A multilevel model with clustered management practices differentiating dairy herd environments in southeastern Sicily

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Abstract

Herd environments constitute productivity potentials, or aggregate opportunity outcomes, resulting from management actions taken with the available inputs. Management outcomes from cow nutrition, udder health and milking practices were quantified with the help of surveys of 254 dairy producers in southeastern Sicily. Objectives were to disentangle environmental opportunities by disaggregating herd effects into causal inputs. Average ME milk production was 8640 kg/lactation for the 183 Friesian herds containing 35 lactating cows and 10 dry cows. Seventy-one Brown Swiss herds averaged 6443 kg ME milk from 25 lactating and 10 dry cows. For Friesian (Brown Swiss) herds 10 (11) management practices affected milking performance and 9 (8) practices influenced somatic cell concentration ($P<0.05$). Multilevel analysis and herd clustering procedures differentiated low from high opportunity herd environments but altering relative weightings among management practices did not further discriminate them. This clustering methodology helps ensure unbiased estimation of management input effects and could help target priority management substitutions and technical support priorities in dairy extension programs.

Keywords

- Herd environmental definitions;
- Management practices;
- Animal breeding

1. Introduction

In dairy cattle breeding, genetic evaluations are calculated from performance data collected on each cow at the farm and pedigree information. Cow performance comprises genetic potential (i.e., its genotype) and the environmental opportunity corresponding to a given record. Many environmental factors affect cow performance (e.g., climatic conditions, diet and feeding methods, disease exposure) and may lead to unequal genetic expression from genotype by environment interactions (Raffrenato et al., 2003). Typically herd management factors are treated as fixed herd-year-season effects. This adjustment to the average herd environmental opportunity ignores the specific marginal contributions of management inputs on cow performance (e.g., milk production, udder health, reproduction).

In addition to country or geographic region to distinguish alternative environmental opportunities, herds in many studies have been classified especially by mean herd milk production (Danell, 1982, De Veer and Van Vleck, 1987 and Norman et al., 1988) and its variance using within herd-year-season or herd-year standard deviations (HYSD) (Carvalheira et al., 1998, Cienfuegos-Rivas et al., 1999, Castillo-Juarez et al., 2000, Costa et al., 2000 and Short et al., 1990). Few other criteria have been used to define herd environments. Banos and Shook (1990) used herd average somatic cell score as an udder health management indicator. Castillo-Juarez et al. (2000) distinguished alternative herd environments by combining mature equivalent (ME) milk herd mean, HYSD and mean body weight divided by age at first calving. Windig et al. (2005) defined herd environment by grouping 41 variables into four principal components derived from cow productivity. Herd classifications based on performance variances assume that herds with larger (smaller) within herd milk yield standard deviations provide greater (diminished) cow performance opportunities. Usai et al. (2006) instead used principal component and cluster analyses to stratify 151 Sardinian goat flocks into three management systems based on inputs of nutrition, health and reproduction.

Sicilian dairy farmers utilize two production systems: low-input grazing and a high-input confinement. Traditional grazing systems typically utilize Brown Swiss or Modicana cows for the manufacture of Ragusano, provola, and ricotta cheeses. Farmers owning herds under confinement, generally higher-yielding Holstein-Friesian cows, produce milk for fluid and manufacturing purposes relying on harvested forages (Licitra et al., 1998). Farms in these systems differ in their resource endowments, input allocations, training of personnel, and management skills and preferences. Therefore, because herd stratification based on average cow performance, or within-herd variance, is only indirectly coupled to causal inputs, estimates of genetic and residual variances may be biased (Famula, 1989). Consequently, our objective was to evaluate a methodology where herd environmental opportunity is specified as a function of inputs administered through practices ascertained from herd manager interviews comparing it with the frequently-used HYSD criterion ignoring this causal information.

