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The Adoption of Best-Management Practices by Louisiana Dairy Producers

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This study examines the adoption of best-management practices (BMPs) in terms of the total number of practices implemented up to a certain period, using count data analysis. Poisson and negative binomial regressions were used to examine the likely determinants of producers' decisions to adopt greater numbers of technologies, and the specific case of dairy producers' adoption of BMPs was explored. Our results emphasize the significant effect of producers' awareness of the efforts to control non–point source pollution, information about BMPs, farm size, producer's educational attainment, and risk aversion on the number of BMPs adopted.

Key Words: Best management practices (BMP), count data analysis, dairy industry, negative binomial regression, Poisson regression

JEL Classifications: Q12, Q16

Although the agricultural community has been traditionally viewed as a good steward of the environment, such beliefs have been challenged in recent years, with agriculture being identified as a major non–point source of water pollution. Sediment, nutrients, pesticides, salt, and pathogens may originate from agricultural activities and reach water resources through runoff and leaching, becoming pollutants. These pollutants, in turn, may impair both surface and ground waters. The voluntary implementation of specific best-management practices (BMPs) has been promoted to reduce non–point source pollution. The focus on BMPs has been particularly strong since the passage of the Clean Water Act of 1972 and the Coastal Zone Management Act of 1972 and its related amendments. The present study examined the current adoption of BMPs by Louisiana dairy producers and investigated the factors that influence producers' decisions to implement them.

Over the past couple of decades, the rising concentration of fecal coliform bacteria in a number of U.S. streams and other water bodies has raised major concern. For instance, in Louisiana, Drapcho, Beatty, and Achberger found that woodland and dairy farm pastures were among several sources that had contributed to the pathogen-contaminated water supply in the Tangipahoa River. Health advisories in Louisiana have limited primary contact recreation because of elevated fecal coliform counts in Lake Pontchartrain, the Tchefuncte River, the Bogue Falaya River, and the Tangipahoa River, all of which are located in the vicinity of the primary dairy-producing region in the state. As a result, BMPs associated with wastewater and runoff from dairy farms have been promoted to help reduce the volume of pollution reaching water bodies and improve overall water quality. The BMPs chosen for promotion in Louisiana have been selected while keeping in mind a number of factors.

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Annual rainfall in much of Louisiana is in excess of 60 inches, so water runoff is of major concern. This is much higher than the level of rainfall in most of the major dairy production areas of the United States, such as California and the Upper Midwest. Most of the dairies in Louisiana are pasture-based rather than free stall–based. Thus, BMPs that focus on forage management are of importance. Also, most Louisiana dairies are relatively small compared with those in much of the rest of the United States, with average herd sizes of 120 cows. Considering the level of technology of the farms, the waste lagoon system is considered to be a central BMP for most operations.

Significant effort has been devoted to encouraging dairy producers to adopt BMPs. Twenty-one specific BMPs were identified by a panel of research scientists within the Louisiana State University Agricultural Center (LSUAC) as particularly useful for dairy operations (Table 1). Descriptions of each and methods for effective implementation are found in LSUAC publication 2823, a publication endorsed by the U.S. Department of Agriculture (USDA) Natural Resources and Conservation Service, Louisiana Department of Agriculture and Forestry, and the Louisiana Farm Bureau. In addition to this publication, information is available through Louisiana Cooperative Extension Service agents, Natural Resource Conservation Service agents, and other agricultural groups. A recent program developed by the Louisiana Cooperative Extension Service, the Master Farmer Program, is designed to educate producers about BMPs and their effective implementation. In practice, the Louisiana Department of Environmental Quality agrees that, if the USDA Natural Resource Conservation Service certifies that a dairy has installed and is maintaining a "no-discharge" system, no individual discharge permit is required.

