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Dust Control During Bedding Chopping

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Environmental measurements were made to assess the effectiveness of a dust control technique used during the mechanical chopping of hay and straw in dairy barns. The method involved simply the addition of portions of water directly to the bales prior to chopping. Measurements were made with and without this technique at eight dairy barns in central New York. Airborne dust was measured using gravimetric, photometric, and microscopic techniques. Additionally, various components of the dust (endotoxin, histamine, bacteria, and fungi) were quantified. Significant reduction in dust and specific dust components (typically about a five-fold decrease) was achieved with this treatment. Although there was not a statistical association between carbon monoxide levels and treatment, there were occasional high peak exposures (>200 ppm) recorded during both dry and wet trials. Emphasis is given to the microscopic features of the aerosol generated during bedding chopping and also to the interpretation of the photometric measurements. JONES, W.G.; DENNIS, J.W.; MAY, J.J.; WHITMER, M.P.; SIEGEL, P.D.; SORENSON, W.G.; SCHWEGLER-BERRY, D.; KULLMAN, G.J.: DUST CONTROL DURING BEDDING CHOPPING. APPL. OCCUP. ENVIRON. HYG. 10(5):467–475; 1995.

Bedding choppers are used by many farmers in the central New York area to chop hay or straw to be used as bedding for dairy cows. Rectangular bales are put into these machines and chopped into smaller pieces by the mechanical action of rotating blades. The bedding chopper is generally operated along a central walkway inside the dairy barn to fill each stall with bedding. The hay or straw used for bedding is typically of poor quality and not suitable for feed, often because of high levels of microorganisms.

Past work has shown that the operation of a bedding chopper can produce high concentrations of organic dust and associated components (bacteria, fungi, and endotoxins).[1] Exposure to this type of dust has been associated with hypersensitivity pneumonitis and organic dust toxic syndrome. The staff at the New York Center for Agricultural Medicine and Health learned of a practice used by some farmers in the area to control dust emissions from bedding choppers. The method involved the addition of small quantities of water (approximately 1 to 2 pints) to the cut side of each bale prior to chopping. Although the practice reportedly reduced visible dust, there were no data to quantify any reduction in dust or specific dust components. This prompted a collaborative effort between the New York Center and the National Institute for Occupational Safety and Health to test the effectiveness of the treatment using more tangible measures of exposure.

The focus of this article is to deliver the results of these measurements. In the process, though, emphasis is given to the microscopic features of the generated aerosol and to the interpretation of photometric dust measurements made in the barns.

Methods

Study Design

Sampling was done at eight dairy farms in central New York. Each farm was sampled over a 2-day period. On day one, sampling was done during normal bedding chopping. On the next day, measurements were made again during chopping, this time after 1 quart of water was added to the cut side of each bale. The water was applied evenly across the bales by means of a small sprinkling can. Farmers used hay or straw from the same cutting to ensure similar composition during both dry and wet sampling trials. Other variables were also held constant, including number of animals, bedding chopper operator, and ventilation conditions. The surveys were done in the winter, and the barns were typically kept closed. Identical environmental measurements were made at the same locations and on the same operator during both days.

The nature of the differences between measurements made during wet and dry chopping was explored by means of matched pair analysis using the Wilcoxon signed-rank test. The relationship between the photometric measurements and various gravimetric measures of dust was evaluated by regression analysis.

Measurement Techniques

PARTICULATE (GRAVIMETRIC). Personal samples for dust were collected on the bedding chopper operators by drawing air at a flow rate of 2 L/min through a 15-mm-diameter inlet positioned in the breathing zone and fixed to face outward. These samplers were made by modification of standard 25-mm cassettes. Note that this sampler has some of the features of a previously reported inhalable sampler.[2] Key differences are that only the filter was weighed so that dust deposited on the internal surfaces of the cassette was not quantified, and the inlet did not have a lip. An "inhalable-like" design was selected since organic dust can cause effects throughout the entire respiratory system, including the nose.[3] The cassettes contained polyvinylchloride filters which were preweighed and postweighed on a microbalance to the nearest 0.01 mg. Area samples were collected by drawing air at a flow rate of 10

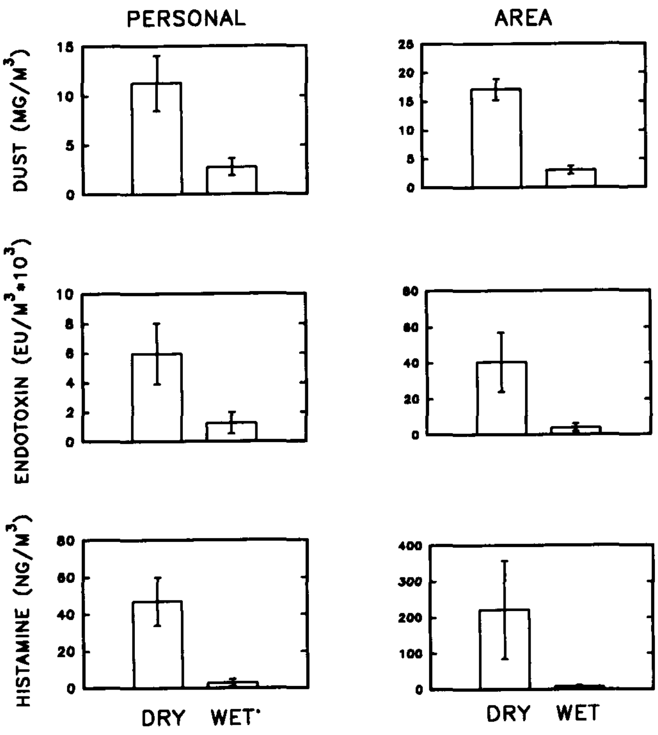

FIGURE 1. Effect of treatment on personal and area measures of dust and dust components.

