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Grain Jan

Source Assessment Harvesting of Grain State-of-the Art

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Prepared for

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SECTION III

SOURCE DESCRIPTION

A. PROCESS DESCRIPTION

1. Source Definition

This source includes the grains listed in the U.S. Department of Agriculture Official Standards for Grain: wheat, rye, oats, barley, flaxseed, soybeans, corn, and sorghum.[1] Harvesting of these crops refers to the activities performed to obtain the cereal kernels of the plant for grain or the entire plant for forage and/or silage uses. These activities are accomplished by machines that cut, thresh, screen, clean, bind, pick, and shell these crops in the field. Harvesting also includes the loading of the harvested crops into trucks and transport of the crops on the grain field.

2. Source Characteristics

Grain crops are harvested for use of the cereal kernels or the remainder of the grain plant. The various machines and methods employed for harvesting depend on the use of the crop.

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[1]The Official United States Standards for Grain. U.S. Department of Agriculture, Agricultural Marketing Service, Grain Division. U.S. Government Printing Office. Washington. Stock No. 0116-00094. June 2, 1974. 66 p.

Crops harvested for the cereal kernels are cut as close as possible to the inflorescence (the flowering portion containing the kernels).[2] This portion is threshed, screened, and cleaned to separate the kernels from the plant. The grain is then stored in the harvest machine while the remainder of the plant is discharged back onto the field.

Combines perform all of the above activities in one operation. Binder machines are used just to cut the grain plants and tie them into bundles or leave them in a row (called a windrow) in the field.[3,4] The crop is then allowed to dry for threshing at a later date by a combine with a pickup attachment.

Corn is the only exception to the above procedures. It is harvested by mechanical pickers, picker-shellers, and combines with corn head attachments. These machines cut and husk the ears from the standing stalk. The sheller unit also removes the kernels from the ear. A binder is sometimes used to cut and bind the entire corn plant. These bundles are placed into piles (called shocks) to dry for husking at a later date.[4]

Mowers, crushers, windrowers, field choppers, binders, and similar cutting machines are used for harvesting the grasses, stalks, and cereal kernels for forage and/or silage.[5] These machines cut the plants as close to the ground as possible

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[2]Private communication. Mr. H. B. Drake. Montgomery County Agricultural Extension Agency (Ohio). July 8, 1975.

[3]Wilson, H. K. Grain Crops, 2nd Edition. New York, McGraw-Hill Book Co., 1955. 396 p.

[4]Kipps, M. S. Production of Field Crops, 6th Edition. New York, McGraw-Hill Book Co., 1970. 790 p.

[5]Encyclopaedia Brittanica, 1974 Edition. Volume 1 - Technology of Agriculture. Chicago, Encyclopaedia Brittanica, Inc., 1974. p. 357-361.

and leave them in a windrow. The plants are later picked up by a baler which ties them into bundles. Pickup balers are also used on previously threshed crops that were left in the field.[4]

Harvested crops are loaded into trucks on the field. Grain kernels are loaded through a spout from the combine. Forage and silage bales are manually or mechanically placed in the trucks. The harvested crop is then transported on the field to a storage facility.

3. Emission Sources

Emissions are generated by three grain harvesting operations: (1) crop handling by the harvest machine, (2) loading of the harvested crop into trucks, and (3) transport by trucks on the field.

Machines create particulates at the various areas where the harvesting actions take place. Emissions occur at the points where these activities are open, or material is discharged, to the atmosphere. Wind then entrains particulate matter which is composed of soil dust and plant tissue fragments (chaff). This particulate matter has a respirable fraction that contains free silica.

Particulate matter may also contain a residue of pesticides that were applied to the crop prior to harvest.[6] The proportion of pesticide in the plant, increased by three orders of magnitude, is assumed to represent the proportion present in the dust. This results in a concentration (at

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[6]Spear, R. C., and W. J. Popendorf. Preliminary Survey of Factors Affecting the Exposure of Harvesters to Pesticide Residues. American Industrial Hygiene Journal. 35:374-380, June 1974.