We investigated the adoption of BMPs in the Louisiana dairy industry, concentrating on the importance of information in encouraging adoption. The study focused on the sum total of all BMPs adopted for a measure of adoption intensity (how many of the 21 BMPs were adopted). The factors that influence adoption intensity were then analyzed, as well as types of producers most likely to adopt greater numbers of BMPs. Using such analysis to measure adoption intensity requires several assumptions. First, use of any one of the 21 BMPs would not preclude the use of any of the other 20 BMPs. However, the implementation of one BMP may not be independent of the implementation of another BMP, because many of them may be complimentary. Examples might include using livestock exclusion along with fencing and a watering facility or a waste treatment lagoon along with a waste management system. Second, in our case, the use of a greater number of BMPs is assumed to be preferred to the use of fewer BMPs. Any of the 21 BMPs could be used by a Louisiana dairy farmer, with the possible exception of stream-bank and shoreline protection, which would be useful only in cases in which there is a water body on the property. (A dummy variable was used to account for the presence of a stream in the analysis.) A limitation of this assumption is that some BMPs may be considered to be of greater importance than others. For instance, a waste treatment lagoon would be considered to be a high priority for most, if not all Louisiana dairies. Third, there are no physical limits to the number of BMPs that can be used on the farm, except in the case in which stream-bank and shoreline protection do not apply. Overall, results showing which BMPs are being adopted, along with which farmers have the most intensive levels of adoption, may be used in targeting adoption efforts.

Previous Studies

Since Griliches' 1957 exploration of the differences in the rate of adoption of hybrid seed corn, the economics of technology adoption has captured researchers' interests, yielding literally hundreds of publications. Some studies have examined the likely determinants of technology adoption (e.g., Caswell and Zilberman; Ghosh, McGuckin, and Kumbhakar; Moser and Barrett; Shields, Rauniyar, and Goode), whereas more recent ones have explored the need for appropriate econometric tools to account for the interrelationships

Table 1. Description of the Best Management Practices Used in Dairy Production

Best Management Practice	Description
Conservation Tillage	System designed to manage the amount, orientation, and distribution of crop and other plant residues on the soil surface.
Cover and Green Manure	Establishment of crop of close-growing grasses, legumes, or small grains for soil improvement and seasonal protection.
Critical Area Planting	Planting of vegetation such as trees, shrubs, vines, grasses, or legumes on highly erodible or critically eroding areas.
Field Borders	Strips of perennial vegetation at the edge of the field to reduce erosion.
Filter Strips	Establishment of vegetative areas to trap sediment, organic material, nutrients, and chemicals from runoff and wastewater.
Grassed Waterways	Natural or constructed channels graded to required dimensions, with suitable vegetation to stabilize the conveyance of runoff.
Heavy Use Area Protection	Establishment of vegetative cover, suitable surfacing material, or structures to stabilize areas frequently and intensively used.
Regulating Water in a Drainage System	Use of water control structures to regulate the outflow from drainage systems and remove surface runoff.
Riparian Forest Buffer	Areas of trees, shrubs, and other vegetation adjacent to and uphill from water bodies to create shade, improve habitat for aquatic organisms, and remove excess amounts of sediment, organic material, nutrients, pesticides, and other pollutants in surface water.
Sediment Basin	Constructed structure for manure, waterborne sediment, and debris storage purposes and for maintaining the capacity of lagoons.
Streambank and Shoreline Protection	Establishment of vegetation or structures to stabilize and protect the banks of streams, lakes, estuaries, and excavated channels against scour and erosion.
Roof Runoff Management	Collection, control, and disposal of runoff water from roofs to prevent water from flowing across concentrated waste areas, barnyards, roads, and alleys.
Waste Management System	Planned system installed for managing liquid and solid waste.
Waste Storage Facility	Constructed waste impoundment.
Waste Treatment Lagoon	Constructed waste impoundment for temporarily storing and biologically treating organic wastes from animals and other activities on land.
Waste Utilization	Use of wastes from agricultural and other activities on land in an environmentally acceptable manner.
Nutrient Management	Management of the application of plant nutrients from organic waste, fertilizer, and crop residues.
Pest Management	Management of agricultural pest infestations including weeds, insects, and diseases coherent with crop production and environmental standards.
Fencing	Part of conservation management system to address soil, water, air, plant, animal, and human resources issues.
Prescribed Grazing	Part of conservation management system to improve and maintain controlled harvest vegetation, water, and soil conditions on grazing lands.
Trough or Tank	Livestock watering facilities provided at selected location to protect vegetative cover.

