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Regional Air Emissions Reduction from Dairy Operations Via Best Management Practices

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Abstract: The Yakima Regional Clean Air Agency (YRCAA) in collaboration with the Dairy industry and environmental scientists, has developed, over a period of three years, an Air Quality Management Policy for Dairy Operations. The Policy is geared towards a systematic implementation of proven Best Management Practices (BMPs), which are specific for each dairy operation, to reduce air emissions in the Yakima Valley, WA. The BMPs are grouped in tiers with respect to effectiveness, cost, ease of implementation, and compatibility with the State mandated nutrient management plans for dairies. Tier 1 BMPs are generally the least expensive and easiest to implement, while Tier 3 BMPs are the most challenging and expensive to implement. The BMPs focus on air emission reduction of major air pollutants from dairy operations, namely; ammonia, nitrous oxide, hydrogen sulfide, volatile organic compounds, odor, particulate matter and methane. The dairy operations are broken down into the following components/systems: nutrition, feed management, milking parlor, housing (freestall and drylots), grazing, manure management and land application. The components in each dairy depend on the overall management design and not every dairy has all these components. A total of 41 dairy operations within the YRCAA jurisdiction were included in the policy representing a total of 145,000 head of cattle (lactating cows, dry cows, heifers and calves). To obtain baseline data, the YRCAA staff conducted site visits for each facility in 2014 and assigned a "score" for each dairy component ranging from A to D. The results presented here are not specific to each facility but aggregated. Based on all participating dairies; 21% scored an "A", 30% scored a "B", 37% scored a "C", and 12% scored a "D". These data will be used as a baseline to compare future BMPs implementations to determine air emission reductions. In general, results show that guided and voluntary implementation of BMPs has the potential to significantly reduce ammonia, volatile organic compounds, and odor emissions in the Valley.

Keywords: Dairy Operation, Air Quality, Air Emissions Reduction, Best Management Practices, Cost and Tiers, Implementation Dairy Systems/Component, Baseline Data

1. Introduction

The Yakima Valley in Washington State is one of the largest dairy producing areas in the nation and home to more than 90 dairy operations and over 110,000 milk cows [29]. Within the Yakima Regional Clean Air Agency (YRCAA) jurisdiction, however, there are 41 dairy operations and 59 facilities (i.e. some dairy operations have more than one facility). The spatial distributions of these facilities are shown in Figure 1. In general, a dairy operation, in this paper, is thus one or more facilities under the same ownership where animals are confined for feeding and milking posing significant potential for emissions of air pollutants [19, 21]. Numerous studies have shown that cattle feeding operations and dairy operations are sources of airborne contaminants such as particulate matter (PM) and ammonia, both of which are associated with health issues such as asthma, and cardiovascular and pulmonary disease [8, 23, 21, 30, 15, 31].