100 m downwind) which is four orders of magnitude less than the threshold limit value (see Appendices A and B). Thus further consideration of pesticides is not necessary.

Particulates from harvesting operations also contain various microorganisms, such as bacteria and fungal growths.[7] There are 236 common types of microorganisms associated with grain plants.[8] These growths are present on the dust and release spores when agitated by the vibration of the harvesting machine.[9] A standard for grain handling dust exposure has not been promulgated due to lack of specifically identified hazards other than the free silica in the particles.

Particulate emissions are generated in two other operations which are not as complex as the harvest machine activities. The loading of the harvested grain crop generates particulates that are subject to wind entrainment during the free fall of the harvested crop into the truck. Particulates containing free silica are emitted during transport of the material by trucks from the action of the truck tires on the field.

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[7]Harris, L. H. Allergy to Grain Dusts and Smuts. Journal of Allergy and Clinical Immunology. 10:327-336, 1939.

[8]Dickson, J. G. Diseases of Field Crops, 2nd Edition. New York, McGraw-Hill Book Co., 1956.

[9]Hirst, J. M. Chapter 47 - Spore Liberation and Dispersal. In: Plant Pathology - Problems and Progress, 1908-1958, Hotton, C. S. et al. (ed.). Madison, The University of Wisconsin Press, 1959. p. 529-538.

SECTION IV

EMISSIONS

A. SELECTED POLLUTANTS

The emissions from grain harvesting which possess a hazard potential to public health are respirable (<7 μm) particulates which contain a free silica fraction.

Particulate matter is one of the criteria pollutants for which air quality standards exist.[12] Those particles with less than 1% (by weight) free silica are also termed "inert." The American Conference of Governmental Industrial Hygienists (ACGIH) has published a threshold limit value (TLV) of 10 mg/m^3 for these particles.[13] In addition, inhalation of grain dusts causes a granulomatous reaction in the lungs with associated interstitial fibrosis. Progressive pulmonary fibrosis results from repeated exposure.[14] This type of

[12] Code of Federal Regulations, Title 42 - Public Health, Chapter IV - Environmental Protection Agency, Part 410 - National Primary and Secondary Ambient Air Quality Standards, April 28, 1971. 16 p.

[13] TLVs® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1973. American Conference of Governmental Industrial Hygienists. Cincinnati. 1973. 94 p.

[14] Frank, R. C. Farmer's Lung - A Form of Pneumoconiosis Due to Organic Dusts. The American Journal of Roentgenology. 79:189-215, February 1958.

reaction is termed farmer's and/or thresher's lung.[15] Grain smuts have been cited as possible causes for the production of these grain dusts.[16] Farmer's lung has been associated with the long-term inhalation of these smuts.[17]

Free silica particulate matter has long been associated with silicosis. This disease results from the prolonged inhalation of these particulates, which produces a pulmonary fibrosis. Symptoms of the condition may appear after several years of exposure or after exposure is terminated. Death has resulted in some cases due to extensive damage to the lung tissues.[18] The TLV for particulates with a free silica content greater than 1% varies with the percent of free silica detected.

B. MASS EMISSIONS

The total respirable particulate emission factor for grain harvesting is a combination of the emission factors from the following three sources: (1) harvest machine activity, (2) loading of trucks, and (3) transport on the field. Emissions data were determined following established procedures (see Appendix C) for each of these activities. The results of this study are presented in Appendix D.

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[15] Fuller, C. J. Farmer's Lung: A Review of Present Knowledge. Thorax (London). 8:59-64, 1953.

[16] Harris, L. H. The Nature of the Grain Dust Antigen. Journal of Allergy and Clinical Immunology. 10:433-442, 1939.

[17] Blaknikova, D., M. Tumova, and A. Valisova. A Syndrome Resembling Farmer's Lung in Workers Inhaling Spores of Aspergillus and Penicillin Moulds. Thorax (London). 15:212-217, 1960.

[18] Sax, N. I. Dangerous Properties of Industrial Materials, 3rd Edition. New York, Reinhold Book Corp., 1968. p. 1088-1089.