2. Material and methods

A survey of the 292 dairy farms enrolled in the local province dairy recording program, Associazione Provinciale Allevatori (APA), was conducted in collaboration with a local dairy research center, Consorzio Ricerca Filiera Lattiero-Casearia (CoRFiLaC). Owners were personally interviewed by questionnaire comprising sections on general herd description and management practices regarding health, nutrition, milking procedures, housing information, and reproduction. Most questions were close-ended with a list of predetermined alternatives to facilitate clarity of response, and so that responses could be entered directly for data processing.

Three interviewers were trained and provided with guidelines for potentially uncooperative respondents and unanticipated responses. Pre-testing was assessed by some farmers also belonging to the APA administration council who verified final format and clarity of the questions. Survey respondents were initially contacted by telephone to explain the purpose of the study and to request an appointment. More costly than a mail survey, personal interviews are more likely to generate accurate information. Responses were evaluated for reliability by local extension agents and by nutritionists from local feed companies. Eighty-seven percent of the total APA membership participated in the study, which included 183 Friesian and 71 Brown Swiss herds.

Herd productivity data, provided by the APA, consisted of ME milk production and somatic cell score records (SCS=$\log_2$ (somatic cell count/100,000)+3) from 4114 Friesian and 880 Brown Swiss cows in these herds. A weighted somatic cell score (WSCS) was obtained for each lactation record using test day milk yields (m_i) as weighting factors to adjust for stage of lactation:

(1)

$$\mathrm{WSCS} = \frac{\sum_{i=1}^{n}(m_i \times \mathrm{SCS}_i)}{\sum_{i=1}^{n} m_i}.$$

A total of 32 management practices (Table 1) on milking, health and nutrition management and housing conditions were examined for ostensible relationships with lactation performance and WSCS. Selection was for those practices believed or shown to influence milk yield or mammary health. For simplicity, independent variables were uniformly coded as binary variables (present or absent) even if continuous variables (as opposed to binary) would have permitted quantifying responses to the use intensity of a practice.

Table 1. Management categories, variables and their use frequencies (%) for all herds.

Management practices	Friesian	Brown Swiss
Nutrition management		
Use of a nutrition consultant	93	86
Feeding silage	74	54
Forage analysis	54	15
TMR for lactating cows	44	15
Pasture in the diet	37	50

Management practices	Friesian	Brown Swiss
Mineral supplements for lactating cows	28	29
TMR for dry cows	16	12
TMR for heifers	16	11
Feeding groups	14	9
Haylage	14	10
Milking management		
Equipment washed with detergent at least 2/day	84	83
Postpone milking if milk is abnormal	78	87
Fore stripping before milking	57	57
Teats dried after pre-dip or washing	57	52
Cows milked in milking parlor	53	77
Post milking teat disinfection	49	38
Equipment professionally checked at least 2/year	47	42
Use of dry towels before milking	38	25
1-day dry off	33	23
Analysis of abnormal milk	29	30
Postpone milking if abnormal milk	24	37
Health management		
Use of antibiotics to treat clinical mastitis	78	77
Antibiotic dry cow treatment	66	66
Milk discarded with presence of antibiotics	30	40
Record-keeping system	17	6
Housing		
Shade during the summer	89	84
Bedding	78	68
Newborn calves housed in individual pens	63	47
Special pen for sick cows	54	40
Maternity pen	34	15
Others		
Consulting for general information	78	72
Semen storage tank	46	26

A two-level unconditional means model was applied to these hierarchically structured data to estimate the effects of management practices on lactation performance and WSCS. Dairy farming provides a clear case of a system in which individuals (cows) are subject to the influence of grouping (herds). Such a model partitions variation at each specified level, which accounts for important dependencies from herd clusters (Raudenbush, 2002). The collected data may be imbalanced at any level. In our case cow-level outcomes Y_{ij} were depicted with two linked models: one for the cow and another for its herd (Proc MIXED, SAS version 9.1, SAS Institute Inc., Cary, NC). Cow-level outcomes were represented as the sum of the intercept for the herd effect plus a random error term associated with each animal. For herd outcomes, the intercept was expressed as the sum of the grand mean plus sequences of random deviations according to invoked management practices. Season of calving was added to the basic model as a cow level predictor: season 1 corresponded to calvings from November through February; season 2 for calvings from March through May; and season 3 for the remainder of the year. By adding this level-one predictor not only are outcomes obtained as a function of the cows' season of calving but the specified relationship between the outcome and calving season may vary across herds. Consequently, the model contains intercepts and slopes that vary across herds. After addition of the first explanatory variable x_1 (Rasbash, 2000) the basic multilevel model becomes