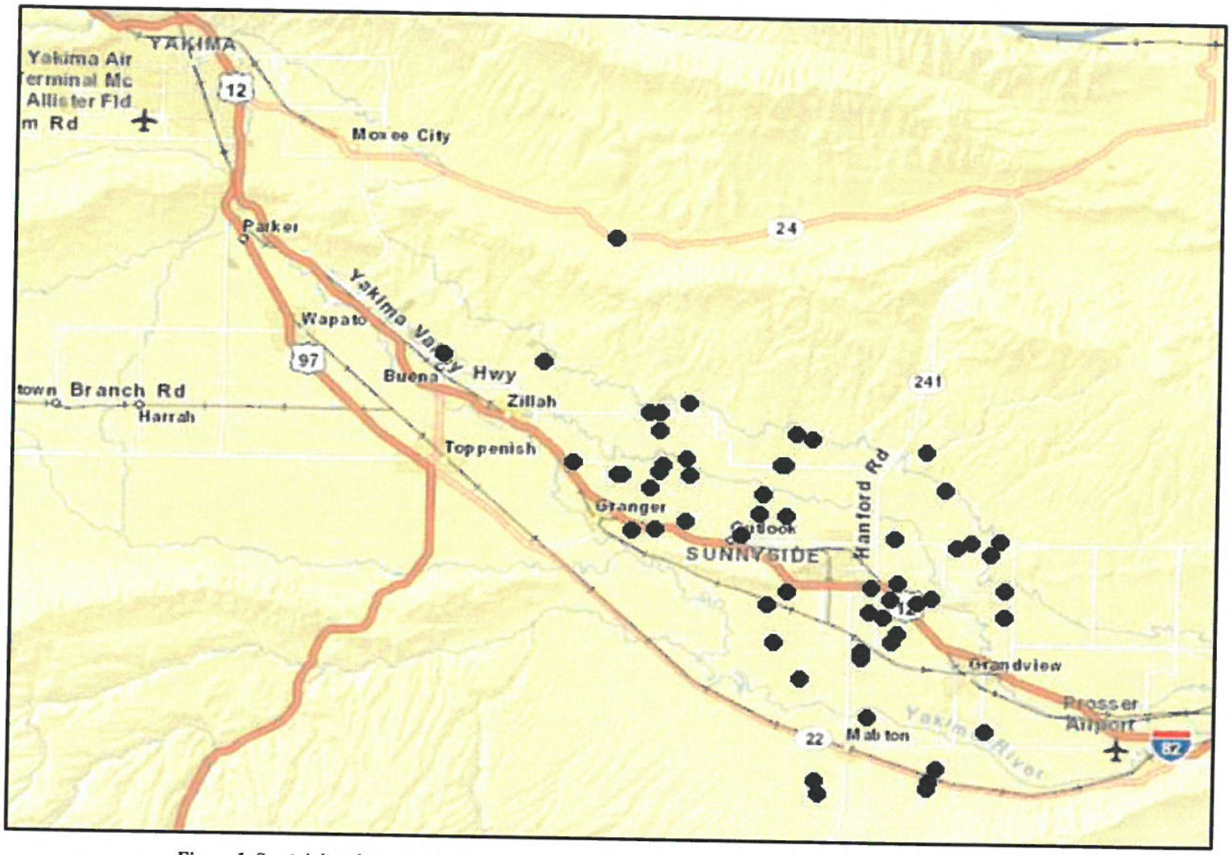

***Figure 1.** Spatial distribution of the dairy facilities within the Yakima Regional Clean Air Agency's jurisdiction.*

Researchers and scientists have determined emissions of ammonia, methane, N_2O and others for dairy operations [2, 12, 13]. From a regulator's viewpoint, however, it is difficult to regulate emissions from dairy operations because of the complexity of quantifying the emissions, which are mostly fugitive from such operations. Furthermore, the processes of generating the various pollutants vary from one operation to another because they are dependent on several variables such as atmospheric conditions (e.g. wind, temperature, and humidity) and biological processes amongst others. Several studies, however, have provided or suggested proven management practices, which can significantly control fugitive air emissions [5, 20]. Deliberate incorporation of these practices at every dairy operation is the first step towards mitigation of air emissions.

In response to citizen and the YRCAA Board of Directors concerns about air quality impacts from dairy operations, the YRCAA staff, in conjunction with scientists and stakeholders, drafted a policy in 2010 entitled "Air Quality Management Policy and Best Management Practices for Dairy Operations". The Policy comprehensively covers all syestems/components of a typical dairy operation, to include: nutrition, feed management, confinement (freestall barns, drylot pens), grazing, manure management, land application (fertilizer and manure) and others (road condition and shelterbelts). Potential air pollutants addressed in this policy include: nitrous oxide (N_2O); methane (CH_4); hydrogen sulfide (H_2S); odor; ammonia (NH_3); particulate matter (PM); and volatile organic compounds (VOCs).