The emission factors (@ 95% confidence level) for respirable particulates from each of the harvesting operations and the entire source are listed in Table 3.

Table 3. EMISSION FACTORS FOR RESPIRABLE PARTICULATES FROM GRAIN HARVESTING

Operation	Emission factor (@ 95% level)	
	Symbol	Value, g/km^2
Machine activity	E_M	414
Loading	E_L	14.7
Transport	E_{TR}	137.7
Total respirable particulate emission factor	E_T	566.3

Free silica particulates are emitted from the soil during the harvest machine activity and transport on the field. The emission factor for free silica (E_S) is 551.6 ± 406.6 g/km^2 at the 95% confidence level. (These data are the result of sampling emissions from the harvesting of two grain crops.)

The total respirable particulate emission factor is used in computing statewide emission levels. These levels are the products of the area of grain harvested per state (A_S; Table 2) and this emission factor. The results are presented in Table 4 which also lists the state emission burdens.[19] These values are the ratio of each state's respirable particulate emissions from grain harvesting to the total respirable emissions of that state as reported in the National Emission Data System, NEDS.[19] Respirable emissions are assumed to be about 1/3 of the total reported in NEDS.

[19] 1972 National Emissions Report. Environmental Protection Agency. Research Triangle Park. Publication No. EPA-450/2-74-012. June 1974. 422 p.

Table 4. STATE AND NATIONAL PARTICULATE EMISSIONS BURDENS FROM THE HARVESTING OF GRAIN[19]

State	Total particulates, metric ton[a]	Respirable particulates due to harvesting of grain, metric ton[a]	Contribution of[b] harvesting of grain to overall state emissions, %
Alabama	1,178,643	3.45	<0.001
Arizona	72,685	1.04	0.004
Arkansas	137,817	10.69	0.023
California	1,006,452	4.97	0.001
Colorado	201,166	8.32	0.012
Connecticut	40,074	0.11	0.001
Delaware	36,808	0.94	0.008
Florida	226,460	1.39	0.002
Georgia	404,574	5.93	0.004
Idaho	55,499	4.26	0.023
Illinois	1,143,027	42.70	0.011
Indiana	748,405	22.5	0.009
Iowa	216,493	42.3	0.058
Kansas	348,351	37.5	0.032
Kentucky	546,214	5.4	0.003
Louisiana	380,551	4.25	0.003
Maine	49,155	0.16	<0.001
Maryland	494,221	2.41	0.001
Massachusetts	96,160	0.07	<0.001
Michigan	705,921	7.96	0.003
Minnesota	266,230	31.9	0.036
Mississippi	168,355	6.74	0.012
Missouri	202,435	18.7	0.028
Montana	272,688	13.2	0.014
Nebraska	95,338	21.6	0.068

[a] 1 metric ton = 1×10^6 g = 2,204 lb.

[b] This value is estimated by taking 1/3 of the state total emissions as respirable.

Table 4 (continued). STATE AND NATIONAL PARTICULATE EMISSIONS BURDENS FROM THE HARVESTING OF GRAIN[19]

State	Total particulates, metric ton[a]	Respirable particulates due to harvesting of grain, metric ton[a]	Contribution of[b] harvesting of grain to overall state emissions, %
Nevada	94,040	0.08	<0.001
New Hampshire	14,920	0.04	<0.001
New Mexico	102,785	1.35	0.004
New York	160,044	3.03	0.006
North Carolina	481,017	7.01	0.004
North Dakota	78,778	31.2	0.12
Ohio	1,766,056	17.7	0.003
Oklahoma	93,595	13.1	0.042
Oregon	169,449	2.92	0.005
Pennsylvania	1,810,598	5.14	<0.001
Rhode Island	13,073	0.01	<0.001
South Carolina	198,767	4.2	0.006
South Dakota	52,336	20.5	0.12
Tennessee	409,704	5.24	0.004
Texas	549,399	22.6	0.012
Utah	71,692	1.0	0.004
Vermont	14,587	0.2	0.004
Virginia	477,494	3.33	0.002
Washington	161,934	6.92	0.012
West Virginia	213,715	0.29	<0.001
Wisconsin	411,558	10.39	0.008
Wyoming	75,427	1.13	0.004
TOTAL	17,872,000[c]	455.8	

[a] 1 metric ton = 1×10^6 g = 2,204 lb.