L/min first through an open-faced 37-mm cassette inlet and then through a polyvinylchloride filter. The higher flow was chosen to ensure adequate amounts of dust for each assay since bedding chopping is of rather short (15 to 30-minute) duration.

PARTICULATE (PHOTOMETRIC). Miniram aerosol monitors (MIE, inc., Billerica, Massachusetts) were used to make direct reading dust measurements during the bedding chopping activity. The analog signals from each of three area monitors were stored by means of Metrosonics dataloggers. Stored data were then downloaded into a spreadsheet for graphing. Minirams were run in the passive mode.

PARTICLE SIZE DISTRIBUTION. Area samples for the measurement of the aerodynamic particle size distribution of the dust were collected using a previously described cascade impactor.[4] At a flow of 2 L/min, effective cutoff diameters for the stages ranged from 3.5 to 20 μm. Greased aluminum foil served as the collection substrate and the back-up filter was polyvinylchloride.

MICROSCOPY. Area samples were collected specifically for microscopic examination by drawing air at a flow of 2 L/min through cellulose ester and polycarbonate filters placed in open-faced cassettes. The cellulose ester filters were acetone cleared for light microscopy examination, and the polycarbonate filters were used for scanning electron microscopy. Additionally, settled dust samples were collected for examination of bulk amounts of dust. To bring out specific features of the particulate, a variety of microscopic techniques were used, including dark field, bright field, phase contrast, differential interference contrast, fluorescence, Rheinburgh illumination,

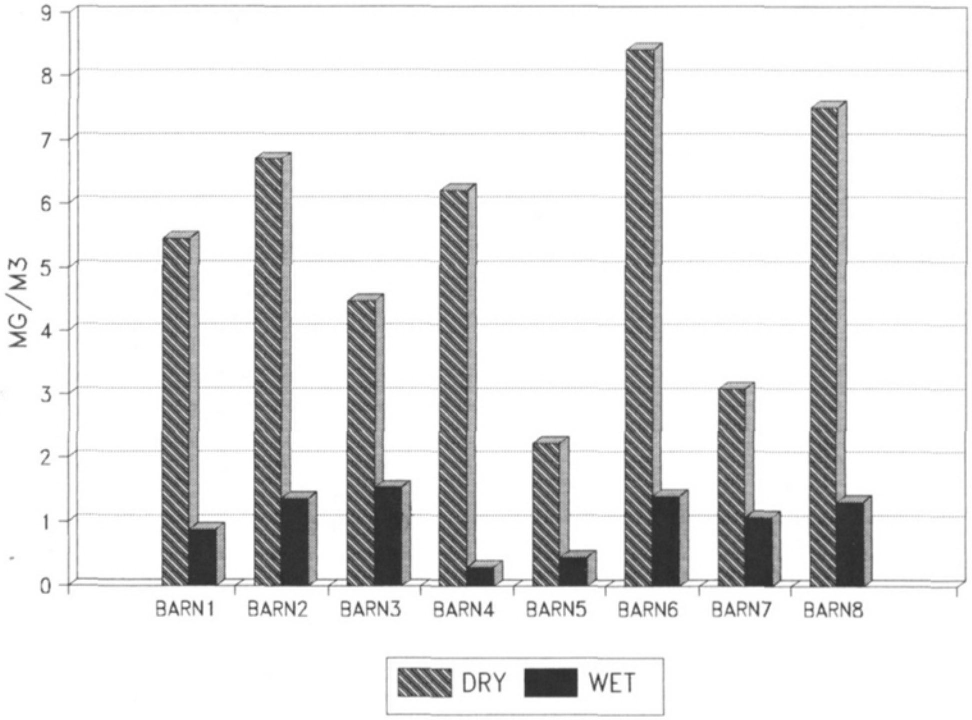

FIGURE 2. Dust levels during bedding chopping (average values for each barn).

