AP42 Section:	9.1
Related:	4
Title:	Letters and comments on unpublished 1995 draft report.

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MRI Memo

To: Tom Lapp

From: Chat Cowherd

Date: March 26, 1997

Subject: Comment/Response Log for the Wayne Coates Report

Attached is my comment/response log for the report, "AP-42 Emission Factor Equation for Tilling Operations: Critique and Recommendations," by Wayne Coates of the University of Arizona. Hopefully this log should provide the basis for EPA's response to his report within the context of finalizing the draft revision to the AP-42 section on agricultural tilling. Without the detailed data that even he admits is needed for independent review, it is impossible to determine why his measured TSP emission factors for agricultural tilling are generally lower than AP-42 predictions. There are at least two possible contributing factors:

1. His plume profiling procedure does not account for the full extent of the dust plume.

2. The operations that he tested disturb the soil less than the baseline operations associated with conventional tilling, as used in developing the current AP-42 emission factor equation.

I look forward to discussing these issues with you and Dallas.

COMMENT/RESPONSE LOG for
"AP-42 Emission Factor Equation for Tilling Operations: Critique and Recommendations"
by Wayne Coates, University of Arizona

Comment	Response
This report summarizes the problems that appear to exist with the development of the current AP-42 equation by Midwest Research Institute (MRI). Available documentation indicates that errors were made when the equation was developed. The resultant inaccuracies, combined with other discrepancies in two relevant MRI reports, indicate that the AP-42 equation cannot accurately predict emissions from tilling operations.	These general comments are best addressed in terms of responses to the specific comments given below.
Only Total Suspended Particulates (TSP), and not PM-10 or any other size range is discussed, since the current AP-42 equation has been given an "A" rating if used to estimate total particulate emissions but only a "B" rating if used to estimate emissions for a specific particle range. Thus additional inaccuracies exist for the other particle sizes, as has been acknowledged by MRI.	As stated in the proposed AP-42 section, the "B" rating applies to use of the emission factor equation for a specific particle size range.
This report does not question the validity of MRI's measurement processes from a technical standpoint, that is in terms of positioning of the collection devices, taking of samples, meteorological conditions that existed during the tests, etc. Rather, this discussion assumes that MRI's technical expertise in this area is adequate for the tasks performed.	No response is needed.

Comment	Response
Table 1 summarizes the data that were used to generate the current AP-42 emission factor equation for tilling operations, and presents any other pertinent information, all of which is extracted from the two MRI reports (MRI 1974, 1981). Based on several discrepancies found within and between the two reports, the accuracy of these two reports is in question. For example: - depth information for soil moisture content is inconsistent within the 1974 report - width of implements listed in the 1981 report varies from one section to another - silt content values given for the 1974 data are different in the two reports - soil samples taken in 1981 were "several shovelfuls" vs. plugs in 1974	- On page 51 of the 1974 report, it states that core samples of 4 in. and 6 in. depths were obtained so that moisture content as a function of depth could be analyzed (see Table 17 on page 61 of the report). - As stated in Table 11 (page 51) of the 1981 report, the width of implements for all but one of the thirteen exposure profiling tests was 4.9 m (16 ft); the width of the other implement was 6.4 m (21 ft). - In the 1981 report, silt content based on dry sieving was used as the measure of soil "dustiness," to be consistent with the other emission factor equations for fugitive dust sources. Thus, it was necessary to develop estimates of dry silt content (<200 mesh) for the agricultural tilling tests contained in the 1974 report, which originally used the conventional wet soil texture analysis. - On page 45 of the 1981 report, it states that "shovelfuls of soil collected to a depth of approximately 15 cm (6 in.) were composited for analysis. For disturbed soil, the texture of the soil is probably not very sensitive to depth in the 4 in. to 6 in. range.

Comment	Response
Also from Table 1 it can be seen that a limited number of implements (4 in total) were used in the test programs, hence extrapolation of the data to implements in general is questionable. Furthermore, a limited number of sites were used in the test program (6 in total). This further brings into question the validity of using the data to predict tilling emissions over a broad range of conditions. Another significant concern is that part of the California data was collected using a tracked tractor, while a wheeled tractor was used at the second site. This could have influenced the emissions, but does not appear to have been taken into account.	While more test sites and implements are always desirable, the statistical results in the 1981 report showed that a single emission factor model for dust emissions from tilling operations is viable as a predictive tool for emission inventorying purposes. Also, because most dust is generated by the tilling implement, the effect of a tracked vehicle is expected to be minor.

Comment	Response
Because the AP-42 equation was developed by MRI from measured silt and TSP data which are contained in the 1981 report, this author performed a regression analysis to develop two equations from the data in the 1981 report. This analysis was undertaken to verify that the data presented in the 1981 report were what had been used to develop the AP-42 equation and to determine if a linear equation could represent the data equally as well as a log-log equation. The two equations are: TSP (lb/ac) = 8.04 + 0.77*silt content (%) $R^2 = 0.77$ *the linear equation* TSP (lb/ac) = 4.65*silt content (%)$^{0.59}$ $R^2 = 0.92$ *the log-log equation* Note that the log-log equation is very similar to the AP-42 equation: TSP (lb/ac) = 4.80*silt content (%)$^{0.60}$ $R^2 = 0.94$ It is unclear why the log-log equation developed by this author from the data in the MRI report does not completely agree with the AP-42 equation. A possibility could be rounding of the numbers provided in the report. Figure 1 presents a plot of the raw data from the MRI report, as well as the three regression equations referred to above.	The commenter has closely reproduced the regression equation in the 1981 report. There is a 3% difference in the coefficient. [We could repeat the analysis to check for this small difference.]

Comment	Response
The greatest area of concern relates to the Kansas data. The silt values used for the Kansas data are the sum of silt and clay as determined using the Buoyocous hydrometer method. This method of analysis is routinely used to determine soil texture but is not the EPA approved method to be used for determining silt content for the AP-42 equation. Using the textural classification procedure assumes that no conglomeration of the soil existed. This is highly unlikely, particularly for the clay fraction. Given the data presented in the 1974 and 1981 reports, it is not possible to arrive at a correct value for silt content, as this is to be determined by mechanically sieving soil samples, with the fractions smaller than 200 mesh (75 μm) being the silt content. Thus the Kansas data should not be used in the regression. If the Kansas data are excluded, the AP-42 equation becomes: TSP (lb/ac) = 8.66 + 0.66*silt content (%) $R^2 = 0.78$ *the linear equation* TSP (lb/ac) = 5.51*silt content (%)$^{0.48}$ $R^2 = 0.84$ *the log-log equation* The range of silt contents over which these equations are valid is the range for which there is data (i.e., 1.7 to 24.7 percent), not 1.7 to 88 percent as is the case for the current AP-42 equation. Figure 2 presents plots of the raw data and the two equations, along with the AP-42 equation. Clearly, the current AP-42 equation over predicts emissions.	As stated in a response to an earlier comment, the dry silt content (<75 μm) has traditionally been used as the most appropriate measure of soil dustiness. The only exception was agricultural tilling in the original (1974) report. For purposes of combining the Kansas and California data sets in the 1981 report, the agricultural silt values in the 1974 report were converted to equivalent dry silt values, by taking the 0-75 μm fraction from Figure 14 (page 62) of the 1974 report. [Note that the vertical scale in Figure 14 should be shifted by a factor of 10; for example, 0.01 mm becomes 0.001 mm]. Combining the Kansas and California data sets adds to the credibility of the predictive emission factor model for agricultural tilling. With regard to Figure 2, it is not surprising that the best fit equation for only the California data is different from the best fit equation for the combined data set.

Comment	Response
Using only the California data poses additional problems since the data now really can be represented by two groupings of data in terms of soil silt content, one centered at approximately 3 percent the other at 20 percent. This does not provide a sound basis on which to develop a regression equation.	This is exactly the rationale for combining the California data with the Kansas data.
If the Kansas data are excluded from the analysis process, another very important factor comes into play. That is, the remaining data show a strong correlation between moisture content and tilling emissions. The equation is: TSP (lb/ac) = 28.31 - 1.48*moisture content (%) $R^2 = 0.89$ *a linear equation* A plot of these data are shown in Figure 3 along with the regression equation. This finding is contrary to what is stated by MRI for the current AP-42 emission factor equation, that is moisture content had no relationship to emissions (MRI, 1981). This further demonstrates that the data from Kansas should not have been used for development of the equation, and that the equation should be revised to include both silt content (as determined by the approved EPA method) and moisture content as variables. Since speed of operation was not listed for the California data it is not possible to say whether or not a similar situation exists, that is if speed of operation also is strongly correlated with emissions.	Except for the California data set collected from the alfalfa fields, the moisture content for the rest of the tests in the combined data set fit a relatively tight range. This probably explains why no significant correlation of emissions with moisture content was found in the combined data set. The more limited data set addressed by the commenter (California data only) provides a much stronger moisture variation, which is correlated with emissions. However, the relationship based on California data only (as the commenter has already pointed out) is very restricted in its applicability..

Comment	Response
Figure 4 presents a plot of MRI's California data (MRI, 1981), plus additional California data (Flocchini, 1994) and the two extreme data points in terms of emissions that were determined from Arizona trials (Coates, 1996)., Clearly there is a significant discrepancy between 1981 data, and recent tests by other researchers. If all of the Arizona data were plotted on Figure 4, they would show that for a silt content of approximately 5 percent, a large range in emissions were recorded, varying from 0.6 to 32 lb/ac. Such data indicate that different implements generate different amounts of emissions, and hence one equation cannot be used for all implements. In the case of the 1994 California data, each data point represents 3 tests for each implement, but the data have been discounted by MRI (MRI, 1995), while the Arizona data represents 15 passes, the Arizona data clearly are equivalent to MRI's data and should not be ignored, as MRI has chosen to do.	When considering the level of agreement between any new measured emission factors and the predictions of the AP-42 equation, enough detail in each respective test report must be presented so that the reliability of the measured emission factors can be evaluated independently. Such was not the case for the Flocchini (1994) report, for reasons stated in the draft AP-42 background document. Nonetheless, except for two tilling operations of a less intensive nature, there is very good agreement with AP-42. Even the stubble discing and chiseling operations are within a factor of 3 agreement with AP-42. Again, the purpose of AP-42 is to provide estimating tools for emission inventorying purposes so that, on average, reliable area-wide emission estimates can be determined. With regard to the Arizona data (Coates, 1996), Table 5 of his report shows agreement with AP-42, within a factor of about two. It is not unexpected that the reduced tillage systems tested in Arizona would be over predicted by AP-42. One of the challenges of agricultural emission inventorying is to scale various lower energy operations to conventional tillage as a reference level for which AP-42 is most applicable. Finally, with regard to the Arizona results (Coates, 1996), more detail is needed on the calculation scheme for generating the emission factors from the raw field data. For example, no information is provided on the point values of particulate concentration (or flux) across the sampling array. Of critical importance is the demonstration that all of the plume mass is accounted for, especially in situations when crosswinds are encountered. In principle, the plume profiling strategy used in Arizona appears valid, if these situations can be dealt with.

Comment	Response
1. Based on the information presented in this report, the current AP-42 equation should be withdrawn.	1. The current equation retains its usefulness for predicting conventional tilling operations which impart high disturbance to the soil. As with any AP-42 emission factor, revisions should be made, as necessary, whenever new data with sufficient documentation are added to the database.
2. All of the raw data that were used to generate the equation should be made available to an independent organization. These data should be reanalyzed to determine whether or not additional problems exist, that could not be examined given the limited amount of information contained in the reports.	2. This comment is entirely appropriate, as long as the independent organization is fully experienced in relevant field activities.
3. Additional tests need to be performed over a far broader range of field conditions and implement types, to arrive at a more accurate emission factor equation. The revised equation should also incorporate moisture and implement speed, along with silt content, or show cause for exclusion.	3. This comment is also entirely appropriate. Any time new data can be added to the database, regression analysis should again consider all relevant source conditions as potential correction parameters for any updated emission factor equation.

Rec'd 2/15/96
gtd

ARIZONA DEPARTMENT OF ENVIRONMENTAL QUALITY

Fife Symington, Governor Russell F. Rhoades, Director

AQD:AAS:1171

January 26, 1996

Mr. Dallas W. Safriet
Environmental Engineer
Emission Factor and Inventory Group
Office of Air Quality Planning and Standards
Mail Drop 14
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

Dear Dallas:

RE: Cotton Tillage/Quantification of Particulate Emissions
Final Report: 1991-1994 Trials

During the past year we have sent you a copy of the above report produced by the University of Arizona for the Arizona Department of Environmental Quality. Recently, some errors in calculations were identified and corrected in several pages of the report. I am sending eight pages to replace in your copy (pages 3, 4, 12, 13, 14, 15, 16 and 17) and one additional page (17a). There are no corrections for the appendices. Please call me at (602) 207-2353 if you have questions about these corrections.

Sincerely,

Kathy Stevens
Air Quality Analyst

KDS:rcb

Attachments

LOCATION OF TRIALS

The test site was located at the University of Arizona's Yuma Valley Agricultural Center. The field selected for the trials had been planted to cotton the year prior to commencement of the test program, and thus all of the first year's operations took place in a field which had been prepared the previous season using conventional cotton tillage practices. The field was laid out in a randomized complete block design, with five replicates. This design facilitated statistical analysis of the data, and precluded field variation from confounding the results.

A second site, for which data was obtained for one season, was located approximately 25 miles northwest of Tucson, at the University of Arizona's Marana Agricultural Center. Tests were conducted using two fields: D1, the site of a tillage study which took place from 1986 through 1994, and A4, a control field which had been planted to cotton using conventional tillage practices. The results of the Marana study were send to ADEQ in November 1992. The Marana study is mentioned here only to bring it to the attention of the reader, and to lay groundwork for some of the comparisons which will be made in this report.

A standard soil analysis of the Yuma field indicated that the top three inches of soil was comprised of 17% sand, 53% silt and 30% clay. The values for Marana fields D1 and A4 were 28, 40 and 32%, and 34, 35 and 31%, respectively. Using the EPA classification to define silt content, that is particles less than 200 mesh (74 Um), the three fields would contain 83, 72 and 66 percent silt, respectively.

If the EPA values are input into the AP-42 emission factor equation shown below, and the particulates predicted to be emitted by each tillage operation are calculated, the emissions shown in Table 2 would be expected:

$$E = k(4.80)S^{0.6} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Table 2. Particulate Generation Predicted using the AP-42 Emission Factor Equation and Assuming that all Soil Particulates Less Than 200 Mesh were not Conglomerated.

Field	Total Particulates (lb/ac)	PM_{10} (lb/ac)
Yuma	68.0	14
D1	62.5	13
A4	59.3	12

These figures assume that all of the silt and clay particles are in a free state, and are not conglomerated in any manner. Most certainly this would not be the case, and emissions should therefore be much less. The extent of conglomeration that existed would depend upon the soil breakup that had taken place prior to the operation, as well as the moisture content.

In an attempt to obtain representative values that would be predicted by AP-42 for each of the test fields, soil samples were taken in the fall/winter of 1994-95. These samples were obtained after a number of conventional tillage operations had taken place, and would represent a typical amount of soil breakup. The soil samples were analyzed using EPA accepted procedures to determine silt content. The mean values for the Yuma, D1 and A4 fields were 5.0, 3.9 and 5.3, respectively. These were substituted into equation (1), and the emissions calculated. The results are given in Table 3.

Table 3. Particulate Generation Predicted from the AP-42 Emission Factor Equation using the Silt Percentages Obtained from the Fields Following several Tillage Operations.

Field	% Silt	Total Particulates (lb/ac)	PM_{10} (lb/ac)
Yuma	4.98	12.6	2.64
D1	3.90	10.9	2.28
A4	5.28	13.0	2.73

The total particulate values listed above are used later in this report in the comparison with the measured values.

PROBLEMS ENCOUNTERED

Agriculture is dependent on many factors, among them weather and pests. This project has been affected by both of these variables to some extent. The most notable problem has been vertacilium wilt. This disease increased with time, reducing yields and the portion of the field which could be considered representative of a commercial operation. The presence of a severe whitefly infestation during the first year of the study also reduced yields. This was not an uncommon situation in the Yuma valley that year, however.

Similar problems with vertacilium wilt were encountered in the Marana plots. This problem, and how it was dealt with, was discussed in the 1992 report.

EQUIPMENT AND PROCEDURES

The test equipment and field procedures described in the 1990 report were used for the Yuma trials. As a consequence, they are not described here.

RESULTS

The data in Table 4 show that average wind velocities during each run were below the 8 mph value which had been set as the upper limit for the trials, except during ripping of the conventional plots during the third year.

Peak velocities exceeded 8 mph in a few cases. This was thought not to be a significant problem since infrequent gusts of short duration would have little influence on the overall results. During the trials every attempt was made to ensure that implement travel direction relative to wind direction was constant to prevent this from confounding the results.

Table 9. Predicted and Measured Tillage Emissions for Yuma.

System	Number of Operations	Emissions (lb/ac) Predicted	Measured*	Ratio Pred/Meas
Sundance	4	50.4	60	0.84
Conventional	7	87.5	36	2.43
Mod Conventional	4	50.4	32	1.57
USM	3	37.5	23	1.63
Puller	4	50.4	20	2.52

* average value for the three year test program

Based on the results shown in Table 9 it can be seen that the AP-42 emission equation overpredicted emissions, on average, by two times the measured values, except in the case of the Sundance system. This difference is significant, and indicates that the equation is inaccurate for predicting emissions in the conditions tested. Since these conditions are representative of most Arizona cotton tillage operations, it can be assumed that the equation is inaccurate for Arizona and should not be used to predict emissions.

Table 10. Predicted and Measured Tillage Emissions for Marana.

System	Number of Operations	Field	Emissions (lb/ac) Predicted	Measured	Ratio Pred/Meas
Sundance	3*	D1	32.7*	74*	0.44
Conventional	7	D1	76.3	86	0.88
USM	3	D1	32.7	71	0.46
Sundance	4	A4	52.0	105**	0.49
Conventional	7	A4	91.0	117	0.78
USM	3	A4	39.0	88	0.44

* Does not include the uprooting operation as no data were obtained in the field

** Uprooting done under very wet field conditions, thus minimal emissions generated

From Table 10 one can note that for this location the AP-42 emission factor equation does not over predict tillage emissions, rather it underpredicts emissions. Further examination of the data showed that two of the operations varied significantly in terms of measured emissions between the two locations. These operations were shredding and mulching.

The shredder used at Marana was a different design, and inherently produces more dust than does the type used at Yuma. Secondly, the soil moisture content was much greater at Yuma than at Marana when the mulching operation took place. This clearly reduced emissions at Yuma. If the measured values for the two operations obtained at Yuma are substituted in for the Marana data, Table 10 can be revised as follows.

Table 10(revised). Predicted and Measured Tillage Emissions for Marana.

System	Number of Operations	Field	Emissions (lb/ac) Predicted	Measured	Ratio Pred/Meas
Sundance	3*	D1	32.7*	28*	1.18
Conventional	7	D1	76.3	29	2.63
USM	3	D1	32.7	24	1.31
Sundance	4	A4	52.0	32**	1.62
Conventional	7	A4	91.0	41	2.21
USM	3	A4	39.0	24	1.62

* Does not include the uprooting operation since no data were obtained in the field

** Uprooting done under very wet field conditions, thus minimal emissions generated

From revised Table 10 it can be seen that the ratios of predicted to measured emissions now agree with those calculated for Yuma, except for the Sundance system. The Marana data indicate that the AP-42 emission factor equation even overpredicts emissions for the Sundance system. Thus simply changing implements, or changing the time when an operation is performed, in essence changing the moisture content of the soil, can have profound effects on the amount of emissions generated.

Clearly the AP-42 equation is not appropriate for predicting emissions for the field conditions and/or implements tested during the study. Since these conditions are fairly typical of those found in Arizona, it brings into question whether this equation should be used when conducting an emissions inventory for the agricultural tillage operations commonly used in Arizona.

OTHER BENEFITS OF REDUCED TILLAGE SYSTEMS

Although reduction in particulate generation is in itself worthwhile, it is uncertain that farmers will adopt these tillage practices for this reason alone. Rather, realization of an economic benefit by growers will probably be needed to promote statewide adoption of reduced tillage systems.

Tests have been underway at the University of Arizona's Marana Agricultural Center to provide such information. Energy required by two reduced tillage systems and a conventional system, as well as field operating times required by each were recorded over six seasons. The data are summarized in Tables 11 and 12. Table 11 lists the mean energy required by each system and presents the total energy required by each system for each year that the test was conducted. Table 12 presents the time required to prepare an acre from harvest to planting for each system, and allows a comparison among systems to be made.

Cotton lint yields for the trials are presented in Table 13. A common question raised by growers is whether or not adopting minimum tillage systems will reduce yield. Many are convinced that yields will be reduced. From Table 13 it can be seen that this is not the case. Yields are statistically the same, regardless of the tillage system.

Similar results are available from the Yuma studies. These are presented in tables 14 and 15 for the energy and yield data, respectively.

Table 11. Mean tillage energy requirements (HP-HR/AC) of conventional, Uprooter-Shredder-Mulcher (USM), and Sundance tillage systems at the Marana Agricultural Center, 1987-94.

	1987-88	1988-89	1989-90	1990-91	1992-93	1993-94	6-Year Average	% of Conv.
Conventional	68.30 a*	69.95 a*	75.05 a*	55.11 a*	66.42 a*	66.52 a*	66.89 a*	100
USM	57.26 b	45.04 b	43.44 b	40.33 b	43.97 b	44.93 b	47.16 b	71
Sundance	30.76 c	34.02 c	32.46 c	22.81**c	30.35 c	25.20 c	31.95 c	48

*Means followed by the same letter within a column are not significantly different at the 0.05 level.
**Does not include the energy requirement of the uprooting operation, which was performed in the mud that year.

Table 12. Mean field work time (Hrs/Ac) to plow down cotton and prepare a seedbed for a subsequent cotton crop with conventional, Uprooter-Shredder-Mulcher (USM) and Sundance tillage systems at the Marana Agricultural Center, 1987-94. These data are not adjusted for field efficiency.

	1987-88	1988-89	1989-90	1990-91	1992-93	1993-94	6-Year Average	% of Conv.
Conventional	1.47 a*	1.44 a*	1.65 a*	1.37 a*	1.45 a*	1.57 a*	1.49 a*	100
USM	1.08 c	0.79 c	0.72 c	0.85 b	0.97 b	0.82 b	0.87 b	58
Sundance	1.15 b	0.89 b	0.82 b	0.77**c	0.92 c	0.65 c	0.87 b	58

*Means followed by the same letter within a column are not significantly different at the 0.05 level.
**Does not include the time requirement for the uprooting operation, which was performed in the mud that year.

Table 13. Lint yields (Lbs/Ac) with Conventional, Uprooter-Shredder-Mulcher (USM), and Sundance tillage systems at the Marana Agricultural Center, 1988-1993.

	1988	1989	1990	1992	1993	5-Year Average
Conventional	778 a*	929 a*	325 b*	601 a*	1108 a*	749 a*
USM	730 a	1030 a	367 ab	597 a	1059 a	757 a
Sundance	888 a	969 a	433 a	623 a	1054 a	794 a

*Means followed by the same letter within a column are not significantly different at the 0.05 level.

Table 14. Mean tillage energy requirements (HP-HR/AC) of the conventional, USM, Sundance, modified conventional, and puller tillage systems at the Yuma Agricultural Center, 1991-94.

	1991-92	1992-93	1993-94	3 Year Average	% of Conv.
Conventional	51.51 a*	64.44 a*	72.27 a*	67.21 a•	100
USM	49.53 a	49.79 b	44.76 b	48.02 b	71
Sundance	28.71 b	29.59 c	30.68 c	29.86 cd	44
Mod. Conventional	31.48 b	32.26 c	33.13 c	32.03 c	48
Puller	22.82 b	28.25 c	25.80 d	25.63 d	38

*Means followed by the same letter within a column are not significantly different at the 0.05 level.

Table 15. Seed Cotton yields (Lbs/Ac) with the requirements of the conventional, USM Sundance, modified conventional, and puller tillage systems at the Yuma Agricultural Center, 1992-94.

	1992	1993	1994	3 Year Average
Conventional	2049	3387	2332	2563
USM	2451	3546	3510	3169
Sundance	2413	3299	3006	2906
Mod. Conventional	2222	3297	2473	2664
Puller	2296	3792	2695	2927

CONCLUSIONS

1. In general, higher particulate generation was observed in the Marana plots than the Yuma plots. This is the reverse of what would be expected, given the silt content of the soils and the AP-42 emission factor model.
2. The Sundance system at Yuma produced consistently more particulates than did any of the other systems. At Marana this was not the case, with no statistically significant differences among systems recorded.
3. The puller system produced significantly fewer particulates than did the conventional system, and generated approximately half of the particulates of the conventional system.
4. The USM system produced approximately 65% of the particulates of the conventional system, with statistical differences being noted for only one year. Total particulates generated during the three year study was significantly less for the USM system, than the conventional.
5. No consistent trends with respect to particulate generation, as influenced by implement speed and soil moisture content, were detected over the range of variables studied.
6. A comparison of measured emissions to predicted values showed the latter to generally over predict emissions, with the range being anywhere from 1.5 to 2.5 times the measured values.
7. Energy required by the reduced tillage systems was significantly less than the conventional system. This translates into an economic advantage for these systems.
8. Yield was not significantly different among systems.

RECOMMENDATIONS FOR FURTHER WORK

Although these studies have provided some information relative to the particulate reduction that can be brought about by alternative tillage systems, additional work is required. The information gained during the studies indicates that a wide range of particulate generation exists among implements, and hence a judicious choice of implements can reduce particulate generation.

One area of study that could be undertaken is the evaluation of systems made up of other combinations of implements, or the evaluation of new implements that are currently under development. An example of a new implement, called Pegasus, appears to hold significant potential for reducing particulate generation. This one pass plowdown system appears worthy of evaluation in terms of reducing particulate generation.

Another area that appears worthy of study is development of methods which suppress particulate emissions during implement operation. The most straight forward, and the one which does not require additional components, is tillage of soil at higher moisture contents than is normally practiced. The problem with this approach, however, is that higher soil moisture content can increase compaction.

A more complicated and expensive process which could be used to reduce particulates during implement operation is the addition of devices to accomplish just that. Two systems which merit investigation are water misting, and electrostatic precipitation. One which could possibly work, but which would require significantly more development, is the use of a filter system to remove soil particulates from the dust plume generated by an implement.

Another task that should be undertaken is combining PM_{10} sampling equipment with the TSP procedures developed for this study. Although estimates of PM_{10} levels can be obtained from the TSP values, they are only estimates. Installation of appropriate PM_{10} sampling equipment upwind, and at

several locations downwind from the tillage operation would yield valuable information on particulate fallout and PM_{10} emissions from tillage operations.

Extending the study to other operations involved in cotton farming, particularly harvesting, would also appear to be warranted since this operation is inherently dusty. Similarly, dusty farming operations such as landplaning and combining, should be studied to determine their particulate generation. Perhaps these operations, rather than tillage operations, are responsible for the majority of particulates produced by current farming operations.

Cotton Tillage ISA
Contract #2283-0000-4-6-CW-9056

COTTON TILLAGE/QUANTIFICATION OF PARTICULATE EMISSIONS

FINAL REPORT: 1991-94 trials

submitted to

Arizona Department of Environmental Quality
Air Assessment Division, Office of Air Quality

by

Wayne Coates, Professor
Office of Arid Lands Studies
The University of Arizona
Tucson, Arizona
85721

INTRODUCTION

The purpose of the study was to quantify the amount of particulate matter generated by the agricultural field operations which comprise five cotton tillage systems. Three systems under study at the University of Arizona since 1986 were included in the test program. These are the conventional, the Sundance and the Uprooter-Shredder-Mulcher(USM) systems. The latter two are categorized as reduced tillage systems, and as such are thought to generate fewer particulates than conventional tillage systems. In addition, two other reduced tillage systems were included in the trials. These have been identified as the puller system, and the modified conventional system. A list of operations which comprise each of the five systems is provided in Table 1.

Table 1. Field operations which comprise each tillage system, and the implements used for each.

SYSTEM	OPERATION	IMPLEMENT
Conventional	Shred stalks	Rotary Shredder
	First disking	Tandem Disk
	Rip diagonally	Ripper (subsoiler)
	Second disking	Tandem Disk
	Disk herbicide	Tandem Disk
	List	Lister
	Mulch	Power Mulcher
Sundance	Shred stalks	Rotary Shredder
	Uproot (pull) stalks	Sundance Uprooter
	Rip/list	Sundance Disk
	Mulch	Power Mulcher
USM	Uproot/shred/bury	USM
	Rip/list	Rip/lister
	Mulch	Power Mulcher
Modified Conventional	Shred stalks	Rotary Shredder
	Disk	Tandem Disk
	Rip/list	Sundance Disk
	Mulch	Power Mulcher
Puller	Pull stalks	Prototype Puller
	Collect stalks	Large Round Baler*
	Rip/list	Sundance Disk
	Mulch	Power Mulcher

* Used only the last two years of the test program, the stalks were gathered with a front end loader the first year.

LOCATION OF TRIALS

The test site was located at the University of Arizona's Yuma Valley Agricultural Center. The field selected for the trials had been planted to cotton the year prior to commencement of the test program, and thus all of the first year's operations took place in a field which had been prepared the previous season using conventional cotton tillage practices. The field was laid out in a randomized complete block design, with five replicates. This design facilitated statistical analysis of the data, and precluded field variation from confounding the results.

A second site, for which data was obtained for one season, was located approximately 25 miles northwest of Tucson, at the University of Arizona's Marana Agricultural Center. Tests were conducted using two fields: D1, the site of a tillage study which took place from 1986 through 1994, and A4, a control field which had been planted to cotton using conventional tillage practices. The results of the Marana study were send to ADEQ in November 1992. The Marana study is mentioned here only to bring it to the attention of the reader, and to lay groundwork for some of the comparisons which will be made in this report.

A standard soil analysis of the Yuma field indicated that the top three inches of soil was comprised of 17% sand, 53% silt and 30% clay. The values for Marana fields D1 and A4 were 28, 40 and 32%, and 34, 35 and 31%, respectively. Using the EPA classification to define silt content, that is particles less than 200 mesh (74 Um), the three fields would contain 83, 72 and 66 percent silt, respectively.

If the EPA values are input into the AP-42 emission factor equation shown below, and the particulates predicted to be emitted by <u>each</u> tillage operation are calculated, the emissions shown in Table 2 would be expected:

$$E = k(4.80)S^{0.6} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Table 2. Particulate Generation Predicted using the AP-42 Emission Factor Equation and Assuming that all Soil Particulates Less Than 200 Mesh were not Conglomerated.

Field	Total Particulates (lb/ac)	PM_{10} (lb/ac)
Yuma	680	14
Marana - D1	625	13
Marana - A4	593	12

These figures assume that all of the silt and clay particles are in a free state, and are not conglomerated in any manner. Most certainly this would not be the case, and emissions should therefore be much less. The extent of conglomeration that existed would depend upon the soil breakup that had taken place prior to the operation, as well as the moisture content.

In an attempt to obtain representative values that would be predicted by AP-42 for each of the test fields, soil samples were taken in the fall/winter of 1994-95. These samples were obtained after a number of conventional tillage operations had taken place, and would represent a typical amount of soil breakup. The soil samples were analyzed using EPA accepted procedures to determine silt content. The mean values for the Yuma, D1 and A4 fields were 5.0, 3.9 and 5.3, respectively. These were substituted into equation (1), and the emissions calculated. The results are given in Table 3.