[b] This value is estimated by taking 1/3 of the state total emissions as respirable.

[c] This total includes five sources not listed by state.

+ equations + results

APPENDIX C

SAMPLING METHODOLOGY - ANALYSIS AND PROCEDURES

INSTRUMENTATION

: GCA® Model RDM 101-4 respirable dust monitor[a] was used sample the downwind concentration of respirable particu-:es from the harvesting of wheat and sorghum. This is an ‚anced instrument designed for on-the-spot measurements mass concentrations of the respirable fraction or the :al mass loading of particulates. It is a portable and lly self-contained monitor with automatic and direct ;ital readout of the mass concentration of airborne parti-lates. Readings can be taken for from 4 minutes to minutes sampling time, and a traverse of points around a ırce of interest can be accomplished quickly.

sults are obtained by electronic measurement of the beta sorption of the collected sample. A cyclone collection stem is used as a first stage for respirable (<10 μm) asurements. Using the respirable concentration values tained with the GCA, the emission rate of particulates can obtained through use of the appropriate model.[35]

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Lilienfeld, P., and J. Dulchinos. Portable Instantaneous Mass Monitor for Coal Mine Dust. American Industrial Hygiene Association Journal. 33:136, March 1972.

2. MODELS

Open source sampling uses diffusion models in reverse. Normal use is to predict concentrations surrounding a point source of known strength. Several concentration readings are taken to calculate the source strength of an open source.

Models applicable to the sampling arrangement and source characteristics are chosen and utilized for each source of emissions. For grain harvesting there are three sources; (1) harvest machine activity, (2) loading the truck, and (3) truck transport on the field.

Two models are used in this study. The first represents emissions from machine activity and loading operations. This is the point source model[23] where:

$$\chi\ (x,\ y,\ z;\ H) = \frac{Q}{2\pi\sigma_y\sigma_z u} \exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right] \cdot\cdot$$
$$\cdot\cdot\cdot \left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right] + \exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\} \qquad \text{(C-1)}$$

The notation used to depict the concentration is $\chi(x,y,z;H)$. H, the height of the plume centerline from the ground level when it becomes essentially level, is the sum of the physical stack height, h, and the plume rise, ΔH. The following assumptions are made: the plume spread has a Gaussian distribution in both the horizontal and vertical planes, with standard deviations of plume concentration distribution in the horizontal and vertical of σ_y and σ_z, respectively; the mean wind speed affecting the plume is u; the uniform emission rate of pollutants is Q; and total reflection of the plume takes place at the earth's surface, i.e., there is no deposition or reaction at the surface. Any consistent set of units may be used. The most common is χ in g/m^3, Q in g/s, u in m/s, and σ_y, σ_z, H, x, y, and z in meters. The concentration χ is a mean over the same time interval as the time interval for which the σ's and u are representative. The values of both σ_y and σ_z are evaluated in terms of the downwind distance, x, and stability class. Stability classes are determined conveniently by graphical methods, Figure C-1.[36] Continuous functions are then used to calculate values for σ_y, and σ_z, Tables C-1[37] and C-2,[38] given the downwind distance, x. In open source sampling the sampler is maintained in the center of the plume at a constant distance; the plume has no effective height (H=0); and the concentrations are calculated at ground level. Equation C-1 thus reduces to:[23]

$$\chi\ (x,\ 0,\ 0;\ 0) = \frac{Q}{\pi\sigma_y\sigma_z u} \qquad \text{(C-2)}$$

The second model is used to describe emissions from transport on the field. In this equation instantaneous puff concentrations are represented by Equation C-3:[39]

$$\psi = \left(\frac{2}{\pi}\right)^{1/2} \frac{Q_D}{\sigma_{zI} u} \qquad \text{(C-3)}$$

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[36]Blackwood, T. R., T. F. Boyle, T. L. Peltier, E. C. Eimutis, and D. L. Zanders. Fugitive Dust from Mining Operations. Monsanto Research Corporation. Dayton. Report No. MRC-DA-442. (EPA Contract 68-02-1320, Task 6.) May 1975. p. 34.