among adoption decisions (Dorfman; El-Osta and Morehart; Feder, Just, and Zilberman; Zepeda). Studies on the adoption of environmentally sound technologies have explored the roles of factors such as producers' awareness of soil erosion, quality of information, land tenure, and economic incentives on the voluntary adoption of management practices (Barbier; Cardona; Cooper; Gould, Saupe, and Klemme; Govindasamy and Cochran; Ipe et al.; Soule, Tegene, and Wiebe; Westra and Olson).

Our study differs from more commonly used approaches, which focused on each specific technology; we view adoption in terms of the total number of technologies implemented over a period of time. The study used count data analysis, similar to that used by Gale in an analysis of the adoption of technology by rural manufacturers. This type of analysis is advantageous in situations where there are large numbers of technologies that might be adopted and the researcher wishes to examine the intensity of technology adoption. Other analyses that have examined the adoption of multiple technologies have used multinomial probit or logit (e.g., Dorfman; Zepeda) or multivariate probit (e.g., Cardona; Rahelizatovo) frameworks. Such models, however, provide significant computational difficulties—the number of technologies becomes greater than two, in the case of multinomial logit, or four or five, in the case of multivariate probit.

The rather obvious disadvantages of count data analyses compared with the others are that they provide little information as to the type of producer who would adopt a specific technology, and, as considered earlier, each technology is treated equally in the sense that the total number of technologies is the measure of interest. The use of number of technologies as a measure for intensity of technology adoption is by no means new. Others who have used this measure include Doms, Dunne and Roberts; Little and Triest; and, most recently, Gale. Although the measure is not perfect, significant insights can be gained through the identification and analysis of the most intensive adopters of BMPs. Policies can then be formulated to target the less intensive adopters.

The use of count data analysis has become established in biometric studies. The modeling of count data has received econometric interest since Cameron et al. investigated the number of doctor visits in 1984. Cameron and Trivedi (1986) investigated the applicability of some estimators and tests in models on the basis of count data. They discussed models such as the basic Poisson, compound Poisson, and negative binomial, as well as more general count data models. Their analysis of the number of consultations with a doctor or specialist showed that the possibility of using increasingly flexible and data-coherent models, starting with the basic Poisson model, and was supportive of the quasi-generalized pseudo-maximum-likelihood estimation (QGPML) procedure. Barron explored the effect of overdispersion and autocorrelation in the analysis of count data. His analysis of the founding of labor unions in the United States suggested the use of the negative binomial to model overdispersion. A generalized model would also allow for dealing with autocorrelation.

Data and Methods

The data used in the present analysis were collected via a mail survey of the population of Louisiana dairy producers (428) that was conducted during summer 2001. Data included information on dairy farm characteristics, producer characteristics and attitudes, and current adoption of 21 BMPs. Dillman was used as a guide in survey implementation. The first mailing was followed by a postcard reminder to all who received the survey. Two weeks later, a second copy of the survey was sent to nonresponders. Ten dollars was offered to all responders, to be mailed on receipt of the survey. A total of 131 surveys were returned, with 124 completed.

