APPENDIX C

Monitoring fugitive dust emissions from off highway vehicles traveling on unpaved roads: a quantitative technique

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Land between the Lakes dust monitoring project

Objectives

Roughly 1,700 acres have been set-aside in the Turkey Bay Off Highway Vehicle (OHV) area for use by any operator of an OHV. The area was originally designated by the Tennessee Valley Authority around 1975 and has been operated as an open riding (that is, no requirement to stay on trails) area ever since. The Forest Service acquired the property in 1999. Under National Forest System guidelines, the area must be managed for preservation of the resource in addition to recreation opportunities. Changes in, and increases in usage have left the area severely scared and impacted. Impacts include severely denuded and eroded hillsides, loss of leaf litter and topsoil, compacted soils, heavily disturbed and dead flora, and dust everywhere. Off trail dust deposition is an indication of soil migration. This study was designed to quantify soil migrating, and determine far away from trail it was moving. The study also investigated the effects of dust on the local ecology and provided insight on visibility and health effects for riders and national forest employees.

National forest management is trying to develop both short-and-long term management plans that will rehabilitate and protect the land. Information that describes the quantities and effects of soil migration as a result of OHV traffic could prove to be an effective tool for monitoring trail use, keeping natural resources in balance, while providing a healthy, pleasant recreation experience for the user. Such information could suggest to managers when to use seasonal closures, dust abatement techniques and how to design trails to reduce soil migration.

Experimental approach:

This study was designed to measure the amount of soil displaced by aerial erosion due to vehicle movement along established trails. The goal is to understand the relationship among soil types, vehicle use intensity, and dust creation. The amount of dust generated was determined by weight using sticky-traps, the particle sizes generated were determined using electronic instruments for PM2.5, and visualization of particles was conducted using scanning electron microscopy (SEM). Trips past the collectors were determined using automated counters. Portable weather stations were used to measure wind speed and direction, temperature and relative humidity at the test sites.

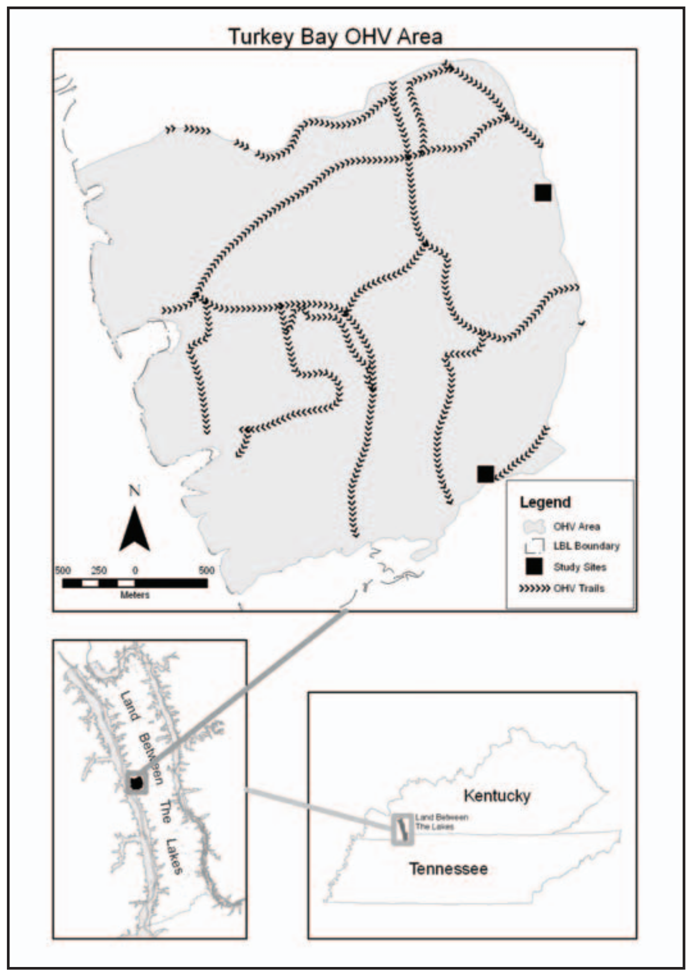


Figure 1—Turkey Bay off highway vehicle riding area, Land Between the Lakes National Recreation Area, Golden Pond, Kentucky.