[37]Eimutis, E. C., and M. G. Konicek. Derivations of Continuous Functions for the Lateral and Vertical Atmospheric Dispersion Coefficients. Atmospheric Environment. 6:859-863, March 1972.

[38]Martin, D. O., and Tikvart, J. A. A General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources. (Presented at the 61st Annual Meeting of the Air Pollution Control Association. St. Paul. June 23-27, 1968.) 18 p.

[39]Gifford, F. A., Jr. Chapter 3 - An Outline of Theories of Diffusion in the Lower Layers of the Atmosphere. In: Meteorology and Atomic Energy 1968, Slade, D. A. (ed.). Oak Ridge, Tennessee, U.S. Atomic Energy Commission Technical Information Center. Publication No. TID-24190. July 1968. p. 445.

where ψ = dose, g-s/m^3

Q_D = line source emissions per length of line, g/m

σ_{zI} = instantaneous vertical dispersion parameter, m

u = mean wind speed, m/s

For neutral stability:

$$\sigma_{zI} = 0.15\ x_C^{0.7} \qquad \text{(C-4)}$$

where x_C = crosswind distance from the line source, m

Equation C-3 is a line source diffusion model and is used to find the mass emissions per length of road. The value of the dose, ψ, is determined by multiplying the concentration by the actual sampling time.

3. DATA COLLECTION

Each variable for these models was determined in the field by use of the sampling arrangement shown in Figure C-2. For each concentration reading, displayed by direct digital readout, the mean wind speed was determined by averaging 15-s readings (a stopwatch was used) of the wind meter. This meter is connected to the anemometer which sits atop a 3.05-m (10-ft) pole. Distance x was measured by visual observation of the number of combine swaths downwind of the source. The 6.1-m (20-ft) wide swaths could be counted by the rows of threshed grain stalks left on the field.

All these data were recorded for each sampling run on the form shown in Figure C-3 while in the field. The time of day and atmospheric stability (determined following Figure C-1) were recorded periodically on the bottom of the form.

The terms used on the field data form are explained below.

Table C-3. EXPLANATION OF FIELD DATA FORM TERMS

Term (units)	Meaning
Read (mg/m^3)	Concentration reading
Conc. ($\mu g/m^3$)	Converted concentration for sampling times greater than 4 minutes (lower right hand corner).
R/T	R = respirable reading T = total mass reading
BGD ($\mu g/m^3$)	Background concentration
Δ ($\mu g/m^3$)	The difference between the converted concentration and the background
Q (g or g/sec)	Calculated emission rate
S'	Stability for the time of day the unit operation was sampled
M	The model used referenced as 1, 2, or 3 (point, line, or dose, respectively)

Any factors that might have affected concentration or emission rate were mentioned in the column labeled "Comments." When this form was completed the data were programmed into a computer and the emission rate, Q, calculated in accordance with the model specified in the column labeled "M."

4. PROCEDURES

a. Harvest Machine Activity

The harvest machine is a mobile source which travels along a line. The original intent was to sample this source from a stationary position (using the arrangement in Figure C-1) and apply a line source model. However, while sampling in the field the concentration was undetectable with this method. The speed of the combine (9.65 km/hr) and length of

APPENDIX D

SAMPLING RESULTS

1. EMISSION RATES

The total emission rate from grain harvesting is a composite of the emission rates from each of the harvesting activities. However, each of these activities takes a different length of time. This fact will be reflected in the total emission rate by weighting each of the emission rates by its duration. The reference or common denominator time used is the time required to harvest and load a truck-full of grain.