Table 3. Particulate Generation Predicted from the AP-42 Emission Factor Equation using the Silt Percentages Obtained from the Fields Following several Tillage Operations.

Field	% Silt	Total Particulates (lb/ac)	PM_{10} (lb/ac)
Yuma	4.98	126	2.64
Marana - D1	3.90	109	2.28
Marana - A4	5.28	130	2.73

The total particulate values listed above are used later in this report in the comparison with the measured values.

PROBLEMS ENCOUNTERED

Agriculture is dependent on many factors, among them weather and pests. This project has been affected by both of these variables to some extent. The most notable problem has been vertacilium wilt. This disease increased with time, reducing yields and the portion of the field which could be considered representative of a commercial operation. The presence of a severe whitefly infestation during the first year of the study also reduced yields. This was not an uncommon situation in the Yuma valley that year, however.

Similar problems with vertacilium wilt were encountered in the Marana plots. This problem, and how it was dealt with, was discussed in the 1992 report.

EQUIPMENT AND PROCEDURES

The test equipment and field procedures described in the 1990 report were used for the Yuma trials. As a consequence, they are not described here.

RESULTS

The data in Table 4 show that average wind velocities during each run were below the 8 mph value which had been set as the upper limit for the trials, except during ripping of the conventional plots during the third year.

Peak velocities exceeded 8 mph in a few cases. This was thought not to be a significant problem since infrequent gusts of short duration would have little influence on the overall results. During the trials every attempt was made to ensure that implement travel direction relative to wind direction was constant to prevent this from confounding the results.

Table 4. Date when particulate measurements were made. Average and peak wind velocities in miles per hour for each test.

System	Operation	1991 - 92			1992 - 93			1993 - 94		
			Wind			Wind			Wind	
		Date	Avg	Peak	Date	Avg	Peak	Date	Avg	Peak
Conven-	Shred	11/11	4.5	9.8	10/13	3.4	3.4	9/21	4.4	4.8
tional	1st Disk	11/19	6.4	6.7	10/19	4.3	4.5	9/22	3.8	4.0
	Rip Diag	11/20	2.9	3.3	10/20	6.4	6.4	9/28	10.2	11.5
	2nd Disk	11/21	6.9	7.2	10/22	6.5	6.8	11/10	5.2	6.0
	Disk Herb	2/11	4.5	5.3	2/16	3.4	3.7	2/15	4.3	6.7
	List	2/12	4.7	5.9	2/16	4.1	4.5	2/15	3.9	4.4
	Mulch	3/17	5.8	7.2	3/10	5.4	6.7	3/10	3.2	3.8
Sundance	Shred	11/18	7.3	8.9	10/14	2.8	2.9	9/21	4.2	4.8
	Uproot	11/20	5.4	6.3	10/19	2.6	2.6	9/29	4.8	8.5
	Sund Disk	11/25	2.0	2.5	10/26	3.7	3.7	11/09	6.4	7.2
	Mulch	3/17	5.8	7.2	3/10	5.4	6.7	3/10	2.3	2.7
USM	USM	11/13	3.4	4.6	10/13	7.4	7.6	9/23	4.2	5.4
	Rip/lister	2/12	7.6	8.4	2/06	3.9	4.1	2/15	3.8	3.9
	Mulch	3/17	5.8	7.2	3/10	5.4	6.7	3/10	5.3	5.7
Modified	Shred	11/18	7.3	8.9	10/14	3.7	4.6	9/21	4.2	4.9
Conven-	Disk	11/19	6.4	6.7	10/19	4.7	5.7	9/22	3.1	3.3
tional	Sund Disk	11/25	5.6	7.0	10/26	3.8	4.4	11/09	4.7	5.9
	Mulch	3/18	4.8	7.0	3/10	5.4	6.7	3/10	1.8	2.0
Puller	Puller	-	-	-	-	-	-	-	-	-
	Baler	-	-	-	10/22	3.7	4.6	9/28	4.3	4.9
	Sund Disk	2/11	4.1	5.2	10/26	3.8	4.4	11/09	5.5	5.9
	Mulch	3/18	4.8	7.0	3/10	5.4	6.7	3/10	4.6	4.9

Table 5 lists the soil moisture data and the average particulates generated by each operation on an area basis. Total particulates generated by each system are also presented in Table 5. Moisture contents ranged from a low of 2.2% to a high of 14.7%. In general, the lower moisture contents were associated with the fall tillage operations, while the higher values were found for the spring operations. This is typical, since the spring operations are performed following the winter rains, or subsequent to pre-irrigation in preparation for planting. On the other hand, the fall operations are performed long after irrigation has ceased, and prior to the winter rains.

In comparing the total emissions generated by each system, it can be noted that the highest values were recorded for the Sundance system each year. It is also interesting to note that the Sundance implement generated the greatest amount of particulates, on average, of any of the tillage operations.

In two of the three years, the conventional system generated the second greatest amount of particulates, while for the other year it was the third greatest. Although the puller system appears to be far superior to the others, it must be remembered that the particulates generated during the pulling operation itself are not included in the totals. Extreme technical difficulties modifying the collection apparatus to account for the trajectory pattern of the pulled stalks, while maintaining commonality of collection methodology, prevented collection of particulate data for the pulling operation.

To determine whether or not statistically significant differences existed among operations and/or systems, numerous analyses of variance were conducted. Ryan's Multiple Range Tests were used to rank the various means and to determine which were significantly different from others. A level of confidence of 0.05 was used in all cases.

Table 5. Soil moisture contents, particulates generated by the individual operations, and system totals.

System	Operation	1991 - 92		1992 - 93		1993 - 94	
		Soil Moisture (%)	Particulate Mass (lb/ac)	Soil Moisture (%)	Particulate Mass (lb/ac)	Soil Moisture (%)	Particulate Mass (lb/ac)
Conven-	Shred	3.6	10.8	3.2	15.8	3.2	6.0
tional	1st Disk	3.7	3.6	3.0	5.4	3.2	2.2
	Rip Diagonal	4.0	5.3	3.6	2.9	4.4	4.9
	2nd Disk	4.0	4.2	4.0	3.9	2.6	3.3
	Disk Herb	10.1	0.7	7.5	0.2	4.8	0.9
	List	7.7	2.7	11.3	2.8	6.5	13.1
	Mulch	13.3	8.3	10.6	7.9	13.2	1.8
TOTAL			35.5		38.9		32.3
Sundance	Shred	3.6	12.5	2.9	10.4	4.2	7.2
	Uproot	4.1	44.7	3.4	30.1	3.3	22.3
	Sund Disk	3.6	9.1	3.4	14.3	2.0	10.5
	Mulch	12.2	8.8	10.2	5.8	14.2	4.6
TOTAL			75.2		60.6		44.7
USM	USM	4.8	1.6	2.9	0.8	4.1	1.2
	Rip/List	8.8	4.6	5.0	8.6	3.7	22.8
	Mulch	14.6	18.4	12.2	5.5	11.6	6.4
TOTAL			24.6		14.9		30.4
Modified	Shred	3.6	11.3	3.1	11.3	3.4	4.4
Conven-	Disk	4.0	3.6	3.2	5.4	3.4	2.3
tional	Sund Disk	3.0	10.6	3.8	20.0	2.6	8.9
	Mulch	11.1	9.6	11.9	6.3	13.0	2.1
TOTAL			34.8		42.9		17.7
Puller	Puller	-	-	-	-	-	-
	Baler	-	-	4.1	0.4	2.3	0.9
	Sund Disk	10.9	2.4	3.8	15.5	2.2	12.5
	Mulch	12.6	10.7	11.6	10.4	14.7	6.7
TOTAL			13.1*		26.3*		20.1*

* particulates were not collected from one or more operations

NOTE: The entire data set is provided in Appendix 1, along with implement operating speeds.

Table 6 presents a summary of the results of the statistical analyses. These are presented on a yearly basis, for the average over the duration of the test, and for the sum of particulates generated by each system over three years. The complete statistical analysis is provided in Appendix 2.

Table 6. Particulates generated, in lb/ac, by the five cotton tillage systems at Yuma.

System	1991-92	1992-93	1993-94	Average	Total
Sundance	75.2 A	60.6 A	44.7 A	60.2 A	180.5 A
Conventional	35.5 B	38.8 B	32.3 B	35.6 B	106.7 B
Mod Conventional	34.8 B	42.9 B	17.7 C	31.8 BC	95.5 B
USM	24.6 BC	14.9 C	30.4 BC	23.3 BC	69.9 C
Puller	13.1 C	26.3 BC	20.1 BC	19.8 C	59.5 C

Note: means in a column followed by the same letter were found not to be statistically different at the 0.05 level

From Table 6 it can be seen that yearly, on average and in total, the Sundance system produced significantly more particulates than any of the other systems. This indicates that not all reduced tillage systems produce fewer particulates than conventional tillage systems. If one compares tillage systems on a yearly basis, it can be seen each year that one minimum tillage system generated significantly fewer particulates than did the conventional system. This was not the same system each year, however. If the mean (average) values are considered, it can be noted that only the puller system produced fewer particulates than the conventional system. If the total particulates generated by each system over the three year test are considered, both the puller and USM systems generated significantly less particulates than did the conventional system. The puller system produced approximately half of the particulates of the conventional system, while the USM system generated approximately 65 percent of that of the conventional. Clearly these results indicate that some reduced tillage systems significantly reduce particulate generation as compared to a conventional system.

A comparison of particulates generated by each of the systems among years showed no statistically significant differences for the Sundance, conventional and puller systems. This indicates that these three system were generating relatively constant amounts each year. For the USM system, significantly fewer particulates were generated the second year of the trials, while for the modified conventional system significantly less particulates were generated the third year. No explanation for these findings is available. The complete statistical analysis of the yearly comparisons for each system is provided in Appendix 3.

Table 7 presents mean emissions for the operations which comprise the five systems, over the three year test period. The complete statistical analysis of this data, along with an individual analysis of each year's data, is provided in Appendix 4.

Table 7. Mean particulates generated by each operation during the three year test. (dashed lines separate broad groupings of operations)

REGWQ Grouping					LB/AC	OPERATION	SYSTEM
			A		32.369	UPROOTER	SUNDANCE
			B		13.154	RIP/LIST	MOD CONVENTIONAL
			B				
	C		B		12.009	RIP/LIST	USM
	C		B				
	C		B	D	11.322	RIP/LIST	SUNDANCE
	C		B	D			
	C		B	D	10.933	SHREDDING	CONVENTIONAL
	C		B	D			
	C		B	D	10.132	RIP/LIST	PULLER
	C		B	D			
	C		B	D	10.099	MULCHING	USM
	C		B	D			
	C		B	D	10.038	SHREDDING	SUNDANCE
	C		B	D			
	C		B	D	9.257	MULCHING	PULLER
	C		B	D			
	C	E	B	D	9.029	SHREDDING	MOD CONVENTIONAL
	C	E	B	D			
F	C	E	B	D	6.436	MULCHING	SUNDANCE
F	C	E	B	D			
F	C	E	B	D	6.196	LISTING	CONVENTIONAL
F	C	E	B	D			
F	C	E	B	D	5.993	MULCHING	MOD CONVENTIONAL
F	C	E	B	D			
F	C	E	B	D	5.989	MULCHING	CONVENTIONAL
F	C	E		D			
F	C	E		D	4.370	RIPPING	CONVENTIONAL
F		E		D			
F		E		D	3.793	2nd DISK	CONVENTIONAL
F		E		D			
F		E		D	3.757	DISK	MOD. CONVENTIONAL
F		E		D			
F		E		D	3.692	1st DISK	CONVENTIONAL
F		E					
F		E			1.196	USM	USM
F							
F					0.648	BALING	PULLER
F							
F					0.610	DISK HERB	CONVENTIONAL

Of the 21 operations evaluated, many were found not to be significantly different in terms of particulate generation. Clearly the Sundance uprooter generated the most particulates. If the listing and ripping operations for the conventional plots were combined, total emissions would be 10.566 lb/ac. This places the combined operation, which could now be called rip/listing, immediately below conventional shredding in Table 7. Given this scenario, it

can be seen that with the exception of shredding the conventional plots, Table 7 can be generally divided into the following classifications of operations in order of decreasing particulate generation: Sundance uprooter, rip/listing, shredding and mulching, disking, and miscellaneous operations. Statistically, the rip/listing, shredding and mulching operations were found not to be significantly different in terms of particulate generation. Based on this, over 60 percent of the field operations examined could be placed in a group having emissions ranging from 6 to 13 lb/ac.

The results of the statistical analyses conducted using the Marana data are included in Appendix 5 of this report. It can be seen that no statistical differences in particulate generation were recorded among the tillage systems for either field D1 or A4. If particulates generated by each of the systems are compared between fields, only for the conventional system were any differences recorded. In this instance, more particulates were produced in field A4 than in D1. The reason for this difference is unknown, but could possibly be attributed to differences in soil composition.

When the Yuma and Marana data are combined, (Appendix 6) and each system at each site is considered independently, it can be noted that for the conventional and USM system, more particulates were generated in field A4 than in D1. Also more particulates were generated by the USM and conventional systems at Marana than at Yuma. For the Sundance system field A4 generated the most particulates, followed by Yuma in 1991, then by D1, however the differences were not statistically significant. It should be noted that the data for field D1 do not include particulates generated by the uprooter (the reasons for this were discussed in the 1992 report). If this value was added to the total, the same trend that was observed for the other two systems would be anticipated. That is A4, followed by D1, and then the Yuma trials.

From a statistical standpoint it can be said that the Yuma plots produced fewer particulates than did the Marana plots when the conventional and USM systems were used. For the Sundance system, fewer particulates were generated in field A4 than at Yuma for the last two years of the trials. This was not the case for field D1.

An attempt was made to determine if implement speed, soil moisture content, or a combination of both parameters could be used to predict particulate generation. A stepwise regression analysis was conducted for each of the implements using the Yuma data. In most cases the R^2 values were very small, with only a few considered sufficiently high to conclude that a reasonable fit had been achieved. In a number of cases the regressions were the opposite of what would be expected, with a decrease in speed or an increase in moisture resulting in increased particulate generation. Here again the R^2 values were very small, lending little statistical validity to the results.

POTENTIAL FOR PARTICULATE REDUCTION

Based on the results of the study it is clear that <u>some</u> reduced tillage systems have the potential to significantly reduce particulate generation. The puller and the USM systems have that potential, although the latter not statistically so. Other systems, which were not included in the test, but have been, are being, or could be developed also have the potential to reduce particulates.

Table 8 presents the reduction, on average, that could be achieved using the two most promising systems tested.

Table 8. Reduction in Particulate Generation by County for two Reduced Tillage Systems.

Acres of Cotton by County*		Reduction in Particulate generation using: USM System (tons/year)	Puller System (tons/year)
Cochise	14,800	91	117
Graham	22,100	136	174
La Paz	34,100	210	269
Maricopa	132,200	813	1044
Pima	13,700	84	108
Pinal	127,100	782	1004
Yuma	21,900	135	173
TOTAL	373,000	2294	2947

* From 1993 Arizona Agricultural Statistics

It should be noted that although significant reductions can be achieved, the values are not as large as earlier studies had predicated. This is due to two factors: 1) earlier predictions were based on preliminary test work, and 2) cotton acreage in Arizona has dramatically declined. Earlier predictions were based on a total cotton acreage of 485,000 acres (1989 data) as compared to the current value of 373,000 acres, a 23 percent reduction in just five years.

COMPARISON OF RESULTS TO AP-42 PREDICTIVE EMISSIONS

In an attempt to compare the test results to values predicted using AP-42, soil samples were taken from the Yuma and Marana fields in late 1994 and early 1995. The samples were taken as specified in the AP-42 procedure, with the fields having received several tillage operations following shredding of the cotton stalks. Normally one would take a soil sample in conjunction with each individual operation, thus taking into account the change in soil structure brought about by each operation. The problem with this methodology is that it is unclear when the sample should be taken - that is prior to, or following the tillage operation. One could argue that the soil condition the implement encountered, and hence the one which produced the particulates, was that which existed prior to its passage. Or one could argue that the soil condition that remained following implement operation produced the particulates, since the soil breakup that occurred was a direct result of the implement's operation. Since it is unclear which procedure would provide the more accurate results, it is thought that the sampling procedure used in this study should be substantially correct, and provides a reasonable estimate of emissions.

To predict emissions from each tillage system, the number of field operations each was comprised of was taken into account. The results of the calculations for the Yuma site are shown in Table 9 along with the measured values, with the Marana results shown in Table 10.

Table 9. Predicted and Measured Tillage Emissions for Yuma.

System	Number of Operations	Emissions (lb/ac) Predicted	Measured*
Sundance	4	504	60
Conventional	7	875	36
Mod Conventional	4	504	32
USM	3	375	23
Puller	4	504	20

* average value for the three year test program

Based on the results shown in Table 9 it can be seen that the AP-42 emission equation overpredicted emissions, on average, by more than an order of magnitude. This difference is significant, and indicates that the equation is inaccurate for predicting emissions in the conditions tested. Since these conditions are representative of most Arizona cotton tillage operations, it can be assumed that the equation is inaccurate for Arizona and should not be used to predict emissions.

Table 10. Predicted and Measured Tillage Emissions for Marana.

System	Number of Operations	Field	Emissions (lb/ac) Predicted	Measured
Sundance	4	D1	436	74
Conventional	7	D1	763	86
USM	3	D1	327	71
Sundance	4	A4	520	105
Conventional	7	A4	910	117
USM	3	A4	390	88

From Table 10 one can again note that the AP-42 emission factor equation vastly over predicts tillage emissions. Clearly the AP-42 equation is not appropriate for predicting emissions for the field conditions and/or implements tested during the study. Since these conditions are fairly typical of those found in Arizona, it brings into question whether this equation should be used when conducting an emissions inventory for the agricultural tillage operations commonly found in Arizona.

OTHER BENEFITS OF REDUCED TILLAGE SYSTEMS

Although reduction in particulate generation is in itself worthwhile, it is uncertain that farmers will adopt these tillage practices for this reason alone. Rather, realization of an economic benefit by growers will probably be needed to promote statewide adoption of reduced tillage systems.

Tests have been underway at the University of Arizona's Marana Agricultural Center to provide such information. Energy required by two reduced tillage systems and a conventional system, as well as field operating times required by each were recorded over six seasons. The data are summarized in Tables 11 and 12. Table 11 lists the mean energy required by each system and presents the total energy required by each system for each year that the test was conducted. Table 12 presents the time required to prepare an acre from harvest to planting for each system, and allows a comparison among systems to be made.

Table 11. Mean tillage energy requirements (HP-HR/AC) of conventional, Uprooter-Shredder-Mulcher (USM), and Sundance tillage systems at the Marana Agricultural Center, 1987-94.

	1987-88	1988-89	1989-90	1990-91	1992-93	1993-94	6-Year Average	% of Conv.
Conventional	68.30 a*	69.95 a*	75.05 a*	55.11 a*	66.42 a*	66.52 a*	66.89 a*	100
USM	57.26 b	45.04 b	43.44 b	48.33 b	43.97 b	44.93 b	47.16 b	71
Sundance	38.76 c	34.02 c	32.46 c	22.81**c	38.35 c	25.28 c	31.95 c	48

*Means followed by the same letter within a column are not significantly different at the 0.05 level.
**Does not include the energy requirement of the uprooting operation, which was performed in the mud that year.

Table 12. Mean field work time (Hrs/Ac) to plow down cotton and prepare a seedbed for a subsequent cotton crop with conventional, Uprooter-Shredder-Mulcher (USM) and Sundance tillage systems at the Marana Agricultural Center, 1987-94. These data are not adjusted for field efficiency.

	1987-88	1988-89	1989-90	1990-91	1992-93	1993-94	6-Year Average	% of Conv.
Conventional	1.47 a*	1.44 a*	1.65 a*	1.37 a*	1.45 a*	1.57 a*	1.49 a*	100
USM	1.08 c	0.79 c	0.72 c	0.85 b	0.97 b	0.82 b	0.87 b	58
Sundance	1.15 b	0.89 b	0.82 b	0.77**c	0.92 c	0.65 c	0.87 b	58

*Means followed by the same letter within a column are not significantly different at the 0.05 level.
**Does not include the time requirement for the uprooting operation, which was performed in the mud that year.

Cotton lint yields for the trials are presented in Table 13. A common question raised by growers is whether or not adopting minimum tillage systems will reduce yield. Many are convinced that yields will be reduced. From Table 13 it can be seen that this is not the case. Yields are statistically the same, regardless of the tillage system.

Similar results are available from the Yuma studies. These are presented in tables 14 and 15 for the energy and yield data, respectively.

CONCLUSIONS

1. In general, higher particulate generation was observed in the Marana plots than the Yuma plots. This is the reverse of what would be expected, given the silt content of the soils and the AP-42 emission factor model.
2. The Sundance system at Yuma produced consistently more particulates than did any of the other systems. At Marana this was not the case, with no statistically significant differences among systems recorded.
3. The puller system produced significantly fewer particulates than did the conventional system, and generated approximately half of the particulates of the conventional system.
4. The USM system produced approximately 65% of the particulates of the conventional system, with statistical differences being noted for only one year. Total particulates generated during the three year study was significantly less for the USM system, than the conventional.
5. No consistent trends with respect to particulate generation, as influenced by implement speed and soil moisture content, were detected over the range of variables studied.
6. A comparison of the measured emissions to the predicted values showed the latter to over predict emissions by approximately an order of magnitude.
7. Energy required by the reduced tillage systems was significantly less than the conventional system. This translates into an economic advantage for these systems.
8. Yield was not significantly different among systems.

RECOMMENDATIONS FOR FURTHER WORK

Although these studies have provided some information relative to the particulate reduction that can be brought about by alternative tillage systems, additional work is required. The information gained during the studies indicates that a wide range of particulate generation exists among implements, and hence a judicious choice of implements can reduce particulate generation.

One area of study that could be undertaken is the evaluation of systems made up of other combinations of implements, or the evaluation of new implements that are currently under development. An example of a new implement, called Pegasus, appears to hold significant potential for reducing particulate generation. This one pass plowdown system appears worthy of evaluation in terms of reducing particulate generation.

Another area that appears worthy of study is development of methods which suppress particulate emissions during implement operation. The most straight forward, and the one which does not require additional components, is tillage of soil at higher moisture contents than is normally practiced. The problem with this approach, however, is that higher soil moisture content can increase compaction.

A more complicated and expensive process which could be used to reduce particulates during implement operation is the addition of devices to

Table 13. Lint yields (Lbs/Ac) with Conventional, Uprooter-Shredder-Mulcher (USM), and Sundance tillage systems at the Marana Agricultural Center, 1988-1993.

	1988	1989	1990	1992	1993	5-Year Average
Conventional	778 a*	929 a*	325 b*	601 a*	1108 a*	749 a*
USM	730 a	1030 a	367 ab	597 a	1059 a	757 a
Sundance	888 a	969 a	433 a	623 a	1054 a	794 a

*Means followed by the same letter within a column are not significantly different at the 0.05 level.

Table 14. Mean tillage energy requirements (HP-HR/AC) of the conventional, USM, Sundance, modified conventional, and puller tillage systems at the Yuma Agricultural Center, 1991-94.

	1991-92	1992-93	1993-94	3 Year Average	% of Conv.
Conventional	51.51 a*	64.44 a*	72.27 a*	67.21 a*	100
USM	49.53 a	49.79 b	44.76 b	48.02 b	71
Sundance	28.71 b	29.59 c	30.68 c	29.86 cd	44
Mod. Conventional	31.48 b	32.26 c	33.13 c	32.03 c	48
Puller	22.82 b	28.25 c	25.80 d	25.63 d	38

*Means followed by the same letter within a column are not significantly different at the 0.05 level.

Table 15. Seed Cotton yields (Lbs/Ac) with the requirements of the conventional, USM Sundance, modified conventional, and puller tillage systems at the Yuma Agricultural Center, 1992-94.

	1992	1993	1994	3 Year Average
Conventional	2049	3387	2332	2563
USM	2451	3546	3510	3169
Sundance	2413	3299	3006	2906
Mod. Conventional	2222	3297	2473	2664
Puller	2296	3792	2695	2927

accomplish just that. Two systems which merit investigation are water misting, and electrostatic precipitation. One which could possibly work, but which would require significantly more development, is the use of a filter system to remove soil particulates from the dust plume generated by an implement.

Another task that should be undertaken is combining PM_{10} sampling equipment with the TSP procedures developed for this study. Although estimates of PM_{10} levels can be obtained from the TSP values, they are only estimates. Installation of appropriate PM_{10} sampling equipment upwind, and at several locations downwind from the tillage operation would yield valuable information on particulate fallout and PM_{10} emissions from tillage operations.

Extending the study to other operations involved in cotton farming, particularly harvesting, would also appear to be warranted since this operation is inherently dusty. Similarly, dusty farming operations such as landplaning and combining, should be studied to determine their particulate generation. Perhaps these operations, rather than tillage operations, are responsible for the majority of particulates produced by current farming operations.

APPENDIX 1

MOISTURE CONTENTS, OPERATING SPEEDS AND TOTAL PARTICULATES

Yuma Percent Moisture Content

Conventional 91-92	Shred	1 Disk	Rip	2 Disk	Disk Herb	List	Mulch
Rep A	3.91	3.98	4.29	4.29	10.29	9.20	10.66
Rep B	3.85	3.79	3.76	3.76	11.14	9.48	17.99
Rep C			4.16	4.16	9.90	7.09	10.55
Rep D		3.43	3.69	3.69	10.19	7.34	14.10
Rep E	3.00		3.87	3.87	8.78	5.51	13.33
Mean	3.586667	3.733333	3.954	3.954	10.06	7.724	13.326
STD	0.415559	0.228084	0.232258	0.232258	0.761604	1.463784	2.726379
CV	0.115862	0.061094	0.05874	0.05874	0.075706	0.189511	0.204591

Yuma Percent Moisture Content

Conventional 92-93	Shred	1 Disk	Rip	2 Disk	Disk Herb	List	Mulch
Rep A	3.19	2.58	4.12	3.67	7.13	12.44	8.26
Rep B	3.68	3.56	4.64	2.80	7.48	11.41	11.81
Rep C	3.68	2.83	2.85	5.53	7.45	11.07	13.08
Rep D	3.45	3.82	4.58	4.32	8.99	10.99	12.99
Rep E	2.22	2.01	2.11	3.92	6.28	10.43	6.87
Mean	3.244	2.96	3.66	4.048	7.466	11.268	10.602
STD	0.542977	0.657784	1.007671	0.892982	0.876644	0.665204	2.557932
CV	0.167379	0.222224	0.27532	0.220598	0.117418	0.059035	0.241269

Yuma Percent Moisture Content

Conventional 93-94	Shred	1 Disk	Rip	2 Disk	Disk Herb	List	Mulch
Rep A	2.43	2.43	4.37	2.29	4.92	8.51	11.72
Rep B	4.13	4.13	3.86	2.93	5.36	4.80	16.41
Rep C	3.67	3.67	4.35	2.71	3.96	4.93	10.44
Rep D	3.47	3.47	7.86	3.12	5.49	6.07	15.11
Rep E	2.33	2.33	1.69	1.89	4.36	8.38	12.11
Mean	3.206	3.206	4.426	2.588	4.818	6.538	13.158
STD	0.708282	0.708282	1.980269	0.44517	0.583383	1.619079	2.23336
CV	0.220924	0.220924	0.447417	0.172013	0.121084	0.247641	0.169734

Yuma Percent Moisture Content

Sundance 91-92	Shred	Uproot	Rip/List	Mulch
Rep A	3.69	4.58	3.81	14.36
Rep B		4.34	3.42	16.01
Rep C	4.08	3.48	3.45	12.40
Rep D		4.29		9.17
Rep E		3.99		9.23
Mean	3.885	4.136	3.56	12.234
STD	0.195	0.377921	0.1772	2.728286
CV	0.050193	0.091373	0.049775	0.223008

Yuma Percent Moisture Content

Sundance 92-93	Shred	Uproot	Rip/List	Mulch
Rep A	3.07	3.69	3.47	10.02
Rep B	2.75	4.09	3.79	10.64
Rep C	3.16	2.99	3.83	8.97
Rep D	2.84	3.34	3.22	12.50
Rep E	2.80	2.78	2.63	9.14
Mean	2.924	3.378	3.388	10.254
STD	0.161071	0.471992	0.439654	1.275768
CV	0.055086	0.139725	0.129768	0.124417

Yuma Percent Moisture Content

Sundance 93-94	Shred	Uproot	Rip/List	Mulch
Rep A	4.42	3.28	2.14	18.51
Rep B	4.53	3.18	2.32	13.38
Rep C	3.48	3.33	2.13	15.99
Rep D	4.69	3.00	2.05	10.59
Rep E	3.99	3.63	1.62	12.29
Mean	4.222	3.284	2.052	14.152
STD	0.437603	0.206553	0.233358	2.797187
CV	0.103648	0.062897	0.113722	0.197653

Yuma Percent Moisture Content

USM 91-92	USM	Rip/List	Mulch
Rep A	4.60	8.91	12.49
Rep B	4.67	8.89	14.98
Rep C	4.91	11.00	13.86
Rep D	4.99	8.13	16.59
Rep E		7.05	15.09
Mean	4.7925	8.796	14.602
STD	0.161922	1.293949	1.367061
CV	0.033787	0.147107	0.093621

Yuma Percent Moisture Content

USM 92-93	USM	Rip/List	Mulch
Rep A	2.84	4.99	8.53
Rep B	3.56	4.68	12.04
Rep C	2.90	3.93	11.60
Rep D	2.50	4.67	15.63
Rep E	2.94	6.96	13.32
Mean	2.948	5.046	12.224
STD	0.343302	1.01856	2.318229
CV	0.116452	0.201855	0.189646

Yuma Percent Moisture Content

USM 93-94	USM	Rip/List	Mulch
Rep A	3.30	3.53	13.23
Rep B	3.10	3.14	11.14
Rep C	3.38	3.58	11.74
Rep D	6.71	4.07	11.39
Rep E	4.08	4.17	10.66
Mean	4.114	3.698	11.632
STD	1.339397	0.378069	0.873004
CV	0.32557	0.102236	0.075052

Yuma Percent Moisture Content

Puller 91-92	Puller	Baler	Rip/List	Mulch
Rep A			10.96	13.26
Rep B			11.36	12.42
Rep C			11.36	14.34
Rep D			10.93	12.68
Rep E			10.11	10.31
Mean			10.944	12.602
STD			0.456535	1.322579
CV			0.041716	0.10495

Yuma Percent Moisture Content

Puller 92-93	Puller	Baler	Rip/List	Mulch
Rep A		4.89	3.69	9.31
Rep B		4.31	4.25	11.80
Rep C		4.36	4.16	14.85
Rep D		3.90	3.74	12.24
Rep E		3.10	3.35	9.77
Mean		4.112	3.838	11.594
STD		0.595832	0.329569	1.980147
CV		0.144901	0.08587	0.170791

Yuma Percent Moisture Content

Puller 93-94	Puller	Baler	Rip/List	Mulch
Rep A		2.07	1.75	15.28
Rep B		2.56	2.47	16.75
Rep C		2.35	2.84	13.85
Rep D		2.30	2.15	13.88
Rep E		2.33	2.03	13.67
Mean		2.322	2.248	14.686
STD		0.155872	0.375468	1.182685
CV		0.067128	0.167023	0.080531