Secondary objectives were to evaluate the effect dust has on native vegetation and human health. Leaf samples were be collected and viewed by SEM to determine damage to cuticle surface and interference with stomata opening. Portable electronic particulate monitors were deployed along the two test sites in order to quantify atmospheric concentrations of particles less than 2.5μm – the EPA standard for damage to respiratory tissues.

Experimental design

Two test sites were chosen. The first site was along a broad main trail close to the entrance station. The trail was bordered on the north side with forest, and on the south side with an open field. The second site was further into the trail network where the trails are narrower. The second site (referred to as the "tunnel") was bordered by dense forest vegetation on both sides and a nearly enclosed canopy. The trail ran north-south therefore the sampling grids were on the east and west sides of the trail. The sampling transects were established along the edges of the trails with points 50m intervals along the trail and in 3 rows 50 and 100 meters away from the trail, for a total of 20 sampling points along the main trail and 30 sampling points along the tunnel trail. Adjustments to the grid were made to accommodate terrain and rider safety.

The study employed three techniques for assessing dust production and characteristics, two portable active particulate monitors, SEM, and passive dust collectors. The portable monitors were MEI DataRam 2000, which calculate atmospheric concentrations by light scattering techniques. The monitors were loaned to the study by Andy Trent at Missoula Technology and Development Center. They were outfitted with critical cut point nozzles so that only particles smaller than 2.5μm were measured. The monitors were deployed continuously during the exposure period.

The JEOL-T-330 scanning electron microscope is housed at the Hancock Biological Station research facility, part of Murray State University, near the Turkey Bay OHV Area. The microscope was used to assess damage to leaf surface, accumulation patterns of dust on leaves, and to determine the physical characteristics of the dust particles. Leaves were harvested from along the trails and from trees 25m or more away from the trails to evaluate the effects of high and low deposition. Four common species were chosen: autumn olive (*Eleaganus umbellata*), staghorn sumac (*Rhus typhina*), sycamore (*Platanus occidentalis*), and wild grape (*Virtis spp*). Discs of leaves were prepared using a single hole punch, and each disc cut in half so that the upper and lower surfaces of the same sample could be viewed. Leaf discs were mounted on aluminum stubs with double-stick tape and sputter coated with a gold/palladium mix. Polaroid micrographs were taken of representative samples to catalog dust and cuticle features. The micrographs were subsequently scanned into Photoshop for electronic duplication and presentation.

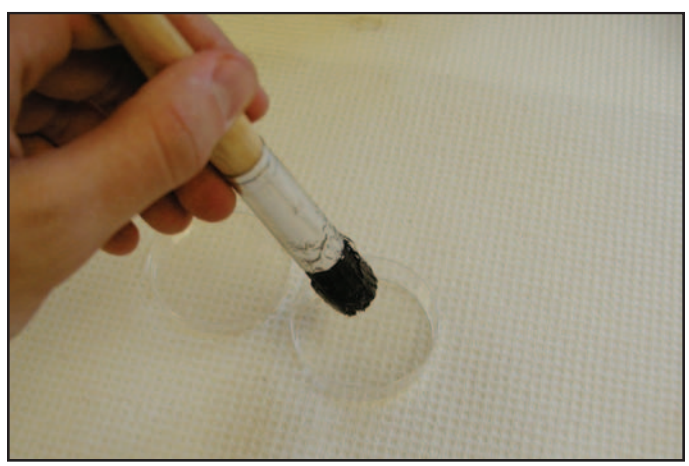


Figure 2—Preparation of "sticky-trap" dust collector.

The passive dust collectors were constructed from 5.5 cm disposable Petri dishes. Each dish was coated with a thin layer of environmentally stable Tangle-Trap® brush-on insect trap. A 1-cm^2 strip of heavy duty Velcro was glued to the back before each collector was weighed for the pre-exposure ("before") weight. The dust collectors were mounted on 15-foot aluminum conduit using Velcro at 4, 6, 10, and 15 feet above the ground. The poles were held in place by sliding the hollow conduit over 3 foot length of rebar pounded into the ground. A grid pattern consisting of 3 rows, 50m apart, with 4 or 5 poles in each row, also 50m apart, was established at the 2 test sites. One grid was on the north side of the main trail (woods side) and another grid was established on the south side of the same trail in the front field. A second pair of grids were established roughly ½ mile from the entrance station along a trail nearly completely enclosed by vegetation (the tunnel site). In addition to the 4 grid locations a series of 18 passive collectors (9 on each side of the trail) were deployed along the tunnel site within 1m of the trail at roughly head height for the riders. These collectors were mounted on trees and were designed to get a measure of the dust load at mouth height.