Count Data Models

We investigated the likelihood of a producer of a specific description to implement BMPs. The events of adopting BMPs were assumed to occur at a constant rate within each dairy farm but were allowed to vary across dairies. The events can, therefore, be considered as generated by a Poisson process. The density function associated with the Poisson model is expressed in Equation (1):

$$(1)\qquad f(y_i|x_i) = \frac{e^{-\mu_i}\mu_i^{y_i}}{y_i!} \qquad y_i = 0, 1, 2, \ldots,$$

where x_i are variables that affect the adoption of BMPs. The mean parameter μ_i represents the expected number of events and is expressed as in Equation (2):

$$(2)\qquad \mu_i = E[y_i|x_i] = \exp(X_i'\beta).$$

If we assume the independence of the observations, one can express the log-likelihood function associated with the estimation as in Equation (3):

$$(3)\qquad \ln L(\beta) = \sum_{i=1}^{n} [y_i x_i'\beta - \exp(x_i'\beta) - \ln y_i!].$$

Properties of the Poisson regression model require the mean and variance of y_i to be equal. However, the assumption of a constant rate of adoption may not be realistic in practice. The variance of y_i can be greater (lower) than its mean value, indicating the presence of over- (under-) dispersion in the count data. In such a case, the Poisson regression would not be fully efficient, and the estimated standard errors would be biased and inconsistent.

The negative binomial analysis allows for an adjustment for the presence of overdispersion and permits a flexible modeling of the variance (Greene). The variance function for the negative binomial model is presented in Equation (4), in which α is the dispersion parameter to be estimated:

$$(4)\qquad \mathrm{var}(y_i) = \mu_i + \alpha\mu_i^2.$$

The Poisson regression is a special case of the negative binomial with $\alpha = 0$. Under the assumption that the specification of the mean the same as that in the Poisson regression model, the log-likelihood function associated with the negative binomial formulation is expressed in Equation (5):

$$(5)\qquad \ln L(\alpha, \beta) = \sum_{i=1}^{n} \left\{ \sum_{j=0}^{y_i-1} \ln(j + \alpha^{-1}) - \ln(y_i!) - (y_i + \alpha^{-1})\ln[1 + \alpha \exp(X_i'\beta)] + y_i \ln \alpha + y_i X_i'\beta \right\}.$$

As discussed in Cameron and Trivedi (1998), the negative binomial maximum-likelihood estimator (NBMLE) is robust to distributional misspecification if the dispersion parameter α is known and the variance function correctly specified. In the case where α is unknown, one can conduct a QGPML estimation while using a consistent estimator $\hat{\alpha}$. The estimation would yield a fully efficient estimator $\hat{\beta}_{QGPML}$ with the same variance as $\hat{\beta}_{NBMLE}$.

In the survey, dairy producers were asked which of the 21 BMPs they had adopted. Table 1 lists the BMPs and describes each. The producer's response regarding his or her current adoption of each BMP was considered as an event. Count numbers of BMPs (**TBMP**) implemented on the farm operation constituted the dependent variable in the study. Furthermore, the expected number of events **E(Y)** and the hypothesized independent variables were assumed to have a log-linear relationship, as in Equation (2).

Factors Influencing Dairy Producers' Decisions to Adopt BMPs

This section discusses variables that are hypothesized to influence the adoption of BMPs and are used in the count data-regression models. The enactment of the Clean Water Act constituted the primary federal law to address both point and non–point sources of pollution. Since that act, a number of other legislative acts have addressed water quality concerns. Producer awareness of the Clean Water Act to control pollution is hypothesized to influence producer willingness to contribute to the efforts by adopting BMPs. Producers were asked, "Are you aware of the efforts to control non-point sources of water pollution through the Clean Water Act? (Yes/No)" Dummy variable CWA was included to account for producers' awareness.

Past studies have shown that larger-sized farms are generally more likely to adopt technology than smaller ones (e.g., El-Osta and Morehart; Westra and Olson). The adoption of new technology often involves substantial initial capital investment, and farmers with greater resources are better able to afford the technology and fully utilize it. Total number of cows in the dairy herd (*COWS*) was used as a farm-size variable in this study. Other studies, such as that of Cardona, have found that larger-sized farms were more likely to adopt BMPs.

Variable *MILKYIELD* was a continuous variable representing the number of pounds of milk produced annually per cow, divided by 100 for computational purposes. In most technology adoption studies, farm productivity has been used to reflect producers' openness to new productivity-increasing technology, causing potential endogeneity problems in the models. In our case, cow productivity was not considered to be an endogenous variable, because conservation management practices typically target primarily environmental enhancement rather than short-term farm productivity. Therefore, *MILKYIELD* was considered to be an exogenous determinant of BMP adoption, to account for the differential ability of the productive farm to bear the fixed adoption costs of conservation management.