Yuma Percent Moisture Content

Mod Conv. 91-92	Shred	1 Disk	Rip/List	Mulch
Rep A		4.21	3.31	13.17
Rep B	3.79	4.11	3.03	10.38
Rep C	3.45	4.05	2.82	13.76
Rep D				11.38
Rep E	3.11	3.79		7.05
Mean	3.45	4.04	3.053333	11.148
STD	0.277609	0.155242	0.200721	2.381104
CV	0.080466	0.038426	0.065738	0.21359

Yuma Percent Moisture Content

Mod Conv. 92-93	Shred	1 Disk	Rip/List	Mulch
Rep A	3.54	3.22	4.56	10.77
Rep B	3.43	4.19	4.01	14.24
Rep C	3.15	3.05	3.53	9.52
Rep D	2.73	3.20	3.84	13.81
Rep E	2.53	2.42	3.15	11.10
Mean	3.076	3.216	3.818	11.888
STD	0.390876	0.567472	0.472669	1.827801
CV	0.127073	0.176453	0.1238	0.153752

Yuma Percent Moisture Content

Mod Conv. 93-94	Shred	1 Disk	Rip/List	Mulch
Rep A	4.54	4.54	2.29	12.15
Rep B	4.06	4.06	2.93	14.78
Rep C	3.21	3.21	2.71	12.98
Rep D	3.11	3.11	3.12	14.56
Rep E	2.34	2.34	1.89	10.62
Mean	3.452	3.452	2.588	13.018
STD	0.770127	0.770127	0.44517	1.548398
CV	0.223096	0.223096	0.172013	0.118943

Yuma Ground Speed

Conventional 91-92	Shred	1 Disk	Rip	2 Disk	Disk Herb	List	Mulch
Rep A	2.97	3.34	2.82	5.27	5.23	4.17	2.06
Rep B	2.73	4.88	2.94	4.79	5.13	5.01	2.04
Rep C			2.89	4.93	4.99	4.55	2.05
Rep D		4.85	3.31	5.02	5.17	5.27	2.08
Rep E	2.06		3.20	4.77	5.10	5.06	2.06
Mean	2.586667	4.356667	3.032	4.956	5.124	4.812	2.058
STD	0.385083	0.718996	0.189251	0.181945	0.0799	0.397814	0.013266
CV	0.148872	0.165034	0.062418	0.036712	0.015593	0.082671	0.006446

Yuma Ground Speed

Conventional 92-93	Shred	1 Disk	Rip	2 Disk	Disk Herb	List	Mulch
Rep A	2.87	3.91	3.34	3.86	4.39	4.10	2.99
Rep B	2.83	3.93	3.20	3.97	4.53	3.67	2.93
Rep C	2.92	3.94	3.09	3.93	4.49	3.68	2.92
Rep D	2.58	3.97	3.21	3.89	4.46	4.16	2.97
Rep E	2.87	3.96	3.16	3.89	4.45	3.67	2.99
Mean	2.814	3.942	3.2	3.908	4.464	3.856	2.96
STD	0.120433	0.021354	0.081731	0.038158	0.046303	0.224553	0.029665
CV	0.042798	0.005417	0.025541	0.009764	0.010373	0.058235	0.010022

Yuma Ground Speed

Conventional 93-94	Shred	1 Disk	Rip	2 Disk	Disk Herb	List	Mulch
Rep A	2.79	4.61	2.70	4.75	4.53	3.82	3.02
Rep B	2.67	4.59	2.47	4.71	4.84	3.90	2.84
Rep C	2.10	4.57	2.50	4.75	4.71	3.90	2.82
Rep D	2.78	4.63	2.63	4.74	4.57	3.80	2.86
Rep E	2.80	4.58	2.63	4.73	4.52	3.85	2.86
Mean	2.628	4.596	2.586	4.736	4.634	3.854	2.88
STD	0.268134	0.021541	0.086856	0.014967	0.123386	0.040792	0.071554
CV	0.10203	0.004687	0.033587	0.00316	0.026626	0.010584	0.024845

Yuma Ground Speed

Sundance 91-92	Shred	Uproot	Rip/List	Mulch
Rep A	3.03	5.38	4.78	2.05
Rep B		5.11	4.23	2.04
Rep C	2.70	5.54	4.13	2.02
Rep D	2.71	5.73	4.24	2.10
Rep E		5.66	3.53	2.07
Mean	2.813333	5.484	4.182	2.056
STD	0.153261	0.221504	0.397764	0.027276
CV	0.054477	0.040391	0.095113	0.013267

Yuma Ground Speed

Sundance 92-93	Shred	Uproot	Rip/List	Mulch
Rep A	3.01	4.96	4.58	2.95
Rep B	3.03	5.10	4.57	2.93
Rep C	3.01	5.15	4.47	2.93
Rep D	3.01	5.03	4.42	2.93
Rep E	3.01	5.11	4.42	2.97
Mean	3.014	5.07	4.492	2.942
STD	0.008	0.067231	0.070257	0.016
CV	0.002654	0.013261	0.01564	0.005438

Yuma Ground Speed

Sundance 93-94	Shred	Uproot	Rip/List	Mulch
Rep A	2.78	5.52	4.40	2.90
Rep B	2.09	5.39	4.34	2.91
Rep C	2.12	4.75	4.32	2.92
Rep D	2.45	5.45	4.22	2.93
Rep E	2.46	5.46	4.24	2.95
Mean	2.38	5.314	4.304	2.922
STD	0.254165	0.284998	0.066212	0.017205
CV	0.106792	0.053632	0.015384	0.005888

Yuma Ground Speed

USM 91-92	USM	Rip/List	Mulch
Rep A	2.83	4.77	2.05
Rep B	2.74	4.70	2.03
Rep C	2.68	5.55	1.95
Rep D	2.37	4.14	2.01
Rep E	2.33	4.19	2.04
Mean	2.59	4.67	2.016
STD	0.202089	0.509235	0.035553
CV	0.078027	0.109044	0.017635

Yuma Ground Speed

USM 92-93	USM	Rip/List	Mulch
Rep A	2.70	3.24	2.85
Rep B	2.87	3.80	2.95
Rep C	2.87	3.52	2.90
Rep D	2.70	3.19	2.93
Rep E	2.63	3.45	2.91
Mean	2.754	3.44	2.908
STD	0.098102	0.218449	0.033705
CV	0.035622	0.063503	0.01159

Yuma Ground Speed

USM 93-94	USM	Rip/List	Mulch
Rep A	1.92	3.20	2.80
Rep B	1.92	3.20	2.83
Rep C	2.08	3.11	2.81
Rep D	2.29	3.43	2.85
Rep E	2.20	3.47	2.82
Mean	2.082	3.282	2.822
STD	0.148108	0.141619	0.017205
CV	0.071137	0.04315	0.006097

Yuma Ground Speed

Puller 91-92	Puller	Baler	Rip/List	Mulch
Rep A	1.99		4.63	2.03
Rep B	1.96		4.69	2.05
Rep C	1.96		4.77	2.07
Rep D	2.04		4.18	2.10
Rep E	2.03		5.09	2.06
Mean	1.996		4.672	2.062
STD	0.033823		0.292739	0.023152
CV	0.016945		0.062658	0.011228

NOTE: Did not Bale stalks first year

Yuma Ground Speed

Puller 92-93	Puller	Baler	Rip/List	Mulch
Rep A	1.50	1.84	4.69	2.92
Rep B	1.56	1.76	4.66	2.73
Rep C	1.58	1.75	4.33	2.91
Rep D	1.53	1.76	4.13	2.94
Rep E	1.51	1.77	4.43	2.95
Mean	1.536	1.776	4.448	2.89
STD	0.030067	0.032619	0.209227	0.08124
CV	0.019575	0.018367	0.047038	0.028111

Yuma Ground Speed

Puller 93-94	Puller	Baler	Rip/List	Mulch
Rep A	2.10	1.83	3.59	2.91
Rep B	2.07	1.89	3.95	2.88
Rep C	3.24	1.86	3.81	2.91
Rep D	3.24	1.86	3.95	2.92
Rep E	3.30	2.08	3.65	2.92
Mean	2.79	1.904	3.79	2.908
STD	0.576125	0.090022	0.149131	0.014697
CV	0.206496	0.047281	0.039349	0.005054

Yuma Ground Speed

Mod Conv. 91-92	Shred	1 Disk	Rip/List	Mulch
Rep A		4.86	4.06	2.03
Rep B	2.43	4.86	4.01	2.04
Rep C	2.73	4.86	3.99	2.05
Rep D			3.85	2.03
Rep E	1.80	4.89	4.18	2.10
Mean	2.32	4.8675	4.018	2.05
STD	0.387556	0.01299	0.106846	0.026077
CV	0.16705	0.002669	0.026592	0.01272

Yuma Ground Speed

Mod Conv. 92-93	Shred	1 Disk	Rip/List	Mulch
Rep A	2.98	3.96	3.92	2.92
Rep B	3.05	3.99	3.92	2.93
Rep C	3.03	3.98	4.44	2.94
Rep D	3.05	3.92	4.30	2.93
Rep E	3.04	3.86	4.25	2.95
Mean	3.03	3.942	4.166	2.934
STD	0.026077	0.047497	0.210295	0.010198
CV	0.008606	0.012049	0.050479	0.003476

Yuma Ground Speed

Mod Conv. 93-94	Shred	1 Disk	Rip/List	Mulch
Rep A	2.11	4.64	4.62	2.93
Rep B	2.10	4.63	4.21	2.89
Rep C	2.12	4.64	3.88	2.86
Rep D	2.43	4.62	4.08	2.91
Rep E	2.44	4.58	3.97	2.95
Mean	2.24	4.622	4.152	2.908
STD	0.159374	0.022271	0.25872	0.031241
CV	0.071149	0.004818	0.062312	0.010743

Yuma Dust Lb/Ac

Conventional 91-92	Shred	1 Disk	Rip	2 Disk	Disk Herb	List	Mulch	Sum
Rep A	13.08	4.28	5.58	1.79	0.72	0.86	11.50	37.81
Rep B	10.94	3.23	6.11	1.81	1.01	4.08	6.20	33.38
Rep C			5.14	8.98	1.02	2.25	7.58	24.97
Rep D		4.69	5.36	2.97	0.80	4.97	8.06	26.85
Rep E	2.51		4.13	5.36	0.18	1.16	8.04	21.38
Mean	8.843333	4.066667	5.264	4.182	0.746	2.664	8.276	28.878
STD	4.562765	0.614835	0.652092	2.72857	0.306176	1.613104	1.748755	5.927122
CV	0.515955	0.151189	0.123878	0.652456	0.410424	0.605519	0.211304	0.205247

Yuma Dust Lb/Ac

Conventional 92-93	Shred	1 Disk	Rip	2 Disk	Disk Herb	List	Mulch	Sum
Rep A	25.19	5.65	4.52	4.92	0.19	6.30	6.43	53.20
Rep B	8.50	4.11	4.38	3.02	0.22	1.27	2.38	23.88
Rep C	17.36	6.65	1.19	3.02	0.16	2.57	3.62	34.57
Rep D	16.29	5.87	2.44	2.48	0.21	2.03	11.24	40.56
Rep E	11.91	4.56	1.89	5.96	0.11	1.82	16.00	42.25
Mean	15.85	5.368	2.884	3.88	0.178	2.798	7.934	38.892
STD	5.643676	0.917658	1.339352	1.330203	0.039699	1.799838	5.0539	9.620988
CV	0.356068	0.17095	0.464408	0.342836	0.223027	0.643259	0.636993	0.247377

Yuma Dust Lb/Ac

Conventional 93-94	Shred	1 Disk	Rip	2 Disk	Disk Herb	List	Mulch	Sum
Rep A	3.18	1.62	5.21	1.10	0.68	15.10	2.95	29.83
Rep B	2.72	1.76	5.05	6.26	0.92	14.88	0.56	32.15
Rep C	3.27	2.53	5.77	1.53	1.18	17.62	1.44	33.35
Rep D	8.53	1.94	3.60	5.90	1.53	9.67	1.74	32.91
Rep E	12.59	2.90	5.18	1.80	0.22	8.36	2.09	33.15
Mean	6.058	2.15	4.962	3.318	0.90405	13.12676	1.75832	32.27713
STD	3.898099	0.486621	0.724525	2.269047	0.443117	3.517913	0.78188	1.287767
CV	0.643463	0.226335	0.146015	0.68386	0.490147	0.267995	0.444675	0.039897

Yuma Dust Lb/Ac

Sundance 91-92	Shred	Uproot	Rip/List	Mulch	Sum
Rep A	20.94	61.93	4.44	12.78	100.09
Rep B		28.23	18.64	16.32	63.19
Rep C	17.62	64.97	7.72	4.79	95.10
Rep D	8.39	22.06	8.41	4.78	43.64
Rep E		46.53	6.27	5.40	58.20
Mean	15.65	44.744	9.096	8.814	72.044
STD	5.309507	17.29113	4.962187	4.820588	21.88604
CV	0.339266	0.386446	0.545535	0.546924	0.303787

Yuma Dust Lb/Ac

Sundance 92-93	Shred	Uproot	Rip/List	Mulch	Sum
Rep A	4.53	27.86	17.26	4.81	54.46
Rep B	4.17	28.94	13.53	3.48	50.12
Rep C	6.50	28.26	8.66	6.42	49.84
Rep D	16.99	35.75	19.51	2.95	75.20
Rep E	19.59	29.59	12.67	11.61	73.46
Mean	10.356	30.08	14.326	5.854	60.616
STD	6.578059	2.895838	3.767273	3.118042	11.33001
CV	0.635193	0.096271	0.262968	0.532634	0.186915

Yuma Dust Lb/Ac

Sundance 93-94	Shred	Uproot	Rip/List	Mulch	Sum
Rep A	6.40	23.12	5.54	3.72	38.78151
Rep B	3.40	16.47	22.38	4.03	46.28423
Rep C	3.11	12.54	2.76	5.76	24.169
Rep D	8.01	27.46	19.53	2.85	57.8529
Rep E	15.17	31.83	2.51	6.84	56.35095
Mean	7.218	22.284	10.544	4.641719	44.68772
STD	4.381403	7.033692	8.614115	1.449181	12.39196
CV	0.607011	0.315639	0.816968	0.312208	0.277301

Yuma Dust Lb/Ac

USM 91-92	USM	Rip/List	Mulch	Sum
Rep A	1.50	5.29	12.95	19.74
Rep B	1.15	5.99	18.07	25.21
Rep C	2.16	5.39	16.82	24.37
Rep D	1.91	3.50	23.18	28.59
Rep E	1.34	2.86	20.97	25.17
Mean	1.612	4.606	18.398	24.616
STD	0.371236	1.205796	3.514572	2.838602
CV	0.230295	0.261788	0.19103	0.115315

Yuma Dust Lb/Ac

USM 92-93	USM	Rip/List	Mulch	Sum
Rep A	0.81	8.64	4.03	13.48
Rep B	1.42	10.92	3.93	16.27
Rep C	0.62	10.99	8.17	19.78
Rep D	0.58	5.00	6.81	12.39
Rep E	0.50	7.35	4.79	12.64
Mean	0.786	8.58	5.546	14.912
STD	0.332962	2.263475	1.671186	2.796951
CV	0.423616	0.263808	0.301332	0.187564

Yuma Dust Lb/Ac

USM 93-94	USM	Rip/List	Mulch	Sum
Rep A	0.92	17.95	11.79	30.66
Rep B	1.28	37.23	2.70	41.21
Rep C	1.11	12.82	5.27	19.20
Rep D	1.45	28.56	2.85	32.86
Rep E	1.19	17.65	9.15	27.99
Mean	1.19	22.842	6.3516	30.3836
STD	0.176068	8.843518	3.582934	7.12992
CV	0.147956	0.38716	0.564099	0.234663

Yuma Dust Lb/Ac

Puller 91-92	Puller	Baler	Rip/List	Mulch	Sum
Rep A			0.92	8.49	9.41
Rep B			4.56	12.55	17.11
Rep C			1.47	15.62	17.09
Rep D			0.50	4.25	4.75
Rep E			4.69	12.49	17.18
Mean			2.428	10.68	13.108
STD			1.820499	3.932368	5.137799
CV			0.749794	0.368199	0.391959

Yuma Dust Lb/Ac

Puller 92-93	Puller	Baler	Rip/List	Mulch	Sum
Rep A		0.65	15.39	6.48	22.52
Rep B		0.61	8.73	6.19	15.53
Rep C		0.42	21.01	12.61	34.04
Rep D		0.04	9.89	4.72	14.65
Rep E		0.08	22.49	22.14	44.71
Mean		0.36	15.502	10.428	26.29
STD		0.257294	5.595307	6.450747	11.53117
CV		0.714704	0.360941	0.618599	0.438614

Yuma Dust Lb/Ac

Puller 93-94	Puller	Baler	Rip/List	Mulch	Sum
Rep A		0.56	1.96	5.02	7.54
Rep B		0.40	29.28	4.09	33.77
Rep C		1.83	3.83	5.03	10.69
Rep D		0.68	24.05	4.75	29.48
Rep E		1.21	3.21	14.43	18.85
Mean		0.936	12.466	6.66354	20.06554
STD		0.523167	11.72629	3.897852	10.22351
CV		0.558939	0.940662	0.584952	0.509506

Yuma Dust Lb/Ac

Mod Conv. 91-92	Shred	1 Disk	Rip/List	Mulch	Sum
Rep A		2.63	14.52	5.93	23.08
Rep B	11.05	2.25	9.94	7.09	30.33
Rep C	10.31	2.47	8.26	13.02	34.06
Rep D			14.76	10.87	25.63
Rep E	4.70	5.97	5.65	10.90	27.22
Mean	8.686667	3.33	10.626	9.562	28.064
STD	2.835141	1.530163	3.551966	2.636706	3.80956
CV	0.326378	0.459509	0.334271	0.275748	0.135745

Yuma Dust Lb/Ac

Mod Conv. 92-93	Shred	1 Disk	Rip/List	Mulch	Sum
Rep A	8.20	5.74	16.09	4.54	34.57
Rep B	3.93	2.98	10.45	3.98	21.34
Rep C	12.17	7.21	19.80	12.22	51.40
Rep D	18.03	5.53	27.44	3.67	54.67
Rep E	14.31	5.40	26.02	6.98	52.71
Mean	11.328	5.372	19.96	6.278	42.938
STD	4.879198	1.360961	6.294706	3.190714	12.971
CV	0.43072	0.253344	0.315366	0.508237	0.302087

Yuma Dust Lb/Ac

Mod Conv. 93-94	Shred	1 Disk	Rip/List	Mulch	Sum
Rep A	2.41	1.62	7.24	1.92	13.19
Rep B	3.18	2.17	5.40	1.52	12.27
Rep C	2.63	2.14	8.04	2.05	14.86
Rep D	4.99	2.09	11.70	2.00	20.78
Rep E	8.82	3.46	12.00	3.20	27.48
Mean	4.406	2.296	8.876	2.137096	17.7151
STD	2.386031	0.615552	2.576522	0.562304	5.710362
CV	0.541541	0.268097	0.29028	0.263116	0.322344

APPENDIX 2

COMPARISON OF SYSTEMS - YEARLY, 3 YEAR AVERAGE AND 3 YEAR TOTAL

---------- YEAR=91 ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	11623.03639	1452.87955	10.75	0.0001
Error	16	2162.80106	135.17507		
Corrected Total	24	13785.83746			

R-Square	C.V.	Root MSE	DUST Mean
0.843114	31.71228	11.62648	36.6624000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
OPER	4	10945.91382	2736.47845	20.24	0.0001
REP	4	677.12258	169.28064	1.25	0.3290

REGWQ Grouping		Mean	N	SYSTEM	
	A	75.194	5	13	SUNDANCE
	B	35.570	5	8	CONVENTIONAL
	B				
	B	34.824	5	27	MOD. CONVENTIONAL
	B				
C	B	24.616	5	17	USM
C					
C		13.108	5	22	PULLER

---------- YEAR=92 ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	7038.586872	879.823359	8.77	0.0001
Error	16	1605.130224	100.320639		
Corrected Total	24	8643.717096			

R-Square	C.V.	Root MSE	DUST Mean
0.814301	27.26961	10.01602	36.7296000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
OPER	4	5993.866136	1498.466534	14.94	0.0001
REP	4	1044.720736	261.180184	2.60	0.0753

REGWQ Grouping	Mean	N	SYSTEM	
A	60.616	5	13	SUNDANCE
B	42.938	5	27	MOD. CONVENTIONAL
B				
B	38.892	5	8	CONVENTIONAL
B				
C B	26.290	5	22	PULLER
C				
C	14.912	5	17	USM

---------- YEAR=93 ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	3142.600360	392.825045	6.96	0.0005
Error	16	902.608240	56.413015		
Corrected Total	24	4045.208600			

R-Square	C.V.	Root MSE	DUST Mean
0.776870	25.87632	7.510860	29.0260000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
OPER	4	2329.264840	582.316210	10.32	0.0003
REP	4	813.335520	203.333880	3.60	0.0281

REGWQ Grouping		Mean	N	SYSTEM	
	A	44.686	5	13	SUNDANCE
	B	32.278	5	8	CONVENTIONAL
	B				
C	B	30.384	5	17	USM
C	B				
C	B	20.066	5	22	PULLER
C					
C		17.716	5	27	MOD. CONVENTIONAL

---------- 3 YEAR AVERAGE----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	15421.28984	1927.66123	10.57	0.0001
Error	66	12034.01143	182.33351		
Corrected Total	74	27455.30127			

R-Square	C.V.	Root MSE	DUST Mean
0.561687	39.55289	13.50309	34.1393333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SYST	4	15107.83920	3776.95980	20.71	0.0001
REP	4	313.45064	78.36266	0.43	0.7866

REGWQ Grouping		Mean	N	SYSTEM	
	A	60.165	15	2	SUNDANCE
	B	35.580	15	1	CONVENTIONAL
	B				
C	B	31.826	15	5	MOD. CONVENTIONAL
C	B				
C	B	23.304	15	3	USM
C					
C		19.821	15	4	PULLER

---------- 3 YEAR TOTAL----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	46263.86952	5782.98369	24.63	0.0001
Error	16	3756.85988	234.80374		
Corrected Total	24	50020.72940			

R-Square	C.V.	Root MSE	DUST Mean
0.924894	14.96154	15.32331	102.418000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
OPER	4	45323.51760	11330.87940	48.26	0.0001
REP	4	940.35192	235.08798	1.00	0.4356

REGWQ Grouping	Mean	N	SYSTEM	
A	180.496	5	13	SUNDANCE
B	106.740	5	8	CONVENTIONAL
B				
B	95.478	5	27	MOD. CONVENTIONAL
C	69.912	5	17	USM
C				
C	59.464	5	22	PULLER

APPENDIX 3

SYSTEM COMPARISON AMONG YEARS

---------- CONVENTIONAL ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	309.2069067	51.5344844	0.83	0.5775
Error	8	496.0510933	62.0063867		
Corrected Total	14	805.2580000			

R-Square	C.V.	Root MSE	DUST Mean
0.383985	22.13157	7.874413	35.5800000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
YEAR	2	109.3632400	54.6816200	0.88	0.4507
REP	4	199.8436667	49.9609167	0.81	0.5548

REGWQ Grouping	Mean	N	YEAR
A	38.892	5	92
A			
A	35.570	5	91
A			
A	32.278	5	93

---------- SUNDANCE ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	2513.421987	418.903664	0.99	0.4908
Error	8	3388.227187	423.528398		
Corrected Total	14	5901.649173			

R-Square	C.V.	Root MSE	DUST Mean
0.425885	34.20542	20.57981	60.1653333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
YEAR	2	2328.368413	1164.184207	2.75	0.1234
REP	4	185.053573	46.263393	0.11	0.9759

REGWQ Grouping	Mean	N	YEAR
A	75.19	5	91
A			
A	60.62	5	92
A			
A	44.69	5	93

---------- MODIFIED CONVENTIONAL ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	2407.521000	401.253500	6.02	0.0119
Error	8	533.644360	66.705545		
Corrected Total	14	2941.165360			

R-Square	C.V.	Root MSE	DUST Mean
0.818560	25.66250	8.167346	31.8260000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
YEAR	2	1657.783240	828.891620	12.43	0.0035
REP	4	749.737760	187.434440	2.81	0.0997

REGWQ Grouping	Mean	N	YEAR
A	42.938	5	92
A			
A	34.824	5	91
B	17.716	5	93

---------- USM ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	703.0536667	117.1756111	3.87	0.0409
Error	8	241.9384933	30.2423117		
Corrected Total	14	944.9921600			

R-Square	C.V.	Root MSE	DUST Mean
0.743978	23.59810	5.499301	23.3040000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
YEAR	2	611.3670400	305.6835200	10.11	0.0065
REP	4	91.6866267	22.9216567	0.76	0.5806

REGWQ Grouping	Mean	N	YEAR
A	30.384	5	93
A			
A	24.616	5	91
B	14.912	5	92

---------- PULLER ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	774.2774133	129.0462356	1.05	0.4591
Error	8	980.1199600	122.5149950		
Corrected Total	14	1754.3973733			

R-Square	C.V.	Root MSE	DUST Mean
0.441335	55.84210	11.06865	19.8213333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
YEAR	2	434.8617733	217.4308867	1.77	0.2302
REP	4	339.4156400	84.8539100	0.69	0.6176

REGWQ Grouping	Mean	N	YEAR
A	26.290	5	92
A			
A	20.066	5	93
A			
A	13.108	5	91

APPENDIX 4

COMPARISON OF THE INDIVIDUAL OPERATIONS BY YEAR AND 3 YEAR AVERAGE

---------- YEAR=91 ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	23	8702.676153	378.377224	12.32	0.0001
Error	76	2333.702506	30.706612		
Corrected Total	99	11036.378659			

R-Square	C.V.	Root MSE	DUST Mean
0.788545	60.34954	5.541355	9.18210000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
OPER	19	8572.824859	451.201308	14.69	0.0001
REP	4	129.851294	32.462824	1.06	0.3836

REGWQ Grouping		Mean	N	OPERATION		SYSTEM
	A	44.744	5	10	UPROOTING	SUNDANCE
	B	18.398	5	16	MULCHING	USM
	B					
C	B	12.540	5	9	SHREDDING	SUNDANCE
C	B					
C	B	11.352	5	23	SHREDDING	MOD CONVENTIONAL
C	B					
C	B	10.892	5	1	SHREDDING	CONVENTIONAL
C	B					
C	B	10.680	5	21	MULCHING	PULLER
C	B					
C	B	10.626	5	25	RIP/LIST	MOD CONVENTIONAL
C	B					

C	B	9.562	5	26	MULCHING	MOD CONVENTIONAL
C	B					
C	B	9.096	5	11	RIP/LIST	SUNDANCE
C	B					
C	B	8.814	5	12	MULCHING	SUNDANCE
C	B					
C	B	8.276	5	7	MULCHING	CONVENTIONAL
C						
C		5.264	5	3	RIPING	CONVENTIONAL
C						
C		4.606	5	15	RIP/LIST	USM
C						
C		4.182	5	4	DISK 2	CONVENTIONAL
C						
C		3.602	5	24	DISK 1	MOD CONVENTIONAL
C						
C		3.558	5	2	DISK 1	CONVENTIONAL
C						
C		2.664	5	6	LIST	CONVENTIONAL
C						
C		2.428	5	20	RIP/LIST	PULLER
C						
C		1.612	5	14	USM	USM
C						
C		0.746	5	5	DISK HERB	CONVENTIONAL

---------- YEAR=92 ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	24	5593.349575	233.056232	15.08	0.0001
Error	80	1236.688248	15.458603		
Corrected Total	104	6830.037823			

R-Square	C.V.	Root MSE	DUST Mean
0.818934	44.95916	3.931743	8.74514286

Source	DF	Type I SS	Mean Square	F Value	Pr > F
OPER	20	5344.606543	267.230327	17.29	0.0001
REP	4	248.743032	62.185758	4.02	0.0050

REGWQ Grouping			Mean	N	OPERATION		SYSTEM
	A		30.080	5	10	UPROOTING	SUNDANCE
	B		19.960	5	25	RIP/LIST	MOD CONVENTIONAL
	B						
C	B		15.850	5	1	SHREDDING	CONVENTIONAL
C	B						
C	B		15.502	5	20	RIP/LIST	PULLER
C	B						
C	B	D	14.326	5	11	RIP/LIST	SUNDANCE
C		D					
C	E	D	11.328	5	23	SHREDDING	MOD CONVENTIONAL
C	E	D					
C	E	D	10.428	5	21	MULCHING	PULLER
C	E	D					
C	E	D	10.356	5	9	SHREDING	SUNDANCE

C		E	D					
C	F	E	D	8.580	5	15	RIP/LIST	USM
C	F	E	D					
C	F	E	D	7.934	5	7	MULCHING	CONVENTIONAL
	F	E	D					
	F	E	D	6.278	5	26	MUCLHING	MOD CONVENTIONAL
	F	E	D					
	F	E	D	5.854	5	12	MULCHING	SUNDANCE
	F	E						
	F	E		5.546	5	16	MULCHING	USM
	F	E						
	F	E		5.372	5	24	DISK 1	MOD CONVENTIONAL
	F	E						
	F	E		5.368	5	2	DISK 1	CONVENTIONAL
	F	E						
	F	E		3.880	5	4	DISK 2	CONVENTIONAL
	F	E						
	F	E		2.884	5	3	RIP	CONVENTIONAL
	F	E						
	F	E		2.798	5	6	LIST	CONVENTIONAL
	F							
	F			0.786	5	14	USM	USM
	F							
	F			0.360	5	19	BALER	PULLER
	F							
	F			0.178	5	5	DISK HERB	CONVENTIONAL

---------- YEAR=93 ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	24	4212.737956	175.530748	7.06	0.0001
Error	80	1988.012267	24.850153		
Corrected Total	104	6200.750223			

R-Square	C.V.	Root MSE	DUST Mean
0.679392	72.13277	4.984993	6.91085714

Source	DF	Type I SS	Mean Square	F Value	Pr > F
OPER	20	4019.087543	200.954377	8.09	0.0001
REP	4	193.650413	48.412603	1.95	0.1105

REGWQ Grouping			Mean	N	OPERATION	SYSTEM
	A		22.842	5	15 RIP/LIST	USM
	A					
	A		22.284	5	10 UPROOTING	SUNDANCE
	A					
B	A		13.126	5	6 LIST	CONVENTIONAL
B						
B	C		12.466	5	20 RIP/LIST	PULLER
B	C					
B	C	D	10.544	5	11 RIP/LIST	SUNDANCE
B	C	D				
B	C	D	8.876	5	25 RIP/LIST	MOD CONVENTIONAL
B	C	D				
B	C	D	7.218	5	9 SHREDDING	SUNDANCE
B	C	D				
B	C	D	6.664	5	21 MULCHING	PULLER

B	C	D					
B	C	D	6.352	5	16	MULCHING	USM
B	C	D					
B	C	D	6.058	5	1	SHREDDING	CONVENTIONAL
B	C	D					
B	C	D	4.962	5	3	RIP	CONVENTIONAL
B	C	D					
B	C	D	4.640	5	12	MULCHING	SUNDANCE
B	C	D					
B	C	D	4.406	5	23	SHREDDING	MOD CONVENTIONAL
B	C	D					
B	C	D	3.318	5	4	DISK 2	CONVENTIONAL
B	C	D					
B	C	D	2.296	5	24	DISK 1	MOD CONVENTIONAL
B	C	D					
B	C	D	2.150	5	2	DISK 1	COMVENTIONAL
B	C	D					
B	C	D	2.138	5	26	MULCHING	MOD CONVENTIONAL
B	C	D					
B	C	D	1.756	5	7	MULCHING	CONVENTIONAL
	C	D					
	C	D	1.190	5	14	USM	USM
		D					
		D	0.936	5	19	BALER	PULLER
		D					
		D	0.906	5	5	DISK HERB	CONVENTIONAL