In 2011, the Agency with its partners (Whatcom Conservation District and Washington State University) conducted a pilot research project with limited number of dairies to test the effectiveness and appropriateness of the 'draft Policy' and to determine the economic and technical feasibilities of implementing air quality BMPs. Further testing of the draft Policy and trial implementation were continued in 2012 with additional facilities. The experiences and lessons learned during those two phases were incorporated in the draft Policy, which then was approved as 'final Policy' or 'the Policy' in June 2013, and became effective July 1, 2013. Subsequently, all dairies in the YRCAA jurisdiction were required to register with the YRCAA and to submit an Air Quality Management Plan (AQMP) for their operation. Interested readers are encouraged to refer to the entire Policy found at the Agency's website https://www.yakimacleanair.org/img/pdf/109.pdf.

The BMPs that have proven effective for reducing air emissions from different dairy systems are fully described in the Air Quality Management Policy for Dairy Operations [22]. A summary by the dairy operation's components, expected pollutants, and the BMPs identified in the Policy are presented in Table 1. The dairy policy was based on the hypothesis that a comprehensive and consistent implementation of proven BMPS, on all aspects of a dairy operation, will mitigate the emissions from the dairies throughout the Valley, which is a significant step towards improving air quality in the Yakima Valley.

Table 1. *Summary of the BMP Tier system (where 1 is easiest and least expensive, and 3 is more complex and most costly) for all dairy components or systems and respective pollutants under consideration.*

Systems	Expected pollutants	BMPs -Tier 1	BMPs -Tier 2	BMPs -Tier 3
Nutrition	NH_3, CH_4, H_2S, N_2O	1. Properly Manage Level of Dietary Protein (%CP) in Diet 2. Properly Manage and Minimize Overfeeding Sulfur	Practice Group Feeding	1. Increase the Level or Quality of Starch 2. Utilize feed additives to maximize efficiency
Feed Management	VOC, PM, Odor	1. Regularly remove Spilled and Unused Feed from Feeding Area 2. Manage or Minimize the Mixing of Feed During Windy Times	Properly Cover and Manage Ensiled Feedstuffs	Store Feed in a Sheltered Storage Structure
Milk Parlor	NH_3, VOC, Odor, H_2S	1. Use Recycled Parlor (Clean) Water Used for cleaning Parlor 2. Ensure Proper Ventilation	Remove Manure from Parlor and Holding Area Frequently	Treat Recycled Water Used for Flushing/Cleaning Holding Area
Freestall Barns	NH_3, VOC, Odor, CH_4, H_2S	1. Remove Manure from Barns Frequently 2. Ensure Proper Ventilation	1. Bedding Selection and Management 2. Manure Removal Technology and Efficiency	1. Treat Recycled Lagoon Water Used for Flushing 2. Alleyway Floor Texture and Type 3. Manure Removal Technology and Efficiency
Drylot Pen	NH_3, PM, Odor, H_2S, CH_4, VOC, N_2O	1. Spread (Harrow) Manure Frequently 2. Surface Moisture Content Management	1. Remove Manure Frequently 2. Incorporate Wood Chips in Surface Layer 3. Use Straw Bedding in the pen 4. Knockdown and Remove Fence Line Manure	1. Urease Inhibitors - Provide Shade for Cattle 2. Sitting of Water Trough within Pen
Grazing Management	NH_3, N_2O	1. Stock Appropriate Number of Animals 2. Use Rotational Grazing	Move Water and Feeding Areas Frequently	Irrigate Immediately after Grazing
Manure Storage	Liquid: NH_3, H_2S, CH_4, Odor, VOC Solid: NH_3, H_2S, PM, CH_4	1. Manure Solids Separation 2. Properly Manage the Composting of Solid Manure 3. Properly Manage Stockpiled Manure	1. Lagoon or Storage Covers 2. Scrub Exhaust of Enclosed Waste Containers	1. Anaerobic Digester 2. Surface Aeration of Lagoons 3. Reduce the pH of Manure 4. Encourage Purple Sulfur Bacterial Formation in Lagoons
Land Application	NH_3, PM, Odor, N_2O	1. Apply Nutrients According to Agronomic Recommendations 2. Inject or Incorporate within 24 Hours of Application 3. Do Not Over-irrigate 4. Apply During Cool Weather	1. Utilize Cover Crops 2. Apply N Fertilizer below No-Till Residue	Installation of Windbreaks or Shelterbelt