(2)
$$Y_{ij}=b_0+b_1x_{1ij}+u_j+e_{ij},$$

where Y_{ij} is the mature equivalent milk record or WSCS for the ith cow in the jth herd, b_0 is the overall intercept across herds, b_1 is the regression coefficient for the explanatory variable season of calving x_{1ij} for the ith cow in the jth herd, u_j, the level 2 residual, is the departure of the jth herd's intercept from the overall value, which is the same for all cows in herd j. Both u_j and e_{ij} are random quantities, whose means are equal to zero. We assume these variables to be uncorrelated and distributed normally with variances $\hat{\sigma}^2_u$ and $\hat{\sigma}^2_e$, respectively. Collecting the coefficients to specify the random variation in Y in terms of random coefficients of the explanatory variable, then
(3)
$$Y_{ij}=b_{0ij}+b_1x_{1ij} \text{ and}$$

(4)
$$b_{0ij}=b_0+u_{0j}+e_{0ij}.$$

The goal of this multilevel analysis is to estimate the pattern of variation in the underlying population of herds, not individual herds in our sample. This pattern may be explained in terms of general farm characteristics and by other management variables (practices) included in the model.

Forward stepwise variable selection aided the selection of herd level practices (Table 1) to include in the final model, thus making it conditional upon the fixed effects from these practices. The initial probability value was set to 0.05 and the remaining one at 0.10 for both breeds. Multicollinearity was ignored because every variance inflation factor was less than 10 (Neter et al., 1996). The selected management variables were used to cluster herds into low and high opportunity environments. The final model thus extended with further explanatory variables at the herd-level becomes

(5)

$$Y_{ij} = b_0 + b_1 \times_{1ij} + (u_{0j} + u_{1j}x_{ij} + \sum_{h=2}^{p} b_h x_{hij} + e_{0ij}),$$

where h represents management factors from 2 to p. To account for heteroscedasticity, the error term was modified according to Pinheiro and Bates (2000) to permit unequal variances at each herd level. Likelihood ratio tests (Pinheiro and Bates, 2000) with a high P-value (0.34) of the likelihood ratio statistic and the plots of standardized residuals versus fitted values by herd confirmed that the heteroscedastic model did not better explain the data than the homoscedastic model. The assumption of normality for the within-group errors was confirmed using normal probability plots of the residuals. The lowest level of aggregation (cow) was not tested because sample size did not allow convergence of the heteroscedastic model at such a low level. Common variance functions used in mixed-effects analysis were also tested (Pinheiro and Bates, 2000).

2.1. Herd environment clustering

2.1.1. Management practices

Questionnaire responses provided herd clustering criteria and contrasting low and high opportunity environments. Distance of Jaccard dissimilarity coefficients were created for each herd using the Distance Macro in SAS (Kuo, 1997). An asymmetric binary variable indicating presence or absence of a management practice was associated with each response. Asymmetry arises because potential outcomes may be unequal. The most important outcome was the presence of a specific practice. Agreement between two invoked practices (positive match) outweighs absent agreement (negative match). Distance of Jaccard matrices were created with and without weights for practices associated with milk yield, for practices associated with WSCS, and for their combination. The management distance of Jaccard between two farms, x x and y, was calculated:

(6)

$$d(x,y) = \frac{\sum_{i=1}^{n} \delta_{x,y}^{i}}{\sum_{i=1}^{n} \vartheta_{x,y}^{i} + \sum_{i=1}^{n} \delta_{x,y}^{i}},$$

where n is the total number of criteria considered, $\delta_{x,y}=1$ if $x_i \neq y_i$, otherwise $\delta_{x,y}=0$ and $\vartheta_{x,y}=1$ if $x_i=y_i$, otherwise $\vartheta_{x,y}=0$.