---------- 3 YEAR AVERAGE ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	24	13382.03153	557.58465	14.46	0.0001
Error	285	10985.98761	38.54732		
Corrected Total	309	24368.01914			

R-Square	C.V.	Root MSE	DUST Mean
0.549164	75.12153	6.208649	8.26480645

Source	DF	Type I SS	Mean Square	F Value	Pr > F
OPER	20	13328.85429	666.44271	17.29	0.0001
REP	4	53.17725	13.29431	0.34	0.8475

REGWQ Grouping			Mean	N	OPERATION	SYSTEM
	A		32.369	15	10 UPROOTER	SUNDANCE
	B		13.154	15	25 RIP/LIST	MOD CONVENTIONAL
	B					
C	B		12.009	15	15 RIP/LIST	USM
C	B					
C	B	D	11.322	15	11 RIP/LIST	SUNDANCE
C	B	D				
C	B	D	10.933	15	1 SHREDDING	CONVENTIONAL
C	B	D				
C	B	D	10.132	15	20 RIP/LIST	PULLER
C	B	D				
C	B	D	10.099	15	16 MULCHING	USM
C	B	D				
C	B	D	10.038	15	9 SHREDDING	SUNDANCE
C	B	D				
C	B	D	9.257	15	21 MULCHING	PULLER

	C		B	D					
	C	E	B	D	9.029	15	23	SHREDDING	MOD CONVENTIONAL
	C	E	B	D					
F	C	E	B	D	6.436	15	12	MULCHING	SUNDANCE
F	C	E	B	D					
F	C	E	B	D	6.196	15	6	LISTING	CONVENTIONAL
F	C	E	B	D					
F	C	E	B	D	5.993	15	26	MULCHING	MOD CONVENTIONAL
F	C	E	B	D					
F	C	E	B	D	5.989	15	7	MULCHING	CONVENTIONAL
F	C	E		D					
F	C	E		D	4.370	15	3	RIPING	CONVENTIONAL
F		E		D					
F		E		D	3.793	15	4	DISK 2	CONVENTIONAL
F		E		D					
F		E		D	3.757	15	24	DISK 1	MOD. CONVENTIONAL
F		E		D					
F		E		D	3.692	15	2	DISK 1	CONVENTIONAL
F		E							
F		E			1.196	15	14	USM	USM
F									
F					0.648	10	19	BALER	PULLER
F									
F					0.610	15	5	DISK HERB	CONVENTIONAL

APPENDIX 5

RESULTS OF THE MARANA TESTS (1990-91)

---------- FIELD D1 ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	4024.752075	804.950415	1.90	0.2288
Error	6	2543.909817	423.984969		
Corrected Total	11	6568.661892			

R-Square	C.V.	Root MSE	DUST Mean
0.612720	26.63448	20.59090	77.3091667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SYST	2	528.113517	264.056758	0.62	0.5678
REP	3	3496.638558	1165.546186	2.75	0.1349

REGWQ Grouping	Mean	N	SYSTEM	
A	86.57	4	1	CONVENTIONAL
A				
A	73.95	4	2	SUNDANCE
A				
A	71.40	4	3	USM

---------- FIELD A4 ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	6751.329467	964.475638	2.12	0.1573
Error	8	3642.536627	455.317078		
Corrected Total	15	10393.866094			

R-Square	C.V.	Root MSE	DUST Mean
0.649549	20.60053	21.33816	103.580625

Source	DF	Type I SS	Mean Square	F Value	Pr > F
SYST	2	2210.394224	1105.197112	2.43	0.1500
REP	5	4540.935243	908.187049	1.99	0.1839

REGWQ Grouping	Mean	N	SYSTEM	
A	117.50	5	1	CONVENTIONAL
A				
A	105.04	6	2	SUNDANCE
A				
A	87.90	5	3	USM

---------- CONVENTIONAL ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	7906.073672	1581.214734	21.61	0.0147
Error	3	219.557350	73.185783		
Corrected Total	8	8125.631022			

R-Square	C.V.	Root MSE	DUST Mean
0.972980	8.245215	8.554869	103.755556

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FIELD	1	2125.234722	2125.234722	29.04	0.0125
REP	4	5780.838950	1445.209738	19.75	0.0171

REGWQ Grouping	Mean	N	FIELD
A	117.500	5	2 A4
B	86.575	4	1 D1

---------- SUNDANCE ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	4761.629373	793.604895	1.16	0.4905
Error	3	2055.465037	685.155012		
Corrected Total	9	6817.094410			

R-Square	C.V.	Root MSE	DUST Mean
0.698484	28.26511	26.17547	92.6070000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FIELD	1	2320.557660	2320.557660	3.39	0.1630
REP	5	2441.071713	488.214343	0.71	0.6553

REGWQ Grouping	Mean	N	FIELD	
A	105.04	6	2	A4
A				
A	73.95	4	1	D1

---------- USM ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	3132.607250	522.101208	1.16	0.4894
Error	3	1348.200200	449.400067		
Corrected Total	9	4480.807450			

R-Square	C.V.	Root MSE	DUST Mean
0.699117	25.89831	21.19906	81.8550000

Dependent Variable: DUST

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FIELD	1	728.365042	728.365042	1.62	0.2927
REP	5	2404.242208	480.848442	1.07	0.5107

REGWQ Grouping	Mean	N	FIELD
A	88.82	6	2 A4
A			
A	71.40	4	1 D1

APPENDIX 6

COMPARISON OF THE MARANA AND YUMA FIELDS

---------- CONVENTIONAL ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	8	30006.66806	3750.83351	11.10	0.0001
Error	15	5068.69432	337.91295		
Corrected Total	23	35075.36238			

R-Square	C.V.	Root MSE	DUST Mean
0.855491	30.06322	18.38241	61.1458333

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FIELD	4	28379.07132	7094.76783	21.00	0.0001
REP	4	1627.59674	406.89918	1.20	0.3497

REGWQ Grouping	Mean	N	FIELD
A	117.50	5	2 A4
B	86.57	4	1 D1
C	38.89	5	5 YUMA 92
C			
C	35.57	5	4 YUMA 91
C			
C	32.28	5	6 YUMA 93

---------- SUNDANCE ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	12304.17366	1367.13041	3.05	0.0275
Error	15	6729.34033	448.62269		
Corrected Total	24	19033.51400			

R-Square	C.V.	Root MSE	DUST Mean
0.646448	28.95835	21.18072	73.1420000

Dependent Variable: DUST

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FIELD	4	10963.69649	2740.92412	6.11	0.0040
REP	5	1340.47718	268.09544	0.60	0.7025

REGWQ Grouping		Mean	N	FIELD	
	A	105.04	6	2	A4
	A				
B	A	75.19	5	4	YUMA 91
B	A				
B	A	73.95	4	1	D1
B					
B		60.62	5	5	YUMA 92
B					
B		44.69	5	6	YUMA 93

---------- USM ----------

Dependent Variable: DUST

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	9	22999.36751	2555.48528	12.80	0.0001
Error	15	2995.74970	199.71665		
Corrected Total	24	25995.11722			

R-Square	C.V.	Root MSE	DUST Mean
0.884757	30.24568	14.13211	46.7244000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
FIELD	4	21909.04969	5477.26242	27.43	0.0001
REP	5	1090.31782	218.06356	1.09	0.4046

REGWQ Grouping	Mean	N	FIELD	
A	88.823	6	2	A4
A				
A	71.403	4	1	D1
B	30.384	5	6	YUMA 93
B				
B	24.616	5	4	YUMA 91
B				
B	14.912	5	5	YUMA 92

MIDWEST RESEARCH INSTITUTE

February 27, 1996

To: Dallas Safriet

From: Chat Cowherd

Subject: Meeting to Discuss Updates to AP-42 Sections on Agricultural Field Operations

---

On February 8, 1996, I met in Kansas City with the following individuals attending the first International Conference on Air Pollution from Agricultural Operations:

- Wayne Coates, Agricultural Engineer, University of Arizona
- Roger Isom, Director of Technical Services, California Cotton Ginners and California Cotton Growers Associations
- Sylvia Oey, District Liaison, California Air Resources Board
- Robert Matsumura, Staff Research Associate, University of California at Davis
- Phillip Wakelyn, Manager of Environmental Health & Safety, National Cotton Council

The purpose of the meeting was to exchange views on the procedure already initiated in updating the AP-42 section for agricultural tilling. A major concern of the group was that decisions on the need to control agricultural emissions from tilling operations have been based on a simplified emission factor equation that does not adequately reflect the technical complexity of the variety of operations and conditions that fall under the area of agricultural tilling.

It was the opinion of these individuals that the millions of dollars of field studies recently undertaken in the West will provide a more complete database and a set of improved emission factors. This, however, assumes that the recent and ongoing studies of agricultural tilling are based on sound testing strategies (methods and instruments). The investigators say that they are willing to provide all of the supporting data necessary to confirm the validity of the new emission factor measurements. Some investigators contend that portions of the data have already been offered.

Because of the importance of the new data in establishing whether prior emission inventories and control strategies based on the previous emission factor are valid, there was a strong opinion that a greater effort should be made by the EPA to contact the investigators and others interested in this field. This might be expedited by alerting such individuals through conferences such as the one where the subject meeting occurred.

The individuals present at this discussion recommended that in the AP-42 revision process a more thorough communications protocol should be followed, especially for factors that relate to source categories that are viewed by regulators as large contributors to non-attainment problems. This communications protocol would include (a) announcing that a pending revision (or new section) is forthcoming, (b) seeking and acquiring relevant test data, and (c) working with the investigators to evaluate the new data. Moreover, the industry that is the subject of any section should be consulted as to the most current description of relevant emission sources and controls.

I assured the group that, as a first step, I would prepare and submit to you this summary of what I believe to represent the thoughts of the group and distribute copies to them. The second step would be a continuation of the discussion with wider participation. Finally, it was asked whether EPA would reconsider its timetable for updating the agricultural tilling section and in the interim designate this section as "in progress."

EQUIPMENT MANUFACTURERS INSTITUTE
10 South Riverside Plaza • Chicago, Illinois 60606-3710 • 312 321-1470 • FAX 312 321-1480

May 6, 1996

Mr. Dale Shimp
California Air Resources Board
Emission Inventory Analysis Section
P.O. Box 2815
Sacramento, CA 95814

SUBJECT: CARB Agricultural PM Survey

Dear Mr. Shimp:

Recently we learned of the California Air Resources Board's survey of agricultural extension agents for the purpose of developing matrices containing "relative comparisons of dust production of an activity compared to discing." We were surprised (and concerned) that CARB, as a regulatory agency, would take such an unscientific approach for the purpose of creating a database that would be used for regulatory purposes. We know of no basis to accept that a random sample of extension personnel is a viable way to develop regulations.

The Equipment Manufacturers Institute (EMI) is the principal U.S. trade association representing manufacturers of agricultural field, farmstead and dairy equipment as well as industrial and construction equipment manufacturers. Earlier this year, we were contacted by the Midwest Research Institute to comment on a proposal whereby they plan to use the existing AP-42 emission factor equation for agricultural tillage equipment in combination with "best professional judgment," to create ratios to compare the amount of visible dust created by various tillage implements to one-way discs and sweeps. This work is being conducted for the federal EPA.

We strongly objected to their arbitrary approach and communicated that to our knowledge no scientific research had been conducted to substantiate this method of comparison. We also conveyed our thoughts that any report on fugitive dust generated by agricultural operations that would attempt to demonstrate a cause and effect relationship or a comparative analysis without adequate scientific basis is unacceptable.

It would appear that the CARB "Agricultural PM Survey" takes a similar approach to the MRI proposal. For the reasons mentioned above, we object in the strongest sense to this approach and feel that it is totally unacceptable for arbitrary value judgments by government personnel, or any others, who have no training or scientific background, to serve as the basis for establishing a database on particulate matter generated by agricultural operations.

We believe that it is important -- and that there is a strong willingness -- that the agricultural equipment industry and research community be included in the earliest phases of any information gathering or regulatory process CARB undertakes.

The prospect of regulatory initiatives related to particulate matter generated in agricultural and construction activities is of significant concern to EMI, our members and their user-customers. We are especially serious about this activity where limited and unqualified data would be used to "quantify" the situation, and even more perplexed when extemporaneously gathered data are used to "qualify" remedies!

EMI respectfully requests that all "survey" work by CARB be stopped until the scientific community has verified the nature of the situation and confirmed the efficacy of the research methods used to define the remedies. We would also encourage CARB to work closely with the U.S. Secretary of Agriculture and the Agricultural Air Quality Research Oversight Committee as it addresses air quality issues. The committee is a result of the 1996 "FAIR" Act, and will strive to determine the true extent to which agricultural activities contribute to air pollution and to determine cost-effective ways in which the agricultural industry can reduce any pollution that may exist.

We would be pleased to participate in an appropriate discussion group that would lead to a valid approach by CARB to investigate the role of fugitive particulate matter from agricultural and construction operations.

Sincerely,

Emmett Barker
EMI President

cc: Secretary Glickman
John Kautz
Bob Vice
Dallas Safriet
John Woodard

E:\Product Councils\Tillage & Crop Production Equipment Council\General\CARB Coments on PM Survey.doc

Enclosed for information

J. G. BOSWELL COMPANY
CALIFORNIA OPERATIONS

April 10, 1996

Mr. Darrin Drollinger
Equipment Manufacturers Institute
10 South Plaza, Suite 1220
Chicago, IL 60606

Darrin;

~~The airfare and hotel accommodation costs for the Des Moines meeting are attached to this letter.~~
I've also attached a copy of a survey letter sent to the agricultural extension service by the California Air Resources Board. The survey requests that the extension specialists rank field operations by 'dustiness' -- sound familiar?

Darrin, would EMI comment on the survey form to the California Air Resources Board? CARB did not solicit comment from the industry on this type of survey, and the extension service personnel had no idea how this data was going to be used. The farm interests object to this type of 'subjective' data collection being used to promulgate regulations.

Comments may be directed to:

Mr. Dale Shimp
California Air Resources Board
Emission Inventory Analysis Section
P.O. Box 2815
Sacramento, Ca. 95814
(916) 322-3807
http://www.arb.ca.gov/

Darrin, it was a pleasure participating in the tillage conference. EMI has demonstrated its leadership for the agricultural industry in regulatory issues, good luck.

Sincerely,

Dennis C. Tristao
Environmental Affairs Officer

U:\WINWORD\PM10\EMI1.DOC

Post Office Box 457 Corcoran, California 93212-0457 (209) 992-2141 FAX: (209) 992-3558

INSTRUCTIONS FOR FILLING OUT THE SURVEY

This survey only includes the crops that we believe are likely to cause the largest amounts of particulate matter pollution during certain agricultural activities. We are primarily interested in agricultural practices in the southern San Joaquin Valley, and especially the region in and around Kings County. Separate pages of the survey are devoted to each of the following crops:

CROP	CROP	CROP
Alfalfa	Rice	Carrots
Barley	Cotton	Tomatoes
Wheat	Sugar Beets	Lettuce
Sorghum	Dry Beans	Garlic
Field Corn	Onions	Cantaloupes
Safflower	Potatoes	

RELATIVE COMPARISON OF DUST PRODUCTION OF AN ACTIVITY COMPARED TO DISCING FOR THE SAME CROP

Please place check marks in the proper column to indicate how each activity for a given crop roughly compares in dustiness to the discing activity for the same crop. There is already one X in the table in the "Disc" row, since it is by definition equal to itself. The activities are for the most part in the order of their performance by the farmer.

There are spaces at the bottom of each overall activity category (e.g., land preparation) to allow you to specify additional activities where appropriate. If you disagree with data on the sheet, please feel free to mark up the survey sheet to indicate how you think the crop's farming operations should be depicted. The aim of this survey is to as accurately as possible depict the typical agricultural activities for each crop in the southern San Joaquin Valley.

Each crop's "dustiness" survey page also has a comments page attached. In your comments please indicate potential factors that mitigate or exacerbate the dustiness of a particular operation (e.g., soil moisture, incorporated vegetation, vegetative cover during operation, operation duration, etc.). Please feel free to use the margins on the back of the form if you need additional space for comments.

COTTON

Relative Comparison of Dust Production of an Activity Compared to Discing for the Same Crop

(Please Place Check Mark In the Appropriate Column to Indicate How Each Activity Compares in Relative Dustiness to Discing Activity for Cotton)

Activity to Compare in Relative Dustiness To Discing	Twice as Dusty or More	50 % Dustier	25% Dustier	Equally Dusty	3/4 as Dusty	1/2 as Dusty	1/4 as Dusty	Small Amount of Dust	Minimal or No Dust	Number of Passes for a Single Crop Cycle
Land Preparation										
Deep Rip							X			
Primary Discing				X						
Inc. Herbicide w/Disc				X						
Make Beds										
Make Ditch										
Close Ditch								X		
Planting										
Plant						X				
Cultivation										
Uncap Beds										
Cultivate								X		
Make Ditch							X	X		
Close Ditch										
Harvesting										
Harvest						X				
Postharvest										
Cut Stalks							X			
Cross-disc					X					

Bruce Roberts

COTTON

Comments (e.g. soil moisture, vegetation incorporation, dust reduced by crop vegetation)	
Land Preparation	
Deep Rip	
Primary Discing	
Inc. Herbicide w/Disc	
Make Beds	
Make Ditch	
Close Ditch	
Planting	
Plant	
Cultivation	
Uncap Beds	
Cultivate	
Make Ditch	
Close Ditch	
Harvesting	
Harvest	
Postharvest	
Cut Stalks	
Cross-disc	

INTEROFFICE COMMUNICATION

MIDWEST RESEARCH INSTITUTE

January 29, 1997

To: Tom Lapp

From: Chat Cowherd

Subject: Dale Shimp—Emission Factors for Agricultural Tilling

---

On January 24, 1997, I had a lengthy telephone conversation with Dale Shimp of the California Air Resources Board (ARB). The topics of the conversation related to recent developments in the PM-10 emission inventory process for agricultural field operations in the San Joaquin Valley.

ARB has just completed a revised PM-10 emission inventory for the San Joaquin Valley, as required for the PM-10 SIP. In order to refine the inventory for agricultural operations, consideration was given to all aspects of the emission calculations:

1. Emission factors (and associated correction parameters),

2. Source extent (with spatial and temporal resolution), and

3. Mitigation effects.

Delineation of these aspects of the emission inventory process for agricultural operations was aided by meetings with representatives of the growers (including Manual Cunha) in June and July of 1996. In these meetings, it was determined that approximately 20 crops would need to be considered, in order to account for 90% of the agricultural acreage in the San Joaquin Valley. These crops included cotton, corn, wheat, hay, citrus, almonds, grapes, tomatoes, beans, garlic, lettuce, melons, onions and safflower. The discussions focused on the types of farming operations required for each crop, the frequency of these operations, and the time of year these operations occur.

Emission Factors

Although agricultural field emission studies have been in progress with the San Joaquin Valley, including work led by Lowell Ashbaugh at UC-Davis, **no data on emission factors for land preparation have been released**. Therefore, the decision was made to stay with the current AP-42 predictive emission factor equation for agricultural tilling and to apply it to all land preparation activities. The AP-42 emission factor for agricultural tilling averages about 4 lb/acre. Except for walnut/ almond harvesting (~35 lb/acre), emissions for all other field operations were believed to be negligible in relation to land preparation. For example, emissions from cotton harvesting (mostly from shredding) are in the range of 1/4 lb/acre.

The most formidable problem in using the AP-42 equation for agricultural tilling was developing a database for silt content (dry basis) that could be related to USDA soil classification maps. For this purpose, Dale's group used data collected by Lowell Ashbaugh on comparative analyses of San Joaquin Valley soils. These soils were analyzed by both the wet sedimentation method (used by soil scientists and in USDA soil classification) and the dry sieving method specified in AP-42. Dale's technical approach to the conversion scheme followed a suggestion that I made in a memo to him on January 10, 1996 (copy attached). Dale's group was able develop an excellent stagewise correlation for converting wet silt to dry silt. Dale is sending me a paper that he has presented on this work.

However, when the USDA soil texture database for San Joaquin Valley was used in conjunction with the wet/dry silt conversion system, the predicted dry silt values for the soils tested by Lowell Ashbaugh were much higher than the values that he had measured by the AP-42 method. This problem was taken to USDA officials in California, resulting in the discovery of a systematic error in the soil texture database. When this error was corrected, the predicted dry silt values came to line very well with those measured by Ashbaugh.

Source Extent

With regard to the spatial distribution of agricultural lands with the San Joaquin Valley, GIS maps developed for tracking of water usage were found to provide an ideal source of data. The sequences of agricultural field operations for various crops were developed through deliberations of grower subgroups. These data were used to update the activity levels and seasonal profiles for the agricultural tilling emission category.

Most land preparation operations in the San Joaquin Valley are conducted in November and, to a lesser extent, December (before the rainy season). November alone accounts for one-third of the annual emissions from agricultural field operations. Even for the spring crops, operations such as land planing are performed in November.

Documentation

Dale expects to have the documentation for the revised ARB emission inventory procedure completed by about July 1, 1997. In the meantime, I am sure he is willing to provide whatever technical information we need to finalize the AP-42 section on agricultural tilling.

Attachment A

MIDWEST RESEARCH INSTITUTE

January 10, 1996

To: Dale Shimp, CARB

From: Chat Cowherd, MRI

Subject: Use of Silt Content as Predictor of Agricultural Soil Dustiness

---

As you know, most of EPA's predictive emission factor equations for fugitive dust sources (see Section 13.2 of AP-42, Fifth Edition) use **aggregate silt content** as a predictor of the dustiness of an exposed surface material. The aggregate silt content (as specified by the American Association of State Highway Officials) is defined as the amount of loose, dry material that passes a 200-mesh screen (75 micron opening) using conventional sieving according to ASTM Method C-136.

In MRI's original (1974) study[1] that advanced the earliest versions of the predictive emission factor equations, all of the equations except for one employed the aggregate silt content as a site-specific "correction parameter." The exception was the equation for agricultural tilling (based on tests in western Kansas), which used the **soil silt content** (i.e., particles between 50 μm and 2 μm) as determined by the Buoyocous hydrometer method.[2] The hydrometer method entails (a) placing the sample in a liquid column with a dispersing agent to disaggregate the clay (<2 μm) particles, and (b) timing the fall of particles through the column. Table 1 shows that the soil silt contents for the field tests of tilling emissions in Kansas were in the range of 26-49%.

The results of MRI's tests in Kansas were combined with subsequent (1980) MRI tests of agricultural tilling operations in California[3] to form the current AP-42 predictive emission factor equation for agricultural tilling. At that time the decision was made to use aggregate silt content (rather than the soil silt content) as the appropriate correction parameter. This decision was based on the proposition that soil dustiness should be represented by the actual rather than the disaggregated texture of the agricultural soil.

This made it necessary to estimate a value of aggregate silt content for each Kansas soil that was tested, so that aggregate silt content could be used as a correction parameter for both the California and Kansas tests. Unfortunately little documentation is provided in Reference 3 on the procedure used to convert Kansas soil silt values to equivalent aggregate silt values shown in Table 2.

In the original MRI report, one surface sample from a dirt road in Kansas was analyzed by both methods. As shown in Figure 1, wet separation increased the 0-75μm fraction from 68% to 76%. However, if the 50-75 μm fraction is removed, the 0-50μm content is about 70%. Finally the 0-2 μm (clay) fraction must be removed to yield the soil silt content. If the clay fraction is assumed to be about 10% for a road surface soil that is partially stripped of fine particles through the emission process, the soil silt content for the subject unpaved road surface material is estimated to be about 60%.

The above analysis shows that for the Kansas dirt road (or any source material with low clay content), the aggregate silt content is comparable to the soil silt content. However, because the clay content of the agricultural soils in Kansas ranged between 20 and 30%[1], the aggregate silt content is likely to be significantly larger than the soil silt content for each of these soils, as discussed below.

Because clay particles within an agricultural soil tend to be attached to coarse particles, and tend to form resistive clods, soils with high clay contents tend to have a much coarser texture than represented by the standard soil characterization using the hydrometer method. To assess the magnitude of this effect, two questions must be answered:

1. How much clay that is attached to dry-sieved particles in the 0-75 μm range would be removed by the hydrometer method and be "lost" from the aggregate silt fraction?

2. How much clay that is attached to >75 μm dry-sieved particles would (when removed by a dispersing agent) yield particles in the 2-50μm range?

The answers to these questions would require that a number of soil samples of various types and points in the tillage cycle be analyzed by both methods. As an aside, MRI may still have samples of the agricultural soils collected in the referenced studies.

I hope this information is helpful to you. I will be happy to discuss this topic with you further by telephone or when I come to Sacramento later this month.

References

1. C. Cowherd, Jr., et al., *Development of Emission Factors for Fugitive Dust Sources,* EPA-450/3-74-037, U.S. Environmental Protection Agency, Research Triangle Park, NC.

2. Buoyocous, G. J., *"Recalibration of the Hydrometer Method for Making Mechanical Analysis of Soils,"* Argon. J., 43, 434-438 (1951).

3. T. A. Cuscino, Jr., et al., *The Role of Agricultural Practices in Fugitive Dust Emissions,* California Air Resources Board, Sacramento, CA, June 1981.

Table 10. ESTIMATED VS ACTUAL EMISSIONS (Unpaved Roads)

Run	Site	Vehicle Speed (mph)	Percent Silt	Emission Factor (lb/vehicle-mile) Estimated	Emission Factor (lb/vehicle-mile) Actual	Percent Difference
1	R1	30	12	9.7	10.0	-3
2	R2	30	13	10.5	10.3	2
3	R2	40	13	14.0	13.9	1
8	R3	30	20[a/]	16.2	16.3	-1
10	R3	40	5[a/]	5.4	6.0	-10
13	R4	30	68	55.1	55.9	-1

a/ Estimated value

TABLE 40. DATA BASE FOR PREDICTIVE EQUATION DEVELOPMENT--
SOIL PREPARATION OPERATIONS

Run	Source	Silt (%)	Moisture (%)	Measured emission factors kg/km^2 (lb/acre) TP	IP	FP
N-3	Land plane	24.7	4.0	2,320 (20.7)	309 (2.76)	80.5 (0.719)
N-4	Land plane	24.7	4.0	2,600 (23.2)	291 (2.60)	116 (1.04)
N-5	Land plane	22.5	3.1	2,520 (22.5)	231 (2.06)	137 (1.22)
N-6	Disc	18.9	2.1	2,960 (26.4)	613 (5.47)	217 (1.94)
N-7	Disc	17.5	2.9	2,720 (24.3)	797 (7.12)	200 (1.79)
N-8	Disc	1.7	13.3	522 (4.66)	66.2 (0.591)	24.4 (0.218)
N-9	Disc	2.6[a]	12.6[a]	865 (7.72)	379 (3.38)	138 (1.23)
N-10	Disc	3.5	12.0	1,630 (14.6)	646 (5.77)	314 (2.80)
N-11	Disc	4.9	10.8	1,610 (14.4)	540 (4.82)	249 (2.22)
N-12	Disc	3.6	13.0	1,300 (11.6)	361 (3.22)	120 (1.52)
N-13	Disc	3.2	10.7	1,120 (9.98)	412 (3.68)	200 (1.79)
5[b]	Disc	54	10.5	6,270 (56)	-	-
6[b]	Disc	54	10.5	5,820 (52)	-	-
7[b]	Disc	54	10.5	6,720 (60)	-	-
9[b]	Disc	71	11.0	4,700 (42)	-	-
11[b]	Sweep plow	88	15.9	7,170 (64)	-	-
12[b]	Sweep plow	87	13.4	9,520 (85)	-	-
14[b]	Disc	73	12.3	8,740 (78)	-	-

[a] Assumed average of N-8 and N-10.

[b] Tests performed in Kansas (see Ref. 1).

Figure 1

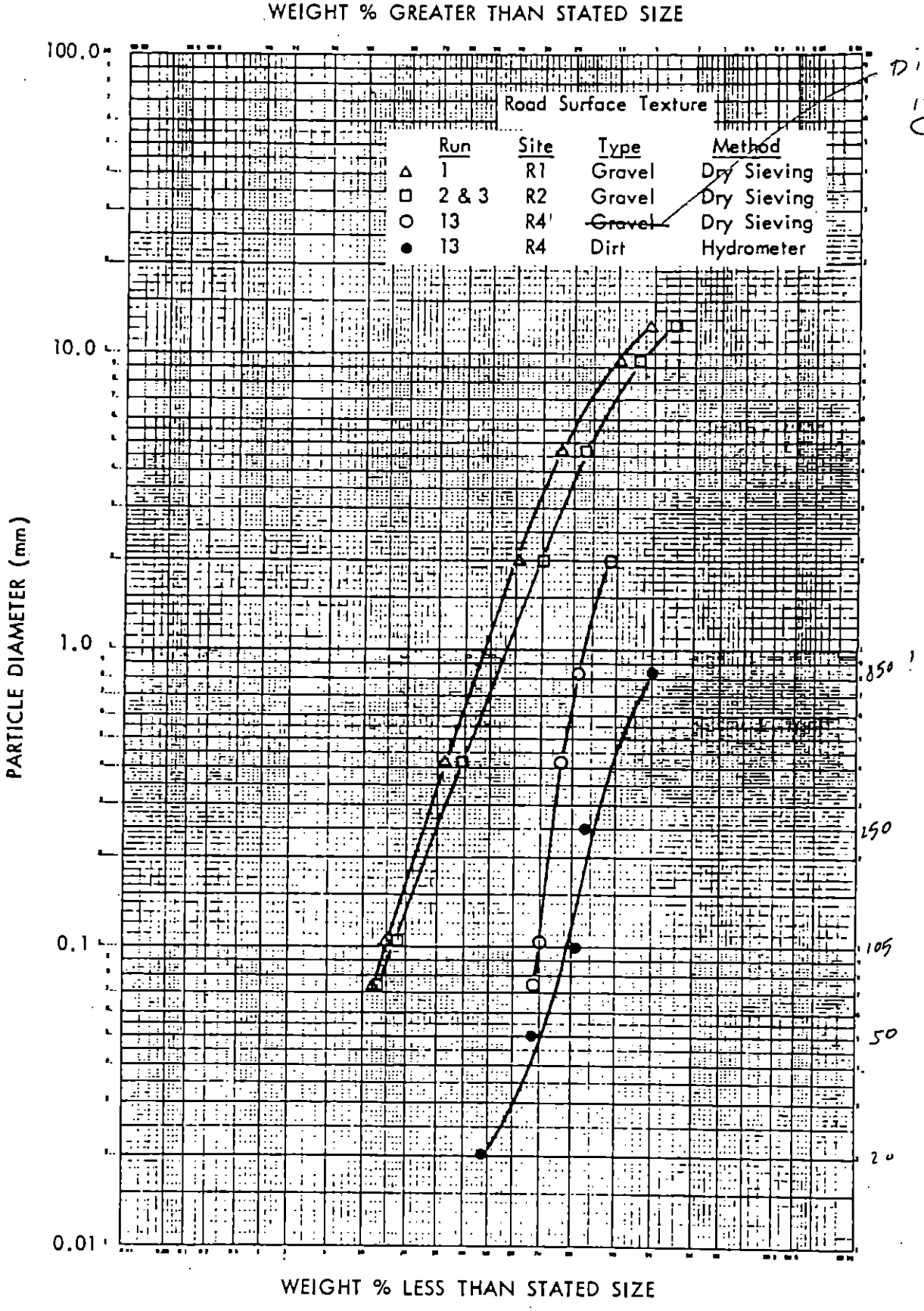

Figure 8. In-place road dust texture.