2. Methodology

2.1. Best Management Practices and Implementation

Scientist, Engineers and the Agency, associated with development of the Policy, first assembled into a single text, brief descriptions of available best management practices (BMPs) for controlling air emissions from dairy operations based on available literature [6, 10-11, 24-28, 30, 18, 4, 1, 16, 14, 9, 17, 3]. The BMPs were categorized according to the pertinent components of a typical dairy operation needing management to curb air emissions, which invariably include: nutrition, feed, housing (freestall barns or drylots), grazing, manure handling, and land application (fertilizer and manure). The effectiveness of each BMP in mitigating emissions of a specific pollutant was provided wherever possible for a well (100%) implemented BMP. Because implementing one BMP when targeting reduction of another specific pollutant may affect other pollutants, tradeoffs, limitations, or both were noted for each BMP wherever applicable. This document and field experiences were used to generate the maximum or potential BMP scores used in the BMPs score sheet, which was used to conduct evaluations of the BMPs in each dairy as shown in the excerpts from this score sheet in Table 2 and Table 3. And as explained further in using equation 1 through equation 4 in method/section 2.2. below.

2.2. Field Inspections and BMPs Score Sheet

Prior to field inspections, a workshop and field visits were organized to teach producers and YRCAA inspectors on how to conduct evaluations of the BMPs being implemented at each of the dairy system and how to score the level of implementation on the BMP score sheet. The YRCAA inspectors would then visit each dairy to evaluate BMPs being implemented at the facility with respect to management of: nutrition, feed, milking parlor, housing, grazing, manure, and other components unique to each operation. A performance score sheet, whose extracts are presented in Table 2 and Table 3, was used by the inspectors in their assessment to provide an overall score or grade for the dairy operation (the entire score sheet is presented in the entire Policy document found on the web-link provided above). The score sheet was designed with a list of all known, proven and effective BMP's germane to all dairy components/systems (listed above) and their relative reduction potential, or effectiveness score, for each pollutant of interest. Effectiveness scores ranged between zero and five to indicate the relative impact of that BMP on the pollutant in question (zero for no impact and five for highest impact). The inspector would then enter in an implementation score for each BMP ranging from one to five (according to degree of implementation: one = lowest, 5 = highest). As alluded to earlier, inspectors had previously been trained on how to identify and evaluate BMPs for each pollutant for consistency and accuracy of scoring. For each dairy component, the pertinent BMP evaluated was weighted and an overall score given for each pollutant to represent the overall impact of the combined BMPs pertinent to that component (Eq. 1). The worksheet would then automatically sum-up all of the weighted subtotals for the component in question (Eq. 2), correct for the highest possible achievable score (Eq. 3) and finally compute a "total percent score" for each pollutant (Eq. 4). The "total percent score" was the combined relative effectiveness of all the BMP's implemented for reducing the pollutant under consideration.

$$WT_{c,\,p}=\sum_{i=n}^{n}\frac{I_{BMP_i}\times IC_{BMP_i}}{5} \tag{1}$$

$$WT_{p}=\sum_{c=1}^{m}\sum_{i=1}^{n}\frac{I_{BMP_i}\times IC_{BMP_i}}{5} \tag{2}$$

$$W_{potential,\,p}=\sum_{c=1}^{m}\sum_{i=1}^{n}IC_{BMP_i} \tag{3}$$

$$T_{p}=\frac{WT_{p}}{W_{potential,\,p}} \tag{4}$$

Where: I = degree of implementation of a BMP; IC = impact coefficient of a BMP on a pollutant; BMP_i is BMP number i being implemented for a given dairy component (c); $WT_{c,\,p}$ = weighted total score of pollutant p for a given component; WT_p = weighted total score of pollutant p in the entire dairy; $W_{potential,\,p}$ = highest value achievable for a weighted total score of pollutant p for the entire dairy; T_p = total percent score of pollutant p for the entire dairy; n = number of BMPs in a given dairy component, and m = number of components in the respective dairy operation.