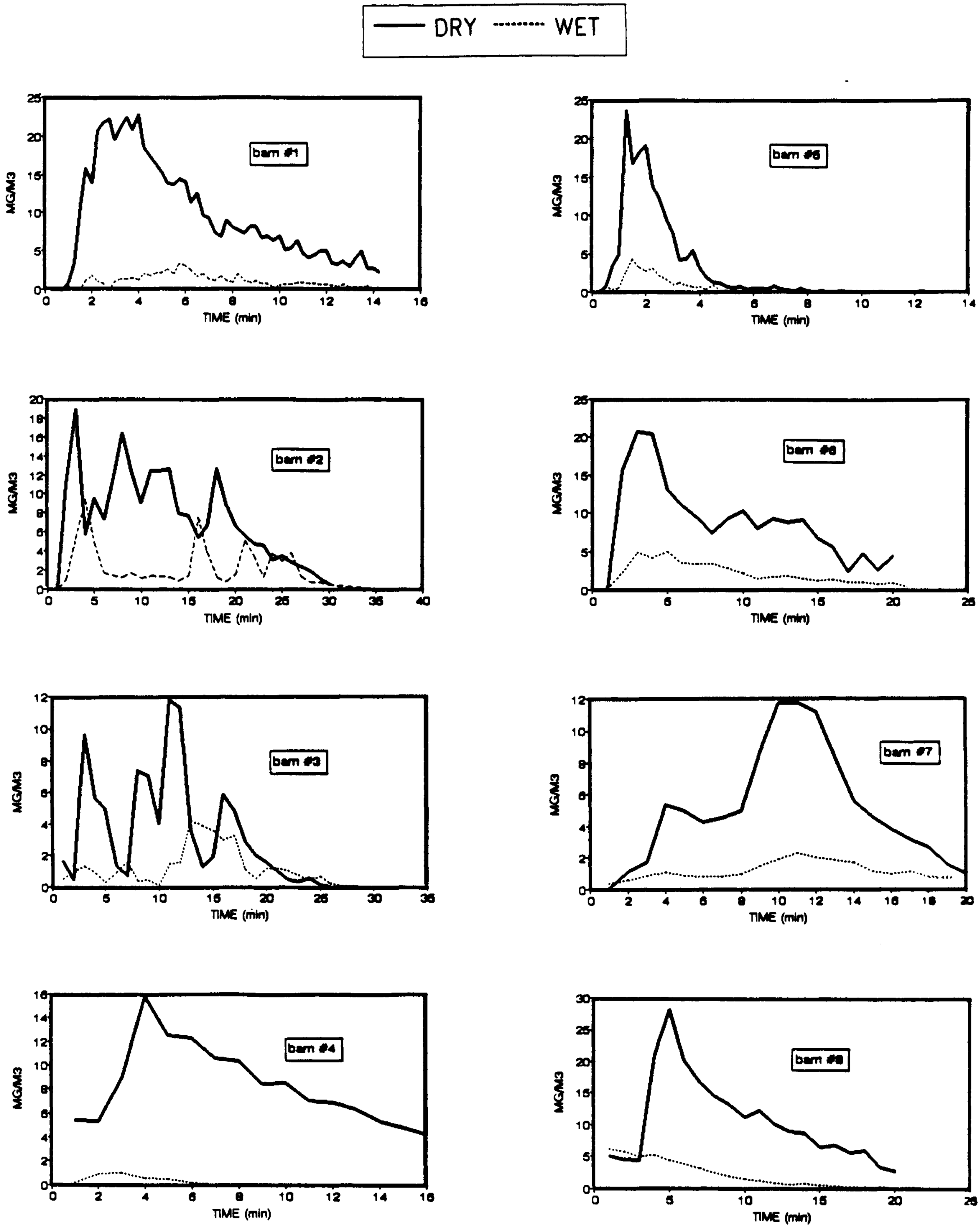

FIGURE 3. Dust levels during bedding chopping (direct reading measurements).

stereomicroscopy, and various forms of polarized light microscopy.

ENDOTOXIN/HISTAMINE. The same filters used for gravimetric assay were also analyzed for both endotoxin and histamine. Endotoxin was measured using a chromogenic modification of the Limulus amebocyte lysate test (Kinetic-QCL, Whittaker Bioproducts, Walkersville, Maryland) and histamine was measured as recently described by radioimmunoassay.[5]

MICROORGANISMS. Area samples for microorganisms were collected at 2 L/min through polycarbonate filters placed in open-faced cassettes. Collected dust was water extracted and a series of dilutions were made for plating analysis of culturable bacteria and fungi. For bacteria, tryptic soy agar and eosin methylene blue media were used. The latter is a selective media which inhibits the growth of gram-positive bacteria. Incubation temperature for both was 36°C. On a limited number of samples, counts of total bacteria were made using epifluorescence counting of preparations stained with acridine orange.[6] For culturable fungi, Rose Bengal Streptomycin and DG18 media were plated. Although both are used for mesophilic fungi, the DG18 medium is preferential to xerophilic organisms. Incubation temperature was 25°C.

CARBON MONOXIDE. Personal direct reading measurements for carbon monoxide were made on the bedding chopper operator using a span gas calibrated Drager model 190 datalogger.

Results

The overall average results from personal and area measurements of dust, endotoxin, and histamine are given in Figure 1. The bars indicate standard error of the mean. Substantial reductions for all three measures were obtained when farmers used the dust control method. For dust and endotoxin the decrease was about fivefold, and for histamine over tenfold. All differences were resolvable statistically by matched pair analysis ($p < 0.05$).

Figure 2 shows the reduction in dust in each barn. These results are the average of three Miniram readings for both wet and dry trials. Aside from illustrating the effectiveness of the treatment, these results also show the variability in dust levels between barns.

Figure 3 contains the Miniram direct reading results for one area in each barn. Note that in each case peak exposures were significantly reduced and the time required to complete the chopping was not substantially affected by treatment.

The aerodynamic size distribution results are given in Figure 4. The dry results are the average of three measurements, while the wet data points are from one sample. Many of the impactor samples were unusable due to insufficient weight gains. The results show a rather wide range of size and a substantial portion (about 50%) of mass associated with particles greater than 10 μm.

As an alternative means for expressing the effectiveness of this dust control measure, Figure 5 contains light photomicrographs of preparations from filter samples collected during both dry and wet trials. These filters were matched in terms of location and sample time so that each of the pairs can be examined together to obtain a visual appraisal of dust reduc-

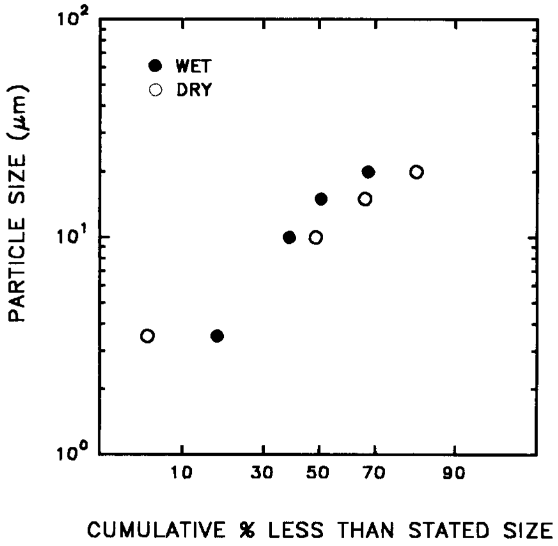

FIGURE 4. Aerodynamic particle size distribution.