MRI FAX

MIDWEST RESEARCH INSTITUTE
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Date: 4/16/97

Telephone No. (816) 753-7600
FAX No. (816) 753-8430

Project or Overhead Charge No.: 0475

To: Dallas Safriet

From: Chat Conherd

This transmission consists of 16 pages (including cover

Receiving Facsimile Telephone No.: (919) 541-0684

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MRI Facsimile Machine: RAPICOM 610 (816) 753-8430 Group III

MRI Verification No.: (816) 753-7600, Ext. 1402

Message:

Dallas

Here is the marked-up copy of the letter. The areas where I made suggested changes are marked by a vertical line in the right margin.

I will be available today to discuss the letter.

Chat

Rec'd 9/29/95
R

THE UNIVERSITY OF
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September 16, 1994

Mr. D. W. Safriet
Environmental Engineer
United States Environmental Protection Agency
Emission Factor and Inventory Group
Research Triangle Park, NC 27711

Re: Draft Report entitled "Emission Factor Documentation for AP-42
Section 9.1 Tillage Operations" (dated July, 1995)

Dear Mr. Safriet,

I am very concerned that the proposed draft report is not only inaccurate, but also that it is incomplete and misleading. The following comments demonstrate this view.

1. On page 2-5 in the first paragraph of section 2.3, titled Emissions, the last sentence states "Dust emissions are greatest when the soil is dry and during final seedbed preparation."

If the first part of this statement is true (and I agree that it is) why then doesn't the emissions factor equation take into account moisture content? As for the second part of the statement - the assertion is very debatable. The emissions that are generated during final seedbed preparation depend upon many factors, not the least of which is the type of implement used. To make a blanket statement such as this is uniformed.

2. On page 2-5 the report goes on to say "The tilling parameters that have the potential for influencing the generation of fugitive dust include: 1. Dry texture of the surface soil." Why dry texture? What is their definition of texture? Is this the classic soil definition, or another? How do you define surface soil - 1 mm deep, 5 mm, etc? Such characterizations are meaningless since they are left open to individual interpretation.

3. On page 2-7 the same section lists other factors which influence emissions:
   - Moisture content of the surface soil - why surface soil only? what is meant by surface?
   - Depth of soil disturbed - why depth, some operations are very deep, 24 inches or more, but generate virtually no emissions.
   - Degree of soil disturbance - this once again is open to interpretation and therefore has no place in a technical document.
   - Speed of the equipment - if this is stated as being important, why is it not included as a variable in the emission factor equation.

4. On page 2-7 the authors state that emissions have been found to vary directly with silt content of the surface soil (depth of 0 to 10 cm). This statement is incomplete, and likely incorrect. When one states that emissions are a function of silt content, one also needs to state what condition the soil is in at the time that silt content is measured. Is it the silt content of the base soil material (that is, solely a function of its geologic makeup), is the silt content determined by screening of the soil prior to the passage of the implement, is it after the passage of the implement, or what? This is an imprecise statement, and hence should not be a part of a technical document.

5. On page 2-7 the authors once again state that soil dustiness is related to moisture content, yet the equation does not reflect this.

6. On page 2-7 they state that there is "no substantial dependence of emissions on the type of conventional tillage implement, if operating at a typical speed." First of all the authors say "no substantial" - this implies there is a dependence, and hence it needs to be included in the equation. Also the term "conventional tillage implement" is so vague that each of us could make our own interpretation of what it means, and we would all be correct. At the start of this section is the phrase "Available test data" - why should EPA use a very limited set of data, taken from a limited number of studies (only 2 - see page 4-1, and then only one of which was comprised of 7 tests to be used for the original AP-42 model) to penalize so many people. Other data are available. These should be used to broaden the data base, and to bring the equation closer to reality.

7. On page 2-7 the report talks about chemicals binding to the soil particles, etc. Has this any bearing on emission factors and the purpose behind this report?

8. On page 2-8 there is a lengthy discussion on wind erosion and particulate emissions. I am not saying this is not important, but of what relevance is this to the AP-42 equation. The equation deals with active emissions, wind events are passive events and need a separate discussion and document, or the title and focus of this one should be changed.

9. The table on page 2-9 makes little, if any sense. I will point out one example. Using a punch planter will not reduce emissions in itself. This is what the table implies. Planting of cotton is an inherently dust free operation - decreasing emissions from near zero, to zero is an insignificant event.

10. The many descriptions of the equipment given on page 2-10 are interesting, to say the least. One example I would like to comment on is the statement "The laser-directed land plane is a novel implement..." I do not know what is novel about this implement. It is commonly used in Arizona, and has become an almost routine operation on many farms. Such a statement lends little credence to the authors' knowledge of agricultural operations.

11. The references cited on pages 2-11 and 2-12 are very limited, many coming from the same source (MRI), and are badly outdated. I think a much more comprehensive review of literature by someone who has a working knowledge of agriculture could greatly increase the value of this report.

12. On page 3-5 the authors state that two basic techniques for the field measurement of fugitive mass emissions have been defined. Why are these not referenced? Who established these definitions? Were they based on valid, documented scientific studies? Why are not other, newer methodologies not equally acceptable?

13. On page 4-1 the authors state that beyond the 2 studies cited, that only one other test was identified. I will submit that the authors did little to search out other studies. They, MRI, were offered access to our data (University of Arizona/Arizona Department of Environmental Quality), but failed to request it, much less even inquire about the type of information we have. Perhaps they are not interested in getting to the bottom of the question of dust emissions from agricultural operations. When our data, as well as that from California, indicate an order of magnitude difference in emissions from MRI's, I think that EPA needs to re-examine the validity of MRI's data.

14. On page 4-3 there is a discussion of two series of tests, one of which was comprised of 11 tests, the other 7. The authors give these tests A and B ratings. This is very hard to understand given the wide range of parameters cited under which the tests were conducted (table 4-1). When moisture contents ranged from 2.1 to 15.9, and silt contents ranged from 1.7 to 88 percent, it incomprehensible how 18 tests could come even close to covering the range in emissions that could be encountered over such a wide range of operating conditions. Given this scenario, it is understandable how the authors concluded that moisture content had no effect on emissions. They simply did not have enough data to determine its effect.

15. On page 4-4 the authors downgrade the California data to a rating of E "because only one site was tested in developing each factor." Given that the original data which was used to develop AP-42 used seven tests, and this is being used to predict emissions for all agricultural tilling operations across the United States, I would not classify this evaluation as technically sound.

16. On page 4-6 the authors state that equation 1 is rated A if used to estimate total particulate emissions. Our field data shows an order of magnitude difference with these data. Our tests were run over three seasons, with each test replicated five times. It would appear that the A rating is given only because it conforms to their practices.

17. On page 9.1-3 the authors once again refer to "novel low-disturbance implements." This is such a vague term that it is impossible to understand what is meant. A second point worthy of mention is that there are a number of implements which are low disturbance, to put it in the words of the authors, that are not novel in any way. Many have been in use for many years.

I would like to close by pointing out:

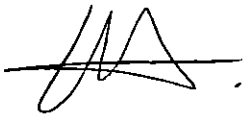
A. We offered to provide our data to MRI upon request, with a description of how the data would be used in their effort to revise the AP-42 emission factor model. They never contacted me, thus our work is not included, much less considered in their work.

B. A member of MRI staff was at a PM-10 workshop held in Lubbock in May that was set up to discuss emissions from agricultural tilling. It was suggested during that meeting that draft copies of the revised AP-42 standard be sent to those in attendance for comment, since these people essentially represented all of the people currently working in, or who had a genuine interest in, the topic. The fact that I received a copy of the draft from D. Drollinger at EMI, not from either MRI or EPA, indicates to me that every opportunity to gain valid technical comments on the revised document was not taken. This indicates that the attempt at revision was only just that, an attempt. EPA needs to seriously consider rejecting the report offered by MRI, then locating others who can provide much more accurate and knowledgeable information about agricultural tilling practices and their influence on emissions.

C. I recently received information from EPA that indicates that MRI has been paid over three million dollars for emission inventory work. Given the poor quality of the work presented in this draft document, I would suggest that this contract be re-examined, and alternative agencies be sought for any additional work required by EPA.

Please do not hesitate to contact me if you have any questions. My goal in writing this letter is simply to point out that the current, and hence future AP-42 equation is inaccurate and needs to be either eliminated, or to be enhanced to the point that it has some semblance of scientific merit.

Sincerely,



Wayne Coates,
Professor

cc: D. Drollinger

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Phone #	Phone #	
Fax #	Fax #	

Dr. Wayne Coates
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Tucson, Arizona 85706

Dear Dr. Coates:

I have completed my review of your memorandum to the Equipment Manufacturers Institute, dated November 18 1996, and your paper published in the Transactions of the ASAE. In addition, I have reviewed the two MRI test reports cited as the data sources used to generate the current AP-42 emission factor equation for tilling operations. This letter primarily addresses the content of your memorandum to the Equipment Manufacturers Institute. There are several comments in your memorandum regarding the AP-42 emission factor equation that I would like to address.

1. **Comment**. Only Total Suspended Particulates (TSP), and not PM-10 or any other size range is discussed, since the current AP-42 equation has been given an "A" rating if used to estimate total particulate emissions but only a "B" rating if used to estimate emissions for a specific particle range. Thus additional inaccuracies exist for the other particle sizes, as has been acknowledged by MRI.

Response: The difference in the rating of the AP-42 equation for Total Suspended Particulate (TSP) emissions and estimated emissions for specific particle size range results from the relative quantity of available data. Test data in the early to mid-1970's was focused principally on TSP with few data on specific particle sizes. Because the emission estimates for specific particle sizes were based primarily on the 1981 data (a smaller data set than for TSP), the factor rating was lowered to a "B" rating.

2. **Comment**. This report does not question the validity of MRI's measurement processes from a technical standpoint, that is in terms of positioning of the collection devices, taking of samples, meteorological conditions that existed during the tests, etc. Rather, this discussion assumes that MRI's technical expertise in this area is adequate for the tasks performed.

Response: As discussed in Section 3 of the background report to draft AP-42 Section 9.1, Tilling Operations, EPA currently feels that profiling is a better measurement technique than the upwind-downwind technique.

3. **Comment**. Table 1 summarizes the data that were used to generate the current AP-42 emission factor equation for tilling operations, and presents any other pertinent information, all of which is extracted from the two MRI reports (MRI 1974, 1981). Based on several discrepancies found within and between the two

reports, the accuracy of these two reports is in question. For example:

a. depth information for soil moisture content is inconsistent within the 1974 report

b. width of implements listed in the 1981 report varies from one section to another

c. silt content values given for the 1974 data are different in the two reports

d. soil samples taken in 1981 were "several shovelfuls" vs. plugs in 1974

Response:

a. On page 51 of the 1974 report, it states that core samples of 4 in. and 6 in. depths were obtained so that moisture content as a function of depth could be analyzed (see Table 17 on page 61 of the report).

b. As stated in Table 11 (page 51) of the 1981 report, the width of implements for all but one of the thirteen exposure profiling tests was 4.9 m (16 ft); the width of the other implement was 6.4 m (21 ft).

c. In the 1981 report, silt content based on dry sieving was used as the measure of soil "dustiness," to be consistent with the other emission factor equations for fugitive dust sources. Thus, it was necessary to develop estimates of dry silt content (<200 mesh) for the agricultural tilling tests contained in the 1974 report, which originally used the conventional wet soil texture analysis.

d. On page 45 of the 1981 report, it states that "shovelfuls of soil collected to a depth of approximately 15 cm (6 in.) were composited for analysis. For disturbed soil, the texture of the soil is probably not very sensitive to depth in the 4 in. to 6 in. range.

4. **Comment**. Also from Table 1 it can be seen that a limited number of implements (4 in total) were used in the test programs, hence extrapolation of the data to implements in general is questionable. Furthermore, a limited number of sites were used in the test program (6 in total). This further brings into question the validity of using the data to predict tilling emissions over a broad range of conditions. Another significant concern is that part of the California data was collected using a tracked tractor, while a wheeled tractor was used at the second site. This could have influenced the emissions, but does not appear to have been taken into account.

Response: While more test sites and implements are always desirable, the statistical results in the 1981 report showed that a single emission factor equation for dust emissions from tilling operations is viable as a predictive tool for emission inventory purposes. Also, because most dust is generated by the tilling implement, the effect of a tracked vehicle is expected to be minor.

Based on available data, a single equation still provides a reasonable fit for most types of equipment. There are insufficient data available to support new equations for reduced energy operations (e.g., conservation tilling).

5. **Comment**. Because the AP-42 equation was developed by MRI from measured silt and TSP data which are contained in the 1981 report, this author performed a regression analysis to develop two equations from the data in the 1981 report. This analysis was undertaken to verify that the data presented in the 1981 report were what had been used to develop the AP-42 equation and to determine if a linear equation could represent the data equally as well as a log-log equation. The two equations are:

$$\text{TSP (lb/ac)} = 8.04 + 0.77 * \text{silt content (\%)} \quad R^2 = 0.77$$

the linear equation

$$\text{TSP (lb/ac)} = 4.65 * (\text{silt content (\%)})^{0.59} \quad R^2 = 0.92$$

the log-log equation

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Note that the log-log equation is very similar to the AP-42 equation:

$$TSP\ (lb/ac) = 4.80 * \text{silt content}\ (\%)^{0.60} \quad R^2 = 0.94$$

It is unclear why the log-log equation developed by this author from the data in the MRI report does not completely agree with the AP-42 equation. A possibility could be rounding of the numbers provided in the report. Figure 1 presents a plot of the raw data from the MRI report, as well as the three regression equations referred to above.

Response: Your equation closely reproduces the regression equation in the 1981 report. There is only a 3 percent difference in the coefficient and this is generally ~~insufficient~~ insignificant within the overall scope of this type of experimental data.

6. **Comment**. The greatest area of concern relates to the Kansas data. The silt values used for the Kansas data are the sum of silt and clay as determined using the Buoyocous hydrometer method. This method of analysis is routinely used to determine soil texture but is not the EPA approved method to be used for determining silt content for the AP-42 equation. Using the textural classification procedure assumes that no conglomeration of the soil existed. This is highly unlikely, particularly for the clay fraction. Given the data presented in the 1974 and 1981 reports, it is not possible to arrive at a correct value for silt

content, as this is to be determined by mechanically sieving soil samples, with the fractions smaller than 200 mesh (75 µm) being the silt content. Thus the Kansas data should not be used in the regression.

If the Kansas data are excluded, the AP-42 equation becomes:

$$TSP\ (lb/ac) = 8.66 + 0.66 * \text{silt content}\ (\%) \quad R^2 = 0.78$$

the linear equation

$$TSP\ (lb/ac) = 5.51 * \text{silt content}\ (\%)^{0.48} \quad R^2 = 0.84$$

the log-log equation

The range of silt contents over which these equations are valid is the range for which there is data (i.e., 1.7 to 24.7 percent), not 1.7 to 88 percent as is the case for the current AP-42 equation. Figure 2 presents plots of the raw data and the two equations, along with the AP-42 equation. Clearly, the current AP-42 equation over predicts emissions.

Response: As stated in a response to an earlier comment, the dry silt content (<75 µm) has traditionally been used as the most appropriate measure of soil dustiness. The only exception was agricultural tilling in the original (1974) report. For purposes of combining the Kansas and California data sets in the 1981 report, the agricultural silt values in the 1974 report were converted to equivalent dry silt values, by taking the 0-75 µm fraction from Figure 14 (page 62) of the 1974 report. [Note that

the vertical scale in Figure 14 should be shifted by a factor of 10; e.g., 0.01 mm becomes 0.001 mm].

Combining the Kansas and California data sets adds to the credibility of the predictive emission factor model for agricultural tilling. With regard to Figure 2, it is not surprising that the best fit equation for only the California data is different from the best fit equation for the combined data set.

It should be remembered that the rationale behind AP-42 is that it is to be used as a top-down process. The AP-42 was not designed for specific areas. It is used to estimate emissions for entire states or regions, not a specific site. AP-42 can be used for those instances where no other data for certain areas are available; however, if data for specific areas are available, it is always preferable to use the specific data.

The utility of this particular AP-42 could be enhanced by including the data for a new area (Arizona) if you would provide the information I have requested so your data could be integrated with the other data.

7. **Comment**. Using only the California data poses additional problems since the data now really can be represented by two groupings of data in terms of soil silt content, one centered at approximately 3 percent the other at 20 percent.

This does not provide a sound basis on which to develop a regression equation.

Response: This is exactly the rationale for combining the data sets of California and Kansas.

8. **Comment**. If the Kansas data are excluded from the analysis process, another very important factor comes into play. That is, the remaining data show a strong correlation between moisture content and tilling emissions. The equation is:

$$TSP\ (lb/ac) = 28.31 - 1.48 * \text{moisture content } (\%) \quad R^2 = 0.89$$

a linear equation

A plot of these data are shown in Figure 3 along with the regression equation.

This finding is contrary to what is stated by MRI for the current AP-42 emission factor equation, that is moisture content had no relationship to emissions (MRI, 1981). This further demonstrates that the data from Kansas should not have been used for development of the equation, and that the equation should be revised to include both silt content (as determined by the approved EPA method) and moisture content as variables. Since speed of operation was not listed for the California data it is not possible to say whether or not a similar situation exists.

that is if speed of operation also is strongly correlated with emissions.

Response: Except for the California data set collected from the alfalfa fields, the moisture content for the rest of the tests in the combined data set fit a relatively tight range. This probably explains why no significant correlation of emissions with moisture content was found in the combined data set. The more limited California data set provides a much stronger moisture variation, which is correlated with emissions. However, the relationship based on California data only (as you have already pointed out) is very restricted in its applicability.

In theory, the inclusion of soil silt content and moisture content into the equation as variables may have some rationale. However, the practicality of this is questionable. Any correction parameter must be readily available and applicable for wide range of areas over the entire country in order for the AP-42 equation to be useful for emission inventory purposes. The estimation of soil moisture content over States and regions would be a major problem.

9. **Comment**. Figure 4 presents a plot of MRI's California data (MRI, 1981), plus additional California data (Flocchini, 1994) and the two extreme data points in terms of emissions that were determined from Arizona trials (Coates, 1996)., Clearly

there is a significant discrepancy between 1981 data, and recent tests by other researchers. If all of the Arizona data were plotted on Figure 4, they would show that for a silt content of approximately 5 percent, a large range in emissions were recorded, varying from 0.6 to 32 lb/ac. Such data indicate that different implements generate different amounts of emissions, and hence one equation cannot be used for all implements.

In the case of the 1994 California data, each data point represents 3 tests for each implement, but the data have been discounted by MRI (MRI, 1995), while the Arizona data represents 15 passes, the Arizona data clearly are equivalent to MRI's data and should not be ignored, as MRI has chosen to do.

Response: When considering the level of agreement between any new measured emission factors and the predictions of the AP-42 equation, enough detail in each respective test report must be presented so that the reliability of the measured emission factors can be evaluated independently. Such was not the case for the Flocchini (1994) report, for reasons stated in the draft AP-42 background document. Based on the experimental design, Flocchini essentially used an upwind-downwind technique which is not the preferred sampling scheme. Nonetheless, except for two tilling operations of a less intensive nature, there is very good agreement with AP-42. Even the stubble discing and chiseling operations are within a factor of 3 agreement with AP-42. Again, the purpose of AP-42 is to provide an estimating tool for

emission inventory purposes so that, on average, reliable area-wide emission estimates can be determined. It is not the purpose of AP-42 to be used for relatively small specific sites unless absolutely no other data are available and the use of AP-42 is appropriately caveated.

With regard to your Arizona data (Coates, 1996), Table 5 of your report shows agreement with AP-42, within a factor of about two. It is not unexpected that the reduced tillage systems that you tested in Arizona would be over predicted by AP-42. One of the challenges of agricultural emission inventories is to scale various lower energy operations to conventional tillage as a reference level for which AP-42 is most applicable.

Finally, with regard to your Arizona results, I have previously discussed with you that more detail is needed on the calculation scheme for generating the emission factors from the raw field data. For example, no information is provided on the individual point values of particulate concentration (or flux) across the sampling array. Of critical importance is the demonstration that all of the plume mass is accounted for, especially in situations when crosswinds are encountered. In principle, your plume profiling strategy used in Arizona appears quite valid, if data are presented to ensure that the entire plume was within the sampling array.

10. **Comment**.

a. Based on the information presented in this report, the current AP-42 equation should be withdrawn.

b. All of the raw data that were used to generate the equation should be made available to an independent organization. These data should be reanalyzed to determine whether or not additional problems exist, that could not be examined given the limited amount of information contained in the reports.

c. Additional tests need to be performed over a far broader range of field conditions and implement types, to arrive at a more accurate emission factor equation. The revised equation should also incorporate moisture and implement speed, along with silt content, or show cause for exclusion.

Response:

a. The current equation retains its usefulness for predicting conventional tilling operations which impart high disturbance to the soil. As with any AP-42 emission factor, revisions should be made, as necessary, whenever new data with sufficient documentation are added to the database.

b. This comment is entirely appropriate, as long as the independent organization is fully experienced in relevant field activities and has no vested interest in the results of the evaluation.

c. This comment is also entirely appropriate. Any time new data can be added to the database, regression analysis should again consider all relevant source conditions as potential correction parameters for any updated emission factor equation. As I have stated previously, not all new variables can be added to the equation because of data availability over a wide area or region. Additionally, I have also stated that AP-42 is not intended for specific sites but is used to estimate emissions over States or regions.

Because few data are available, there is a real need to share data in order to provide the best information available. I have requested data from Dr. Lowell Ashbaugh on two separate occasions but received no response.

With respect to the current AP-42 equation, clearly it is not a perfect equation that fits all possible scenarios. At the present time, the existing equation does provide a good estimate of emissions for intensive tilling operations that result in significant soil disturbance. Certainly the equation is open to modification and improvement as new data become available. The

agency will make every effort to incorporate new test results that have been validated. As the overall database increases, refinements can be made to the equation to allow more accurate predictions over a wider scope of tilling operations.

I would like to thank you for the submission of this information for my review and consideration. As I have stated to you in previous correspondence, AP-42 sections are "living documents" and are periodically updated as significant new test data become available. I have also stated previously that if you would provide the requested background data for your tests, the agency would incorporate your results, to the extent possible, in the AP-42 emission factor equation.

Please direct any comments or questions you may have to me. My address is the U. S. Environmental Protection Agency, Emission Factor and Inventory Group (MD-14), Research Triangle Park, North Carolina 27711. My telephone number is (919) 541-5371 and my fax number is (919) 541-0684.

Sincerely,

Dallas W. Safriet
Environmental Engineer
Emission Factor and Inventory Group

From: BILL HARNETT
To: RTP10.RTPTSD.SAFRIET-DALLAS, RTP10.RTPTSD.MISENHEI...
Date: 4/20/97 9:42am
Subject: Ag Tilling Factors

Sally and I have reviewed your response to the paper from Wayne Coates on the emission factors for Ag Tilling. This is an extremely sensitive issue right now within the Agriculture Air Quality Task Force and with the revision of the proposed PM standards. Rather than a detailed point by point response we recommend that you respond by indicating a willingness to meet with him to discuss his report and your review of it and a willingness to work with him toward the development of improved emission factors for Ag Tilling.

I am in DC on Monday but Sally is in durham if you have questions.

CC: RTP10.RTPTSD.HUNT-BILL, RTP10.RTPTSD.MOBLEY-DAVID,...

9.30
4-2-97

MRI Memo

To: Tom Lapp

From: Chat Cowherd

Date: March 26, 1997

Subject: Comment/Response Log for the Wayne Coates Report

Attached is my comment/response log for the report, "AP-42 Emission Factor Equation for Tilling Operations: Critique and Recommendations," by Wayne Coates of the University of Arizona. Hopefully this log should provide the basis for EPA's response to his report within the context of finalizing the draft revision to the AP-42 section on agricultural tilling. Without the detailed data that even he admits is needed for independent review, it is impossible to determine why his measured TSP emission factors for agricultural tilling are generally lower than AP-42 predictions. There are at least two possible contributing factors:

1. His plume profiling procedure does not account for the full extent of the dust plume.

2. The operations that he tested disturb the soil less than the baseline operations associated with conventional tilling, as used in developing the current AP-42 emission factor equation.

I look forward to discussing these issues with you and Dallas.

Post-it® Fax Note 7671	Date 3/27	# of pages ▶ 9
To DALLAS SAFRIET	From T. LAPP	
Co./Dept. EFIG/MD-14	Co. MRI	
Phone #	Phone #	
Fax #	Fax #	

MRI-V4

COMMENT/RESPONSE LOG for
"AP-42 Emission Factor Equation for Tilling Operations: Critique and Recommendations"
by Wayne Coates, University of Arizona

Comment	Response
This report summarizes the problems that appear to exist with the development of the current AP-42 equation by Midwest Research Institute (MRI). Available documentation indicates that errors were made when the equation was developed. The resultant inaccuracies, combined with other discrepancies in two relevant MRI reports, indicate that the AP-42 equation cannot accurately predict emissions from tilling operations.	These general comments are best addressed in terms of responses to the specific comments given below.
Only Total Suspended Particulates (TSP), and not PM-10 or any other size range is discussed, since the current AP-42 equation has been given an "A" rating if used to estimate total particulate emissions but only a "B" rating if used to estimate emissions for a specific particle range. Thus additional inaccuracies exist for the other particle sizes, as has been acknowledged by MRI.	As stated in the proposed AP-42 section, the "B" rating applies to use of the emission factor equation for a specific particle size range.
This report does not question the validity of MRI's measurement processes from a technical standpoint, that is in terms of positioning of the collection devices, taking of samples, meteorological conditions that existed during the tests, etc. Rather, this discussion assumes that MRI's technical expertise in this area is adequate for the tasks performed.	No response is needed.

MAR.27.1997 10:37AM MIDWEST RESEARCH NC NO.620 P.2/9

Comment	Response
Table 1 summarizes the data that were used to generate the current AP-42 emission factor equation for tilling operations, and presents any other pertinent information, all of which is extracted from the two MRI reports (MRI 1974, 1981). Based on several discrepancies found within and between the two reports, the accuracy of these two reports is in question. For example: - depth information for soil moisture content is inconsistent within the 1974 report - width of implements listed in the 1981 report varies from one section to another - silt content values given for the 1974 data are different in the two reports - soil samples taken in 1981 were "several shovelfuls" vs. plugs in 1974	- On page 51 of the 1974 report, it states that core samples of 4 in. and 6 in. depths were obtained so that moisture content as a function of depth could be analyzed (see Table 17 on page 61 of the report). - As stated in Table 11 (page 51) of the 1981 report, the width of implements for all but one of the thirteen exposure profiling tests was 4.9 m (16 ft); the width of the other implement was 6.4 m (21 ft). - In the 1981 report, silt content based on dry sieving was used as the measure of soil "dustiness," to be consistent with the other emission factor equations for fugitive dust sources. Thus, it was necessary to develop estimates of dry silt content (<200 mesh) for the agricultural tilling tests contained in the 1974 report, which originally used the conventional wet soil texture analysis. - On page 45 of the 1981 report, it states that "shovelfuls of soil collected to a depth of approximately 15 cm (6 in.) were composited for analysis. For disturbed soil, the texture of the soil is probably not very sensitive to depth in the 4 in. to 6 in. range.

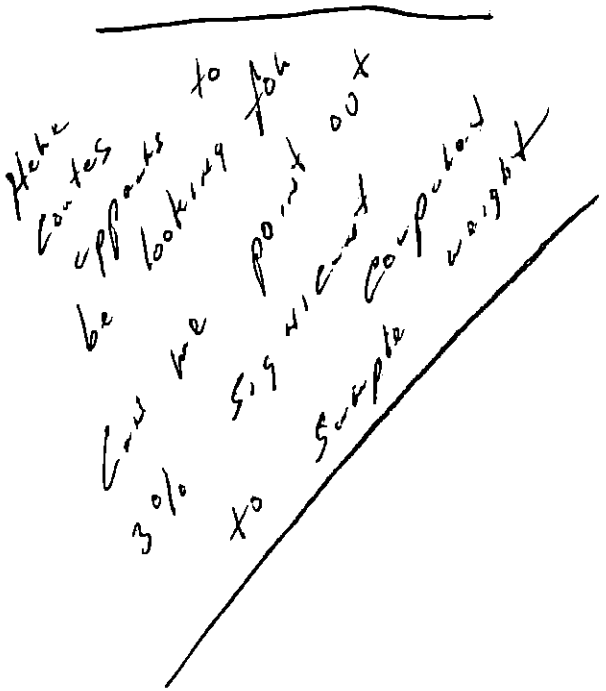
I don't have report #D° You Tom

Did you make conversions from 74 report x 81 report x 80 x 80 could be averaged

MAR.27.1997 10:37AM MIDWEST RESEARCH NC NO.620 P.3/9
11:44 25 97 10:57PM 6R1-PARTICIUM P.3/9

Comment	Response
Also from Table 1 it can be seen that a limited number of implements (4 in total) were used in the test programs, hence extrapolation of the data to implements in general is questionable. Furthermore, a limited number of sites were used in the test program (6 in total). This further brings into question the validity of using the data to predict tilling emissions over a broad range of conditions. Another significant concern is that part of the California data was collected using a tracked tractor, while a wheeled tractor was used at the second site. This could have influenced the emissions, but does not appear to have been taken into account.	While more test sites and implements are always desirable, the statistical results in the 1981 report showed that a single emission factor model for dust emissions from tilling operations is viable as a predictive tool for emission inventorying purposes. Also, because most dust is generated by the tilling implement, the effect of a tracked vehicle is expected to be minor.

MAR.27.1997 10:38AM MIDWEST RESEARCH NC NO.620 P.4/9

Comment	Response
Because the AP-42 equation was developed by MRI from measured silt and TSP data which are contained in the 1981 report, this author performed a regression analysis to develop two equations from the data in the 1981 report. This analysis was undertaken to verify that the data presented in the 1981 report were what had been used to develop the AP-42 equation and to determine if a linear equation could represent the data equally as well as a log-log equation. The two equations are: TSP (lb/ac) = 8.04 + 0.77*silt content (%) $R^2 = 0.77$ *the linear equation* TSP (lb/ac) = 4.65*silt content (%)$^{0.59}$ $R^2 = 0.92$ *the log-log equation* Note that the log-log equation is very similar to the AP-42 equation: TSP (lb/ac) = 4.80*silt content (%)$^{0.60}$ $R^2 = 0.94$ It is unclear why the log-log equation developed by this author from the data in the MRI report does not completely agree with the AP-42 equation. A possibility could be rounding of the numbers provided in the report. Figure 1 presents a plot of the raw data from the MRI report, as well as the three regression equations referred to above.	The commenter has closely reproduced the regression equation in the 1981 report. There is a 3% difference in the coefficient. [We could repeat the analysis to check for this small difference.] 