Variable *DHIA* was included to examine whether those involved in the Dairy Herd Improvement Association record-keeping system were more or less likely to adopt BMPs. Although these producers were likely to be among the most financially able to adopt, they were also likely to be profit maximizers who focus on productivity issues, including cost of production. As found by Basarir, these producers are likely to be more focused on profit and, perhaps, less on conservation. In cases where conservation practices lead to better environmental quality but are costly to adopt and do not improve returns, one would expect lower rates of adoption.

The roles of age and educational attainment in farmers' decisions to adopt technology have been shown in previous studies (Cardona; Dorfman; El-Osta and Morehart; Feder, Just, and Zilberman; Gould, Saupe, and Klemme; Shields, Rauniyar, and Goode; Soule, Tegene, and Wiebe; Westra and Olson; Zepeda). Continuous variable *AGE* of the primary operator was hypothesized to negatively affect farmers' adoption of BMPs, because older operators with shorter planning horizons would be less inclined to adopt new technologies, especially those requiring substantial initial capital investments. Dummy variable *COLLEGE* took the value of 2 if the farmer held a college degree and zero otherwise. Educational attainment was expected to improve the decision-making process and enhance adoption. Consequently, *COLLEGE* was hypothesized to have a positive sign.

Variable *DIVERSIFICATION* represented the number of other crop and livestock enterprises in which the farmer is engaged. Diversification is included in this model to reflect the possibility that a producer has adopted one or more BMPs for one of the other enterprises. For instance, prescribed grazing with fencing and a trough or tank may have been adopted by the producer for his or her beef operation. Thus, one would expect producers with a greater number of enterprises to have adopted a greater number of BMPs. Researchers have also used diversification as a proxy for risk preference (e.g., Fernandez-Cornejo, Beach, and Huang), although risk preference is considered in the *RISKAVERSE* variable, discussed later.

The effect of land tenure has been examined in a number of previous technology adoption studies. Soule, Tegene, and Wiebe showed a negative association between renting land and BMP adoption. Cardona also showed sugarcane farmers' unwillingness to implement BMPs on rented land. Tenants' lack of motivation to adopt is likely caused by the perception of benefits accruing to the landowner rather than to the renter. Thus, a greater percentage of owned farm land (*LANDOWNED*) was hypothesized to increase the adoption of BMPs.

Risk and uncertainty have been discussed in previous empirical studies as impeding technology adoption (Feder, Just, and Zilberman; Fernandez-Cornejo, Beach, and Huang; Ghosh, McGuckin, and Kumbhakar; Krause and Black; Shields, Rauniyar, and Goode). The risk-averse farmer selectively adopts technology that ensures positive net expected marginal benefits. In our study, producers were asked, "Relative to other investors, how would you characterize yourself?", and were asked to circle one of the following answers: (i) I tend to take on substantial levels of risk in my investment decisions; (ii) I neither seek nor avoid risk in my investment decisions; and (iii) I tend to avoid risk when possible in my investment decisions. This question was formulated by Fausti and Gillespie in an analysis of alternative risk-preference elicitation procedures for mail surveys. The variable *RISKAVERSE* was included as a dummy variable that took the value of one if the farmer tended to avoid risk and zero otherwise. *RISKAVERSE* was expected to increase the adoption of BMPs, especially those that reduce soil runoff, ensuring long-run land productivity. BMP adoption also reduces the risk of infringement on business operations by government regulators.

The variable *STREAM* took the value of one if a stream and/or river ran through the farm. The presence of a stream was expected to increase the implementation of BMPs, especially those specific to bodies of water such as stream-bank and shoreline protection. Farms nearer to streams are expected to be more closely scrutinized by regulators and, thus, under greater pressure to adopt BMPs.