tion. The top pair was photographed between crossed polars so that only anisotropic particles are visible. Many of the larger round particles with the internal cross are starch grains. Within this field there are also some mineral fragments and various botanical components. The middle pair was taken under slightly uncrossed polars so that anisotropic, isotropic, and opaque particles can be viewed simultaneously. The particles here that appear dark and are either elongated or round are principally fungal hyphae and spores. The bottom set of photos is from a preparation that was initially stained with acridine orange (a nucleic acid stain) and observed with epifluorescence at high magnification. When so observed, the predominant particles are now individual or small clusters of bacteria.

Figures 6 and 7 are, respectively, light and scanning electron photomicrographs of various particles which were commonly observed in settled dust and air samples collected at the farms. In Figure 6, the round particles that contain yellow and blue segments are starch grains. The pale to dark brown particles are typically fungal spores and hyphae. In Figure 7, the predominant particles are spores and various botanical components. In the upper left photograph the ribbonlike structure is hypha and the large flat particle is probably a fragment of an arthropod.

Figure 8 shows the effect of treatment on airborne levels of culturable mesophilic fungi. On average there was a twelvefold decrease with treatment. The differences seen here, as well as the differences recorded for xerophilic fungi and total and gram-negative bacteria, were all statistically significant when examined by matched pair analysis ($p < 0.05$). Figure 9 provides a comparison between total and culturable bacteria for samples collected in barn 2 during wet and dry chopping. The total counts were done microscopically following an acridine orange stain. Levels of both total and culturable bacteria were reduced dramatically with the treatment. There was also a large (1 to 2 log order) difference between total and culturable bacteria levels under both wet and dry conditions, which indicates that a large proportion of the airborne bacteria in this barn was either nonviable or nonculturable on our media.

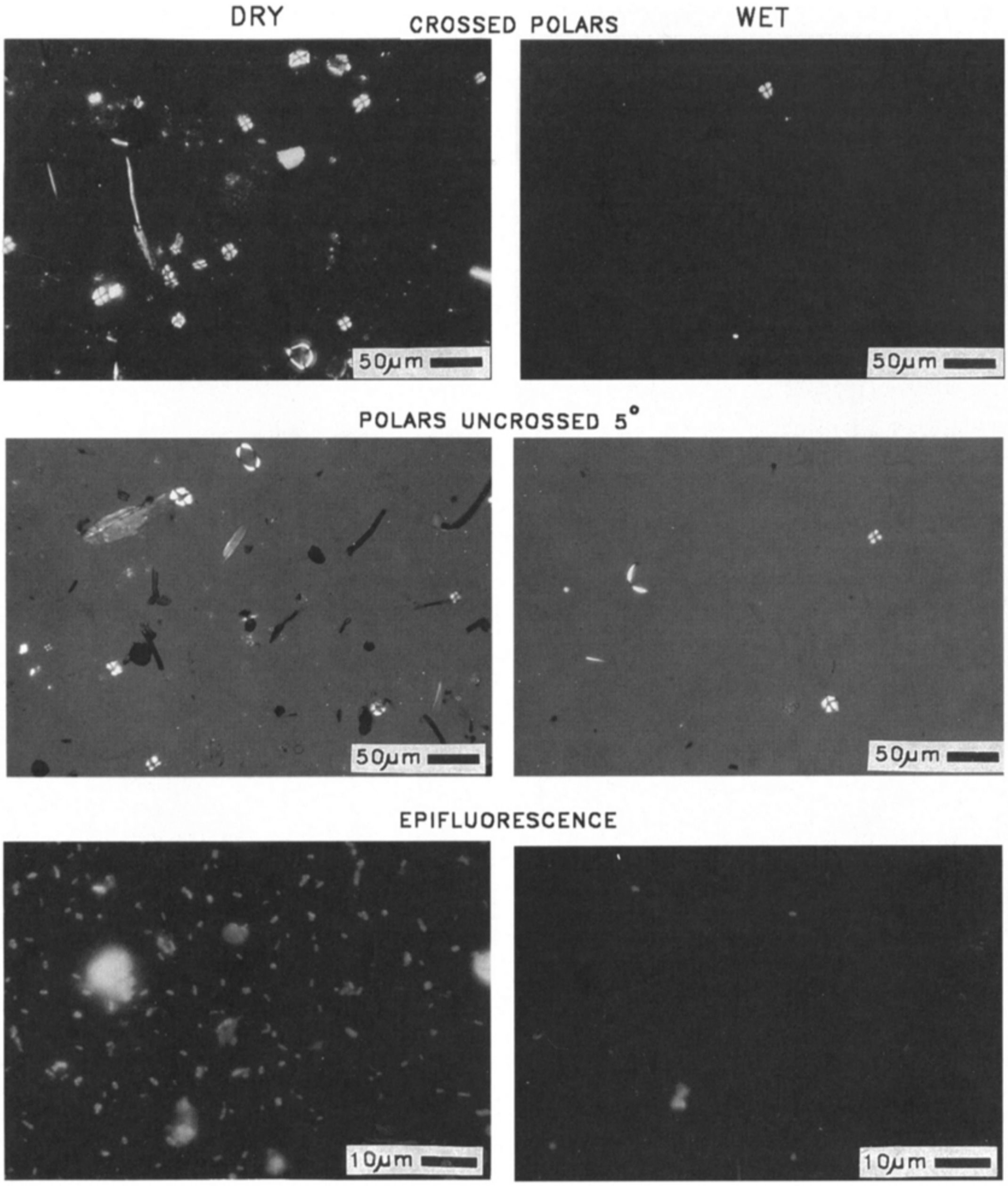

FIGURE 5. Effect of treatment on airborne dust levels as seen by light photomicrographs of matched pair samples (barn 2).