MAR. 27. 1997 10:38AM MIDWEST RESEARCH NC NO. 620 P. 5/9

Comment	Response
The greatest area of concern relates to the Kansas data. The silt values used for the Kansas data are the sum of silt and clay as determined using the Buoyocous hydrometer method. This method of analysis is routinely used to determine soil texture but is not the EPA approved method to be used for determining silt content for the AP-42 equation. Using the textural classification procedure assumes that no conglomeration of the soil existed. This is highly unlikely, particularly for the clay fraction. Given the data presented in the 1974 and 1981 reports, it is not possible to arrive at a correct value for silt content, as this is to be determined by mechanically sieving soil samples, with the fractions smaller than 200 mesh (75 μm) being the silt content. Thus the Kansas data should not be used in the regression. If the Kansas data are excluded, the AP-42 equation becomes: TSP (lb/ac) = 8.66 + 0.66*silt content (%) $R^2 = 0.78$ *the linear equation* TSP (lb/ac) = 5.51*silt content (%)$^{0.48}$ $R^2 = 0.84$ *the log-log equation* The range of silt contents over which these equations are valid is the range for which there is data (i.e., 1.7 to 24.7 percent), not 1.7 to 88 percent as is the case for the current AP-42 equation. Figure 2 presents plots of the raw data and the two equations, along with the AP-42 equation. Clearly, the current AP-42 equation over predicts emissions.	As stated in a response to an earlier comment, the dry silt content (<75 μm) has traditionally been used as the most appropriate measure of soil dustiness. The only exception was agricultural tilling in the original (1974) report. For purposes of combining the Kansas and California data sets in the 1981 report, the agricultural silt values in the 1974 report were converted to equivalent dry silt values, by taking the 0-75 μm fraction from Figure 14 (page 62) of the 1974 report. [Note that the vertical scale in Figure 14 should be shifted by a factor of 10; for example, 0.01 mm becomes 0.001 mm]. Combining the Kansas and California data sets adds to the credibility of the predictive emission factor model for agricultural tilling. With regard to Figure 2, it is not surprising that the best fit equation for only the California data is different from the best fit equation for the combined data set. why not point out

MAR.27.1997 10:38AM MIDWEST RESEARCH NC NO.620 P.6/9
11HR 25.57 01:38PM GRI-PARSIUM P.6/9

Comment	Response
Using only the California data poses additional problems since the data now really can be represented by two groupings of data in terms of soil silt content, one centered at approximately 3 percent the other at 20 percent. This does not provide a sound basis on which to develop a regression equation.	This is exactly the rationale for combining the California data with the Kansas data.
If the Kansas data are excluded from the analysis process, another very important factor comes into play. That is, the remaining data show a strong correlation between moisture content and tilling emissions. The equation is: TSP (lb/ac) = 28.31 - 1.48*moisture content (%) $R^2 = 0.89$ *a linear equation* A plot of these data are shown in Figure 3 along with the regression equation. This finding is contrary to what is stated by MRI for the current AP-42 emission factor equation, that is moisture content had no relationship to emissions (MRI, 1981). This further demonstrates that the data from Kansas should not have been used for development of the equation, and that the equation should be revised to include both silt content (as determined by the approved EPA method) and moisture content as variables. Since speed of operation was not listed for the California data it is not possible to say whether or not a similar situation exists, that is if speed of operation also is strongly correlated with emissions.	Except for the California data set collected from the alfalfa fields, the moisture content for the rest of the tests in the combined data set fit a relatively tight range. This probably explains why no significant correlation of emissions with moisture content was found in the combined data set. The more limited data set addressed by the commenter (California data only) provides a much stronger moisture variation, which is correlated with emissions. However, the relationship based on California data only (as the commenter has already pointed out) is very restricted in its applicability.

seems to want both vars always

has it or not

MAR.27.1997 10:39AM MIDWEST RESEARCH NC NO.620 P.7/9

Comment	Response
Figure 4 presents a plot of MRI's California data (MRI, 1981), plus additional California data (Flocchini, 1994) and the two extreme data points in terms of emissions that were determined from Arizona trials (Coates, 1996)., Clearly there is a significant discrepancy between 1981 data, and recent tests by other researchers. If all of the Arizona data were plotted on Figure 4, they would show that for a silt content of approximately 5 percent, a large range in emissions were recorded, varying from 0.6 to 32 lb/ac. Such data indicate that different implements generate different amounts of emissions, and hence one equation cannot be used for all implements. In the case of the 1994 California data, each data point represents 3 tests for each implement, but the data have been discounted by MRI (MRI, 1995), while the Arizona data represents 15 passes, the Arizona data clearly are equivalent to MRI's data and should not be ignored, as MRI has chosen to do. Box model who is Flocchini do we have this data Lowell Ashbaugh 3'	When considering the level of agreement between any new measured emission factors and the predictions of the AP-42 equation, enough detail in each respective test report must be presented so that the reliability of the measured emission factors can be evaluated independently. Such was not the case for the Flocchini (1994) report, for reasons stated in the draft AP-42 background document. Nonetheless, except for two tilling operations of a less intensive nature, there is very good agreement with AP-42. Even the stubble discing and chiseling operations are within a factor of 3 agreement with AP-42. Again, the purpose of AP-42 is to provide estimating tools for emission inventorying purposes so that, on average, reliable area-wide emission estimates can be determined. With regard to the Arizona data (Coates, 1996), Table 5 of his report shows agreement with AP-42, within a factor of about two. It is not unexpected that the reduced tillage systems tested in Arizona would be over predicted by AP-42. One of the challenges of agricultural emission inventorying is to scale various lower energy operations to conventional tillage as a reference level for which AP-42 is most applicable. Finally, with regard to the Arizona results (Coates, 1996), more detail is needed on the calculation scheme for generating the emission factors from the raw field data. For example, no information is provided on the point values of particulate concentration (or flux) across the sampling array. Of critical importance is the demonstration that all of the plume mass is accounted for, especially in situations when crosswinds are encountered. In principle, the plume profiling strategy used in Arizona appears valid, if these situations can be dealt with.

MAR.27.1997 10:39AM MIDWEST RESEARCH NC
THR 20:57 01:55PM GRI-BRKSIDE NO.620 P.8/9
P.8/9

Comment	Response
1. Based on the information presented in this report, the current AP-42 equation should be withdrawn.	1. The current equation retains its usefulness for predicting conventional tilling operations which impart high disturbance to the soil. As with any AP-42 emission factor, revisions should be made, as necessary, whenever new data with sufficient documentation are added to the database.
2. All of the raw data that were used to generate the equation should be made available to an independent organization. These data should be reanalyzed to determine whether or not additional problems exist, that could not be examined given the limited amount of information contained in the reports.	2. This comment is entirely appropriate, as long as the independent organization is fully experienced in relevant field activities.
3. Additional tests need to be performed over a far broader range of field conditions and implement types, to arrive at a more accurate emission factor equation. The revised equation should also incorporate moisture and implement speed, along with silt content, or show cause for exclusion.	3. This comment is also entirely appropriate. Any time new data can be added to the database, regression analysis should again consider all relevant source conditions as potential correction parameters for any updated emission factor equation.

MAR.27.1997 10:40AM MIDWEST RESEARCH NC NO.620 P.9/9

MEMORANDUM

THE UNIVERSITY OF ARIZONA

Office of Arid Lands Studies, Bioresources Research Facility
250 E. Valencia Road, Tucson, Arizona 85706
Phone: 520-741-0840
Fax: 520-741-1468

Date: March 10, 1997

To: **Dallas Safriet**

From: Wayne Coates

Subject: AP-42 equation for tilling

In response to your letter of February 10, 1997 please find attached two items.

1. A paper which I prepared for the Equipment Manufacturers Institute which I believe describes the problems that exist with the current AP-42 equation that is used to estimate emissions from tilling operations.

2. A paper which was recently published in the Transactions of the American Society of Agricultural Engineers and presents our work at The University of Arizona related to dust emissions from tilling operations.

Once you have had an opportunity to review both of these items please give me a call so that we can discuss them.

I will be most interested in hearing your comments, particularly on what I see to be the problems with the current AP-42 equation. Based on my study of the work that led to the development of the equation I believe that the equation needs to be discarded, and significant additional work must be done before a new equation is adopted.

AP-42 EMISSION FACTOR EQUATION FOR TILLING OPERATIONS:

CRITIQUE AND RECOMMENDATIONS

prepared by

Wayne Coates, Professor
Office of Arid Lands Studies
The University of Arizona
Tucson, Arizona

for

Equipment Manufacturers Institute
10 S. Riverside Plaza
Chicago, Illinois

November 18, 1996

INTRODUCTION

This report summarizes the problems that appear to exist with the development of the current AP-42 equation by the Midwest Research Institute (MRI). Available documentation indicates that errors were made when the equation was developed. The resultant inaccuracies, combined with other discrepancies in two relevant MRI reports, indicate that the AP-42 equation cannot accurately predict emissions from tilling operations.

Only Total Suspended Particulates (TSP), and not PM-10 or any other size range is discussed, since the current AP-42 equation has been given an "A" rating if used to estimate total particulate emissions but only a "B" rating if used to estimate emissions for a specific particle range. Thus additional inaccuracies exist for the other particle sizes, as has been acknowledged by MRI.

This report does not question the validity of MRI's measurement processes from a technical standpoint, that is in terms of positioning of the collection devices, taking of samples, metrological conditions that existed during the tests, etc. Rather, this discussion assumes that MRI's technical expertise in this area is adequate for the tasks performed.

DATA USED TO DEVELOP THE CURRENT AP-42 EQUATION

Table 1 summarizes the data that were used to generate the current AP-42 emission factor equation for tilling operations, and presents other pertinent information, all of which is extracted from the two MRI reports (MRI 1974, 1981). Based on several discrepancies found within and between the two reports, the accuracy of these two reports is in question. For example:

- depth information for soil moisture content is inconsistent within the 1974 report
- width of implements listed in the 1981 report varies from one section to another
- silt content values given for the 1974 data are different in the two reports
- soil samples taken in 1981 were "several shovelfuls" vs plugs in 1974

Also from Table 1 it can be seen that a limited number of implements (4 in total) were used in the test programs, hence extrapolation of the data to implements in general is questionable. Furthermore, a limited number of sites were used in the test program (6 in total). This further brings into question the validity of using the data to predict tilling emissions over a broad range of conditions. Another significant concern is that part of the California data was collected using a tracked tractor, while a wheeled tractor was used at the second site. This could have influenced the emissions, but does not appear to have been taken into account.

Because the AP-42 equation was developed by MRI from measured silt and TSP data which are contained in the 1981 report, this author performed a regression analysis to develop two equations from the data in the 1981 report. This analyss was undertaken to verify that the data presented in the 1981 report were what had been used to develop the AP-42 equation and to determine if a linear equation could represent the data equally as well as a log-log equation. The two equations are:

$TSP(lb/ac) = 8.04 + 0.77*\text{silt content}(\%)$ $R^2 = 0.77$ *the linear equation*

$TSP(lb/ac) = 4.65*\text{silt content}(\%)^{0.59}$ $R^2 = 0.92$ *the log-log equation*

Note that the log-log equation is very similar to the AP-42 equation:

$TSP(lb/ac) = 4.80*\text{silt content}(\%)^{0.60}$ $R^2 = 0.94$

It is unclear why the log-log equation developed by this author from the data in the MRI report does not completely agree with the AP-42 equation. A possibility could be rounding of the numbers provided in the report. Figure 1 presents a plot of the raw data from the MRI report, as well as the three regression equations referred to above.

DISCREPANCIES

The greatest area of concern relates to the Kansas data. The silt values used for the Kansas data are the sum of silt and clay as determined using the Buoyocous hydrometer method. This method of analysis is routinely used to determine soil texture but is not the EPA approved method to be used for determining silt content for the AP-42 equation. Using the textural classification procedure assumes that no conglomeration of the soil existed. This is highly unlikely, particularly for the clay fraction. Given the data presented in the 1974 and 1981 reports, it is not possible to arrive at a correct value for silt content, as this is to be determined by mechanically sieving soil samples, with the fraction smaller than 200 mesh (75 µm) being the silt content. Thus the Kansas data should not be used in the regression.

If the Kansas data are excluded, the AP-42 equation becomes:

$TSP(lb/ac) = 8.66 + 0.66*\text{silt content}(\%)$ $R^2 = 0.78$ *the linear equation*

$TSP(lb/ac) = 5.51*\text{silt content}^{0.48}$ $R^2 = 0.84$ *the log-log equation*

The range of silt contents over which these equations are valid is the range for which there is data (ie 1.7 to 24.7 percent), not 1.7 to 88 percent as is the case for the current AP-42 equation. Figure 2 presents plots of the raw data and the two equations, along with the AP-42 equation. Clearly, the current AP-42 equation over-predicts emissions.

Using only the California data poses additional problems since the data now really can be represented by two groupings of data in terms of soil silt content, one centered at approximately 3 percent the other at 20 percent. This does not provide a sound basis on which to develop a regression equation.

If the Kansas data are excluded from the analysis process, another very important factor comes into play. That is, the remaining data show a strong correlation between moisture content and tilling emissions. The equation is:

$$TSP(lb/ac) = 28.31 - 1.48 * \text{moisture content}(\%) \qquad R^2 = 0.89 \qquad \textit{a linear equation}$$

A plot of these data are shown in figure 3 along with the regression equation.

This finding is contrary to what is stated by MRI for the current AP-42 emission factor equation, that is moisture content had no relationship to emissions (MRI, 1981). This further demonstrates that the data from Kansas should not have been used for development of the equation, and that the equation should be revised to include both silt content (as determined by the approved EPA method) and moisture content as variables. Since speed of operation was not listed for the California data it is not possible to say whether or not a similar situation exists, that is if speed of operation also is strongly correlated with emissions.

ADDITIONAL DATA

Figure 4 presents a plot of MRI's California data (MRI, 1981), plus additional California data (Flocchini, 1994) and the two extreme data points in terms of emissions that were determined from Arizona trials (Coates, 1996). Clearly there is a significant discrepancy between 1981 data, and recent tests by other researchers. If all of the Arizona data were plotted on figure 4, they would show that for a silt content of approximately 5 percent, a large range in emissions were recorded, varying from 0.6 to 32 lb/ac. Such data indicate that different implements generate different amounts of emissions, and hence one equation cannot be used for all implements.

In the case of the 1994 California data, each data point represents 3 tests for each implement, but the data have been discounted by MRI (MRI, 1995), while the Arizona data represents 15 passes, gathered over three seasons (Coates, 1996). From the standpoint of the number of passes, the Arizona data clearly are equivalent to MRI's data and should not be ignored, as MRI has chosen to do.

RECOMMENDATIONS

1. Based on the information presented in this report, the current AP-42 equation should be withdrawn.

2. All of the raw data that were used to generate the equation should be made available to an independent organization. These data should be reanalyzed to determine whether or not additional problems exist, that could not be examined given the limited amount of information contained in the reports.

3. Additional tests need to be performed over a far broader range of field conditions and implement types, to arrive at a more accurate emission factor equation. The revised equation should also incorporate moisture and implement speed, along with silt content, or show cause for exclusion.

REFERENCES

MRI. 1981. The Role of Agricultural Practices in Fugitive Dust Emissions. Draft Final Report, MRI Project No. 4809-L, prepared for the California Air Resources Board.

MRI. 1995. Emission Factor Documentation for AP-42 Section 9.1, Tilling Operations. Draft Report, MRI Project No. 4602-03, prepared for U.S. EPA.

Coates, W. E. 1996. Particulates Generated by Five Cotton Tillage Systems. Transactions of the ASAE.

MRI - Cowherd, C., K. Axetell, C. M. Guenther, G. A. Jutze. 1974. Development of Emission Factors for Fugitive Dust Sources. Prepared for U.S. EPA. EPA document #EPA-450/3-74-037.

Flocchini, R. G., T. A. Cahill, R. T. Matsumura. 1994. Final Report: Study of Fugitive PM-10 Emissions from Selected Agricultural Practices on Selected Agricultural Soils. Prepared for the San Joaquin Valley Unified APCD, U.S. EPA and the California Air Resources Board. Davis, California: University of California.

Table 1. Summary of the MRI data used to develop the current AP-42 equation for emissions from tillage operations.

Year	Location	Previous Crop	Implemt	Width (ft)	Moisture 0-6 in. (%)	Moisture 4-6 in. (%)	Speed (mph)	# Passes Made	Silt (%)	TSP Measure (lb/ac)	AP-42 Predict (lb/ac)
1981	CA #1	Alfalfa	Lndplane	16	4.0			15	24.7	20.7	32.9
1981	CA #1	Alfalfa	Lndplane	16	4.0			14	24.7	23.2	32.9
1981	CA #1	Alfalfa	Disk	16	3.1			15	22.5	22.5	31.1
1981	CA #1	Alfalfa	Disk	16	2.1			10	18.9	26.4	28.0
1981	CA #1	Alfalfa	Disk	16	2.9			8	17.5	24.3	26.7
1981	CA #2	Rice	Disk	16	13.3			15	1.7	4.7	6.6
1981	CA #2	Rice	Disk	16	12.6			14	2.6	7.7	8.5
1981	CA #2	Rice	Disk	16	12.0			14	3.5	14.6	10.2
1981	CA #2	Rice	Disk	16	10.8			15	4.9	14.4	12.5
1981	CA #2	Rice	Disk	16	13.0			15	3.6	11.6	10.4
1981	CA #2	Rice	Disk	16	10.7			14	3.2	10.0	9.6
1974	KS #1	Fallow	One Way	12	10.5	10.7	5-6	15	54.0	56.0	52.6
1974	KS #1	Fallow	One Way	12	10.5	10.7	5-6	10	54.0	52.0	52.6
1974	KS #1	Fallow	One Way	12	10.5	10.7	5-6	16	54.0	60.0	52.6
1974	KS #2	Fallow	Disk	30	11.0	10.7	4	10	71.0	42.0	61.9
1974	KS #3	Fallow	Sweep	30	15.9	19.7	6-7	12	88.0	64.0	70.5
1974	KS #3	Fallow	Sweep	30	13.4	17.5	7	12	87.0	85.0	70.0
1974	KS #4	Fallow	Disk	20	12.3	18.5	5	12	73.0	78.0	63.0

clot will check on this

Comments re 1974 report and data

1. One Way - MRI term is "one way disk plow"
2. Sweep - MRI term is " sweep-type plow"
3. Soil sample depths - the report states "The soil was sampled separately to depths of 4 and 6 in." Table 17 has column headings of 0-4 in. depth and 4-6 in. depth. Table 19 has a footnote that says "0-4 in. depth" was used in the equation. The 0-4 in. depth was used for the Kansas data in the 1981 report to determine silt and moisture content.
4. Table 19 lists the silt contents as 26, 26, 26, 32, 48, 49 and 46 percent. These values are the sum of the 50-20 and 20-2 μm fractions which was determined by Buoyocous hydrometer method.
5. Speed for the KS #4 test was estimated, not measured.

Comments re 1981 report and data

1. Table 46 lists the silt contents for the 1974 data used in the equation as 54, 54, 54, 71, 88, 87 and 73 percent. These values represent the sum of the numbers used in the 1974 equation to which the clay content (<2μm) has been added. The clay values are 20, 20, 20, 28, 30, 28 and 28 respectively.
2. The implement widths are listed as 16 feet on one page, and 16.4 feet on another.
3. Soil samples were comprised of "several shovelfuls" taken to a depth of approximately 6 in. depth, used for determination of silt and moisture content.
4. Speeds of operation are not provided.
5. Some operations were performed with tracked tractor, others with wheeled tractor.

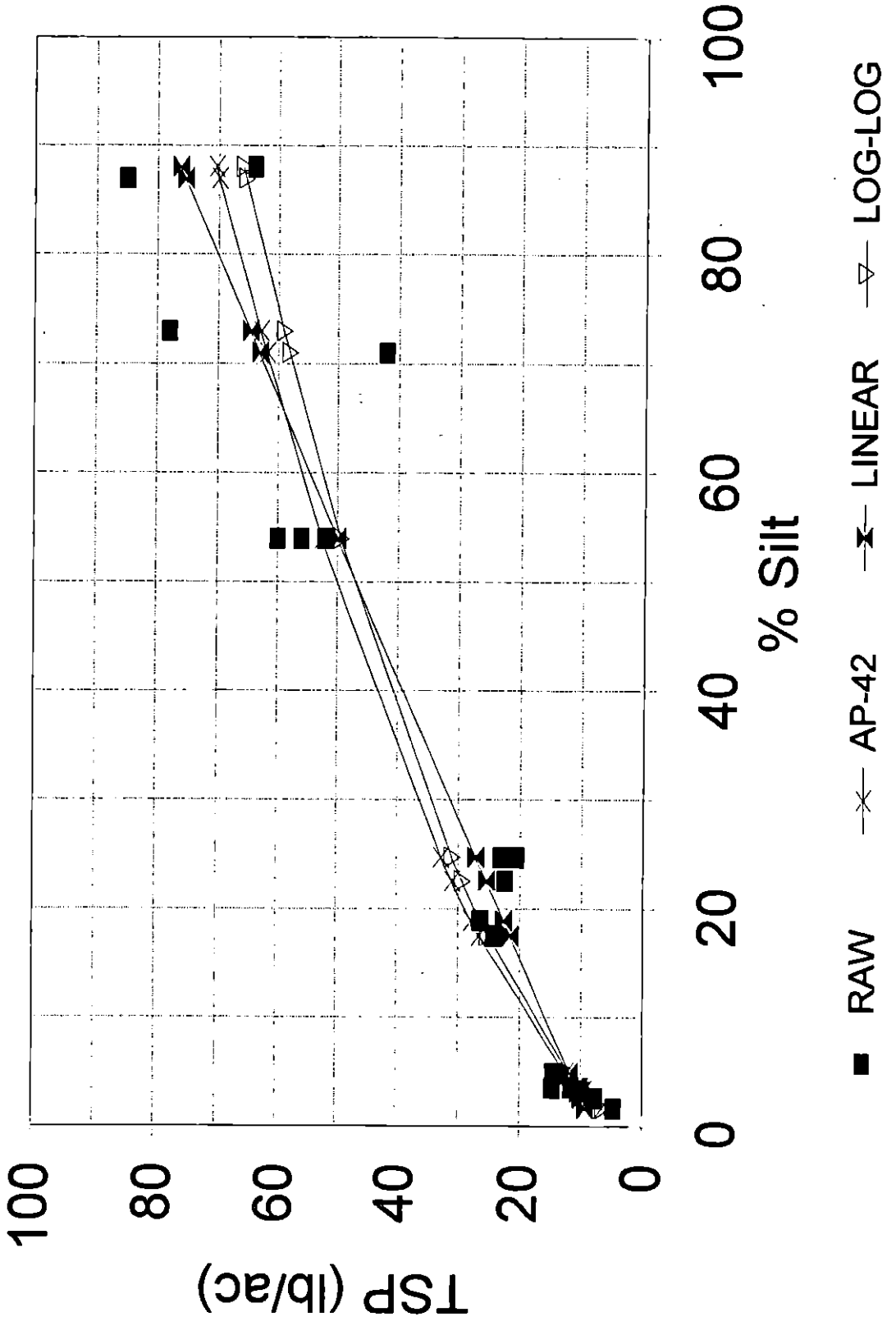


Figure 1. Comparison of MRI raw data (Kansas and California), AP-42 equation, and Coates' linear and log-log equations.

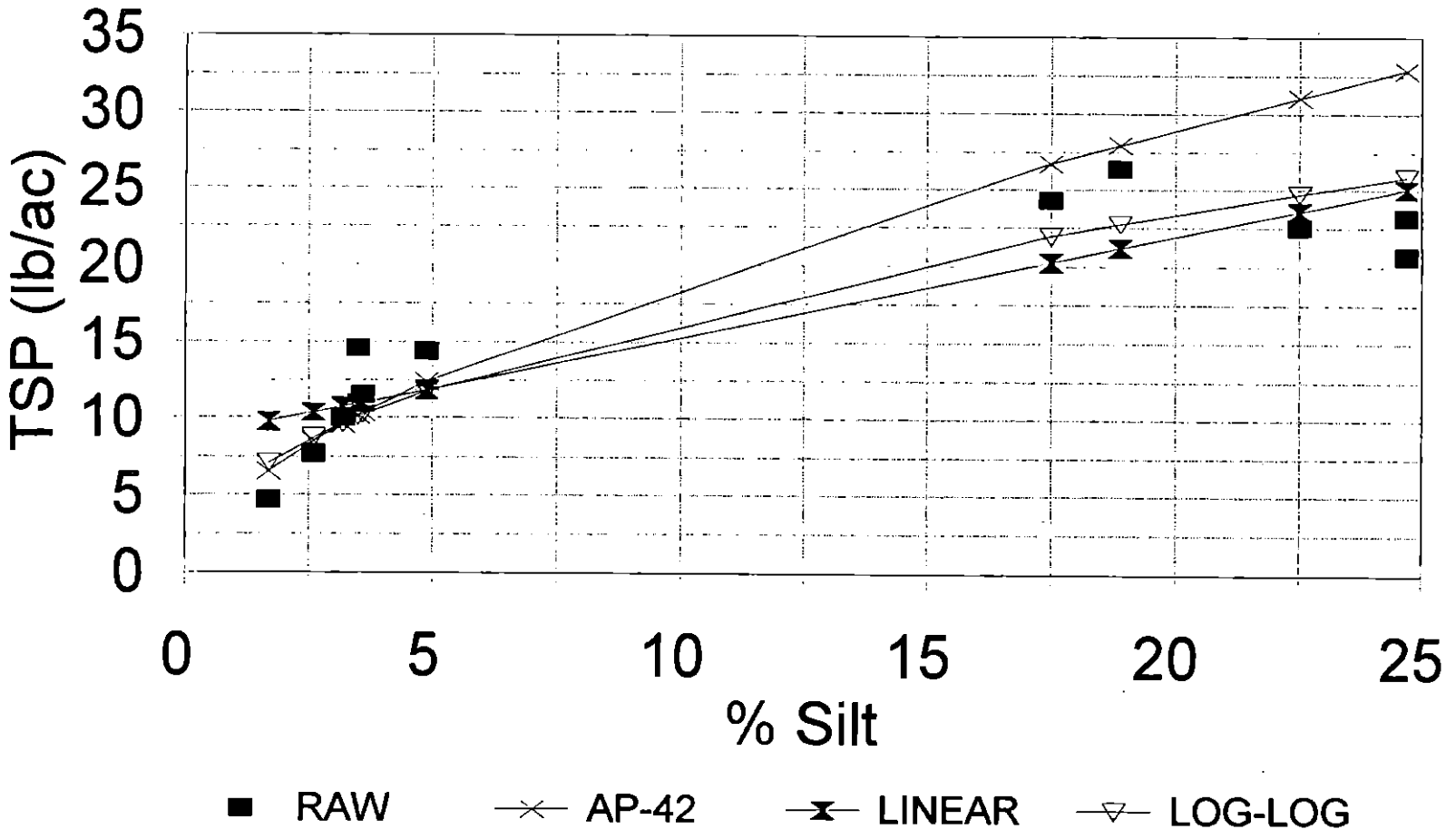


Figure 2. Comparison of MRI raw data (California - 1981), AP-42 equation, and Coates' linear and log-log equations.

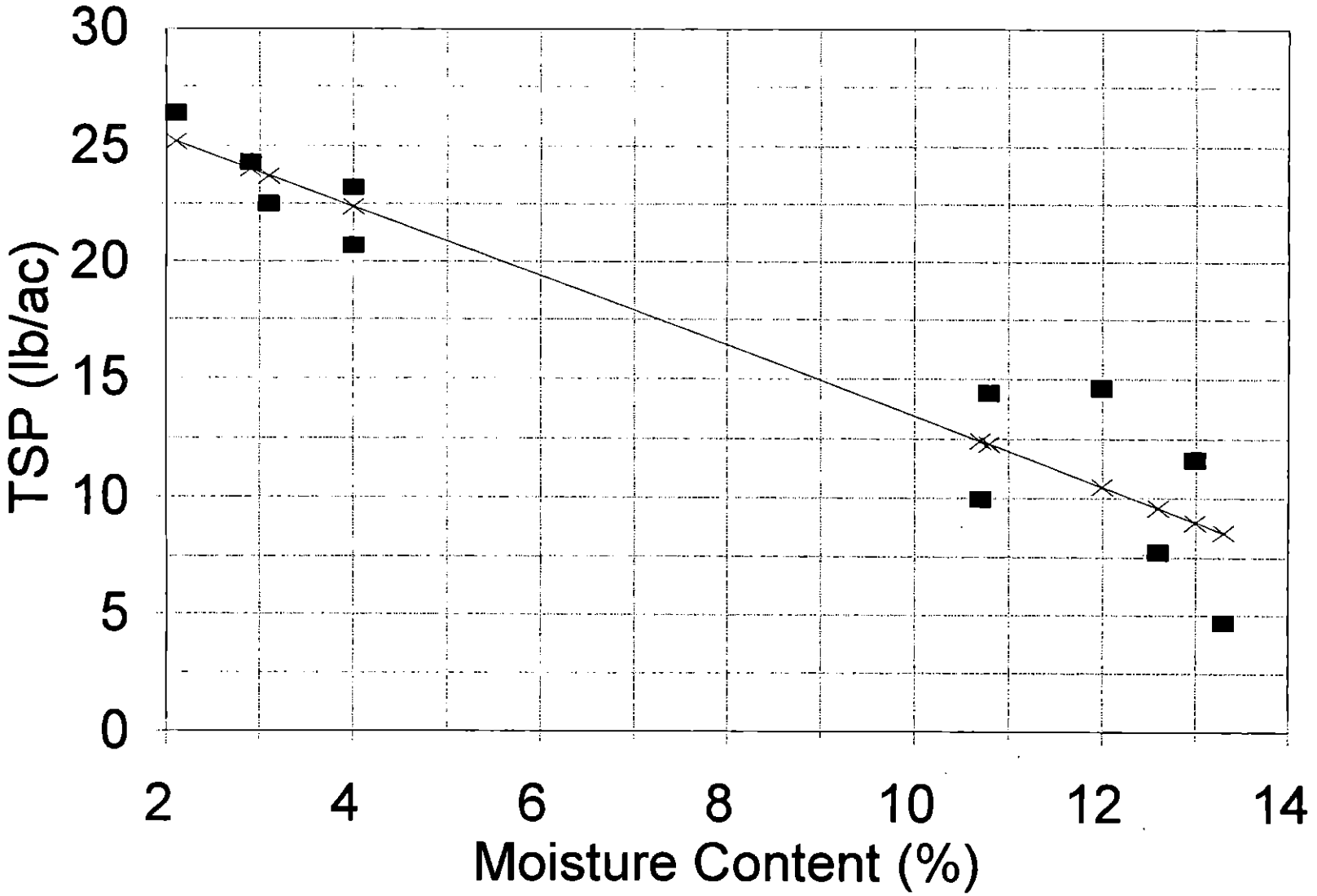


Figure 3. TSP as a function of soil moisture content - MRI raw data (California - 1981) and Coates' regression equation.

