	SYA		
	Pearson r	*P*-value (2-tailed)	n[1]
Herd size (log-transformed)	0.23	<0.001	624
Age of respondent (years)	0.09	0.039	615
Number of years of respondent on the farm	0.09	0.049	614
Milk mastitis and treated cows in separate group[2]	0.12	0.007	549
Use oxytocin for milk letdown[2]	0.17	<0.001	593
Use of intramammary antibiotics at dry off (dry treatment)[2]	0.24	<0.001	613
Use internal teat sealant at dry off[2]	0.20	<0.001	591
Singe hairs on the udders[2]	0.09	0.047	596
Use gram-negative bacterin to control coliform mastitis[2]	0.16	<0.001	594
Use vaccine to control *Staphylococcus aureus* mastitis[2]	0.23	<0.001	575
Clean alleys/gutters after or during each milking[2]	0.10	0.030	597
Use conductivity in milk to identify infected cows[2]	0.24	<0.001	521
Use of natural (organic) therapies to treat clinical mastitis[2]	−0.20	<0.001	559
Use alcohol pads before intramammary tube infusions[2]	0.09	0.032	596
Use of oxytocin to treat clinical mastitis[2]	0.23	<0.001	585
Reducing antimicrobial drug residue in culled cows[3]	0.07	0.091	594
Increase milk production[3]	0.08	0.060	603
Drug company representatives important source of information[3]	0.10	0.031	528
Not following treatment protocol is a problem on my farm[4]	−0.08	0.059	592
Culturing practices (scale)[2, 5]	0.16	<0.001	554
Treatment records (scale)[2, 6]	0.37	<0.001	544
Employee protocols (scale)[2, 7]	0.19	<0.001	566

[1]Unweighted.

[2]Where 1 = never, 2 = sometimes, 3 = frequently, 4 = always.

[3]Where 1 = very unimportant, 2 = unimportant, 3 = neither, 4 = important, 5 = very important.

[4]Where 1 = strongly disagree, 2 = disagree, 3 = neither, 4 = agree, 5 = strongly agree.

[5]Average scale of 3 items: culture milk samples from high SCC or conductivity cows, culture milk samples from clinical mastitis cases, and culture bulk tank milk samples.

[6]Average scale of 2 items: keep written or computer treatment records for all cows and review treatment records before making treatment decisions.

[7]Average scale of 3 items: ensure strict compliance with milk protocols, train employees in mastitis protocols, and train employees in treatment protocols.

collected from our survey) and thus more likely to use IMA or SYA resorted to more frequent culture to determine causative agents, if not to use this information as a selection criterion for therapy for individual cows.

More than twice as many dairy farms responded that they always or frequently used IMA compared with SYA for the treatment of clinical mastitis. This might be expected because several labeled formulations for IMA but no labeled formulations for SYA are available for the treatment of clinical mastitis in the United States. Although advocated as a therapy for severe clinical mastitis cases caused by coliform bacteria due to the possibility of bacteremia (Erskine et al., 2002; Wagner and Erskine, 2013), SYA for the treatment of clinical mastitis is an extra-label drug use and has limited therapeutic value in relation to IMA for mild clinical mastitis. About one-fourth of the survey respondents indicated that they frequently or always used SYA for the treatment of clinical mastitis cases. This is higher than expected because severe cases may account for only 15% of clinical cases (Oliveira et al., 2013), which suggests that some farmers are using SYA for a broader scope of clinical cases, beyond severe coliform mastitis. Or it may reflect a bias among some farmers to define clinical mastitis to be treated as the more severe cases on the spectrum. It is interesting that farms in our study that used conductivity to monitor mastitis were more likely to use SYA. Steeneveld et al. (2015) found that use of mastitis detection sensors (such as conductivity) in automated milking systems may lead to increases in herd SCC but also miss nearly 75% of clinical cases. This is compatible with the rationale that only the more severe cases of clinical mastitis (with ensuing temperature change or decrease in milk yield) would be detected and thus increase the willingness to use SYA for treatment.

A paradoxical finding from our study was that farms that placed greater importance on avoiding drug residues in cull cows were also more likely to use SYA. As mentioned above, SYA for the therapy of mastitis is extra-label drug use that would seemingly increase the risk of residue violations or at least affect the attitude of farmers' willingness to use SYA if antibiotic residues are deemed important.