Clustering is a hierarchical agglomerative method for constructing kinship groups from multivariate data. In our case groups represent similar environmental conditions determined by herd management. The Lance–Williams (Lance and Williams, 1967) flexible-beta method was used, where the value of beta is the weight assigned to the new within-cluster distance after merging two clusters into a single partition. As recommended by Milligan (1989) when outliers are anticipated, a beta value of −0.5 was used to guard against influential (less accurately informed) outliers. A beta value of −0.5 instead of −0.25 has been shown to provide greater information recovery when clustering is more diverse (Scheibler and Schneider, 1985). Assuming merged clusters *K* and *L* form cluster *M*, the distance (*D*) between *J* and *M* was specified as

(7)

$$D_{JM}=(D_{JK}+D_{JL})(1-\beta)/2+D_{KL}\beta$$

Herds in low and high opportunity environments were clustered giving equal weight to practices, and by assigning more weight to practices significantly associated with herd milk production, herd WSCS, or to both outcomes, based on results from the multilevel model. Performance levels and management practices were therefore analyzed in the herd clusters obtained.

2.1.2. Within-herd-year standard deviation

The phenotypic within herd-year standard deviation (HYSD) for 305-day ME milk yield, a common proxy for environmental opportunity, was also used to discriminate herds, separating them into high and low opportunity groups (like in studies of genotype×environment interaction), especially where diets are limiting (Boldman and Freeman, 1990, Cienfuegos-Rivas et al., 1999, Costa et al., 2000, Dong and Mao, 1990, Raffrenato et al., 2003 and Stanton et al., 1991). Low opportunity Friesian (Brown Swiss) herds were defined as those with HYSD<1260 kg (HYSD<990 kg). High opportunity Friesian (Brown Swiss) herds were those with HYSD≥1260 kg (HYSD≥990 kg).

3. Results

Records showed that calvings throughout the year were distributed with a slightly greater occurrence during the fall months. However, average ME milk yield by month of calving showed that cows calving during spring months had highest yields (9200 kg for Friesian, 7100 kg for Brown Swiss). Friesian herds averaged 8640 kg ME milk. Brown Swiss herds averaged 6443 kg ME milk. Largest SCS values were during the rainy months of December and January (4.05 for Friesian and 4.35 for Brown Swiss).

Survey responses revealed important variability in the inputs applied by managers of these production systems, as anticipated. While our objective focuses on the multilevel and clustering methodology, survey results may be obtained from Raffrenato (2002).

3.1. Association between management practices and milk yield and WSCS

The basic multilevel model (without predictors) for milk yield was highly explanatory ($P<0.0001$) in each production system. The estimated $\hat{\sigma}^2_u$s are 2,609,686 kg^2 and 1,410,428 kg^2 and $\hat{\sigma}^2_e$s are 2,157,750 kg^2 and 1,070,575 kg^2 for Friesian and Brown Swiss, respectively. Herds differed in milk yield and with smaller variances among cows within herds than across herds, as expected. The estimated herd effects of 8898 kg and 6378 kg accurately reflected the average herd-level milk yield for Friesian and Brown Swiss herds.

The results from the model conditional on the predictors are given in Table 2 and Table 3. The meaning of the intercept variances (variance between herds) differs from those in the unconditional model because they depend on the presence of management practices. As expected, the residual components (variances within herds) were nearly unchanged, however the variances between herds decreased substantially for both production systems. The estimated $\hat{\sigma}^2_u$s are 987,219 kg^2 and 341,536 kg^2 and $\hat{\sigma}^2_e$s are 2,145,763 kg^2 and 1,049,784 kg^2 for Friesian and Brown Swiss herds, respectively.

Table 2. Results from the conditional means model with predictors included for ME milk (kg) for Friesian.