The Louisiana Cooperative Extension Service has been involved in training programs (e.g., the Master Farmer Program) in recent years, which have educated producers about environmental issues related to agriculture and potential solutions such as BMP adoption. More frequent meetings with extension agents would, thus, potentially influence adoption. The number of times the farmer met with extension agents in 2000 (*LCES*) was included as an explanatory variable to analyze the potential influence of extension agents on BMP adoption.

Table 2. Adoption Rates of Best Management Practices in Dairy Production

Best Management Practice	Percentage Adopted
Erosion and Sediment Control Practices	
Conservation Tillage	77
Cover and Green Manure Crop	38
Critical Area Planting	46
Field Borders	48
Filter Strips	35
Grassed Waterways	43
Heavy Use Area Protection	31
Regulating Water in a Drainage System	48
Riparian Forest Buffer	28
Sediment Basin	43
Streambank and Shoreline Protection	28
Facility Wastewater and Runoff Management	
Roof Runoff Management	34
Waste Management System	83
Waste Storage Facility	70
Waste Treatment Lagoon	78
Waste Utilization	74
Nutrient and Pesticide Management	
Nutrient Management	69
Pesticide Management	62
Gracing Management	
Fencing	80
Prescribed Grazing	72
Trough or Tank	70

Results

The percentages of producers adopting each of the BMPs are included in Table 2. The most frequently adopted BMP was the waste management system, with an 83% adoption rate. Other facility wastewater systems also had relatively high adoption rates, such as the waste treatment lagoon, at 78%, which could be included as a part of an overall waste management system. Grazing management practices also had relatively high adoption rates, with fencing used for keeping animals out of highly erodible areas being adopted at 80% and pre-

Table 3. Descriptive Statistics of the Variables

Variable	Units	Mean	Standard Deviation	Minimum	Maximum
TBMP	Number	11.565	5.436	0	21
CWA	0–1	0.766	0.425	0	1
COWS	Number	135.169	92.99	20	600
MILKYIELD	cwt	149.002	22.783	81	228
AGE	Years	50.911	11.582	26	78
COLLEGE	0–1	0.258	0.439	0	1
DIVERSIFICATION	Number	0.500	0.801	0	3
LANDOWNED	Percent	0.663	0.333	0	1
DHIA	0–1	0.476	0.501	0	1
STREAM	0–1	0.250	0.435	0	1
RISKAVERSE	0–1	0.734	0.444	0	1
LCES	Number	2.105	1.803	0	6

scribed grazing being adopted at 72%. Conservation tillage practices were also highly adopted, at 77%.

Practices with relatively low adoption rates included filter strips, heavy use area protection, riparian forest buffers, stream-bank and shoreline protection, and roof runoff management. Two of these, stream-bank and shoreline protection and riparian forest buffers, are used in cases where there are bodies of water on or adjacent to the property. One expects their adoption rates to be lower, because not all farms have shoreline on the property. Overall, it was observed that, in cases where BMPs have relatively high adoption rates, farmers have been strongly encouraged to adopt (e.g., waste management systems) and/or the economic benefits of adoption have been positive (e.g., conservation tillage).[1]

Descriptive statistics for total BMPs adopted (*TBMP*) in Table 3 showed that the mean number of BMPs adopted was 11.5 (standard deviation 5.4). Four producers had adopted no BMPs, whereas 10 reported having adopted all 21. Thus, there was wide dispersion in the number of BMPs adopted by producers.

The results of the Poisson, NBMLE, and QGPML models are presented in Table 4, and estimates associated with the marginal effects computed at the mean values of the *X*s for the NBMLE are presented in Table 5. Comparison of the values of the mean and variance of the dependent variable *TBMP* showed a larger variance (29.48) compared with the mean (11.56). This would suggest the inappropriateness of using the Poisson model, because the equality property of the mean and variance was not fulfilled. Tests for overdispersion indicate that one should consider a variance function–type negative binomial. The NBMLE model yielded the largest log-likelihood values compared with the Poisson and the QGPML models. The likelihood-ratio test on the NBMLE as the full model and the Poisson as the restricted model (since $\alpha = 0$ with the Poisson model) confirmed the need to select the NBMLE. Indeed, the likelihood ratio value of 47.69 was greater than the 3.84 critical value at a 5% level of significance. Provided that the conditional mean was correctly specified, the NBMLE model was consistent for β. The QGPML model, also presented, provided the robustness of the QGPML to distribution misspecification. The results from the NBMLE and QGPML models were very similar.