The average amount of grain loaded onto a truck, $\bar{G}_L$, is 8,691 kg.[41] In Table D-1 it can be seen that grain has an average weight per volume, $\bar{W}_G$, of 664 kg/m^3 and an average volume per area, $\bar{V}_G$, of 303 m^3/km^2.[42] Therefore, a truck carrying a load of 8,691 kg represents the harvest of an area, A_H, calculated in Equations D-1 and D-2:

$$A_H = \frac{(\bar{G}_L)}{(\bar{W}_G)(\bar{V}_G)} \tag{D-1}$$

$$= \frac{8,691 \text{ kg}}{(664 \text{ kg/m}^3)(303 \text{ m}^3/\text{km}^2)} = 0.043 \text{ km}^2 \tag{D-2}$$

[41] 1972 Highway Statistics. U.S. Department of Transportation, Federal Highway Administration. U.S. Government Printing Office. Washington. Stock No. 5001-00066. 216 p.

[42] Agricultural Statistics 1973. U.S. Department of Agriculture. U.S. Government Printing Office. Washington. Stock No. 0100-02841. 617 p.

Table D-1. AVERAGE GRAIN WEIGHT PER VOLUME AND VOLUME PER AREA

Grain	W_G, kg/m³	V_G, m³/km²
Wheat	773	216
Rye	683	164
Oats	399	381
Corn	657	623
Barley	580	329
Grain sorghum	722	415
Soybeans	773	208
Flaxseed	722	86
Arithmetic mean	664	303

The time required to harvest this area (A_H) is calculated from the speed and swath width of the harvest machine. These machines operate at speeds up to 6.71 m/s,[43] with the mean, $\overline{H}_S$, assumed to be 3.36 m/s. The average swath width, $\overline{S}_W$, of a combine is 6.07 m. Using Equation D-3:

$$T_S = \left(\frac{1 \times 10^6 \text{ m}^2}{\text{km}}\right)\left(\frac{\text{km}}{(S_W)(H_S)}\right)\left(\frac{\text{hr}}{3{,}600 \text{ sec}}\right) \qquad \text{(D-3)}$$

the time to harvest 1 km², T_S, is calculated in Equation D-3 as 13.62 hr/km². The time required to harvest the 0.043 km² area, T_H, is then calculated from Equation D-4 as 0.59.

$$T_H = T_S \cdot A_H \qquad \text{(D-4)}$$

In addition, the time required to load this grain onto the truck, T_L, is approximately 6 minutes. The composite time

[43]Zimmerman, M. D. Field-Going Factories: Agricultures' Amazing Monster Machines. Machine Design. 47(20):16-22, August 1975.

required to harvest and load a truck full of grain, T_T, is calculated in Equation D-5:

$$T_T = T_H + T_L = 0.69 \text{ hr} \tag{D-5}$$

The weighted emission rates can thus be calculated for each of the harvesting activities using this time reference.

The emission rate for the machine harvesting activity, Q_H, is calculated from the sampling results for wheat and sorghum harvesting presented in Tables D-2 and D-3. (The original data sheets and computer printouts are located in Appendix H). Combining these tables, the arithmetic mean emission rate is 8.38 ± 7.0 mg/s at the 95% confidence level. However, an F-test of these tables shows that the ratio of the variances for emission rates for wheat and sorghum harvesting are non-homogeneous. This illustrates the fact that the grain type is not a critical factor.

Table D-2. EMISSION RATES FROM WHEAT HARVESTING MACHINE ACTIVITY

Emission rates, g/s	
3.969×10^{-3}	3.696×10^{-3}
8.353×10^{-3}	4.859×10^{-3}
6.776×10^{-3}	3.031×10^{-3}
2.582×10^{-3}	3.689×10^{-3}
2.129×10^{-3}	2.578×10^{-3}
2.346×10^{-3}	4.653×10^{-3}
2.460×10^{-3}	1.801×10^{-3}
3.760×10^{-3}	1.091×10^{-3}
1.620×10^{-3}	2.082×10^{-3}

The emission rate for loading of the trucks, Q_L, is the arithmetic mean of two values obtained during sampling,

Table D-3. EMISSION RATES FROM SORGHUM HARVESTING MACHINE ACTIVITY

Emission rates, g/s	
4.552×10^{-3}	3.571×10^{-3}
6.411×10^{-3}	2.162×10^{-2}
1.941×10^{-2}	8.406×10^{-2}

1.692×10^{-3} g/s and 1.819×10^{-3} g/s. This value is 1.76 ± 0.8 mg/s at the 95% confidence level.