Covariance parameter	**Estimate**	**Standard error**	***P*-value**
Intercept (herd)	987,219	401,867	<0.0001
Residual	2,145,763	45,929	<0.0001
Fixed effect solution			
Intercept	11,885	402	<0.001
Season 1 [a]	250	52	<0.001
Season 2 [a]	178	57	0.002
Nutrition management			
TMR for lactating cows	918	213	<0.001
Haylage	701	240	0.004
Forage analysis	395	192	0.041
Pasture in the diet	−159	92	0.091
Milking management			
Equipment professionally checked at least 2/year	490	182	0.008
Post milking teat disinfection	366	179	0.002
Health management			
Antibiotic dry cow treatment	502	202	0.061
Record-keeping system	381	231	<0.001
Use of antibiotics to treat clinical mastitis	379	214	0.079
Others			
Semen storage tank	747	196	<0.001

[a] Season 1 includes November through February; season 2 includes March through May.

Table 3. Results from the conditional means model with predictors included for ME milk for Brown Swiss.

Covariance parameter	Estimate	Standard error	*P*-value
Intercept (herd)	341,536	113,933	0.0014
Residual	1,049,784	61,302	<0.0001
Fixed effect solution			
Intercept	7868	679	<0.001
Season 1 [a]	365	107	0.001
Season 2 [a]	362	100	<0.001
Nutrition management			
TMR for lactating cows	1367	454	0.004
Use of a nutrition consultant	714	313	0.028
Silage	528	202	0.013
Pasture in the diet	−1250	375	<0.002
Milking management			
Cows milked in milking parlor	1198	251	<0.001
Equipment washed with detergent at least 2/day	748	287	0.012
Post milking teat disinfection	679	265	0.014
Postpone milking if milk is abnormal	640	251	0.015
Teats dried after pre-dip or washing	365	215	0.010
Health management			
Record-keeping system	2007	504	<0.001
Antibiotic dry cow treatment	707	229	0.003
Others			
Semen storage tank	850	250	0.001

[a] Season 1 includes November through February; season 2 includes March through May.

Smaller values of $\hat{\sigma}^2_u$ indicate that approximately 63% and 76% of the variance in mean milk production among Friesian and Brown Swiss herds were accounted by the management practices in the final model. Howard et al. (1987) found that 26% of the variance in milk yield was accounted by a cubic function of SCC and six productivity variables (SCS was regressed on 17 management practices). The large decrease in herd variance obtained in this study indicates that our hierarchical linear model effectively disentangled underlying management factors within herds (Osborne, 2000).

The basic multilevel model (P<0.001) for WSCS resulted in estimated $\hat{\sigma}^2_u$s of 0.671 and 0.817 and $\hat{\sigma}^2_e$s of 2.206 and 1.914 for Friesian and Brown Swiss herds, respectively. As for milking performance, herds differed (P<0.001) in WSCS and had smaller variances among cows within herds, than across them. The estimated herd effects of 3.822 and 4.052 represent the average herd-level WSCS for Friesian and Brown Swiss, respectively.

Results conditional on the predictors for WSCS are in Table 4 and Table 5. Management predictors of WSCS explained about 62% of the variance among Friesian herds and 78% for Brown Swiss herds. More practices were included in the model for Brown Swiss herds than for Friesian (8 vs. 6). Van Schaik et al. (2005) used backward elimination in multiple linear regression models to remove inconsequential (P>0.05) management factors to explain 35% of the variance in total bacterial count and 18% of the variance of somatic cell count. For Friesian (Brown Swiss) herds, all management practices but one were favorably associated (P<0.10) with milking performance (Table 2 and Table 3), as were all practices related to WSCS (Table 4 and Table 5). Grazing (pasture use) was the management exception not favoring productivity (P=0.097). This outcome likely signifies poor control of dietary (low forage) quality, slightly depressing ME milk in high-input Holstein herds, and with large opportunity losses in milk in Brown Swiss herds. In these herds, relying on grazing effectively cancels (precludes) the potential large increment in milk expected from the greater nutrient intake from TMR (P<0.001).

Table 4. Results from the conditional means model with predictors included for WSCS for Friesian.