Our results suggested that, for Louisiana dairy producers' awareness of government efforts to control non–point sources of water

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[1] The economic benefits of conservation tillage have been mixed, depending on crop and location. For instance, Parsch et al. found conventional tillage to result in higher expected net returns for soybeans, grain sorghum, and corn, while conservation tillage resulted in higher expected net returns for cotton on clayey soils in Eastern Arkansas.

Table 4. Coefficient Estimates of the Poisson and Negative Binomial Regressions

Variable	PMLE	Negative Binomial MLE	Negative Binomial QGPML
Constant	1.4550*** (0.2374)	1.4842*** (0.3954)	1.4881*** (0.4631)
CWA	0.4383*** (0.0728)	0.4610*** (0.1121)	0.4659*** (0.1286)
COWS	0.0009*** (0.0003)	0.0011** (0.0005)	0.0011* (0.0006)
MILKYIELD	0.0046*** (0.0013)	0.0044* (0.0023)	0.0043 (0.0027)
AGE	−0.0065*** (0.0025)	0.0077* (0.0041)	−0.0079* (0.0047)
COLLEGE	0.0993 (0.0687)	0.0937 (0.1415)	0.0927 (0.1650)
DIVERSIFICATION	0.0213 (0.0340)	0.0306 (0.0507)	0.0322 (0.0595)
LANDOWNED	−0.2453*** (0.0824)	−0.2530* (0.1364)	−0.2547 (0.1589)
DHIA	−0.1629*** (0.0609)	−0.1612 (0.1122)	−0.1610 (0.1292)
STREAM	0.1628*** (0.0628)	0.1611 (0.1253)	0.1610 (0.1649)
RISKAVERSE	0.2374*** (0.0679)	0.2553** (0.1184)	0.2593* (0.1373)
LCES	0.0580*** (0.0150)	0.0657** (0.0267)	0.0670** (0.0307)
Alpha (NBLME)		0.8837*** (0.0216)	
ln L	−385.9164	−371.9537	−1659.935
R_D^2[a]	0.3013		
R_{LRI}^2[b]	0.1298		

Notes: *** indicates the variable is significant at the 0.01 level; ** indicates the variable is significant at the 0.05 level; * indicates the variable is significant at the 0.10 level. Values in parentheses are standard errors of the estimate. MLE is maximum-likelihood estimator. PMLE is Poisson MLE. QGPML is quasigeneralized pseudo MLE.

[a] Goodness-of-fit measure based on the deviances. (Cameron and Windmeijer 1993).

[b] Likelihood ratio index (Greene 2002).

Table 5. Marginal Effects for the Negative Binomial Maximum-likelihood Estimator (MLE) Regression

Variable	Negative Binomial MLE
Constant	17.2162*** (4.7856)
CWA	5.3475*** (1.3574)
COWS	0.01228* (0.0063)
MILKYIELD	0.0508* (0.0278)
AGE	−0.0892* (0.0496)
COLLEGE	1.0870 (1.7121)
DIVERSIFICATION	0.3553 (0.6138)
LANDOWNED	−2.9351* (1.6512)
DHIA	−1.8703 (1.3580)
STREAM	1.8688 (1.5171)
RISKAVERSE	2.9613** (1.4326)
LCES	0.7623** (0.3227)

Notes: *** indicates the variable is significant at the 0.01 level; ** indicates the variable is significant at the 0.05 level; * indicates the variable is significant at the 0.10 level. Marginal effects are computed at the means of the *X*s. Values in parentheses are the standard errors.