All passive dust collectors were deployed within 30 minutes of one another beginning at 8:00 am and taken down at 6:00 pm. Following exposure, the collectors were covered and sealed for transport to Riverside, CA, for reweighing. The difference between the weights before and after deployment was assumed to be accumulated dust. Both laboratory control collectors, those that did not leave Riverside, and field control collectors, those that traveled to the site and back but were not open were used to evaluate environmental effects of weight. Ten percent of the collectors were controls. Data was calculated as mg dust per cm^2, and adjusted to m^2 where appropriate.

In addition to the dust monitoring techniques, weather data and the number of vehicles passing the sites were recorded. A portable weather station (HOBO, Onset computers) was deployed in the front field to measure wind speed and direction, temperature, and relative humidity. Small HOBO temperature and relative humidity sensors were used at the tunnel site to check for differences between the two test sites. Trip counters were installed across the trails at both locations.

Experimental results

Particulate PM 2.5 load

Two DataRam real time particulate monitors were deployed to determine ambient dust concentrations of particle less that 2.5μm. Particles smaller than 2.5μm are considered deleterious to human health by damaging respiratory tissues. One DataRam was deployed in the front field, on the south side of the main trail across from the entrance station. A second instrument was deployed in the tunnel-sampling site in a heavily vegetated location. The front field site maintained a consistent low ambient concentration of particles smaller than 2.5μm of approximately 2-μg m^{-3} (micrograms per cubic meter) throughout the day (fig. 3). Spikes in concentrations occurred as vehicles passed. The average concentration for most of the spikes was less than 6μg m^{-3}. Wind conditions had a significant effect on the monitoring data (fig. 4).

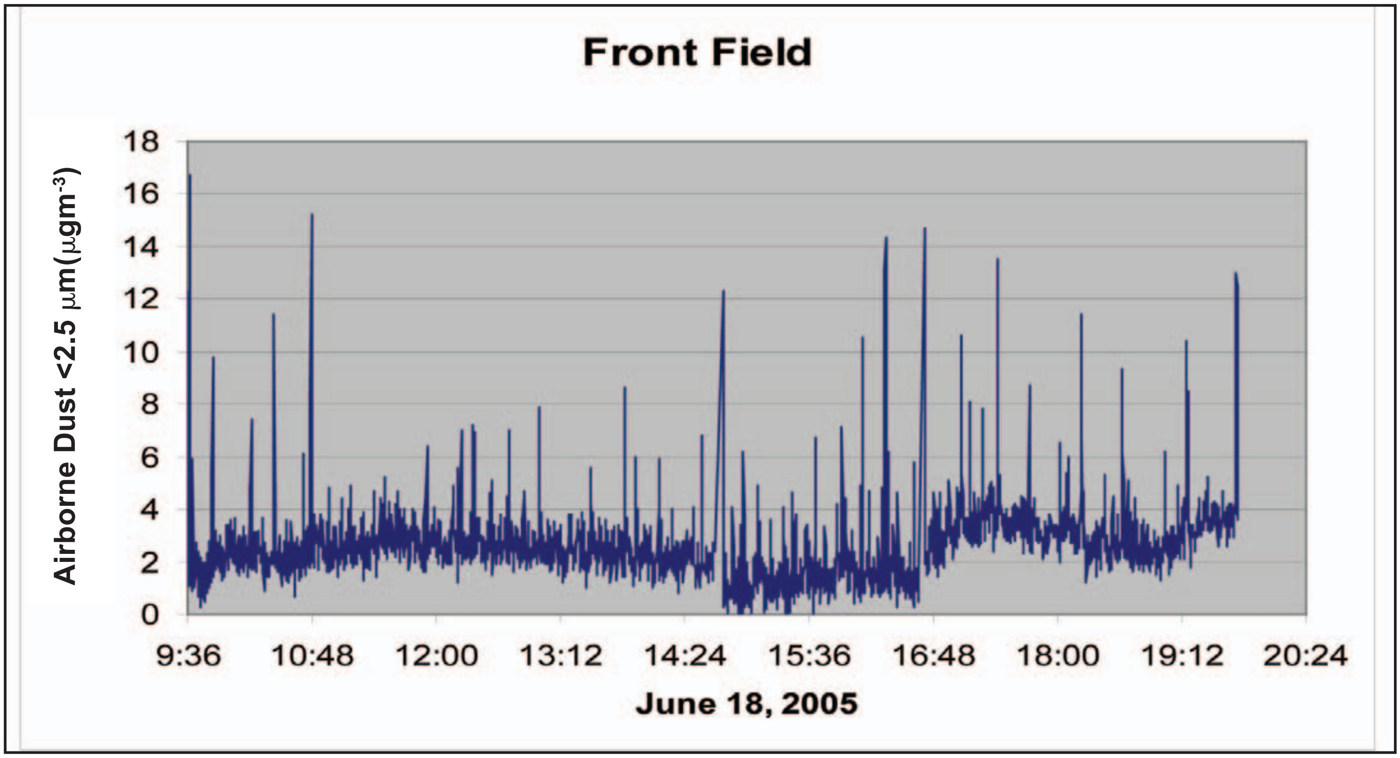
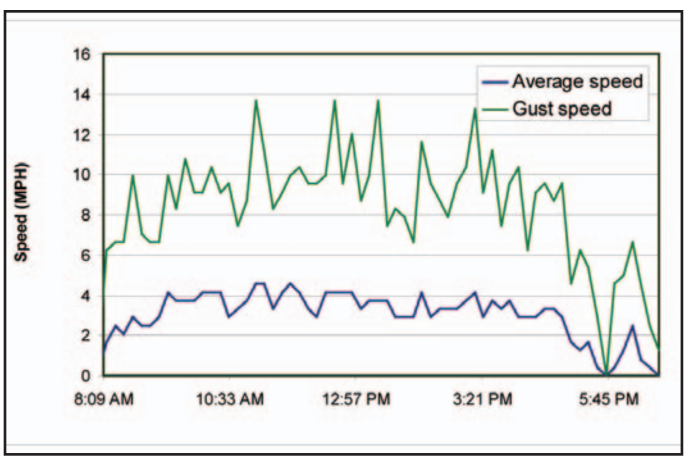