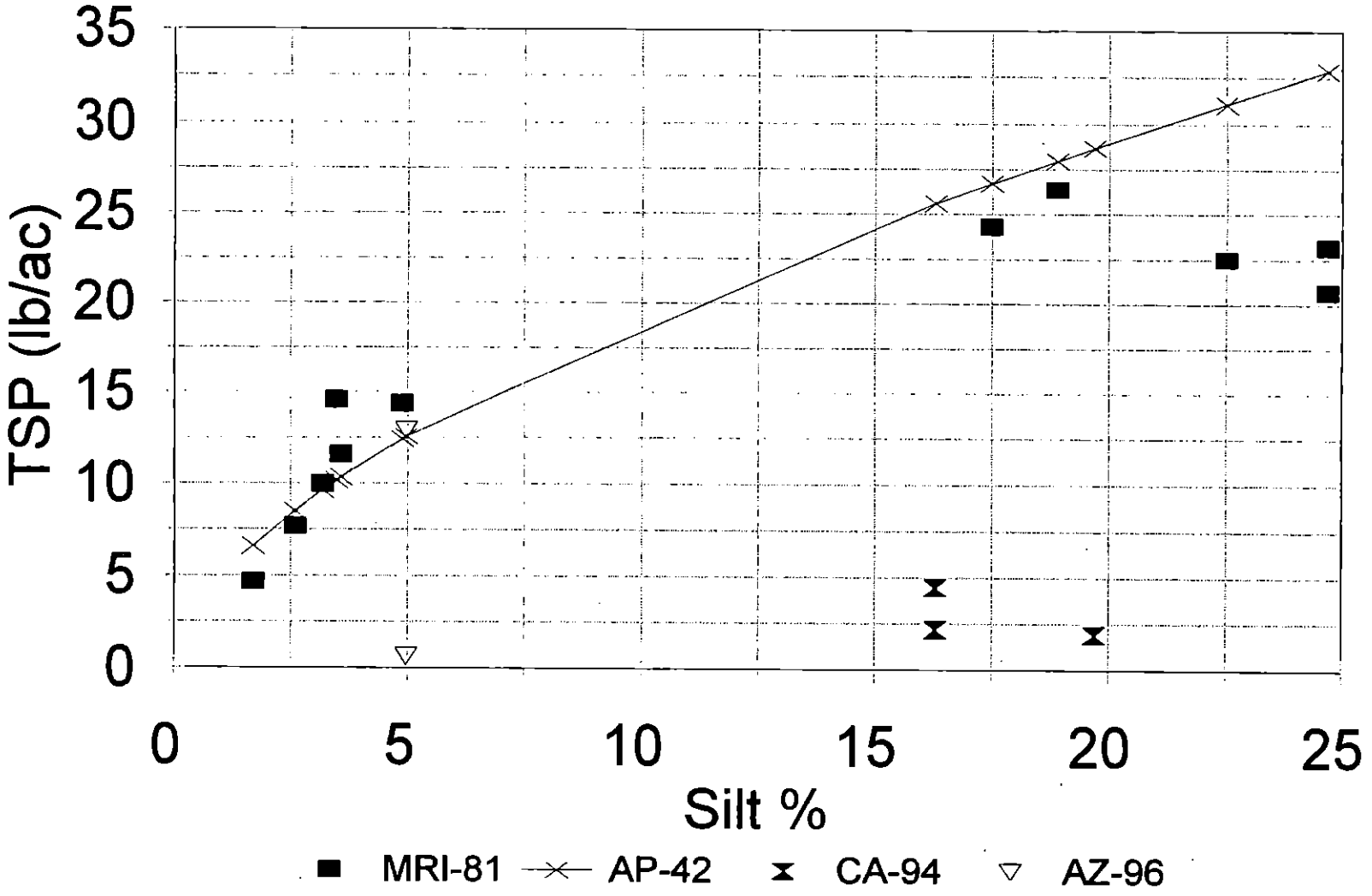


Figure 4. Comparison of MRI raw data (California - 1981), AP-42 equation, California data (Flocchini, 1994) and Arizona data (Coates, 1996).

Dr. Wayne Coates
Office of Arid Land Studies
Bioresources Research Facility
The University of Arizona
250 East Valencia Road
Tucson, Arizona 85706

Dear Dr. Coates:

I have completed my review of your memorandum to the Equipment Manufacturers Institute, dated November 18 1996, and your paper published in the Transactions of the ASAE. In addition, I have reviewed the two MRI test reports cited as the data sources used to generate the current AP-42 emission factor equation for tilling operations. This letter primarily addresses the content of your memorandum to the Equipment Manufacturers Institute. There are several comments in your memorandum regarding the AP-42 emission factor equation that I would like to address.

1. **Comment.** Only Total Suspended Particulates (TSP), and not PM-10 or any other size range is discussed, since the current AP-42 equation has been given an "A" rating if used to estimate total particulate emissions but only a "B" rating if used to estimate emissions for a specific particle range. Thus additional inaccuracies exist for the other particle sizes, as has been acknowledged by MRI.

Response: The difference in the rating of the AP-42 equation for Total Suspended Particulate (TSP) emissions and estimated emissions for specific particle size range results from the relative quantity of available data. Test data in the early to mid-1970's was focused principally on TSP with few data on specific particle sizes. Because the emission estimates for specific particle sizes were based primarily on the 1981 data (a

smaller data set than for TSP), the factor rating was lowered to a "B" rating.

2. **Comment.** This report does not question the validity of MRI's measurement processes from a technical standpoint, that is in terms of positioning of the collection devices, taking of samples, meteorological conditions that existed during the tests, etc. Rather, this discussion assumes that MRI's technical expertise in this area is adequate for the tasks performed.

Response: As discussed in Section 3 of the background report to draft AP-42 Section 9.1, Tilling Operations, EPA currently feels that profiling is a better measurement technique than the upwind-downwind technique.

3. **Comment.** Table 1 summarizes the data that were used to generate the current AP-42 emission factor equation for tilling operations, and presents any other pertinent information, all of which is extracted from the two MRI reports (MRI 1974, 1981). Based on several discrepancies found within and between the two reports, the accuracy of these two reports is in question. For example:

a. depth information for soil moisture content is inconsistent within the 1974 report

b. width of implements listed in the 1981 report varies from one section to another

c. silt content values given for the 1974 data are different in the two reports

d. soil samples taken in 1981 were "several shovelfuls" vs. plugs in 1974

Response:

a. On page 51 of the 1974 report, it states that core samples of 4 in. and 6 in. depths were obtained so that moisture content as a function of depth could be analyzed (see Table 17 on page 61 of the report).

b. As stated in Table 11 (page 51) of the 1981 report, the width of implements for all but one of the thirteen exposure profiling tests was 4.9 m (16 ft); the width of the other implement was 6.4 m (21 ft).

c. In the 1981 report, silt content based on dry sieving was used as the measure of soil "dustiness," to be consistent with the other emission factor equations for fugitive dust sources. Thus, it was necessary to develop estimates of dry silt content (<200 mesh) for the agricultural tilling tests contained in the 1974 report, which originally used the conventional wet soil texture analysis.

d. On page 45 of the 1981 report, it states that "shovelfuls of soil collected to a depth of approximately 15 cm (6 in.) were composited for analysis. For disturbed soil, the texture of the soil is probably not very sensitive to depth in the 4 in. to 6 in. range.

4. **Comment.** Also from Table 1 it can be seen that a limited number of implements (4 in total) were used in the test programs, hence extrapolation of the data to implements in general is questionable. Furthermore, a limited number of sites were used in the test program (6 in total). This further brings into question the validity of using the data to predict tilling

emissions over a broad range of conditions. Another significant concern is that part of the California data was collected using a tracked tractor, while a wheeled tractor was used at the second site. This could have influenced the emissions, but does not appear to have been taken into account.

Response: While more test sites and implements are always desirable, the statistical results in the 1981 report showed that a single emission factor equation for dust emissions from tilling operations is viable as a predictive tool for emission inventory purposes. Also, because most dust is generated by the tilling implement, the effect of a tracked vehicle is expected to be minor.

Based on available data, a single equation still provides a reasonable fit for most types of equipment. There are insufficient data available to support new equations for reduced energy operations (e.g., conservation tilling).

5. **Comment.** Because the AP-42 equation was developed by MRI from measured silt and TSP data which are contained in the 1981 report, this author performed a regression analysis to develop two equations from the data in the 1981 report. This analysis was undertaken to verify that the data presented in the 1981 report were what had been used to develop the AP-42 equation and to determine if a linear equation could represent the data equally as well as a log-log equation. The two equations are:

$$\text{TSP (lb/ac)} = 8.04 + 0.77 * \text{silt content (\%)} \quad R^2 = 0.77$$

the linear equation

$$\text{TSP (lb/ac)} = 4.65 * (\text{silt content (\%)})^{0.59} \quad R^2 = 0.92$$

the log-log equation

Note that the log-log equation is very similar to the AP-42 equation:

$$TSP\ (lb/ac) = 4.80 * silt\ content\ (\%)^{0.60}\ R^2 = 0.94$$

It is unclear why the log-log equation developed by this author from the data in the MRI report does not completely agree with the AP-42 equation. A possibility could be rounding of the numbers provided in the report. Figure 1 presents a plot of the raw data from the MRI report, as well as the three regression equations referred to above.

Response: Your equation closely reproduces the regression equation in the 1981 report. There is only a 3 percent difference in the coefficient and this is generally insignificant within the overall scope of this type of experimental data.

6. **Comment.** The greatest area of concern relates to the Kansas data. The silt values used for the Kansas data are the sum of silt and clay as determined using the Buoyocous hydrometer method. This method of analysis is routinely used to determine soil texture but is not the EPA approved method to be used for determining silt content for the AP-42 equation. Using the textural classification procedure assumes that no conglomeration of the soil existed. This is highly unlikely, particularly for the clay fraction. Given the data presented in the 1974 and 1981 reports, it is not possible to arrive at a correct value for silt content, as this is to be determined by mechanically sieving soil samples, with the fractions smaller than 200 mesh (75 μm) being the silt content. Thus the Kansas data should not be used in the regression.

If the Kansas data are excluded, the AP-42 equation becomes:

$$TSP\ (lb/ac) = 8.66 + 0.66 * silt\ content\ (\%)\ R^2 = 0.78$$

the linear equation

$$TSP\ (lb/ac) = 5.51 * silt\ content\ (\%)^{0.48}\ R^2 = 0.84$$

the log-log equation

The range of silt contents over which these equations are valid is the range for which there is data (i.e., 1.7 to 24.7 percent), not 1.7 to 88 percent as is the case for the current AP-42 equation. Figure 2 presents plots of the raw data and the two equations, along with the AP-42 equation. Clearly, the current AP-42 equation over predicts emissions.

Response: As stated in a response to an earlier comment, the dry silt content (<75 μm) has traditionally been used as the most appropriate measure of soil dustiness. The only exception was agricultural tilling in the original (1974) report. For purposes of combining the Kansas and California data sets in the 1981 report, the agricultural silt values in the 1974 report were converted to equivalent dry silt values, by taking the 0-75 μm fraction from Figure 14 (page 62) of the 1974 report. [Note that the vertical scale in Figure 14 should be shifted by a factor of 10; e.g., 0.01 mm becomes 0.001 mm].

Combining the Kansas and California data sets adds to the credibility of the predictive emission factor model for agricultural tilling. With regard to Figure 2, it is not surprising that the best fit equation for only the California data is different from the best fit equation for the combined data set.

It should be remembered that the rationale behind AP-42 is that it is to be used in a top-down process. It is best used to estimate emissions for entire States or regions, rather than specific site. AP-42 can be used for those instances where no other data for certain areas are available; however, if source test data for specific areas are available, it is always preferable to use the specific data.

The utility of this particular AP-42 could be enhanced by including the data for a new area (Arizona) if you would provide the information I have requested so your data could be integrated with the other data.

7. **Comment.** Using only the California data poses additional problems since the data now really can be represented by two groupings of data in terms of soil silt content, one centered at approximately 3 percent the other at 20 percent. This does not provide a sound basis on which to develop a regression equation.

Response: This is exactly the rationale for combining the data sets of California and Kansas.

8. **Comment.** If the Kansas data are excluded from the analysis process, another very important factor comes into play. That is, the remaining data show a strong correlation between moisture content and tilling emissions. The equation is:

TSP (lb/ac) = 28.31 - 1.48*moisture content (%) R^2 = 0.89

a linear equation

A plot of these data are shown in Figure 3 along with the regression equation.

This finding is contrary to what is stated by MRI for the current AP-42 emission factor equation, that is moisture content had no relationship to emissions (MRI, 1981). This further demonstrates that the data from Kansas should not have been used for development of the equation, and that the equation should be revised to include both silt content (as determined by the approved EPA method) and moisture content as variables. Since speed of operation was not listed for the California data it is

not possible to say whether or not a similar situation exists, that is if speed of operation also is strongly correlated with emissions.

Response: Except for the California data set collected from the alfalfa fields, the moisture content for the rest of the tests in the combined data set fit a relatively tight range. This probably explains why no significant correlation of emissions with moisture content was found in the combined data set. The more limited California data set provides a much stronger moisture variation, which is correlated with emissions. However, the relationship based on California data only (as you have already pointed out) is very restricted in its applicability.

Even if the inclusion of both soil silt content and moisture content into the equation as variables was supportable by regression analysis of the test data, this might create practical difficulties. Ideally regional values for correction parameter must be readily available in order for the AP-42 equation to be useful for emission inventory purposes. The estimation of soil moisture content over States and regions would be a much more significant then the estimation of soil silt content.

9. **Comment.** Figure 4 presents a plot of MRI's California data (MRI, 1981), plus additional California data (Flocchini, 1994) and the two extreme data points in terms of emissions that were determined from Arizona trials (Coates, 1996)., Clearly there is a significant discrepancy between 1981 data, and recent tests by other researchers. If all of the Arizona data were plotted on Figure 4, they would show that for a silt content of approximately 5 percent, a large range in emissions were recorded, varying from 0.6 to 32 lb/ac. Such data indicate that

different implements generate different amounts of emissions, and hence one equation cannot be used for all implements.

In the case of the 1994 California data, each data point represents 3 tests for each implement, but the data have been discounted by MRI (MRI, 1995), while the Arizona data represents 15 passes, the Arizona data clearly are equivalent to MRI's data and should not be ignored, as MRI has chosen to do.

Response: When considering the level of agreement between any new measured emission factors and the predictions of the AP-42 equation, enough detail in each respective test report must be presented so that the reliability of the measured emission factors can be evaluated independently. Such was not the case for the Flocchini (1994) report, for reasons stated in the draft AP-42 background document. Based on his experimental design, Flocchini essentially used an upwind-downwind technique which is not the preferred sampling scheme. Nonetheless, except for two tilling operations of a less intensive nature, there is very good agreement with AP-42. Even the stubble discing and chiseling operations are within a factor of 3 agreement with AP-42. Again, the purpose of AP-42 is to provide an estimating tool for emission inventory purposes so that, on average, reliable area-wide emission estimates can be determined. It is not the purpose of AP-42 to be used for relatively small areas unless absolutely no other data are available and the use of AP-42 is appropriately caveated.

With regard to your Arizona data (Coates, 1996), Table 5 of your report shows agreement with AP-42, within a factor of about two. It is not unexpected that the reduced tillage systems that you tested in Arizona would be over predicted by AP-42. One of the challenges of agricultural emission inventories is to scale

various lower energy operations to conventional tillage as a reference level for which AP-42 is most applicable.

Finally, with regard to your Arizona results, I have previously discussed with you that more detail is needed on the calculation scheme for generating the emission factors from the raw field data. For example, no information is provided on the individual point values of particulate concentration (or flux) across the sampling array. Of critical importance is the demonstration that all of the plume mass is accounted for, especially in situations when crosswinds are encountered. In principle, your plume profiling strategy used in Arizona appears quite valid, if data are presented to ensure that the entire plume was within the sampling array.

10. **Comment.**

a. Based on the information presented in this report, the current AP-42 equation should be withdrawn.

b. All of the raw data that were used to generate the equation should be made available to an independent organization. These data should be reanalyzed to determine whether or not additional problems exist, that could not be examined given the limited amount of information contained in the reports.

c. Additional tests need to be performed over a far broader range of field conditions and implement types, to arrive at a more accurate emission factor equation. The revised equation should also incorporate moisture and implement speed, along with silt content, or show cause for exclusion.

Response:

a. The current equation retains its usefulness for predicting conventional tilling operations which impart high disturbance to the soil. As with any AP-42 emission factor, revisions should be made, as necessary, whenever new data with sufficient documentation are added to the database.

b. I feel the Agency is dedicated to being objective in what goes into AP-42 based on the available information and data that currently exist at the time of updating or preparing a new section. Before a section becomes final we initiate and external peer review process seeking input, information and data to make improvement to a section from knowledgeable individuals or organizations.

c. This comment is also entirely appropriate. Any time new data can be added to the database, regression analysis should again consider all relevant source conditions as potential correction parameters for any updated emission factor equation. As I have stated previously, not all new variables can be added to the equation because of problems of data availability over a wide area or region. Once again, AP-42 is not intended for specific sites but is used to estimate emissions over States or regions.

Because few data are available, there is a real need to share data in order to provide the best information available. I have requested data from Dr. Lowell Ashbaugh on two separate occasions but received no response.

With respect to the current AP-42 equation, clearly it is not a perfect equation that fits all possible scenarios. At the present time, the existing equation does provide a good estimate of emissions for intensive tilling operations that result in significant soil disturbance. Certainly the equation is open to modification and improvement as new data become available. The agency will make every effort to incorporate new test results that have been validated. As the overall database increases, refinements can be made to the equation to allow more accurate predictions over a wider scope of tilling operations.

I would like to thank you for the submission of this information for my review and consideration. As I have stated to you in previous correspondence, AP-42 sections are "living documents" and are periodically updated as significant new test data become available. I have also stated previously that if you would provide the requested background data for your tests, the agency would incorporate your results, to the extent possible, in the AP-42 emission factor equation.

Please direct any comments or questions you may have to me. My address is the U. S. Environmental Protection Agency, Emission Factor and Inventory Group (MD-14), Research Triangle Park, North Carolina 27711. My telephone number is (919) 541-5371 and my fax number is (919) 541-0684.

Sincerely,

Dallas W. Safriet
Environmental Engineer
Emission Factor and Inventory Group

From: John Ungvarsky
To: RTP10.RTPTSD(SAFRIET-DALLAS),RTP3.RTMU258(DUNKINS-...
Date: 7/13/98 1:30pm
Subject: Ag Research in Phoenix

On 7/16, I will be attending the second meeting of a recently formed PM-10 Technical Group. The group was initiated by NRCS to address research needs relating to the development of Best Management Practices for ag sources in the Maricopa County nonattainment area. We are currently compiling and reviewing information related to PM-10 research or program development. The information
I have is mainly on the Columbia Plateau, San Joaquin Valley, and South Coast efforts. I have a copy of the OAQPS Agriculture Studies which was handed out at the recent USDA AAQTF meeting in Amarillo. I noticed that one of the studies listed was an AP-42 update on agricultural tilling (draft section has been out for several years). Can I get a copy of the draft? Will it be finalized (or are the SJV agribusiness reps opposed)?

The Region has found $100,000 which we intend to contribute to the research needs in Maricopa County. Hopefully others (i.e., USDA) will also contribute. The group will be attempting to identify priorities and best use of the funds. I would like to keep you informed and get your advice as this group progresses. Please call me if you have any questions.

CC: RTPMAINHUB.WPXGATE(MCKAUGHAN-COLLEEN)

Sent
7/14

From: Bill Barnard <wbarnard@pechan.com>
To: Bill Kuykendal <kuykendal.bill@epamail.epa.gov>
Date: 5/12/98 4:52pm
Subject: Wind erosion and tilling in CA

Bill,
Here are the pertinent numbers that you requested. For CA, our numbers for wind erosion and tilling for both PM10 and PM2.5 are as follows:

FIPSST	SCC	PM10	PM25	
06	2730100000	38463.8	5769.6	Wind
06	2801000003	102313.4	20462.7	Tilling

According to CARB's Emission Inventory Procedural Manual, Volume III, Methods for Assessing Area Source Emissions, California's Wind erosion emissions from agricultural non-pastural land (which would be equivalent to our estimates) are:

PM10	PM2.5
58929.875	8839.48125

CARB doesn't estimate PM2.5 emissions (yet) so the PM2.5 number is based on our current value for the PM2.5/PM10 ratio of 0.15. These values incorporate CARB's most recent modifications to their wind erosion methodology discussed with Tom Pace and I last May.

Their emissions (from the same procedural document) for Tilling are:

PM10	PM2.5
59176.5	11835.3

Again the PM2.5 value was obtained by using our current PM2.5/PM10 ratio which for tilling is 0.2.

Note that all values are in tons/year (this is the way they were reported in the California procedures document and Patrick Gaffney also indicated that their daily values are derived by using the annual divided by 365). In addition, all values are from 1993, which Patrick indicated was their best inventory. The 1995 values in the summary report we discussed yesterday are derived by growth factor from the 1993 inventory.

As you can see, we are slightly lower in our wind estimates, but high by about a factor of 2 with respect to tilling. Still, I think most inventory preparers would consider a factor of 2 on a fugitive category to be relatively good agreement.

Let me know if you need any more information.

Bill

William R. Barnard
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CC: TOM PACE <PACE.TOM@epamail.epa.gov>, Sharon Nizich...

Honorable Robert F. Smith
Chairman, Committee on Agriculture
House of Representatives
Washington, DC 20515

Dear Mr. Chairman:

I am writing in response to your August 1, 1997 letter to Administrator Carol Browner regarding the revised national ambient air quality standards (NAAQS) for particulate matter (PM)-2.5 and ozone. You raised specific questions in which you needed clarification on in order for the Committee on Agriculture to carry out its responsibility to the Nation's farmers and ranchers.

Question 1: Now that you have decided to regulate PM-2.5 and ozone, do you intend to regulate agricultural producers under these rules? Would agricultural producers be exempt from these regulations? If States choose to include agricultural producers for regulation under a State implementation plan, what would be the Environmental Protection Agency (EPA) response?

Response: The EPA does not directly regulate any air emissions from farming activities and does not intend to change its current relationship with the farming community. The Agency believes that agriculture's contribution to the PM-2.5 problem is a very small part of the overall problem. Based on our analyses of ambient air quality data, we believe that the major sources of PM-2.5 of concern are sulfates from power plants, nitrates from power plants and other fossil fuel fired combustion sources, and diesel and other mobile sources. While it is the States responsibility to develop a plan showing how an area will comply with the standards, EPA has always provided guidance to the States to control the major contributors first. The EPA does not believe a States will pursue agricultural controls to address the PM-2.5 NAAQS if there are no air quality benefits. However, EPA's obligation to approve or disapprove a State's control plan is based on the ability of the state to demonstrate attainment of the NAAQS with the measures identified. If as a part of the plan, a State were to choose to regulate agricultural sources EPA would be obligated to approve the control plan. EPA has no ability to overrule a States choice of a control strategy. However, EPA would advise the States to work through a cooperative effort between the local air pollution control office and the local natural resource conservation districts and the United States Department of Agriculture (USDA), if necessary, to develop any necessary control strategies involving agricultural sources.

Question 2: In Ms. Nichols' June letter, she notes that EPA will work closely with the USDA's Agricultural Air Quality Task Force (AAQTG) on agricultural-related issues. She writes, "To the extent that any localized problems are identified, EPA anticipates that any necessary control strategies would be developed on a case-by-case basis..." In that same paragraph, Ms. Nichols

indicates that "EPA's goal is to site PM-2.5 air quality monitors in high populations areas and other areas likely to have a PM-2.5 problem." Considering that EPA does not intend to concentrate its monitoring in agricultural areas, what time frames are required to develop research findings on agriculturally-related air quality issues that are useful and scientifically supportable? And, how will EPA deal with agricultural air quality research?

Response: As we have previously reported, EPA does not intend to focus on agricultural activities in addressing the PM-2.5 NAAQS. Nevertheless, there are site-specific agriculturally-related air quality issues that still have not been resolved. Most of these issues revolve around the PM-10 NAAQS and not PM-2.5. The AAQTF recently forwarded agriculturally-related air quality research priorities to Secretary Glickman for his consideration. The EPA will rely heavily on the resulting research findings as it pertains to agriculture. The EPA has supported and will continue to support agriculturally-related air quality research in several areas such as the Columbia Plateau and the San Joaquin Valley. Research findings will be used in characterizing the PM-10 problem and evaluating appropriate control actions in these areas and the agreed upon controls will more than likely be included in their respective SIP's.

Question 3: According to the July 17, 1997 Fact Sheet titled, *EPA's Monitoring Requirements for Particulate Matter*, the Network Design will consist of core-community oriented monitors which will be placed in the largest metropolitan areas. Only supplemental monitors will provide coverage in rural areas. How will EPA and states regulate the agricultural community when the proposed monitoring will be inadequate to determine the source of the particulate matter?

Response: The EPA and States will make attainment and nonattainment determinations once 3 years of ambient air quality data becomes available. Monitors are targeted for large metropolitan areas and not rural areas. Therefore, EPA does not anticipate the agricultural communities to be adversely impacted by the PM-2.5 NAAQS since they are typically <u>not</u> located in large metropolitan areas. .

Question 4: In fact, July 18, 1997, <u>Federal Register</u>, Vol 62, No 138, indicates there will be approximately 1500 monitors, of which 50 of the monitors will provide a more comprehensive speciation network. In the same paragraph, it was stated "...these would generally not include agricultural areas". If the agricultural community will not be monitored, how will EPA ensure that no additional restrictions will be placed on the agricultural community by the States?

Response: The States are required by the Clean Air Act to respond to monitored violations of the standard. If an area is not violating the NAAQS, the states would not need to impose additional restrictions on a community.

Question 5: You indicated at a July 22, 1997 hearing before the Senate Agriculture Committee, that ozone regulations could save American agriculture $500 million. What methodology was used to determine this savings? In general, please explain the costs and benefits EPA expects these regulation to have on agriculture producers. Please cite your analysis. USDA's research has indicated that levels of ozone substantially below the 1-hour standard have been shown to produce significant reductions in plant productivity. Are current levels of ozone immediately

surrounding the Nation's croplands at this dangerous exposure level currently? If detrimental levels of ozone are high enough to require these regulations as you indicate, please explain how US farmers have increased annual production despite this current ozone level. Please cite the research you are using to make this determination.

Response: It is true that the Agency's analysis estimates a benefit of approximately $500 million annually if the new ozone and PM NAAQS are fully met. This estimate is based on estimating a relationship between ozone exposure and plant yields. A number of scientific studies provide a Concentration-response" relationship between ambient ozone concentrations and plant yields associated with plant species such as wheat, cotton, citrus, cantaloupes, and trees in commercial forests. The concentration-response relationship allows the estimation of changes in an effect (such as plant yield) given a change in air quality. Available concentration-response relationships allowed the Agency to quantify three broad agricultural benefits categories: commodity crops, fruits and vegetables, and commercial forests.

A second step in estimating the agricultural benefits was to predict changes in ambient ozone concentrations expected to be brought about by the new NAAQS. To generate this data, the Agency projected an air quality scenario for the year 2010 and then imposed an air quality scenario that simulated attainment of the new ozone NAAQS in all areas of the continental U.S. The predicted air quality changes were used in conjunction with the concentration-response relationship to predict the increased crop yield for each plant. The changes on plant yield are fed into a economic model to simulate changes in demand/supply conditions. The changes in economic surplus are then reported as benefits associated with agricultural products.

An explanation of this methodology can be found in the Agency's Regulatory Impact Analysis (RIA), which is available on the Office of Air Quality Planning Standards Technology Transfer Network via the Internet. The address is: http://ttnwww.rtpnc.epa.gov/naaqsfin/ria.htm. The methods described above can be found in Chapter 12 of the RIA, beginning on page 12-50.

Regarding USDA's research indicating that levels of ozone substantially below the 1-hour standard have been shown to produce significant reductions in plant productivity, the data that we examined from the National Crop Loss Assessment Network (NCLAN) project corroborates this finding. Our air quality modeling for the RIA showed that in 2010, ambient ozone concentrations vary depending on the geographic location. For example, ozone concentrations were higher (sometimes exceeding the 1-hour standard) near urban areas when compared to ozone concentrations in rural areas.

You also asked how U.S. farmers have been able to increase annual production despite current ozone levels. Ozone exposure is only one factor that influences crop yields. Other factors include technological advancements and increased application of fertilizers. The Agency's analysis examines the agricultural benefits by varying only one factor: a change in ambient ozone. This relationship between decreased ozone levels and increased crop yields is supported by the NCLAN project (discussed in Section VII-D.2 of the U.S. EPA Staff Paper for Ozone, June 1996).

Question 6: At the July 22nd hearing, you also indicated that monitoring data which includes fires, i.e., sugarcane burning, wheat stubble burning, prescribed burns in national forests, etc; would not be included in the average, and that the "...data would be thrown out..." What are the regulatory criteria for including measured monitored data? Under what circumstances will the data e considered a statistical outlier? Have these criteria been peer reviewed by the Scientific

Advisory Board? How can you ensure a grower community that their farming practices, which currently may include burning, will not have additional restrictions placed on them? Please cite the regulatory and/or statutory provisions under which you have repeatedly informed Congress of the decision by EPA.

Response: On May 30, 1996, EPA issued a memorandum setting forth the Agency's policy for protecting public health in areas where the PM-10 NAAQS are violated due to natural events. I have enclosed a copy of the Natural Events Policy for your information. The policy which was developed in consultation with State and local air pollution control agencies, identifies three categories of natural events which include volcanic and seismic activity, wildland fires, and high wind events. This policy addresses PM-10 NAAQS violations caused by natural events in areas designated unclassifiable or attainment. It also addresses certain reclassification and redesignation questions for the PM-10 nonattainment areas. This policy applies at the time the State determines that a PM-10 NAAQS has been violated due to natural events and addresses the question of what should be done to protect public health. The EPA recognizes the natural role fire and managed burns has in maintaining a balanced ecosystem. As a result, EPA is also developing additional guidance through an Interagency Work Group to address issues raised regarding smoke emissions from wildland prescribed fires. The AAQTF has also identified agricultural burning as an issue they'd like to provide their recommendations on. The Agency welcomes advice from both groups as we develop a policy on managed burns on private and public lands.

Question 7: It has come to my attention that EPA has raised a concern for ammonia emissions from agricultural production and livestock operations. Even though EPA may be unsure of all the sources of ammonia emissions and has concerned that a reduction in ammonia emissions may adversely alter the atmosphere (increase in sulfuric acid), I also understand that ammonia is a precursor for particulate matter. Do you believe that the proposed monitors will adequately detect and measure the sources of ammonia emissions? If not, then what assurances do I have that EPA is not going to require additional restrictions to current livestock production practices? Please cite all relevant regulations and statutes in your response.

Response: The predominant precursor gases for PM formation are sulfur dioxide, nitrogen oxides, ammonia, and volatile organic compounds. Ammonia reacts in the atmosphere with the sulfur dioxide and nitrogen oxides to form ammonia sulfate and ammonia nitrate particles. The EPA is not planning to regulate ammonia emissions from agricultural production and livestock operation. The Agency believes pursuing a regional SO2 reduction strategy such as the acid rain program will significantly reduce ambient PM-2.5 concentrations. This type of strategy as well as the eastern NOx reduction strategy is primarily targeted at power plants. The EPA will continue to gain a better understanding of the chemistry associated with ammonia emissions. In the meantime, however, EPA believes the best course of action is to reduce emissions from SO2, not ammonia. Also, it is important to remember that the Federal Reference Method for PM-2.5 is designed to measure PM mass not the precursor gases. The PM-2.5 monitors were not designed to detect and measure sources of ammonia emissions. Sources of emissions could be determined by chemically analyzing the filter samples but this is not required as part of the Part 58 PM-2.5 reference method.

Question 8: In light of questions 1-3 above, has EPA quantified the increased cost to agriculture that these regulations could have? How do you quantify the economic impact of the regulations in restrictions work activities in nonattainment areas? As you probably know, farming is an extremely time-sensitive activity; when the weather and field conditions are right during planting or harvest seasons, farmers are in the field day and night until the crop is in the group or in the bin. In response, please present the methodology EPA will use in quantifying this economic impact.

Response: EPA's "Regulatory Impact Analyses for the Particulate Matter and Ozone National Ambient Air Quality Standards and Proposed Regional Haze Rule (RIA)" provides defensible national cost estimates associated with implementation of the new standards. While we believe the models employed yield reasonable estimates of national costs, industry-specific impacts could not be reliably estimated with these models. Moreover, since the actual implementation strategy that States will employ is unknown, the RIA assessed just one of many possible implementation approaches. Thus the actual industry-specific impacts associated with future implementation of the NAAQS can not be estimated with any confidence at this time.