The emission rate for the transport of the harvested crop on a field was determined with the results presented in Table D-4. These values were all obtained at a downwind distance of 18 m. Four values were obtained at vehicle speeds of 4.47 m/s and four values at 8.94 m/s. Thus the arithmetic mean emission rate of 0.009 ± 0.004 g/veh-m at the 95% confidence level, used to calculate the emission rate per time period was obtained over these two values of vehicle speed. At 4.47 m/s, the rate was 0.005 ± 0.001 g/veh-m, and at 8.94 m/s, it was 0.012 ± 0.005 g/veh-m, illustrating that emission rate varies with vehicle speed.

Table D-4. EMISSION RATES, TRANSPORT ON THE FIELD

Vehicle speed, m/s	Wind speed, m/s	Concentration, $\mu g/m^3$	Travel distance, m	Emission rate, g/veh-m
4.47	4.1	30	293	0.005
8.94	6.3	40	475	0.006
4.47	3.6	30	293	0.004
8.94	4.5	90	439	0.011
4.47	5.9	20	329	0.004
8.94	4.5	160	439	0.019
4.47	5.9	40	402	0.007
8.94	7.2	50	329	0.012

During the harvesting of the 0.043 km^2 reference ares, the distance traveled, D_T, is twice (round trip) the representative distance, D, calculated in Appendix E, or 660 m. The vehicle travels this distance during the 0.69 hr (T_T) required to harvest and load the next truck. The mean speed a truck travels on the field lies between 2.4 m/s and 6/71 m/s, with a mean speed, $\bar{V}_S$, of 4.48 m/s chosen. The time required to transport (T_{TR}) the grain the distance on the field (D_T) is calculated from Equation D-6.

$$T_{TR} = \frac{D_T}{V_S} \qquad \text{(D-6)}$$

$$= 660 \text{ m}/(4.48 \text{ m/s}) = 125 \text{ s} = 0.035 \text{ hr}$$

The time-based emission rate for transport is calculated in Equation D-7.

$$Q_{TR} = (0.009 \text{ g/veh-m})(660 \text{ m}) \left(\frac{\text{hr}}{3,600 \text{ s}}\right)\left(\frac{\text{veh}}{0.035 \text{ hr}}\right)\left(\frac{1,000 \text{ mg}}{\text{g}}\right) \qquad \text{(D-7)}$$

$$= 47 \pm 20.7 \text{ mg/s at the 95\% confidence level}$$

The weighted emission rate for each of the harvesting activities is calculated from the product of each emission rate and the ratio of time required to perform the activity and composite time, T_T. These values are tabulated and calculated in Table D-5. The composite emission rate, Q_T, is thus the sum of the composite ratio for each activity and is calculated in Equation D-8.

$$Q_T = Q_{TH} + Q_{TL} + Q_{TTR} \qquad \text{(D-8)}$$

$$= 9.8 \pm 14.5 \text{ mg/s at the 95\% confidence level}$$

Table D-5. TIME-AVERAGED EMISSION RATES

Activity	$\frac{\text{Time of activity}}{\text{Composite time}}$ hr	x	Emission rate mg/s	=	Weighted emission rate mg/s
Machine activity	$\left(\frac{T_H}{T_T}\right)$ $\frac{0.59}{0.69}$		(Q_H) 8.38		(Q_{TH}) 7.16
Loading	$\left(\frac{T_L}{T_T}\right)$ $\frac{0.10}{0.69}$		(Q_L) 1.76		(Q_{TL}) 0.26
Transport	$\left(\frac{T_{TR}}{T_T}\right)$ $\frac{0.035}{0.69}$		(Q_{TR}) 47.0		(Q_{TTR}) 2.38

Free silica was detected by sampling the harvest machine activity. For a sample of 0.6 mg collected, 0.014 mg of free silica (detected as quartz) was present. This constitutes 2.3% (by weight) of the particulate from the machine activity. The grain harvested contained 0.012% silicon[44] whereas the soil contained 62.1% silica in the upper 38 mm.[45] Assuming these figures reflect the proportion of free silica in the dust, it is concluded that the free silica originates from the soil.