The overall percent score (T) (0-100) for each facility was calculated as the average of the total percent scores (T_p) for the eight pollutants. A corresponding final grade was also assigned to each dairy operation based on the common A to D grading system as follows: A = 90–100; B = 80–89, C = 70–79, and D < 70. A grade of A or B were classified as good, C as satisfactory or adequate, while a D grade indicated unsatisfactory mitigation efforts. In other words, dairies scoring an "A" were implementing most BMPs most effectively, resulting in the most potential pollution mitigation. Dairies which scored either a "B" or "C" were implementing most BMPs effectively, but also had some BMPs that needed improvement. Operations scoring a "D" needed to improve the implementation of existing BMPs or start utilizing new BMPs to achieve an acceptable reduction level of air emissions from their facility. Table 2 and Table 3 show typical scoring of four units in a dairy including: nutrition and feed managements, Table 2 and milking parlor and barn managements Table 3.

Table 2. An extract from the BMPs score sheet representing the nutrition and feed systems managements.

Producer/Dairy Name:									**Date: May 11, 2011**						
AQ BMP SCORE SHEET															
BMP #	**BMP Scores** NH_3	N_2O	H_2S	**VOC**	**Odor**	**PM**	CH_4	**Best Management Practice**	NH_3	N_2O	H_2S	**VOCs**	**Odor**	**PM**	CH_4
I. Nutrition															
I-1	5	5	0	0	2	0	0	Properly manage level of dietary protein (%CP)	5	5			5		
I-2	0	0	0	2	0	0	5	Feed increased level or quality of starch in diet				5			5
I-3	0	0	5	0	2	0	0	Manage and minimize overfeeding of sulfur-containing feed			5		5		
I-4	5	5	5	0	5	0	2	Practice group and/or stage of lactation feeding	4	4	4		4		4
	10	10	10	2	9	0	7	Weighted Subtotal	9.0	9.0	9.0	2.0	8.0	0.0	6.6
								%	90	90	90	100	89	NA	94
II. Feed Management															
II-1	2	0	0	5	4	3	0	Properly manage ensiled feedstuffs	5			5	5	5	
II-2	0	0	0	3	3	4	0	Store feed in a sheltered storage structure				5	5	5	
II-3	1	0	0	3	3	4	0	Regularly remove spilled and unused feed from feeding area	5			5	5	5	
II-4	0	0	0	0	0	5	0	Manage or minimize feed mixing during windy times						5	
	3	0	0	11	10	16	0	Weighted Subtotal	3.0	0.0	0.0	11.0	10.0	16.0	0.0
								Percentage score (%)	100	NA	NA	100	100	100	NA

Table 3. *An extract from the BMPs score sheet representing the milking parlor and the freestall barn managements.*

Producer/Dairy Name:									**Date: May 11, 2011**						
AQ BMP SCORE SHEET															
BMP #	**BMP Scores**							**Best Management Practice**							
	NH_3	**N_2O**	**H_2S**	**VOC**	**Odor**	**PM**	**CH_4**		**NH_3**	**N_2O**	**H_2S**	**VOCs**	**Odor**	**PM**	**CH_4**
III. Milk Parlor															
III-1	3	0	0	0	0	0	0	Ensure proper ventilation	3						
III-2	5	0	4	4	5	0	0	Use recycled (clean) or treated water for flushing parlor	5		2	3	4		
III-3	5	0	4	4	5	0	0	Use recycled (clean) or treated water for cleaning holding pen	5		2	3	4		
III-4	5	0	0	5	5	0	0	Remove manure from holding area frequently	5			5	5		
	18	0	8	13	15	0	0	Weighted Subtotal	16.8	0.0	3.2	9.8	13.0	0.0	0.0
								%	93	NA	40*	75	87	NA	NA
IV. Housing - Freestall Barns															
IV-1	3	0	0	0	0	0	0	Ensure proper ventilation	5						
IV-2	5	0	0	0	5	3	0	Bedding selection and management	4				4	3	
IV-3	5	0	4	4	5	0	0	Treat recycled lagoon water used for flushing	5		2	4	3		
IV-4	5	0	0	5	5	0	0	Remove manure from barns frequently	5			4	4		
IV-5	5	0	3	5	5	0	0	Manure removal technology and efficiency	4		2	5	4		
IV-6	3	0	0	0	3	0	0	Alleyway floor texture and type	3				3		
	26	0	7	14	23	3	0	Weighted Subtotal	22.8	0.0	2.8	12.2	16.8	1.8	0.0
								Percentage score (%)	88	NA	40*	87	73	60*	NA

* Indicates a pollutant of concern, i.e. improvement needed to reduce that pollutant emissions to a satisfactory level.