Swinkels et al. (2015) reported that extended treatment (defined as any therapeutic regimen beyond labeled dosing) was practiced in 37 of 38 dairy farms and was perceived as part of the social norm of "being a good farmer" and that mastitis is not treated "thoroughly" if clinical symptoms are still visible at the time of cessation of treatment. Interestingly, dairy farmers seemed to administer extended therapy based on wanting to comply with other farmers' and veterinarians' perceived norms that extended treatment is better, resulting in treatment protocols being driven by social approval among peers (Swinkels et al., 2015).

As designed, our survey could not discriminate exactly how these variables were linked to SYA, but the attitudes and beliefs of dairy producers relative to antimicrobial use are multifactorial, and fully characterizing all factors was beyond the scope of this study, as was fully characterizing the sociological factors that might influence the attitude and beliefs. For example, respondents who believed bad luck was a factor in mastitis problems had greater use of IMA, and herds where employees received financial incentives (or penalties) for milk quality had higher use of SYA. A farmer's SCC threshold of concern to decide if mastitis was a problem in their herd was related to the prevalence of mastitis in the herd, as measured by BTSCC (Schewe et al., 2015). But full understanding of the beliefs and attitudes linking IMA to the perception of bad luck or the complex interactions between employee management and SYA illustrate some of the limitations of our study.

Our study was also limited by the scope of questions that were included; for example, questions regarding duration of therapy or use of prescription versus over-the-counter drugs were not included. Additionally, attitudes and beliefs of respondents could have been investigated in more depth to encompass more possible influences on decision making. Our intent was to capture a priori information that we perceived to be most critical but also to keep the survey at an acceptable length to enhance participation, which we believe was very good for a mail survey. We field tested the survey with dairy producers before sending to the sample farms to measure the time needed to respond and identify any questions that were difficult to understand or ambiguous.

Similar to this study, recording antimicrobial use on dairy farms in previous studies has relied on cross-sectional surveys completed by producers (Kaneene and Ahl, 1987; Sawant et al., 2005). However, this method can be problematic because of recall biases, noncompli-

Table 11. Mixed logistic regression analysis of intramammary administration of antimicrobial drugs for the treatment of clinical mastitis on selected variables from a survey of 628 dairy herds in Florida, Michigan, and Pennsylvania

Item	Coefficient[1]	Robust SE[2]	z	$P > \|z\|$	Odds ratio (OR)	95% CI (OR)
Fixed effects						
Constant	0.39	0.35	1.10	0.271	—	—
Geometric mean bulk tank SCC (log-transformed)	−0.40	0.24	−1.68	0.092	0.67	(0.42, 1.07)
Herd in Michigan[3]	−0.35	0.26	−1.34	0.181	0.70	(0.42, 1.18)
Respondent is a member of an Amish community[4]	−0.77	0.10	−8.08	<0.001	0.46	(0.38, 0.56)
Respondent has a high school (or equivalent) diploma[5]	0.33	0.09	3.75	<0.001	1.39	(1.17, 1.64)
Bad luck plays an important role in mastitis problems[6]	0.22	0.11	2.12	0.034	1.25	(1.02, 1.54)
Use of intramammary antibiotics at dry off (dry treatment)[7]	0.46	0.05	8.73	<0.001	1.58	(1.43, 1.75)
Use vaccines to control *Staphylococcus aureus* mastitis[7]	−0.23	0.11	−2.08	0.038	0.79	(0.64, 0.99)
Use of natural (organic) therapies to treat clinical mastitis[7]	−0.49	0.13	−3.87	<0.001	0.61	(0.47, 0.78)
Treatment records (scale)[7, 8]	1.19	0.22	5.46	<0.001	3.30	(2.15, 5.07)
Variance components						
Farm size						
Variance (_constant)	0.06	0.04				(0.02, 0.20)
Evaluation						
−2 log-likelihood	−215.0					
χ^2 deviance (df)[9]	321.2 (9)					
P-value	<0.001					

[1] n = 442 (number of remaining observations in the model). Missing values were excluded from the analysis using listwise deletion method.

[2]Standard errors were adjusted for 5 clusters in farm size.

[3]Where 1 = yes, 0 = no. Referent is Pennsylvania/Florida.

[4]Where 1 = yes, 0 = no.

[5]Where 1 = yes, 0 = no. Referent is other levels of education besides high school.

[6]Where 1 = strongly disagree, 2 = disagree, 3 = neither, 4 = agree, 5 = strongly agree.

[7]Where 1 = never, 2 = sometimes, 3 = frequently, 4 = always.

[8]Average scale of 2 items: keep written or computer treatment records for all cows and review treatment records before making treatment decisions.

[9]Deviance from the null model with no predictor.