Figure 10 contains the direct reading and overall average carbon monoxide levels for seven barns. Although the differences between average carbon monoxide levels during dry and wet chopping were not statistically significant, in some of the barns there were higher peaks and more persistent exposure, particularly toward the end of the wet chopping operation. Note that the comparison between wet and dry chopping carbon monoxide levels is unavailable at barn 8 due to an instrument problem.

Discussion

What was obvious to the farmers has been confirmed with each of our measures of exposure. Applying water to the bales is a simple and effective method of dust reduction. Significant improvement of air quality was seen with measures of overall dust using gravimetric, photometric, and microscopic assays and with measures of specific dust components, including endotoxin, histamine, and various measures of microorganisms.

With regard to possible disadvantages, water is typically a problem for stored hay or straw. Material that gets wet at some point in harvest or storage is more likely to become spoiled due to increased growth of microorganisms. One might suggest, then, that adding water to the bales should be discouraged and may in fact make things worse. To that argument we offer some additional considerations. First, the used bedding material is cleaned out of the stalls each day so that there is limited time for increased microbial growth. Also, consider the general

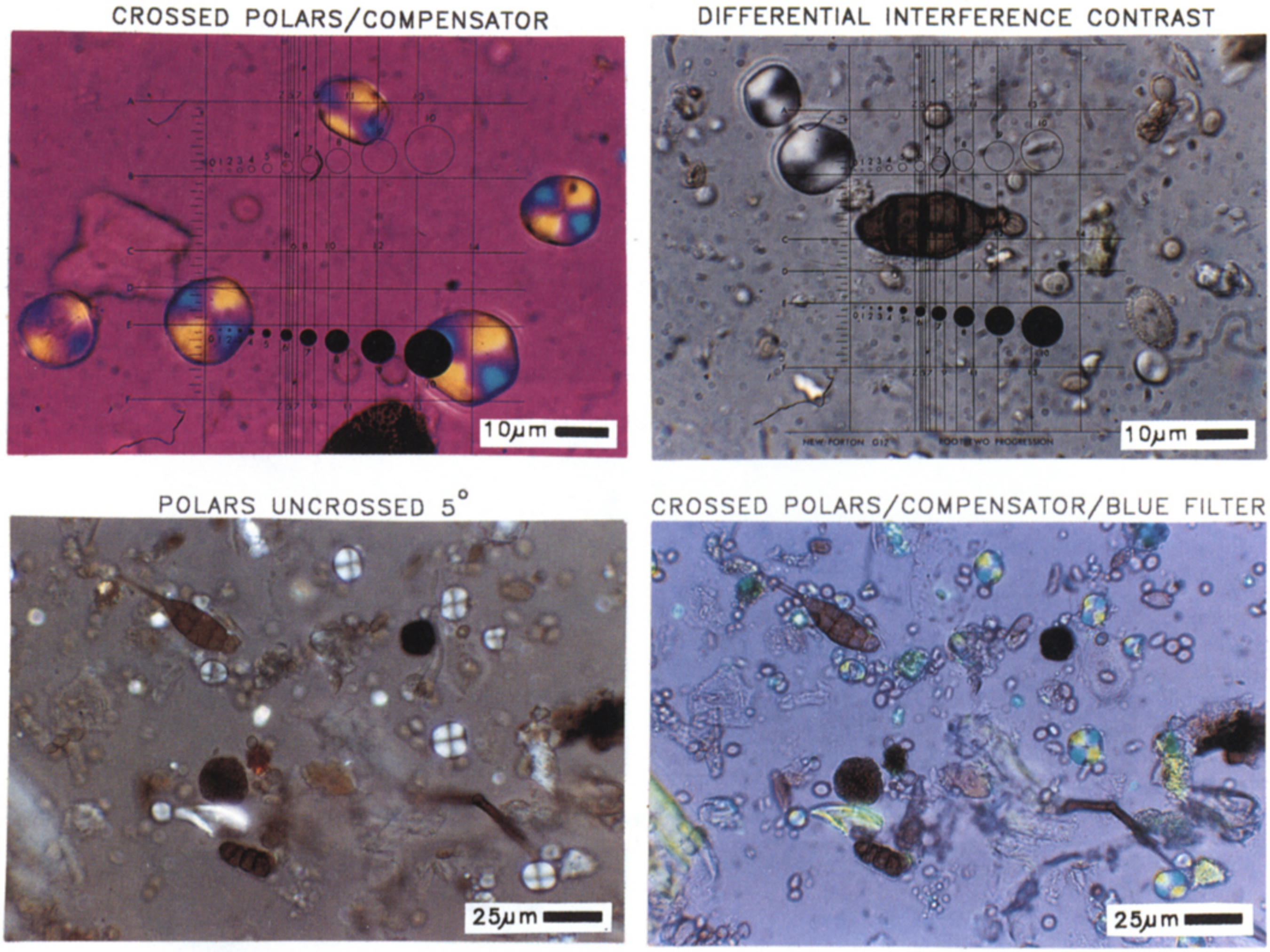

FIGURE 6. Photomicrographs of settled dust samples (barn 3).

dairy barn environment, with urine and feces flying about, along with animal watering systems that leak and spill even when well maintained. Given these conditions, the addition of small amounts of clean water is not considered a contributor to overall microbial contamination. In our opinion, though, water treatment can have a negative effect in that wet hay is harder to chop. Although only one farmer (barn 8) reported difficulty in chopping the water-treated hay, the moderately increased levels of carbon monoxide may be a more sensitive indicator that some of these machines were working harder (Figure 10). The chopper at barn 8 was an older machine. Perhaps the continued use of water control may require more frequent maintenance, particularly blade sharpening.