2.3. Post-BMPs Evaluations

The second important facet of the Policy (after evaluation) was providing guidance, to the dairy operation, on how to improve its performances of mitigating emissions of individual pollutants at each dairy component. To facilitate the latter, the BMPs applicable to each dairy component were next grouped into three tiers. Tier 1 earmarked the least expensive and easy BMPs to implement in each dairy component, while Tier 3 indicated the BMPs considered to be the most advanced, but also the most expensive to implement as shown Table 1. Essentially, this exercise resulted in a second document referred to as "Air Quality BMP Selection Matrix." This matrix did not merely group BMPs into tiers but also outlined the process for identifying sources of emissions for an individual facility as well as providing an orderly selection process of BMPs to implement in a hierarchical manner to achieve the highest emissions mitigation at the lowest investment.

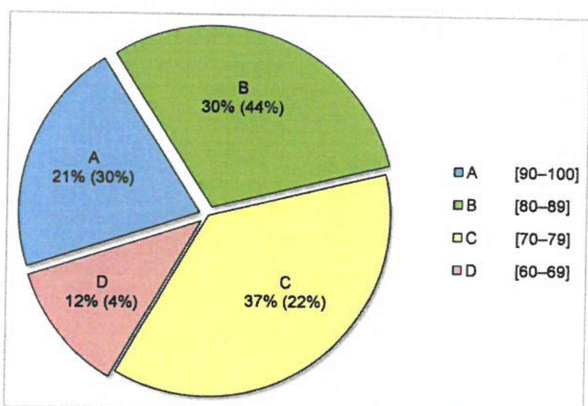

Figure 2. *Percentage grade distribution for all participating dairy operations (the percentage number of animals represented in each grade category is shown in parenthesis).*

3. Results and Discussion

3.1. Baseline BMPs Implementation

The overall distributions of performances of the dairies in each grade category are presented in Figure 2. Twenty one percent of dairies scored an *A* representing 30% of the animals; 30% of dairies scored a *B* and held 44% of the animals; 37% scored a *C* comprising 22% of the animals; and 12% scored a *D*, but represented only about 4% of the animals. Based on these performances, we inferred that, existing BMPs and level of implementation at all dairies evaluated were adequate to provide significant mitigation of air pollutants, as long as they were properly implemented and/or managed.

The statistical analyses of the scores with respect to individual dairy system's components are shown in Figure 3. The numerical score for each dairy component indicates the effectiveness of the BMPs being implemented at that component. In general, the degree of BMP implementation, for each component, varied significantly across dairies. The majority of the dairies had complete records of their nutrition (crude protein, starch, and sulfur content) and all but one practiced group feeding. The BMPs for feed management, overall, were implemented satisfactorily. Two of the dairy operations were in the process of installing a completely enclosed structure over the feed preparation system. The milking parlor was the component with the best overall score for mitigating all emissions but inspectors noted that some facilities could improve ventilation and cleaning of the holding area. The BMPs in the freestall barns were adequately implemented in most dairies. Most dairies could improve their score via improvement of manure removal efficiency and the installation of shade structures in drylot pens (permanent or seasonal) to reduce particulate matter and ammonia emissions. The two dairy operations, under the jurisdiction of this policy, which had a pasture grazing components, were adequately implementing BMPs identified for this system. For land application of manure, ammonia emissions could be reduced further by injecting or incorporating fertilizer/manure into the soil within 24 hours. About 14% of facilities inject manure, while the rest incorporate the manure into the soil following surface application within 24 to 48 hours. Lagoon pH data was usually not available even though it would be very beneficial for evaluating hydrogen sulfide, ammonia, and methane emissions. The lowest score was observed in the category "other" primarily because of non-existence of shelterbelts and inadequate management of unpaved road surfaces. Some BMPs not previously listed in the original Policy document but ascertained during site visits (e.g., total enclosure of the feeding area thus mitigating PM and VOCs emissions) were recognized and will be incorporated in future Policy documents updates.