Table 12. Mixed logistic regression analysis of systemic antimicrobial drug use for the treatment of clinical mastitis on selected variables from a survey of 628 dairy herds in Florida, Michigan, and Pennsylvania

Item	Coefficient[1]	Robust SE[2]	z	$P > \|z\|$	Odds ratio (OR)	95% CI (OR)
Constant	−1.64	0.38	−4.36	<0.001	—	—
Geometric mean bulk tank SCC (log-transformed)	0.32	0.27	1.17	0.244	1.37	(0.81, 2.33)
Herd in Michigan[3]	0.68	0.29	2.33	0.020	1.97	(1.11, 3.49)
Respondent is sole proprietor[4]	0.53	0.29	1.83	0.068	1.70	(0.96, 3.01)
Respondent has less than high school education[5]	0.55	0.18	3.00	0.003	1.73	(1.21, 2.46)
Type of bedding: mattress[6]	−0.64	0.31	−2.10	0.036	0.52	(0.29, 0.96)
Type of bedding: sand[6]	−0.68	0.26	−2.62	0.009	0.50	(0.30, 0.84)
Employees receive a financial or other penalty if SCC increase[4]	0.82	0.40	2.04	0.041	2.27	(1.03, 1.49)
Use an internal teat sealant (at dry off)[7]	0.21	0.10	2.18	0.029	1.23	(1.02, 1.49)
Use conductivity in milk to identify infected cows[7]	0.48	0.12	3.82	<0.001	1.61	(1.26, 2.06)
Treatment records (scale)[7, 8]	0.86	0.27	3.15	0.002	2.36	(1.38, 4.02)
Culturing practices (scale)	−0.26	0.19	−1.34	0.179	0.77	(0.53, 1.13)
Reducing antibiotic residue in culled cows[9]	0.28	0.12	2.45	0.014	1.33	(1.06, 1.67)
Variance components						
Farm size						
Variance (_constant)	0.04	0.04				(0.01, 0.29)
Evaluation						
−2 log-likelihood	338.6					
χ^2 deviance (df)[10]	268.2 (11)					
P-value	<0.001					

[1]n = 347 (number of remaining observations in the model). Missing values were excluded from the analysis using listwise deletion method.

[2]Standard errors adjusted for 5 clusters in farm size.

[3]Where 1 = yes, 0 = no. Referent is Pennsylvania/Florida.

[4]Where 1 = yes, 0 = no.

[5]Where 1 = yes, 0 = no. Referent is college or higher degree.

[6]Where 1 = yes, 0 = no. Referent is other bedding types, including platform with straw, sawdust, or wood shavings; straw, sawdust, or wood shavings; or other bedding types and combinations.

[7]Where 1 = never, 2 = sometimes, 3 = frequently, 4 = always.

[8]Average scale of 2 items: keep written or computer treatment records for all cows and review treatment records before making treatment decisions.

[9]Where 1 = very unimportant, 2 = unimportant, 3 = neither, 4 = important, 5 = very important.

[10]Deviance from the null model with no predictor.

ance, and data that may be incomplete or inaccurate, or not account for duration of protocol use on the farm (Chauvin et al., 2001). Recording numerical cases of disease as indicators of total drug doses includes biases in the size, frequency, and duration of dose. Thus, animal-defined daily doses are preferred to correctly adjust for differences in formulations of antimicrobial drugs (Chauvin et al., 2001). This method has been applied to estimate antimicrobial drug use on farms, although it still relied on case records (Pol and Ruegg, 2007). Another method to audit drug use, independent of case records, used collection of empty antimicrobial containers on beef operations (Carson et al., 2008) and an extensive nationwide survey of Canadian dairies (Saini et al., 2012). Our study was not intended to determine a quantitative measure of total drug use within each herd, which would have been difficult to verify because of the wide variation in record keeping between farms, as exhibited by the high proportion of herds that did not maintain treatment records.

Taken as a whole, most farms in our survey did not follow the management tools that are considered important for prudent antimicrobial use for therapy of mastitis. In fact, farms were as likely to use oxytocin or organic/natural formulations (15 to 20%) for clinical mastitis as they were to use bacteriology in treatment decisions. Our multivariate analysis found that Amish farmers and those that used organic/natural formulations were less likely to use IMA, which may reflect herd size. That these 2 variables are linked is suggested by the fact that we found a greater tendency to use organic/natural formulations in smaller herds. Additionally, because our survey did not ask if the respondents self-identified as being certified organic, we may have missed an opportunity to better understand the attitudes and behaviors of a population of farmers that purposely do not use antimicrobial drugs in contrast to farmers who use antimicrobial drugs.