Covariance parameter	Estimate	Standard error	*P*-value
Intercept (herd)	0.391	0.062	<0.001
Residual	2.190	0.049	<0.001
Fixed effect solution			
Intercept	2.835	0.185	<0.001
Season 1 [a]	0.191	0.577	0.001
Season 2 [a]	0.349	0.577	<0.001
Nutrition management			
Forage analysis	−0.411	0.120	0.006
Mineral supplements for lactating cows	−0.405	0.128	0.020
Pasture in the diet	0.101	0.042	0.097
Milking management			
Cows milked in milking parlor	−0.590	0.129	<0.001
Health management			
Antibiotic dry cow treatment	−0.363	0.128	0.054
Housing			
Newborn calves housed in individual pens	−0.264	0.121	0.031

[a] Season 1 includes November through February; season 2 includes March through May.

Table 5. Results from the conditional means model with predictors included for WSCS for Brown Swiss.

Covariance parameter	Estimate	Standard error	*P*-value
Intercept (herd)	0.180	0.087	0.019
Residual	1.919	0.114	<0.001
Fixed effect solution			
Intercept	4.337	0.407	<0.001
Season 1 [a]	0.293	0.147	0.049
Season 2 [a]	0.277	0.133	<0.040
Nutrition management			
Mineral supplements for lactating cows	0.445	0.206	0.036
Milking management			
Teats dried after pre-dip or washing	0.983	0.210	<0.001
Post milking teat disinfection	0.589	0.213	0.008
Postpone milking if milk is abnormal	0.487	0.211	0.025
Health management			
Antibiotic dry cow treatment	0.485	0.210	0.025
Housing			
Shade during the summer	0.794	0.235	0.001
Maternity pen	0.559	0.263	0.039
Others			
Semen storage tank	0.909	0.215	0.001

[a] Season 1 includes November through February; season 2 includes March through May.

Results showed milk production was increased principally by more effective feeding practices: the use of TMR, haylage (silage), and chemical evaluation of forage quality. Antibiotic dry cow treatment was likely the most important health practice by its mutual favorable associations with WSCS and milk production across all herds. Other variables associated with increased milk yield were post-milking teat disinfection and information-based management. Herds milking cows in a parlor instead of a barn obtained lowest SCS.

3.2. Herd environments for milk yield and WSCS

Table 6 and Table 7 show the numbers of herds and average cow performance in the contrasting environments defined by all management practices, weightings of selected practices, and by the HYSD criterion. High opportunity herds had greater mean milk production with lower somatic cell scores than the low opportunity ones. When selected management practices (Table 2, Table 3, Table 4 and Table 5) were weighted, the performance difference between high and low environmental clusters increased in both production systems. However, differences in HYSD were unaffected by these alternative definitions, which indicate low sensitivity to the causal pathways determining milk yield or mammary health. Smaller herds in general provided less privileged environments, as described by Licitra et al. (1998).

Table 6. High and low opportunity environments by clustering criterion and relative average size, and production (kg) of milk, protein and fat, and somatic cell score by Friesian cows.

Clustering criteria and relative management level/environment	Herds	Size	Milk	Fat	Protein	Score
Unweighted [a]						
High	91	56	10,191	327	315	3.40
Low	92	33	8184	276	249	4.12
Weighted for milk [b]						
High	74	60	10,368	330	320	3.36
Low	109	34	8250	275	252	4.06
Weighted for WSCS [c]						
High	114	52	9933	321	306	3.50
Low	69	32	8045	270	244	4.15
Combined [d]						
High	87	55	10,149	326	313	3.51
Low	96	35	8321	279	255	3.96
HYSD [e]						
High	92	52	10,173	329	314	3.46
Low	91	36	8458	278	258	3.93

[a] Unweighted clustering based on all management practices.
[b] Weights applied to 10 selected management practices from regression on milk.
[c] Weights applied to 6 selected management practices from regression on WSCS.
[d] Weights applied to 16 selected practices from regressions on milk and WSCS.
[e] HYSD classes: low, <1260 kg; high, >1260 kg of milk.

