Unpaved Roads as Sources for Fugitive Dust

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In spite of an apparent sweeping abundance of paved roads, the majority of the roads in the world remain unpaved. For example, more than 3.4 million km or 55 percent of the roads in the United States alone are unpaved (1). Although unpaved roads usually carry fewer than 100 vehicles per day (vpd), they are as necessary as high-volume roads and are essential for the transportation of many important resources, including agricultural products, timber, and minerals. Their low traffic volumes, however, often do not justify the cost of paving.

Unpaved roads are a source of airborne dust, which can cause discomfort, aggravate respiratory ailments, and create a driving hazard. Few attempts have been made to measure or characterize the dust from unpaved road sources. This paper presents preliminary data on the amount, distribution, and mineralogy of dustfall near several unpaved roads.

Most unpaved roads are surfaced with crushed stone or gravel for interlocking stability during adverse weather conditions. The aggregate usually is spread on the road, mixed, and occasionally smoothed with a blade grader or maintainer. A higher type, more permanent road results if the aggregate is proportionally mixed with soil and then spread and compacted. The clay in the soil-aggregate road acts as a binder. Macadam is still a higher type of road. It consists of a carefully proportioned mixture of crushed stone and fines and is used most frequently as a base for bituminous concrete paving.

All unsurfaced roads require occasional grading to fill holes and cut away raveling or "washboarding" caused by resonant bouncing of vehicular wheels. They also require periodic additions of stone. This should be an indirect measure of the amount of dusting, although a common assumption is that the stones are knocked into the roadside ditch. Periodic ditch cleanout is also required to maintain drainage, and the material cleaned out is mostly fines with only minor amounts of stone or gravel. About 50 million tons of stone are added annually as surface treatment to roads in the United States (2), an average of about 15 t/km/year.

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Dust Collection

Dust collectors were set along lines transverse to the centerline of 10 unpaved roads and test sections in Poweshiek, Story, and Linn counties in central and eastern Iowa. The collectors consisted of straight-sided plastic cans 15.2 cm in diameter and 19 cm deep mounted approximately 1 m above ground level on steel stakes, as specified in ASTM D1739-70. Sampling sites were selected in vegetated areas to reduce contamination. At each site, the collectors were spaced at 3- to 150-m intervals along traverses from both sides of the roads. The containers were half filled with distilled water and were checked and refilled at least once a week. After a period of 3 to 4 weeks the collectors were sealed and brought to the laboratory. The insects and chaffe were removed by hand, and the samples were treated with 0.3N H_2O_2 acidified with HCl to further remove organic matter. Samples were then dried at 110 C and weighed. Mineralogical analyses were performed by simultaneous differential and thermogravimetric analyses and by polarizing microscopy and X-ray diffraction; particle size analyses were done by dry sieving.

Dust collectors set out in lines transverse to the road centerline.

Dust created by passing vehicle.

Dust Distribution

All sampling traverses showed the same trend: The closer the container was to the road, the more dust was collected in a given time. Plotted on a linear scale, the curves are almost asymptotic adjacent to the road; but plotted with distance on a logarithmic scale, 2 straight lines result, as shown in Figure 1. Similar distribution trends have been found for loess, a widespread silt deposit usually attributed to wind deposition leeward from glaciofluvial river bar sources (3). The reciprocal of loess thickness also empirically has been found to increase linearly with distance (4); this relation describes a hyperbola. For present purposes, a semilogarithmic plot offers several advantages: Extrapolation may be made to 0 contribution from the road source, which is more in keeping with the data since a 0 contribution was sometimes found; the total amount of dust deposited may be more readily calculated by integration of the area under the curves; and a correction for atmospheric dust may be made by simple subtraction.

Atmospheric Dust

According to the data from comparable dustfall sampling away from secondary road sources (5), the average atmospheric dust deposition in the study area should be of the order of 45 to 50 kg/ha/month, multiplied by a factor of 0.4 to 0.9 for reduced dust deposition during the autumn, reflective of more complete agricultural ground cover. These data coincide rather closely with present measurements of 32.2, 32.7, 33.3, and 30.2 kg/ha/month in the 4 most distant containers along roads treated with a chemical dust palliative. A value of 32 kg/ha/month is therefore assumed to represent an atmospheric base line for calculation of road dust distributions.