There is one additional note on the amount of water used: the local farmers had used between 1 and 2 pints per bale. For our study, we chose the highest volume to increase our chance of observing an effect. One quart was too much, as evidenced by small pools of water observed on the floor when the bales were lifted, indicating that at least a portion had drained completely through. It is suspected, then, that similar reductions in dust are achievable with smaller portions of water.

Since bedding chopping takes only 10 to 30 minutes a day, the 8-hour carbon monoxide time-weighted average exposure to the farmers is probably not a problem. The peak exposures are a concern, though. During both wet and dry chopping there were several peaks that were well above the Occupational Safety and Health Administration ceiling limit of 200 ppm. Our surveys were done during the winter, and during chopping the barns were typically closed. Most of the barns had large doors and windows, however, and it is recommended that they be opened up as much as possible during chopping throughout the seasons to help control both dust and carbon monoxide exposures. Electrically powered bedding choppers are available and may be a better overall solution.

Unfortunately, there is no air quality guideline specifically for organic dust with which to compare our measurements. Assuming that such a reference is needed, what would one measure? We believe that the agents that are typically measured in these sorts of environments are either too general (gravimetric assay) or too specific (endotoxin, histamine, bacteria, fungi, tannins, etc.). In our opinion, a simple, repeatable assay with specificity for the organic character of the dust somewhere in between these extremes is needed. Possibilities might include total protein, organic carbon, or organic nitro-

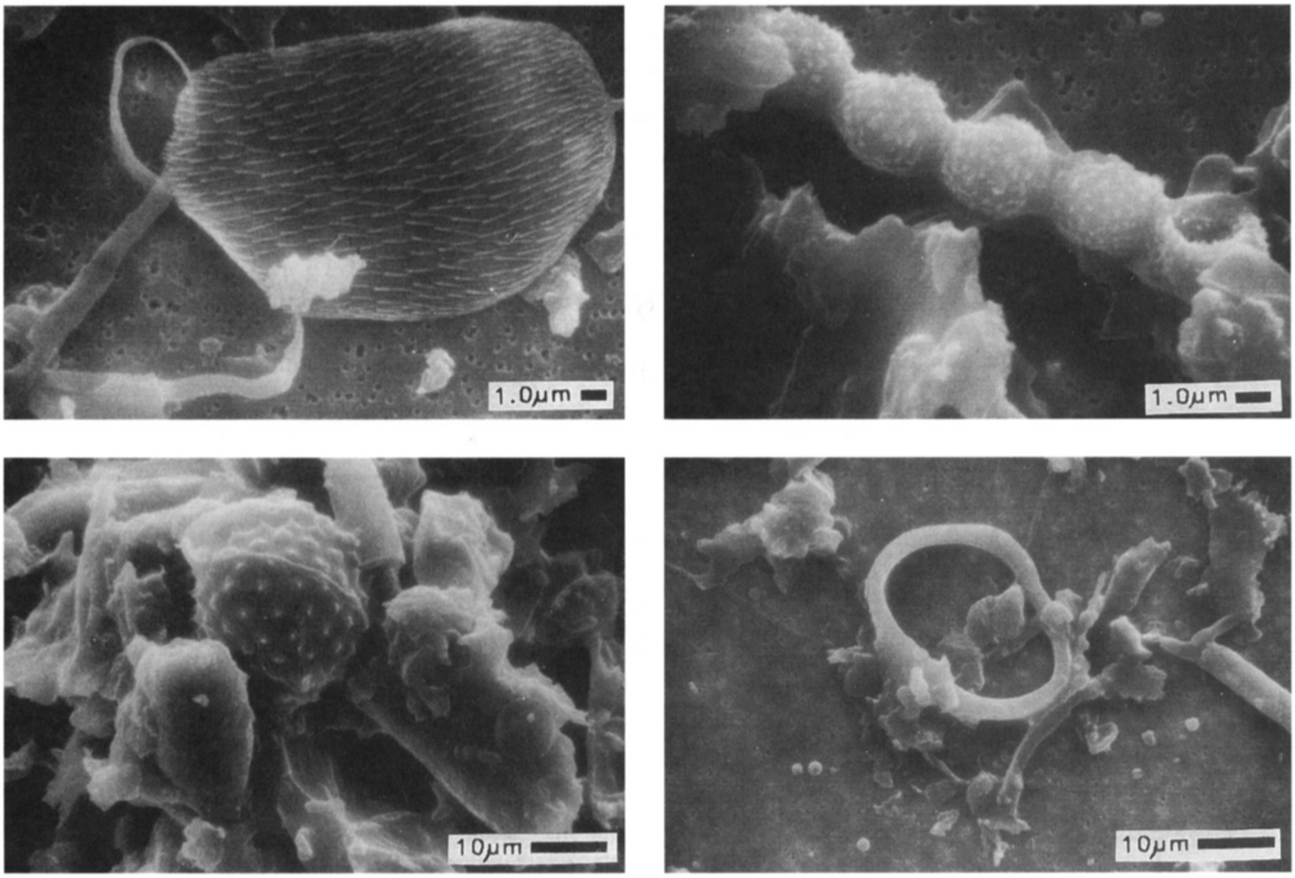

FIGURE 7. Scanning electron images of air samples collected in barns 3 and 6.