Nevertheless, Appendix H of the RIA provides rough industry-specific potential economic impact estimates associated with the new standards (a copy of the RIA is enclosed). Potential impacts on agriculture-related industries in terms of regulatory cost as a percentage of sales revenue are presented in this appendix.

Question 9: In light of question 5, please quantify (with methodology) the impact on increased fuel, utility and equipment expenses.

Response: As indicated in the response to the previous question, the actual industry-specific impacts associated with future implementation of the NAAQS cannot be estimated with any confidence at this time. Further, the models employed in the RIA are not capable of estimating indirect economic impacts on the agriculture community from controls employed in other sectors. Thus, we do not have indirect economic impact estimates on the agriculture community at this time.

Question 10: Does EPA know approximately how much PM occurs naturally? Do your PM regulations take into account that PM does in fact occur naturally? Do your regulations account for differences in PM geographically and in different regions of the Nation, especially in rural areas? Please explain.

Response: Natural or background concentrations as defined by EPA in the PM staff paper are those levels that would be expected to occur in the absence of man-made emissions of PM and precursor compounds. Background levels of PM vary by geographical region and season. The exact magnitude of the natural portion of PM for a given geographical location cannot be precisely determined because it is difficult to separate the long-range transport of man-made particles or precursors. Based on published data in the scientific literature, the PM criteria document estimated annual average background levels for PM-10 and PM-2.5 for the western and eastern regions of the U.S. The PM-10 annual average was estimated to range from 4-8 μg/m3 in the western U.S. and from 5-11μg/m3 in the eastern U.S. The estimated PM-2.5 levels ranged

1-4 μg/m3 in the western U.S. and from 2-5 μg/m3 in the eastern U.S.

The range of expected background concentrations on a short term basis is much greater. Specific natural events such as wildfires, volcanic eruptions, and dust storms can lead to very high levels of PM comparable to or greater than those observed in polluted urban atmospheres. Because such excursions are essentially uncontrollable, as previously mentioned, EPA has developed the Natural Events Policy that removes from consideration in nonattainment determinations data resulting from these types of natural events.

Consideration of natural background levels was one of many factors that EPA examined in assessing the available scientific and technical information that served as the basis for the revised PM NAAQS and in determining appropriate policy responses. By establishing new PM-2.5 standards, rather than tightening the preexisting PM-10 NAAQS, EPA has focussed the Nation's control efforts on combustion emissions rather than on crusted material from agriculture and other activities. In accordance with the Act, the revised PM NAAQS are nationally applicable.

Question 11: Is the AP-42 emissions index used by EPA an effective measure of PM? If AP-42 is acceptable as the standard, is it correct to assume that traditional cultivation practices would be replaced with more extensive use of herbicides? How much increased use of pesticides could result from this standard and what would be EPA's response about his use?

Response: WAITING FOR MOBLEY/EFIG

EPA does not intend to focus it's control programs to reduce emissions from traditional cultivation practices. As previously mentioned that Agency has focussed the Nation's PM-2.5 control efforts away from coarse particle control and on control of combustion emissions.

Question 12: In areas of the western US, risk mitigation measures have been implemented, eg., hay grinding at livestock operations must cease between certain hours of the day. Have these mitigation measures been monitored by EPA or others to record the reduction in PM? Or, risk?

Response: We are not aware of any work being done in this area. NOT SURE WHO TO COORDINATE RESPONSE WITH. I THINK THE ANSWER IS NO WE Have NOT LOOKED AT THIS.

Question 13: As noted in the Subcommittee on Forestry, Resource Conservation and Research hearing held last April in the Committee on Agriculture, Professor Parnell of Texas A&M University criticized the data samples in the proposed regulations because they were based on a ratio of PM-10/PM-2.5 that will vary in different geographical locations as a consequence of different sources of PM. Please respond to this criticism.

Response: EPA did not use a ratio of PM-10/PM-2.5 data in establishing the levels of the PM-2.5 standards. Instead, EPA relied on studies that reported fine particle concentrations.

I appreciate this opportunity to be of service and trust that this information will be helpful

to you.

Sincerely yours,

Richard D. Wilson
Acting Assistant Administrator
for Air and Radiation

OAQPS:AQSSD:IPSG:RDUNKINS:vwyatt:x5628:MD-15:08-19-97
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CONTROL NO. AL972011 DUE DATE AQSSD: 08/15/97

Coordinated with: ISEG(S. Mathias, M. McKeever) - Questions 5, 8, &9.
HESG(J. Haines) - Questions 10 & 13

UNIVERSITY OF CALIFORNIA, DAVIS

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DAVIS, CALIFORNIA 95616-8569

September 8, 1995

Mr. Dallas W. Safriet
EPA Emission Factor and Inventory Group
RTP, NC 27711

Re: Emission Factor Documentation for AP-42 Section 9.1, Tilling Operations, Draft Report

Dear Mr. Safriet:

Thank you for the opportunity to comment on the proposed draft version of Section 9.1, Tilling Operations, dated July 1995 by MRI. I am concerned that the emission factor equation developed in the earlier version is recommended for continued use, but the problems inherent in it have not been adequately addressed. I am particularly concerned about representativeness of the data used to develop the emission factor equation, the interpretation of the data accepted for analysis, and the rating system used to categorize data.

The draft report lists several factors that have the potential to influence the generation of fugitive dust. These include dry soil texture, soil moisture, depth of soil disturbed, degree of soil disturbance, and speed of the equipment. Despite this, the draft report repeats the assertion contained in the earlier version that there is no dependence of emissions on soil moisture or on the type of conventional tillage implement, if used at a typical speed. As I will point out below, the data suggest otherwise.

The draft report relies primarily on results of tests conducted prior to the previous version of this section. Consequently, the data used to develop the emission factor equation are based on older equipment that may involve a greater degree of soil disturbance than the newer, more innovative designs. The report acknowledges that some of these newer designs reduce dust emissions, so the conclusion to retain the emission factor equation, which does not acknowledge different tillage implements, is suspect.

The data cited in reference 1 for section 4 clearly show the dependence of emissions on the type of tillage implement and the soil moisture content for inhalable particulate matter (PM_{15}) and fine particulate matter ($PM_{2.5}$). Figures 37 and 38 of that report show poor correlation between silt content and emission factor when all combinations of tillage implement and soil moisture are included. When the data for a single tillage operation and similar soil moisture are analyzed separately, a good relationship between silt content and emission factor is obtained. This

suggests that there should be a separate emission factor equation for different tillage operations, and there should be a dependence on soil moisture.

I am concerned that the criteria established by MRI for evaluation of test reports contains an unintentional bias against data collected by other organizations. For example, our research group at the University of California is currently conducting emissions tests on numerous harvesting and tilling operations in California's San Joaquin Valley. We prepared a report to the San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD) on some of our early work, and this report is cited in section 4. The data are downgraded, though, because much of the information required by MRI to meet their criteria for acceptability were not included in the report. The San Joaquin Valley district did not require this information in our report to them, so we did not include it. It appears that the criteria established by MRI are so stringent that only their own data fully meet them. My concern is heightened by the statements, on pages 3-3 and 3-4, that "The depth of review of the calculations was dictated by the reviewer's confidence in the ability and conscientiousness of the tester..." and "The use of these criteria is somewhat subjective and depends to an extent upon the individual reviewer."

We have not received a request from MRI for further information on our testing. If they had requested additional information, we most certainly would have provided it.

The description of emission test methods that begins on page 3-5 is incomplete. Rather than being a description of sampling methods in general, the work reflects MRI's familiarity with their own work, and only provides a cursory acknowledgment of other sampling methods. For example, the draft report discusses the use of isokinetic sampling as part of the exposure-profiling method. There is a brief reference to the use of PM_{10} inlets rather than isokinetic sampling, but it appears to be added on rather than integrated into the discussion. Also, the report calls for a sampling time of about 1 hour. We have successfully sampled tests as short as 20 minutes. The shorter sampling time is important for a good test, as the wind direction is more likely to remain consistent and the distance between the operation and the sampler is more constant.

In conclusion, I am concerned that the existing emission factor equation is being retained without proper acknowledgment of its limitations. There is most certainly a need for additional testing in this area; that is why we are working on a large USDA-sponsored research program to develop improved information. Unfortunately, complete results from our work were not available for this report. They will begin to be available in the next year, and additional information will be provided as we complete our analysis. In the meantime, I suggest that the existing equation be used with extreme caution, and only under very limited circumstances of tillage implement and soil moisture. The revised AP-42 section 9.1 should acknowledge its limitations by downgrading its quality rating until additional test information can be obtained.

Sincerely,

Lowell L. Ashbaugh

Dr. Lowell L. Ashbaugh
Associate Research Ecologist

JOHN DEERE DES MOINES WORKS

P. O. BOX 1595, DES MOINES, IOWA 50306-1595

8 September 1995

Dallas Safriet
U.S. Environmental Protection Agency
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

Dear Mr. Safriet:

Thank you for the opportunity to review the draft version of Emission Factor Documentation for AP-42, Section 9.1, Tillage Operations. I was provided the draft report from the Equipment Manufacturers Institute. I have numerous comments on sections 2, 4, and 5 of the draft report. I am not familiar enough with emission test methods to review section 3. The most serious comments relate to the conclusions drawn in sections 4 and 5.

Upon reading the document, I contacted two researchers knowledgeable in this area. I was surprised to learn that they were not given a copy of this document to review. They indicated that there was a meeting on this topic in Lubbock, Texas in May 1995. Many leading researchers and government officials were present at this meeting. I did not get any indication of this meeting in this document nor of any current research conducted in the area of dust emissions from tillage operations. The University of California at Davis is conducting such research. Are there other research studies ongoing to support claims in this document? This is significant, given the conclusion that the emission equation is based on one or two research studies and it has not been validated by other studies. The researchers I spoke to was surprised to learn that soil moisture, type of tillage tool, tillage operational parameters, and other soil factors were not accounted for in the emission equation.

I conclude that the current equation is unvalidated and inappropriate. Further research is needed to develop a scientifically based emissions model. Such a model, at a minimum, should consider factors such as soil moisture, type of tillage tool, and tillage operational parameters. I would recommend the document report be reviewed by ARS scientists at Manhattan, KS (Wind Erosion Lab) and Lubbock, TX and well Michael Singer and his colleagues at the University of California at Davis.

Specific comments on the draft report are attached.

Sincerely

John S Hickman

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Manager, Cropping Systems
515-289-3491 voice
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NX08561@deere.com internet

enc.

cc: Glenn Olson
Ralph Grotelueschen
Dave Bucher
Darrin Drollinger (EMI)
Rich Johnson
Robert Wismer
Bob Schebler

Section 2

Section 2.1, paragraph 1, line 6 - "farmed for different crops" should be replaced with "harvested".

Section 2.1, paragraph 1, line 8 - The acreage of sorghum is about 12 million acres, not 56.4 million acres. The author probably is referring to soybeans, not sorghum.

Section 2.1, paragraph 2, line 1 - Crop production does not necessarily require tilling the surface soil. Nearly 14% of U.S. cropland was no-till planted in 1994 (Conservation Technology Information Center). The percentage varies by crop and has been increasing in recent years.

Section 2.1, paragraph 2, line 2 - Tillage is used for seedbed preparation and weed control, but also for other pest control, incorporation of nutrients and pesticides, alleviation of compaction, warming soils, managing residue, roughening the soil (also an emergency wind erosion control practice), and moisture control.

Section 2.1, paragraph 2, line 5 - What is meant by the term "significant"?

Section 2.2, paragraph 1, line 3 - A soil with large pores extending from the surface to the water table would "not" always be desirable. Considerable ground water contamination could result in such cases.

Table 2-2 - I would use tillage definitions from the Natural Resources Conservation Service or Conservation Technology Information Center. I believe these definitions are more widely accepted than the definitions used in Table 2-2.

Section 2.2, paragraph 2, line 1 - Plowing is not a typical soil preparation practice. USDA reports the plow used on 9, 8, 16, and 6 percent of corn, soybeans, cotton, and winter wheat acreage, respectively. The tillage practices mentioned are more representative of vegetable production rather than typical crop production practices. See USDA Economic Research Service (ERS) Agricultural Handbook 705.

Section 2.2, paragraph 2, line 5 - Broadcast application is the most common method of fertilizer application. Injection, incorporation, or banding (with the planter) will result in less loss of nutrients with dust emissions, however, by pacing the chemical below the surface.

Table 2-3 - I would use the American Society of Agricultural Engineers Standards for tillage tool terminology. This would be a much better reference than the current reference.

Section 2.2, paragraph 4, line 1 - The Natural Resource Conservation Service is recommending the residue level on a field be sufficient to reduce wind and/or water erosion. Many have equated this level to be 30 percent. The actual residue may be above or below this level depending on the specific field situation. Actually for wind erosion purposes, the term small grain equivalent is often used instead of residue cover. The definition of conservation tillage, on the other hand, is to leave 30 percent residue or 1000 pounds of small grain equivalent on the soil surface after planting.

Section 2.2, paragraph 4, line 3 & 5 - Use the latest (1994) statistics from the Conservation Technology Information Center.

Section 2.2, paragraph 5, line 1 and Table 2-4 - Data from tillage trips for California is not representative of crop production in the country. Use of tillage numbers from the USDA-ERS Handbook 705 would be much more appropriate.

Section 2.2, Paragraph 5, line 2 - The USDA-ERS data indicates the number of tillage operations vary by crop. The number of 2.6, 3.0, 6.2, and 4.7 apply to corn, soybeans, cotton, and winter wheat, respectively. These trips include the planting operation as well as tillage operations.

Section 2.3, paragraph 1, line 2 - Replace "dirt" with "soil".

Section 2.3, paragraph 4, line 3 - I would not agree that most tillage operations are performed under dry conditions. This would be very site specific. I have no idea of what you mean by dry. Do you have supporting evidence that most tillage operations are performed when the soil is dry? Please define the term "dry".

Section 2.3, paragraph 6, line 4 - Fertilizers and other chemicals lost in wind erosion are enriched in respect to the mass fraction of the chemical attached to soil. I would expect similar enrichment from dust generated by tilling operations. Consult the ARS-Wind Erosion Unit in Manhattan, KS for specific information. Another method to reduce these losses is to incorporate or place the chemicals below the soil surface.

Section 2.4, paragraph 3, line 1 - Tillage can also be used to create stable clods as is mentioned in the next paragraph. The number of tillage operations for crop production is going down and I do not feel the term "frequent" is appropriate today.

Table 2-5 and Section 2.4 - Several of the control practices will only affect a small percentage of total crop acres. I am unaware of a commercially viable "punch planter" sold today. Such a planter would not allow changing plant population and would be difficult to control depth of planting. There are several planters on the market today which disturb little residue. I am aware of spoke wheel applicators for plant nutrients, but even this technology is used on a very small percentage of acres. Double crop corn and aerial seeding also appear to impact a very small percentage of crop production. The Conservation Technology Information Center reports less than 1 million acres of double crop corn.

Section 4

Section 4.1, paragraph 1, line 1 - Very few studies (2 or 3) have been completed from which to base a recommendation or dust emission equation.

Section 4.1.1, paragraph 1, line 2 - Does this study constitute the original source of test data? I was unsure from the discussion and whether or not this would eliminate this document from consideration as stated in section 3.1.

Table 4-1. The moisture range used in this study appears to be on the low side. This may be appropriate for arid areas, but not the majority of crop land. A range of moisture contents between 2 and 30 percent would be more appropriate

Section 4.1.1, paragraph 4, line 4 - How do you reconcile the statement that moisture is not significantly related to dust emissions with section 2.3, paragraph 4 and section 9.1.2 which indicate there is a relationship between moisture and dust emission?

Section 4.1.2, paragraph 7 - Only predicted emissions from floating and land planing agree with the measured values. Floating and land planing do not represent a large acreage when compared to other tillage methods. Also floating and land planing are often multiple operations, whereas many (but not all) tillage operations are separated by a period of time. Although this study is rated lower for stated reasons, predictions from stubble disking and chiseling are about 3x higher than the measured values. This would indicate the existing equation is inadequate (as opposed the statement in paragraph 8). My conclusion is that the equation does not represent currently used tillage equipment and additional research and studies are needed to predict dust emissions. Use of an equation based on one or two studies that has not been validated by other research is inappropriate.

Section 4.2, paragraph 1, line 1 - I believe the current equation can not be validated for reasons mentioned above.

Section 4.2, paragraph 3, line 7 - In other words, PM-10 (<10um) dust emission loss (when silt content is unknown) is 5.7 pounds/acre per tillage operation regardless of tillage tool, moisture content, or other factors.

Section 5 or 9.1

Section 9.1.1 - Changes indicated in section 2 also apply here.

Section 9.1.2, paragraph 3, - I have a difficult time with the statement that dust emissions from tillage are not related to surface moisture, as do other scientists whom I have visited. The documented concludes since most tillage is performed when the soil is dry, this is really not a significant issue. Verbal communication with the University of California, Davis indicate significant impact of soil moisture on dust emissions between the range of 2 to 5 percent moisture. Again I would like to see evidence that supports the statement that most tillage operations are performed on dry soil. I believe this to be a very site specific factor and that tillage operations are also performed when the soil is moist to wet.

Section 9.1.2, paragraph 4 - Differences in type of tillage tool and dust emissions were noted in study 3 although this study was downgraded because of several reasons. Several statements are made in the document that indicate the importance of type of tillage tool. However, type of tillage tool is not considered in the equation for predicting dust emissions.

Section 9.1.3 - Changes indicated in section 2 also apply here.

Other

I am interested as to what will be the respiratory particulate cutoff for agricultural dusts and whether or not emission dust from agricultural soil poses the same threat as that from urban or industrial sources. Any insight into these factors would be appreciated. Thank you.

Recd 10/19/95
TL

COMMENTS ON EMISSION FACTOR REVIEW
FOR AGRICULTURAL TILLING OPERATIONS

pg. 2-1 Table 2-1 is described as listing acreage farmed for different crops by State. Actually, different crops are not listed.

pg. 2-5 It is not clear why Table 2-4 is included in this report.

pg. 2-10 Several speculative practices are listed as potential ways to reduce emissions from tilling. It would be more useful to focus on actual farming practices being promoted by the USDA Natural Resources Conservation Service that may reduce tilling emissions.

pg. 4-3 The discussion of Reference 1 says that equations for PM-15 and PM-2.5 are less precise for reasons listed in Reference 1. Those reasons should at least be listed in this report. The reader should have to go to Reference 1 only for a better understanding of those reasons.

pg. 4-4 The first sentence refers to TSP samplers used in the San Joaquin Valley tests. Is the TSP term being used properly in this reference. Was an array of ambient total suspended particulate samplers used? If so, how was size segregation above and below PM-2.5 achieved?

Comments from Ken Woodard
via LAN on 10-10-95

Ohio Recd 10/12/95

ARIZONA DEPARTMENT OF ENVIRONMENTAL QUALITY

Fife Symington, Governor Edward Z. Fox, Director

ADQ:AAS:991

October 6, 1995

Mr. Dallas W. Safriet
Environmental Engineer
Emission Factor and Inventory Group
Office of Air Quality Planning and Standards
Mail Drop 14
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

Dear Mr. Safriet:

RE: Draft Version of Section 9.1, Tillage Operations

The purpose of this letter is to provide comments on the draft report and draft emission factor prepared by Midwest Research Institute (MRI) for the Environmental Protection Agency (EPA), and to inform you of Arizona research and findings on agricultural tillage particulate emissions.

Tilling Operations, Draft Report

In Section 2.3, the report contains a listing of tilling parameters that have the potential for influencing the generation of fugitive dust. Of the five parameters listed, none are included in the emission factor equation. What research data is available to support the significance of these parameters? Also, the parameters "dry texture" and "mechanical agitation" need definition to be of value to the user of this document. And, how does one quantify "mechanical agitation"?

In the last paragraph of Section 2.3, agricultural chemicals are mentioned, but are not relevant to particulate emissions as traditionally used in the AP-42. Is the quantification of chemical applications to crops pertinent to the tillage operations emission factor for particulate emissions?

For Figures 3-1 and 3-2, it would make more sense if the activities illustrated were agricultural tillage operations and if these figures were scaled to actual measurements used in upwind-downwind and exposure profiling sampling configurations. This detailed illustration would enable the reader to review the appropriateness of these techniques for quantifying particulate emissions from tillage operations.

In Section 4.1, it is stated that only three studies were identified for review for this revision of this tilling operations report. Since two of these studies are the basis for the current emission

factor and data from the third study was not incorporated into the emission factor, we are concerned that the emission factor should not be "revised" until more research is conducted.

Draft AP-42 Section 9.1

In Section 9.1.3, we believe it is inappropriate to make statements about emissions reductions from tillage operations without data to support this guidance.

Arizona Research

The Arizona Department of Environmental Quality, Division of Air Quality, has conducted research with the University of Arizona, Office of Arid Lands Studies, to quantify particulate emissions from tillage operations for five cotton tillage systems in Yuma and three cotton tillage systems in Marana. In this research, hi-volume total suspended particulate samplers were mounted on the tillage implement to determine emissions during the pass of the equipment across the field. We found that measured particulate emissions in Yuma were an order of magnitude lower than the predicted emissions using the AP-42 emission factor equation. I am enclosing the final report for your review. We believe this data should be considered for inclusion in the documents for developing an emission factor for tillage operations. I am interested in participating with EPA and other agencies to conduct research and/or provide technical review of ongoing agricultural research on particulate emissions. I can be reached at (602) 207-2353 with any questions about our research on tillage operations.

Sincerely,

Kathy Stevens
Air Quality Analyst

Enclosure

cc: John Burchard, ADEQ (without enclosure)
Gary Neuroth, ADEQ (without enclosure)
Wayne Coates, U of A (without enclosure)

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September 11, 1995

Mr. Dallas W. Safriet
Environmental Engineer
U.S. Environmental Protection Agency
Emission Factor and Inventory Group (MD-14)
Research Triangle Park, North Carolina 27711

SUBJECT: Draft Revision of AP-42 Section 9.1, Tilling Operations

Dear Mr. Safriet:

We appreciated receiving the subject draft report with your letter of July 27, 1995. Tillage equipment manufacturers certainly are interested and impacted by the proposed changes to AP-42, Section 9.1.

Because the issue is so highly complex, six weeks has not been sufficient time for us to evaluate the MRI work and comment meaningfully. However, it has been brought to our attention that others have raised a number of extremely significant concerns with Tables 2.1, 2.4,. 2.5 and the severe limitations involved with retaining the existing emission factor equation.

We will forward additional comments in the near future.

Sincerely,

Darrin J. Drollinger
EMI Staff Engineering Specialist

Serving Manufacturers of Agricultural, Construction, Forestry, Materials Handling and Utility Equipment

SEP-11-95 MON 01:14 PM EMI FAX NO. 3123211480 P.01

CALIFORNIA COTTON GROWERS ASSOCIATION

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September 1, 1995

Mr. Dallas Safriet
Environmental Engineer
U.S. EPA
Emission Factor and Inventory Group (MD-14)
Research Triangle Park, NC 27711

Re: **Proposed Draft Report on AP-42: Section 9.1**

Dear Mr. Safriet,

I would like to thank you for the opportunity to comment on the proposed version of Section 9.1 of AP-42. Compilation of Air Pollutant Emission Factors. I must advise you that we have serious concerns with the proposed section. We feel that it is based on questionable and inaccurate data, that would have an unjustifiable and serious impact on the agricultural industry. We have concerns with Table 2.4, and Table 2.5 that must be addressed.

In Table 2.4, the number of typical operations and % of land area tilled is listed. We would question how EPA can classify fertilizer or herbicide application as a "land preparation" activity. Application of pesticides or herbicides typically occur from a spray rig, which would not disturb the soil; or from a plane via aerial application. This should be considered when developing this table. Furthermore, some of these operation may be performed in a single pass, such as application of a herbicide with one of the discing operations. This should be accounted for.

There are also problems with Table 2.5. We would like to see that actual test information demonstrating the control efficiencies that are outlined in this table. Does a punch planter really decrease emissions by 50% in cotton. Does this include the increased emissions from the engine, since the equipment must move at a much slower rate? Where are the tests conducted to demonstrate this control efficiency or any of the other listed control techniques? Application of herbicides is listed as a 100% effective control technique for cultivation or soil preparation. Does anybody else at EPA know this? What increase in VOC emissions would there be? Is this accounted for?

We have already faced this data in California, through the local air pollution control districts and through the California Air Resources Board. They have all agreed that the data is suspect, and must be investigated further before any action is actually taken. As a result, industry, local air

pollution control districts, CARB, EPA and the United States Department of Agriculture (USDA) have undertaken a multi-million dollar study to better understand and estimate PM10 emissions. USDA is spending over $3 million to quantify emissions from agricultural operations. Studies are already underway including cotton harvesting, almond sweeping and harvesting, fig harvesting, walnut harvesting, and land preparation activities. These studies are being performed by the University of California, Davis under contract with USDA. EPA should delay inclusion of this section until this study is complete.

We realize there is a short time frame for review on this proposed section, as we have only just received this section this past week. However, based on the comments above, we feel that EPA should seriously reconsider moving forward at this time, until the data is much more refined. Again, thank you for your time and consideration.

Sincerely,

Roger A. Isom
Director of Technical Services

CITIZENS ADVISORY GROUP OF INDUSTRIES

PO Box 457
Corcoran, CA 93212

September 7, 1995

Dallas Safriet
Environmental Engineer
United States Environmental Protection Agency
Emission Factor and Inventory Group (MD-14)
Research Triangle Park, NC 27711

RE: Proposed Draft Report on AP-42: Section 9.1

Dear Mr. Safriet:

Affected industry is appreciative of the opportunity to comment on the proposed version of AP-42 Section 9.1 Compilation of Air Pollutant Emission Factors. As you are aware, the impact of this publication is significant, and it is critical that the emission factors and control measures published in the document are based on sound science. The agriculture community is extremely concerned about the validity of the data contained in the draft document. It is clear that the authors are also uncertain of the validity of the data given the number of instances in which the words "may", "perhaps" and "might" are used in expressing what emissions reductions will be achieved by the use of listed control measures. Again, it is of utmost importance that the critical assumptions behind this document are solidly grounded in science. It is premature and irresponsible to publish such a document until this is achieved.

TABLE 2.4 California Tillage Operations
The validity of Table 2.4 is questioned. Cultural practices and growing practices vary significantly even within the sate of California. For example, alfalfa is harvested ten times per year in the Imperial Valley of California, but only twice per year in Northern California. These variations must be accounted for in developing a matrix of emissions for a crop. Additionally, it is important to consider that more than one operation may be conducted during a single pass through a field (i.e. discing and herbicide application).

TABLE 2.5 Estimated PM10 Efficiencies for Agricultural Controls
The title of this table speaks to the incompleteness of science based data on this topic. As several of the listed control measures require significant additional cost to operators, cost and availability of equipment must also be addressed.

There is no indication of the nature of the testing done to derive the emission reductions that can be achieved through the use of punch planters. As the fiscal implications of purchase of equipment are significant, a control measure of this sort should not be suggested without a firm grasp of what the air quality benefits would be.

The proposed increased use of herbicides to minimize PM10 emissions is a curious proposition. The California Department of Pesticide Regulation has included in their State

Implementation Plan a commitment of a twenty percent reduction in emissions of Volatile Organic Compounds via pesticides (using 1990 as a baseline) by the year 2005. The control measure presented in this draft would seem in direct opposition of this goal, and other areas may experience similar conflicts.

Again, cost is an issue in evaluating the benefit of sprinkler irrigation and aerial seeding. It is vital that a balance between improvement of air quality and the viability of the agriculture industry be achieved.

4.1.2 Reference 3 (Credibility Of Research Work)

We are very concerned about the devaluation of the work conducted by Dr. Flocchini of UC Davis (*Study of Fugitive PM10 Emissions from Selected Agricultural Practices on Selected Agricultural Soils, 1994*). Because cultural practices, growing conditions and soil types differ by regions, regional research work such as that by Dr. Flocchini is essential in developing accurate emissions inventories and control measures for minimizing PM10 emissions. Additionally, it is our belief that Dr. Flocchini addressed the concerns raised by the authors in both the test protocol and final report documents. These comments should be deleted from the document.

OTHER RESEARCH WORK IN PROGRESS

For some time, the agricultural industry has been concerned about the lack of valid data relative to the industry's contribution to the PM10 problem. As a result, industry leaders have partnered with the local air pollution control districts, the California Air Resources Board, Federal EPA and the United States Department of Agriculture (USDA) to fund a multi-million dollar study on the topic. These studies are being conducted by the University of California, Davis under contract with USDA, and are looking at specific activities such as cotton harvesting, almond sweeping and harvesting, fig harvesting, walnut harvesting and land preparation activities.

It would be premature to publish AP-42 Section 9.1 before the results of these studies are available for incorporation into the document. We, therefore, ask that EPA seriously consider postponing further action on this item until that can be accomplished.

Once again, we thank you for your time and consideration.

Sincerely,

Manuel Cunha, Jr.
President
Citizens Advisory Group of Industries

Dennis C. Tristao
Secretary
Citizens Advisory Group of Industries

Nisei Farmers League

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September 7, 1995

Mr. Dallas W. Safriet
EPA Emission Factor & Inventory Group
Research Triangle Park, NC 27711

RE: EMISSION FACTOR DOCUMENTATION FOR AP-42
SECTION 9.1 TILLING OPERATIONS-DRAFT REPORT

Dear Mr. Sofriet:

I would like to thank you for the opportunity to address the proposed draft version of Section 9.1-Tilling Operation, dated July, 1995 by MRI.

I have grave concerns that your agency and researchers are using inaccurate data that could easily be corrected if they were reconfirmed with the agricultural industry and your control measures are economically unfeasible. Your draft report consists of five sections, each having a description of each area.

2.0 Industry Description

The Agriculture industry in the United States feeds the world! The total number of farmers in the United States is under 2 million. We can not speak for the other eight states that comprise 300 million acres or 50% of the land used for farming, but we can discuss California Agriculture. In Table 2-1-the acreage harvested by California is inaccurate and I question how you could compare dry land farming with irrigated farming and harvested land.

2.3 Agricultural Field Equipment

You listed all types of equipment which are used by farmers throughout the year and I would caution you that California farms 250 different crops and each year those crops can vary. With the change in crops, sometimes 3-4 different crops on one piece of land, come the use of a variety of agricultural equipment. Many of our crops are disked into the soil for pest control, soil building in the highly erodible areas.

2.4 California Tillage Operations

The tillage operation that you have listed in your table are not correct and need to be changed along with the crop classification groups. Your source reference 6 needs to work with California growers rather than with those who lack any agricultural background.

2.4 Control Methods

Again I must restate my concern over the methods of control PM_{10} from agriculture operations i.e. tillage. California again grows and harvests over 250 different crops and each has a specific activity to their own operation.

Under the Literature Search and Screening, I question the upwind-downwind method of direction in which the equipment was placed in the field or road.

4.2 Summary of Charges to AP-42

I question the 18% silt test - wet vs. dry method. We believe that to obtain the most accurate date, the silt content should be based on the dry rather than the wet method.

For further information dealing with Agricultural PM_{10} we hope that you will work with those states (especially California) in trying to understand how we farm and what crops are grown in those state. They should be evaluated on their own merit.

Sincerely,

Manuel Cunha Jr.

Manuel Cunha, Jr.
Executive Vice President

MC:km