Road Dust

The intersection of the 2 linear relationships in plots of amount versus log distance (Figure 1) was always at a distance of about 10 to 12 m, coinciding rather closely with the usual secondary road right-of-way of 10.06 m measured from the centerline. The higher deposition of dust in the right-of-way may relate to geometric and vegetation factors and the fact that deposition continues to occur close to the road even when there is no distributive wind other than that generated by traffic. This is in contrast to wind erosion and deposition in nature, which obviously can proceed only when wind is blowing. The road dust was therefore considered in 2 categories—roadside and distributed—and the amounts were calculated in 2 separate integrations.

Representative results are given in Table 1. Data are given for 3 limestone surface-aggregate roads and 4 mixed-in-place soil-aggregate road test sections. The Poweshiek road was singled out by the county engineer for having experienced an excessive loss of aggregate during the years; our data indicate an annual dust amount of more than 650 000 kg/km of which half, or 325 000 kg/km, was limestone. The Story and Linn roads were qualitatively selected as more typical and yielded similar amounts when expressed on a vehicle-per-day (vpd) basis. The dust loss averaged 568 kg/km/vpd/year, of which mineralogical analyses again indicated about half was limestone.

Only the Poweshiek road data showed a major influence from prevailing winds, and data for the other roads

Table 1. Summary of Dust Amounts

Roads	Limestone (kg/km)	Total Dust (kg/km/ month)	$CaCO_3$ (per- cent)	Dust per Vehicle per Day (kg/km/ year)
Surface aggregate				
Poweshiek		56 640	50	4 370
Story		4 680	n.d.	534
Linn[a]		7 535	46	603
Soil-aggregate				
Section 3	225 000	434	28.0	61
Section 2[a]	225 000	256	1.1	36
Section 6[a]	564 000	207	5.4	29
Section 10[a]	1 015 000	70	33.7	9.9

[a]Calcium lignosulfonate (lignin) liquor added as a surface treatment or as 1 percent addition to the mix.

were therefore averaged from containers on both sides. Although total amounts of dust determined on both sides of the Poweshiek road differed by a factor of 7, the roadside component on the 2 sides was practically identical, lending credence to the suggestion that the major deposition of roadside dust occurred when there was no wind. From other roads, the amount of roadside dust varied from 1200 to 12 000 kg/km/month, constituting 6 to 50 percent of the total dust.

Similarly, extrapolation of the semilogarithmic plots indicated maximum distances of deposition measured from centerlines were quite variable, ranging from 60 m for the Story road to 2500 m for the prevailing leeward side and 400 m for the prevailing windward side of the Poweshiek road. Even the 2 roads that produced nearly identical total dust amounts showed large variations in distributive geometry, the amount being deposited as roadside dust differing by a factor of 10 and the maximum distance carried differing by a factor of 15. This is not surprising for a system in which the source is a constant while the distributive mechanism varies. For example, the Story road, where 50 percent of the dust was roadside and all fell within a distance of only 60 m from the centerline, is a suburban feeder on which traffic is concentrated in the morning and evening hours when there is less wind.

Dust Composition

The percentage of carbonates, determined microscopically and more precisely from weight loss in thermogravimetric analysis, varied from 75 to less than 1 percent, generally decreasing with increasing distance from the road (6). Responsible factors probably include particle size and specific gravity sorting, for the carbonate particles tended to be larger and more dense and therefore settled out faster and concentrated closer to the source.

Clay mineral identification was difficult because of the small amounts of clays in the samples. A degraded illite was found in samples close to the source, reflective of clay in the limestone. Smith et al (5) comment on their unexpected encounter with kaolinite in atmospheric dust samples and the unaccountable scarcity of montmorillonite. This is reasonable if road-pulverized stone is a major contributor to atmospheric dust.