[44]Kent, N. L. Technology of Cereals with Special Reference to Wheat. The Commonwealth and International Library of Science, Technology, Engineering, and Liberal Studies Research Association of British Flour Millers, 1966. 262 p.

[45]Soil Classification - a Comprehensive System - 7th Approximation. U.S. Department of Agriculture, Soil Survey Staff, Soil Conservation Service. U.S. Government Printing Office. Washington. August 1960. 265 p.

Free silica contents of soils where grains are harvested have a maximum respirable free silica content somewhere between 5% and 10%.[46] The free silica content of a soil is basically equal to the free silica content in the dust.[47] Emissions of free silica, Q_S, are therefore generated by the machine activity and transport on the field. The weighted emission rate for these two operations is 9.54 ± 7.03 mg/s at the 95% confidence level.

2. EMISSION FACTORS

The emission factor for the machine activity, E_M, is obtained from the emission rate and the time required to harvest 0.043 km². This is calculated in Equation D-9 as:

$$E_M = \left(\frac{8.38\ \text{mg}}{\text{s}}\right)\left(\frac{\text{g}}{1{,}000\ \text{mg}}\right)\left(\frac{0.59\ \text{hr}}{0.043\ \text{km}^2}\right)\left(\frac{3{,}600\ \text{s}}{\text{hr}}\right) \quad \text{(D-9)}$$

$$= 413.91 \pm 834.8\ \text{g/km}^2$$

The emission factor for loading the harvested crop, E_L, is the product of the emission rate and the time it takes to load the truck divided by 0.043 km², as shown in Equation D-10:

$$E_L = \left(\frac{1.76\ \text{mg}}{\text{s}}\right)\left(\frac{\text{g}}{1{,}000\ \text{mg}}\right)\left(\frac{360\ \text{s}}{0.043\ \text{km}^2}\right) \quad \text{(D-10)}$$

$$= 14.71 \pm 0.75\ \text{g/km}^2$$

For transporting the grain crop, the emission factor, E_{TR}, is the emission rate multiplied by the time of transport

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[46] Personal communication. Dr. Warren Lynn and Dr. Steven Holzhey. National Soil Survey Laboratory, Lincoln, Nebraska. September 4, 1975.

[47] Sheinbaum, M. Comparative Concentration of Silica in Parent Material and in Airborne Particulate Matter. American Industrial Hygiene Association Journal. 22(4):313-317, August 1961.

associated with the harvesting of 0.043 km^2 divided by the harvest area. This is calculated in Equation D-11:

$$E_{TR} = \left(\frac{47 \text{ mg}}{\text{s}}\right)\left(\frac{\text{g}}{1{,}000 \text{ mg}}\right)\left(\frac{126 \text{ s}}{0.043 \text{ km}^2}\right) \qquad \text{(D-11)}$$

$$= 137.7 \pm 76.2 \text{ g/km}^2$$

The composite emission factor, E_T, for the harvesting of grain is the summation of the emission factors for each of the grain activities. This factor is calculated in Equation D-12:

$$E_T = E_H + E_L + E_{TR} \qquad \text{(D-12)}$$

$$= 413.9 + 14.7 + 137.7$$

$$= 566.3 \pm 838.3 \text{ g/km}^2$$

In Equation D-13, the emission factor for free silica, E_S, is computed from the emission factors for machine activity and transport of the harvest of 0.043 km^2.

$$E_S = E_H + E_{TR} \qquad \text{(D-13)}$$

$$= 551.6 \pm 838.3 \text{ g/km}^2$$

The variation of these emission factors represents the deviation at the source sampled; however, these variations do not apply to all sources. Confidence limits are not used since this was a preliminary sampling of one source, two grain types.