Possibly related to the findings regarding Amish herds above, respondents with lower education levels were also less likely to use IMA for the treatment of clinical mastitis. The findings for SYA were more ambiguous; for the most part, we did not observe a clear trend between education level and SYA, except that respondents with some college education were less likely to use SYA then their peers with at least a 4-yr degree.

One of the more intriguing findings in our multivariate analysis was the strong association of use of a bacterin against *Staph. aureus* with lower use of IMA. One possibility to explain our findings is that farmers who are using *Staph. aureus* vaccines may have recognized this as an underlying problem in their herd or believe they cannot control this pathogen through standard practices such as use of accepted milking protocols and blanket dry-cow therapy. Only 59 (12%) herds stated they used *Staph. aureus* bacterins in our trial (the average BTSCC for all herds in the survey was 194,000 cells/mL); thus, the herds using this vaccine in our study may have represented a small subset of herds that had identified *Staph. aureus* mastitis as a problem in their herd. The ability of these vaccines to augment therapy is inconclusive (Middleton et al., 2009) but may suggest reluctance on the part of this subset of farmers to use IMA.

Finally, our logistic regression model showed that dairy farmers in Michigan were more likely to use SYA than their counterparts in Florida and Pennsylvania. As mean herd size in the Michigan herds in our study was between that of Florida and Pennsylvania, it is difficult to arrive at any conclusions for this result.

CONCLUSIONS

It is necessary to improve the acceptance of practices that are consistent with prudent antimicrobial use, such as milk bacteriology and use of records for the treatment of clinical mastitis on dairy farms. Maintaining and reviewing treatment records is strongly associated with a farmer's likelihood of using IMA and SYA. Not unexpectedly, herds that rely on organic/natural formulations were less likely to use IMA. Use of *Staph. aureus* bacterins, which may reflect awareness of the prevalence of this pathogen in a herd, also affected therapy decisions for both IMA and SYA. Biases in defining thresholds for the treatment of clinical mastitis may exist, as evidenced by the association of mastitis sensor technology with increased likelihood of SYA. These findings highlight that attitudes and beliefs among dairy farmers may influence therapeutic choices for clinical mastitis..

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APPENDIX

Table A1. Descriptive statistics of independent variables with a significant ($P < 0.10$) association with one of the dependent variables that were included in the logistic regression models (weighted)

Variable	Mean[1]	SEM	Minimum	Maximum	n[2]
Age of respondent (yr)	47.1	0.6	21	82	615
Number of years of respondent on the dairy farm	27.2	0.7	1	73	614
Respondent has high school education (%)[3]	36.9	0.0	0	1	612
Respondent has at least some college education (%)[3]	28.2	0.0	0	1	612
Herd in state of Florida (%)[4]	0.8	0.0	0	1	627
Herd is in the state of Pennsylvania (%)[4]	77.9	0.0	0	1	627
Respondent is sole proprietor (%)[5]	53.0	0.0	0	1	607
Respondent is part of an Amish community (%)[6]	23.4	0.0	0	1	616
Respondent is part of a Mennonite community (%)[6]	26.4	0.0	0	1	608
English is first language of respondent (%)[6]	75.1	0.0	0	1	616
Herd size (number of milking cows)[7]	107.4	4.7	2	5,200	624
Geometric mean bulk tank SCC (×1,000 cells/mL)	190.3	3.8	37	448	585
Average milk production (bulk tank) per day (× 1,000 kg)	3.6	0.2	0	149	593
Rolling herd average total milk per cow last year (× 1,000 kg)	9.7	0.1	5	16.0	433
Bulk tank SCC of concern is >300,000 cells/mL (%)[6]	34.9	0.0	0	1	613
Entire milking system is evaluated at least twice per year (%)[8]	18.2	1.7	0	1	584
Use of post-milking teat disinfection (%)[6]	93.4	1.2	0	1	605
Gloves worn during milking (%)[6]	55.3	2.4	0	1	608
Teats stripped before milking (%)[6]	70.6	2.2	0	1	608
Liners replaced >5 times per year (%)[6]	46.9	2.3	0	1	627
Tiestall barn (%)[6]	65.8	2.0	0	1	624
Milking parlor (%)[6]	40.0	2.1	0	1	616
Sand bedding (%)[6]	14.0	1.1	0	1	613
Presence of nonfamily employees (%)[6]	37.7	2.3	0	1	559
Employees received a financial or other incentive based on milk quality (%)[6]	12.5	1.6	0	1	544
My mastitis treatment plan was designed with or by my veterinarian (%)[6]	31.1	2.2	0	1	576
Bad luck plays an important role in mastitis problems[9]	2.3	0.1	1	5	597
Milk mastitis and treated cows in separate group[10]	2.4	0.1	1	4	549
Use oxytocin for milk letdown[10]	1.8	0.0	1	4	593
Use of intramammary antibiotics at dry off (dry treatment)[10]	3.4	0.0	1	4	613
Use internal teat sealant at dry off[10]	2.3	0.1	1	4	591
Dock tails[10]	1.6	0.0	1	4	602