Dry sieving of the Poweshiek road dust samples indicated more than 70 percent of each sample was retained on the 0.053-mm sieve and classified as fine sand. The median grain size varied from 0.06 to 0.12 mm, with a tendency toward finer particles farther from the source. The median size was somewhat larger than that previously reported for atmospheric dust (5, 6). Other samples were not sieved because of the small amounts and susceptibility to error.

Soil-Aggregate Roads

The effectiveness of several treatments to improve road surfacing and reduce dusting is indicated by measurements made about a year after construction (Table 1). Simply adding aggregate and mixing it in rather than leaving it on the road surface would appear to reduce dusting by a factor of 10, which agreed with qualitative observations. Addition of 1 percent lignin, a nontoxic by-product from paper manufacture, further reduced dusting by one-half; only a short-term benefit was obtained when lignin was used as a surface treatment.

The carbonate data indicate that lignin treatment preferentially held the limestone, probably because of clay migration to the road surface during wet weather, and formed an observable brown protective patina. Unfortunately, this patina also makes the roads slippery in wet weather, but the use of more limestone reduced this factor and also rather surprisingly decreased the dust, suggesting that mechanical stability and low dusting go together. Certainly the fact that a road is unpaved does not mean that it must be a major dust source. The best road lost rock at the rate of 3.3 kg/km/vpd/year, and the worst road lost 2185 kg/km/vpd/year or more than 600 times as much (Table 1). Furthermore, the amount of stone used to construct the low-dusting road, slightly more than 1 million kg/km, just equals the amount of rock lost from the worst road in 3.1 years. This would appear to be a strong economic as well as environmental argument for improving aggregate-surfaced roads by mixing aggregate and stabilizing agent even though the treatment might have to be repeated every 5 years.

Dust Production Versus Stone Consumption

As previously mentioned, annual consumption of crushed stone in the United States for surface treatment of roads, not including stone used in macadam or road-base construction, is about 15 t/km. If we assume that 80 percent is used as replacement for existing aggregate and divide this amount by the amount of carbonate lost from the Story and Linn roads, 280 kg/km/vpd, we obtain an annual average traffic count of about 40 vpd on all unpaved U.S. roads, not an unrealistic figure.

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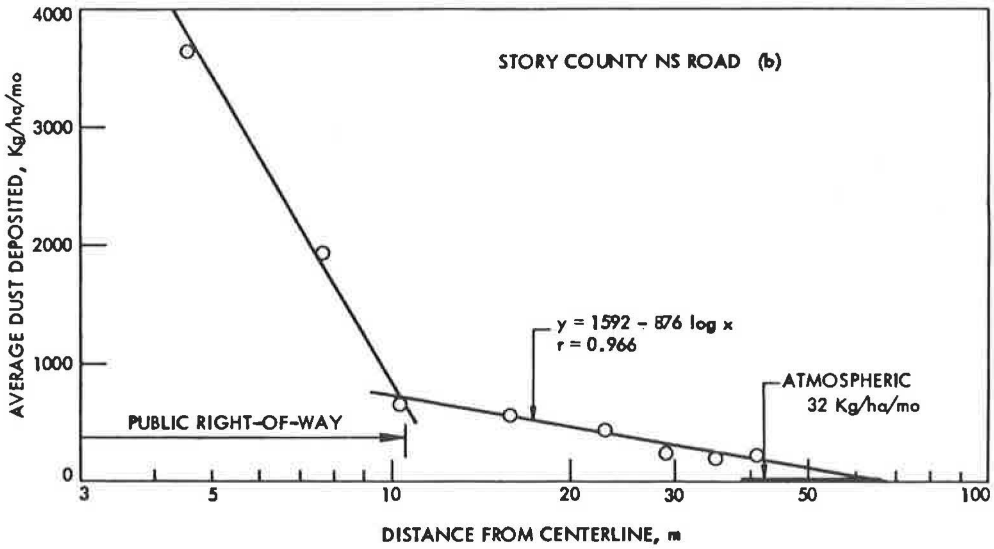

Figure 1. Rate of dust deposition versus distance to the road centerline. Data were averaged from both sides of the road and plotted on a logarithmic scale.