pollution through the Clean Water Act, being a larger dairy farm, having a higher milk yield, having a stream running through the farm, being risk averse, and having greater contact with Cooperative Extension Service personnel were significantly associated with the adoption of a greater number of BMPs. Furthermore, the awareness variable yielded the greatest marginal effects compared with other explanatory dummy variables. Such results show the importance of efforts to stimulate awareness of non–point source pollution problems in inducing adoption. A producer who is fully aware of the need to control non–point sources of pollution would be more willing to adopt than otherwise. The positive effect of a risk-averse attitude suggests that risk-averse producers may view BMP adoption as a risk-reducing strategy, especially in light of the prospect of dairy farms viewed as being environmentally unfriendly being forced to either increase conservation efforts or to shut down. The positive effect associated with having a stream running through the farm suggests that farms at the greatest risk of polluting are targeted by regulators and/or more clearly see the need for adoption of pollution-reducing practices.

The greater the percentage of land owned, the fewer BMPs were adopted. This was not expected and is not easily explained. It was, however, consistent with a number of binomial probit runs for individual BMPs, reported by Rahelizatovo. Rental arrangements, however, often include stipulations requiring the use of suitable conservation practices. It is essentially costless for a landlord to include provisions in a lease requiring suitable care to be taken of the land resource, especially in cases where he or she does not have to bear the cost of adoption. Rental agreements are more likely to include provisions for BMPs than for other technologies that boost production but have no bearing on farm maintenance. The negative effect of producer age on the number of BMPs adopted was as expected. This result is consistent with previous findings, including results obtained in the present study when binomial probit analyses were conducted for the adoption of each individual BMP.

Conclusions and Implications

Several useful conclusions can be drawn from this study. First, the study shows that useful insights can be obtained by using a count data model to explore the adoption of multiple technologies when multinomial logit, multivariate probit, and other models are infeasible. Although count data results do not allow for the investigation of which specific BMPs are adopted by individuals, information on the intensity of BMP adoption is obtained. The disadvantages of such analysis include the inability to determine which specific technologies are adopted, investigation as to the complementary or substitute relationships that may exist among the technologies, and the inability to assign levels of importance to each technology.

Our results suggest that awareness of the Clean Water Act, legislation to control non–point source pollution, along with increased information dissemination through extension efforts, are highly associated with greater BMP adoption. Our results suggest that, if society desires to continue to pursue cleaner water via BMPs, increased emphasis on information dissemination on the subject, as well as the provision of technical training will likely be effective.

With the exception of the land tenure variable, other model results were generally as expected. Our results support those of other studies that have shown larger, more productive producers to be the more intensive adopters of technology. Older farmers were less likely to adopt, likely because the change in technology would represent an untried practice that would have uncertain results, as well as that large investments in capital and knowledge are unlikely to be viewed as feasible when the planning horizon is limited.

One would typically consider producers who are members of the Dairy Herd Improvement Association to be profit maximizers, given their close attention to record keeping. Results by Basarir lend evidence to this. The negative sign on *DHIA*, which was significant in the Poisson regression as well as some other binomial logit analyses run on individual BMPs, thus raises the question of whether profit maximizers are the likely adopters of BMPs that do not necessarily lead to greater profits. The results, thus, suggest that some profit-maximizing producers will need significant economic incentives to adopt BMPs, perhaps through programs such as the Environmental Quality Incentives Program, which was recently expanded in the 2002 Farm Bill.

Overall, the results of the study point out that dairy producers' adoption of BMPs varies greatly, which indicates both success in encouraging adoption and a need for further educational programs and incentives to encourage adoption. Observation indicates that those BMPs with the greatest levels of adoption, such as waste management systems, have been more highly promoted and/or deemed by producers to be economically viable. There appears to be significant opportunity for programs that further educate producers about

BMPs and the economic incentives available for their implementation. These programs will need to include information on the costs and benefits associated with adopting BMPs. Given the lack of available information on the costs and benefits of adoption, this is a good area for further research.

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