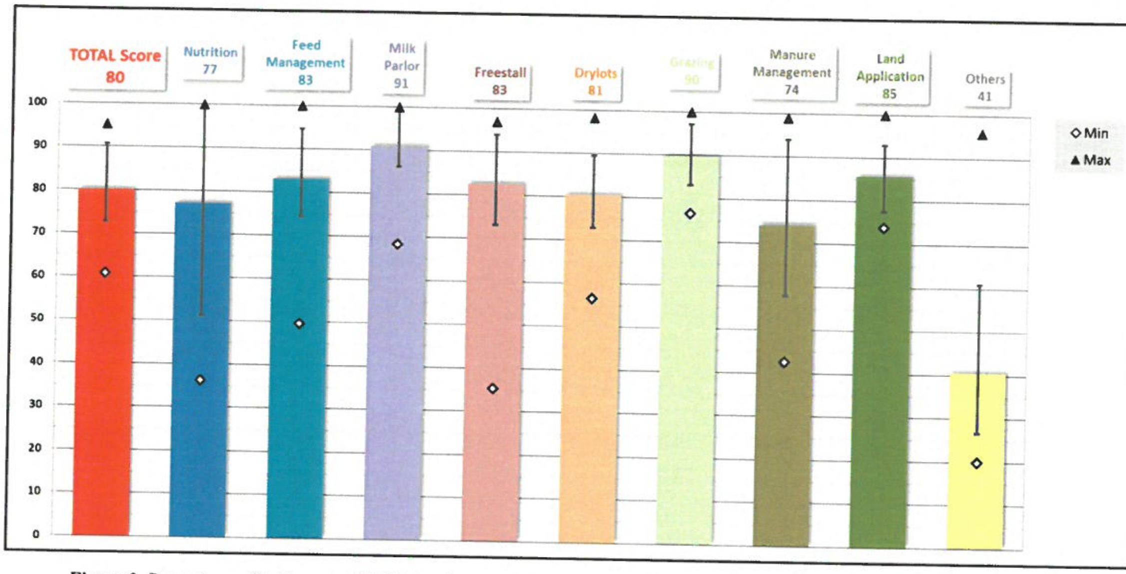

Figure 3. Percentage effectiveness of BMPs implementation for all dairies (total score) and for each respective dairy component.

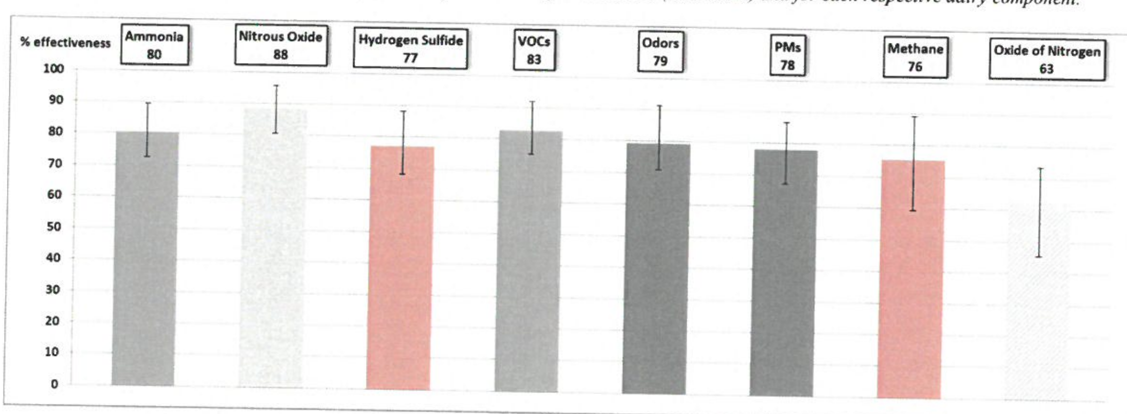

Figure 4. Percentage effectiveness of implemented BMPs at reducing individual pollutants based on all participating dairy operations.