gen. Studies to determine sensitivities, as well as the relationship of such measures to health effects, should be pursued. There are, in fact, some studies that have investigated the links between the protein content of flour dust and asthmatic changes seen in bakery workers.[7,8] Any such assay should be considered not as to whether it is correct or incorrect, but rather as to whether it is more useful than the current alternative, namely nuisance dust. In any event, although the levels of dust and dust components were reduced dramatically, there were still measurable quantities of various contaminants during

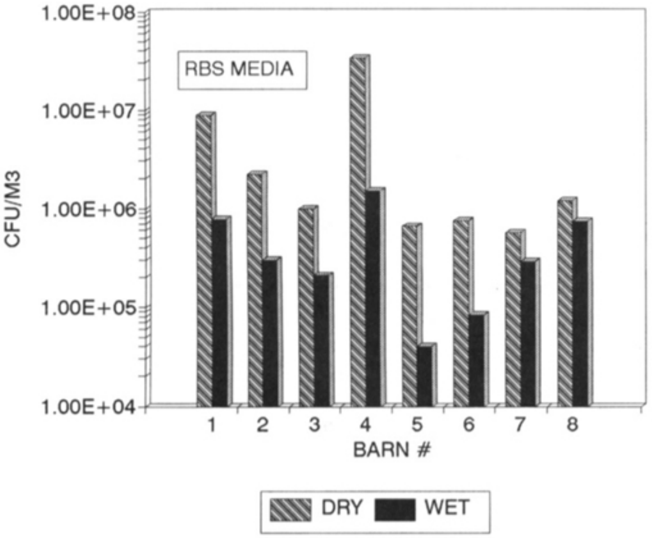

FIGURE 8. Effect of treatment on fungal levels.

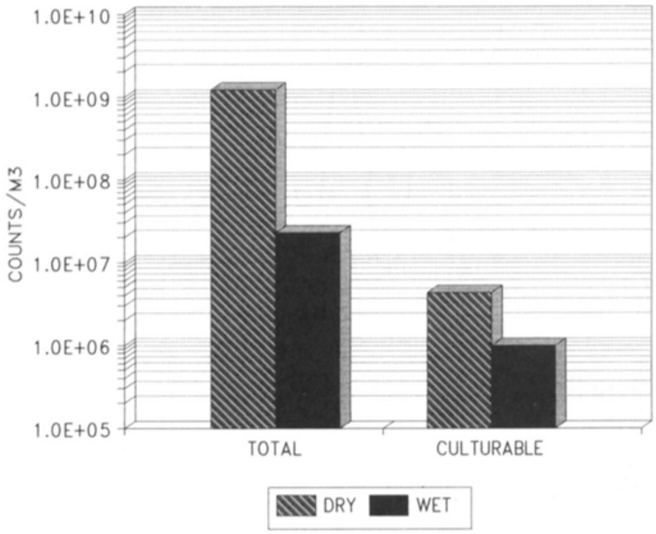

FIGURE 9. Total versus culturable bacteria counts (barn 2).