Continued

Table A1 (Continued). Descriptive statistics of independent variables with a significant ($P < 0.10$) association with one of the dependent variables that were included in the logistic regression models (weighted)

Variable	Mean[1]	SEM	Minimum	Maximum	n[2]
Singe hairs on the udders[10]	1.6	0.0	1	4	596
Use vaccine to control coliform mastitis[10]	2.0	0.1	1	4	594
Use vaccine to control *Staphylococcus aureus* mastitis[10]	1.4	0.0	1	4	575
Clean alleys/gutters after or during each milking[10]	3.6	0.0	1	4	597
Use individual cow SCC to identify infected cows	2.7	0.1	1	4	588
Use conductivity in milk to identify infected cows[10]	1.6	0.0	1	4	521
Use of natural (organic) therapies to treat clinical mastitis[10]	1.9	0.0	1	4	559
Use alcohol pads before intramammary tube infusions[10]	3.6	0.0	1	4	596
Use of oxytocin to treat clinical mastitis[10]	1.7	0.0	1	4	585
Reducing antimicrobial drug residue in culled cows[11]	4.2	0.0	1	5	594
Increase milk production[11]	4.2	0.0	1	5	603
Preparing for retirement[11]	3.5	0.1	1	5	605
Veterinarian important source of information[11]	4.2	0.0	1	5	588
Drug company representatives important source of information[11]	2.8	0.1	1	5	528
Internet important source of information[11]	2.4	0.1	1	5	509
Not following treatment protocol is a problem on my farm[9]	2.2	0.0	1	4	592
Culturing practices (scale)[12]	1.7	0.0	1	4	554
Treatment records (scale)[13]	2.7	0.0	1	4	544
Employee protocols (scale)[14]	3.0	0.0	1	4	566
Long-term farm goals (scale)[15]	3.0	0.0	1	4	566

[1]For binary independent variables, the mean represents the proportion (%) of respondents who answered yes.

[2]Unweighted.

[3]Where 1 = yes and 0 = no. The referent category is less than high school education.

[4]Where 1 = yes and 0 = no. The referent category is state of Michigan.

[5]Where 1 = yes and 0 = no. The referent category is other positions in the dairy farm.

[6]Where 1 = yes and 0 = no.

[7]Herd size was log-transformed to reduce skewness.

[8]Where 1 = less than once a year, 2 = about once a year, 3 = at least twice a year, 4 = at least once a year.

[9]Where 1 = strongly disagree, 2 = disagree, 3 = neither, 4 = agree, 5 = strongly agree.

[10]Where 1 = never, 2 = sometimes, 3 = frequently, 4 = always.

[11]Where 1 = very unimportant, 2 = unimportant, 3 = neither, 4 = important, 5 = very important.

[12]Average scale of 3 items: culture milk samples from high SCC or conductivity cows, culture milk samples from clinical mastitis cases, and culture bulk tank milk samples.

[13]Average scale of 2 items: keep written or computer treatment records for all cows and review treatment records before making treatment decisions.

[14]Average scale of 3 items: ensure strict compliance with milk protocols, train employees in mastitis protocols, and train employees in treatment protocols.

[15]Average scale of 6 items: staying in the dairy business, increasing income or profits, setting up the farm for the next generation, improving the image of dairy products, improving herd health, and reducing feed costs.

Table A2. Herd size by state

	Herd size (number of milking cows)					
State[1]	<50	50–99	100–249	250–599	≥600	Total[2]
Michigan						
n	91	66	61	28	34	280
%	35.9	26.0	24.0	7.4	6.7	21.3
Pennsylvania						
n	140	100	40	23	19	322
%	48.8	35.5	12.0	2.2	1.4	78.0
Florida						
n	0	2	2	7	11	22
%	0.0	9.1	9.1	31.8	50.0	0.7
Total						
n	231	168	103	58	64	624
%	45.7	33.3	14.6	3.6	2.9	100.0

[1]Where n = unweighted count; % = weighted row percentage.

[2]Weighted column percentage.