3.2. Effectiveness of BMPs at Reducing Air Emissions

The degree of air emission reduction for a pollutant is directly proportional to the effectiveness of the associated BMPs implemented. Proper implementation of BMPs can attain reduction of emission rates to reasonable levels. However, it is important to recognize that although near zero-emission is technically possible, it is not economically feasible. The average percentage emissions reductions achieved (ERA) for each pollutant during the 2014 baseline evaluations are summarized in Figure 4. The average ERA score for ammonia was 80%. About half of the operations did not provide data for the nutrient content of the feed which was responsible for the low scores. Better implementation of manure management BMPs, and focusing on manure removal effectiveness, would improve the total score for the mitigation of ammonia. The average ERA score for CH_4 was 76%. About half of the operations did not provide data for the starch content in the feeds which negatively impacted their respective scores in this component, and hence the overall score. To improve the average score for methane, for example, improvements in the diet formulation, manure management, and housing management (both freestsll and drylot) BMPs were recommended. The average ERA score for H_2S was 77%. About half of the operations did not provide data for the sulfur content of the feed which adversely affected the scores. Improvement on the following practices would remedy the total score: properly manage the moisture content in the pens and around the drinking troughs, encourage purple sulfur bacterial formation in the lagoons [7], properly manage composting and stockpiled manure, and incorporation of manure into the soil within 24 hours of application. The average ERA score for PM was 78%. Improvements in stockpiling and management of the composting would improve the overall PM emissions. Removal of spilled feed, addition of windbreaks and shelterbelts, and weatherproof the feed storage structures would as well improve the score. The average ERA score for odor was 79%. In general, addition of a manure separation or centrifuge system, installation of shelterbelts, and less manure stockpiling would increase the total average score for odor. The average ERA score for VOCs was 83%. Feed management BMPs overall were well implemented. Improving the overall implementation of BMPs for the manure management system would reduce VOC emissions. The average ERA score for N_2O was 88%. This pollutant emission is closely associated with nutrition, land application, and grazing components. Those components were well managed in most of the participating dairy operations.

4. Conclusions

Yakima is the first county in Washington State to implement a dairy policy to reduce air emissions. The results obtained in 2014 will be used as a baseline to quantify the progress of BMP implementation in the future. Some dairy operations are already implementing new Tier 3 BMPs such as a total enclosure of the feeding area that will reduce air emissions of PM and VOC emissions. Although properly implemented BMPs may not reduce air emissions down to near zero, they can significantly lower air emissions leading to improved local and regional air quality. Quantifying the exact air pollutant emissions from dairy operations is a complex endeavor. Although efforts to develop emission factors and effective measurement methodologies continue, it would be unwise, in the meanwhile, not to address emissions. Approaches, such the one introduced in this paper, which informs dairy producers how well or not they are implementing proven and practical BMPs to mitigate air emissions and simultaneously guides them on "where" and "how" they can improve such implementations, indicates a high potential of being effective in the Yakima County, Washington.

5. Implication for Policy Makers

This paper presents preliminary results of a policy implementation process for dairy operations within Yakima County, Washington State, to reduce air emissions and improve air quality in the region. Best Management Practices (BMPs) in the policy focus on the following systems/components of a dairy operation: nutrition, feeds, milking parlor, manure, housing (freestall and drylot), and land application. The overall goal of the policy is to reduce air emissions of main pollutants, which include greenhouse gases (methane and nitrous oxide), particulate matter, ammonia, hydrogen sulfide, volatile organic compounds, and odor. The results from the first year of full implementation will be used as the baseline for evaluating future progress in the reduction of emissions in the County. However, lack of adequate inspectors lead to only partial inspections in 2015, 2016 and 2017. Overall, preliminary results are positive.

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