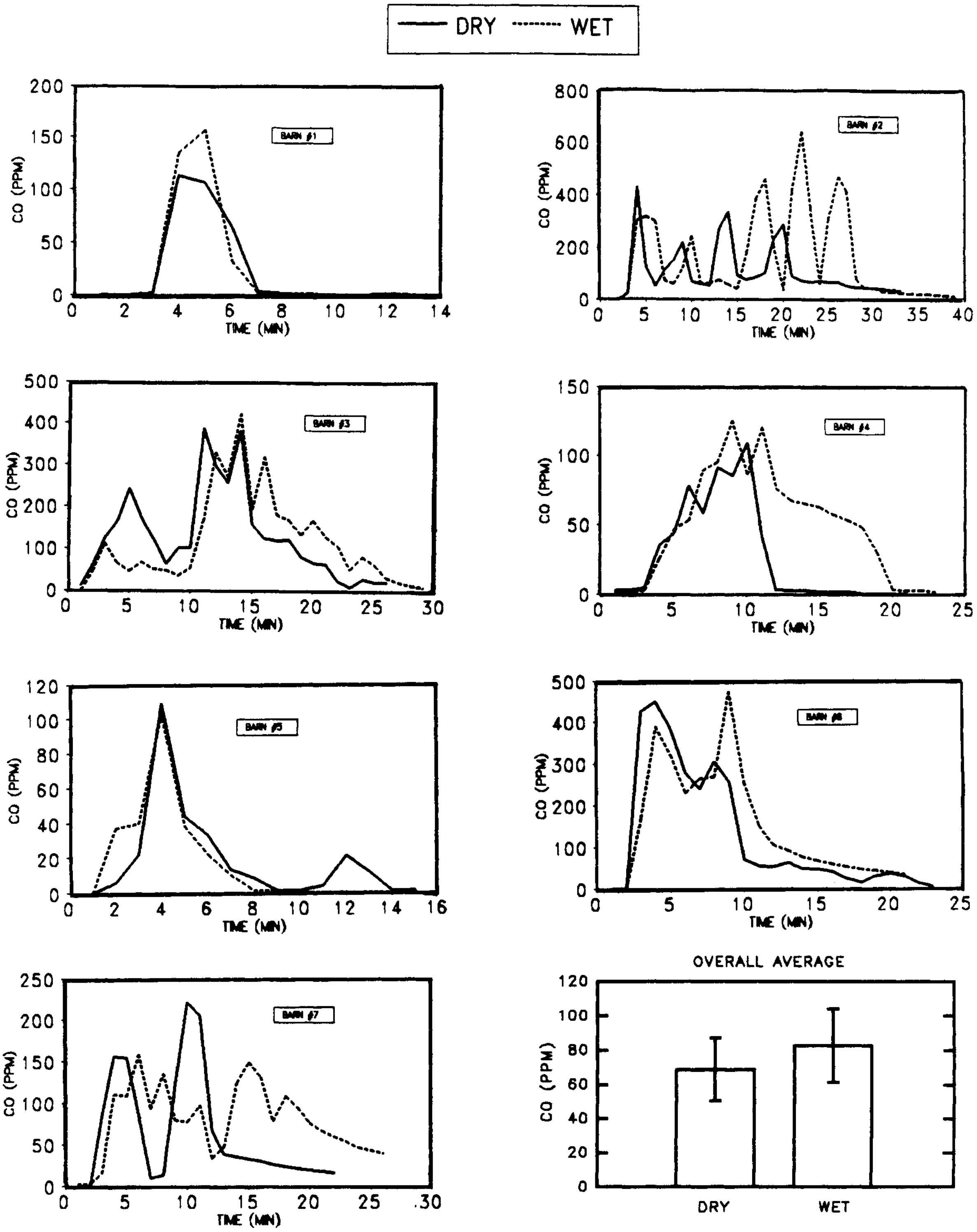

FIGURE 10. Carbon monoxide levels during bedding chopping.

wet chopping, and since there is no criterion for a safe level of exposure, further controls (respirators) may be needed, especially when chopping poor-quality hay.

A final issue is the interpretation of the photometric dust measurements. The readings obtained with this class of instrument are related to various physical features of the dust (absorptivity, refractive index, size, etc.). Therefore, if one is interested in dust level in an absolute sense, the best approach is to calibrate against a gravimetric reference at the sampling site, and preferably over some useful range of concentration. In

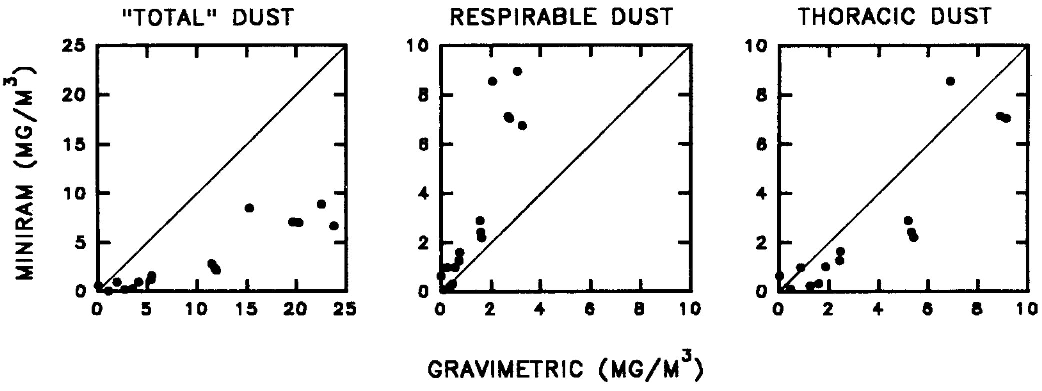

FIGURE 11. Comparison of Miniram measurements with various gravimetric measures of dust.

comparisons of measurements made in our lab of Miniram and gravimetric samplers with coal and cotton dust, we have observed that the Miniram tends to overestimate respirable dust and underestimate various measures of total dust. We wanted to explore the relationship more fully for the dairy barn dust in hopes that the relationship may be applied to organic dust in general and therefore may be of some use to those that may not have the ability to do the calibration themselves. Figure 11 shows the relationship of Miniram measurements to various estimates of gravimetric dust in the dairy barn environment. The respirable and thoracic mass estimates were made by first applying the size distribution data to the ideal respirable and thoracic particulate mass curves to estimate, respectively, the percent respirable and percent thoracic dust. These percentages were then applied to individual measures of total dust made within the barns.

The R squared value was 0.85, suggesting that the Miniram response was reasonably linear over the range of dust level studied. The Miniram tended to overestimate respirable mass by about a factor of 3 (slope = 2.7). Total dust was underestimated by a similar constant (slope = 0.36). A closer association was found, however, with the photometric measurements and our estimates of thoracic particulate mass (slope = 0.81). This may have some advantages in that the health effects seen with organic dusts seem to involve large as well as small airways.[9] The vertical elutriator used for cotton dust sampling also has a collection efficiency which is a reasonable approximation to the thoracic curve.[10] However, some studies have shown neutrophil recruitment to the nose in response to human exposure to organic dust,[3] which may argue that inhalable dust is the most appropriate size-selective sampling criterion for organic aerosols.

This analysis was based on our area measurements of total dust. Note, however, that the same trend was seen when the Miniram results were compared with our personal measures of total dust using a sampler with an inlet geometry similar to commercially available inhalable dust samplers.

Summary and Recommendations

The addition of 1 quart of water to the hay or straw bales prior to chopping has been shown to be an effective dust control technique. Measurements of dust, endotoxin, histamine, bacteria, fungi, and gross microscopic examination of air samples all show significant improvement in air quality. Although there was not a statistically significant difference in carbon monoxide associated with the treatment, levels during both wet and dry chopping were occasionally well above the ceiling value of 200 ppm, indicating the need for improved ventilation or an alternative power supply.

Although we recommend that Miniram readings be calibrated to some gravimetric reference at the sampling site, in the absence of this our data would suggest that these meters tend to respond closer to thoracic particulate mass than to respirable or total dust for organic particulate.

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