Feeding management practices in the multilevel model resulted in different use frequencies between high and low opportunity groupings, while other practices did not. This probably means that the mere existence of a practice in a management protocol (Table 2 and Table 3), as opposed to the intensity of its use, did not further differentiate management potentials within a specific herd opportunity classification. Milking practices effectively discriminated between opportunity classes for WSCS in both production systems. However alternative weightings did not better distinguish low from high-level opportunity herds. Most herds remained in the same class. Under these circumstances weighting might indirectly introduce bias. In contrast, the herd groups based on the HYSD criterion did not differentiate herds for milk production or WSCS (P>0.05).

Table 7. High and low opportunity environments by clustering criterion and relative average size, and production (kg) of milk, protein and fat, and somatic cell score by Brown Swiss cows.

Clustering criteria and relative management level/environment	Herds	Size	Milk	Fat	Prot	Score
Unweighted [a]						
High	32	49	7842	282	253	3.63
Low	39	34	6050	220	212	4.04
Weighted for milk [b]						
High	33	50	8120	286	251	3.77
Low	38	32	5772	216	206	3.88
Weighted for WSCS [c]						
High	34	48	7812	279	264	3.66
Low	37	34	6081	223	201	3.99
Combined [d]						
High	35	46	8010	285	250	3.60
Low	36	36	5883	217	205	4.05
HYSD [e]						
High	35	42	7645	276	255	3.67
Low	36	39	6248	226	210	3.98

[a] Unweighted clustering based on all management practices.
[b] Weights applied to 12 selected management practices from regression on milk.
[c] Weights applied to 8 selected management practices from regression on WSCS.
[d] Weights applied to 20 selected practices from regressions on milk and WSCS.
[e] HYSD classes: low, <930 kg; high, >930 kg of milk.

The multilevel methodology used in this study clearly discriminated low and high herd environmental opportunities based on key management inputs obtained by surveying herd managers of two dairy production systems. Thus, selected management practices can be effectively utilized to causally define herd environments, as also demonstrated in a genetic inquiry by Raffrenato et al. (2003). These management practices are specific for time and place, which means that they need to be scrutinized and updated in a given environment.

The integrated approach presented in this study incorporates as binary variables information about management practices for herds clustered into contrasting environments, which helps ensure unbiased estimation of management input effects. In the absence of management information, HYSD is an undesirable proxy for defining alternative environments because productivity outcomes (herd mean and variance) are themselves used to characterize performance opportunities instead of causal inputs in the management milieu.

4. Conclusions

This study presented a methodology to differentiate herd environments in a structurally unbiased manner. Selected management practices, or inputs, particularly herd nutrition and health obtained by surveying the APA dairy population were utilized to define low and high herd environmental opportunities for milk production and udder health (WSCS). The principal management practices and information affecting milk yield and WSCS were the use of TMR, forage composition information, use of a nutrition consultant, the use of grazing in the diet, cows milked in a parlor, adequate washing of the milking equipment, the antibiotic dry cow treatment, routine professional checking of the milking parlor, and a post milking teat disinfection. All practices except grazing favorably affected cow (herd) performance.

The multilevel methodology in this study used information about management practices as binary variables to cluster herds into input-differentiated environments that are unbiased. For our Sicilian herd population this methodology resulted in different herd opportunity environments compared to the HYSD criterion. This outcome clearly reflected mean performances that varied with inputs bound to specifiable management practices without necessarily influencing within-herd variation. Therefore, a methodology predicated on causality is a preferable tool for evaluating management substitutions to improve herd productivity and associated benefits.

Conflict of interest statement

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

We confirm that the manuscript has been read and approved by all named authors and that there are no other persons who satisfied the criteria for authorship but are not listed. We further confirm that the order of authors listed in the manuscript has been approved by all of us.

We confirm that we have given due consideration to the protection of intellectual property associated with this work and that there are no impediments to publication, including the timing of publication, with respect to intellectual property. In so doing we confirm that we have followed the regulations of our institutions concerning intellectual property.

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