Figure 3—Active monitoring data for ambient concentrations of particle measuring less than 2.5μm.

Overall wind speeds were light, averaging between 2 and 4 miles per hour. Gust speeds up to 13 mph were observed with average gust speeds of 8.27 mph (fig. 4). The direction was predominately toward the west with gust tending to be northwest. Both the wind direction and speed tended to blow dust away from the active monitor contributing to low ambient concentrations. This was confirmed by the passive monitors described below (fig. 9).



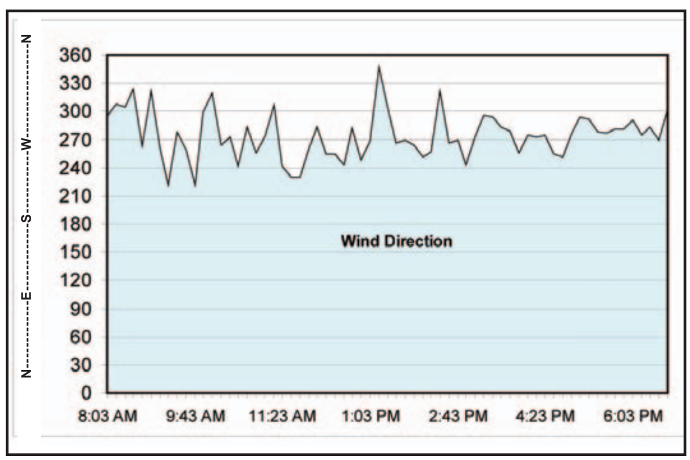


Figure 4—Wind speed (left) and wind direction (right) measured in the front field.

The DataRam set-up in the tunnel site was a meter off the trail, ½ meter off the ground and surrounded by dense vegetation. The location was chosen partially to keep the instrument hidden when not attended, and partially to evaluate the effect of vegetation on dust movement. Ambient concentrations were negligible until a vehicle passed (fig. 5). Average concentrations due to vehicle traffic ranged from 50 to 300μg m^{-3} (top panel) with maximum concentrations 1.5 to 2 times higher (bottom panel). The day the study was conducted rider numbers were quite low as compared to many weekends. Each one of the spikes corresponds to a single passage by an individual or group. If one passing generates average ambient loads of 150 to 250μg m^{-3}, on days where rider numbers are much higher, the ambient concentration would be well into the unhealthful range for continuous exposure at this test site.

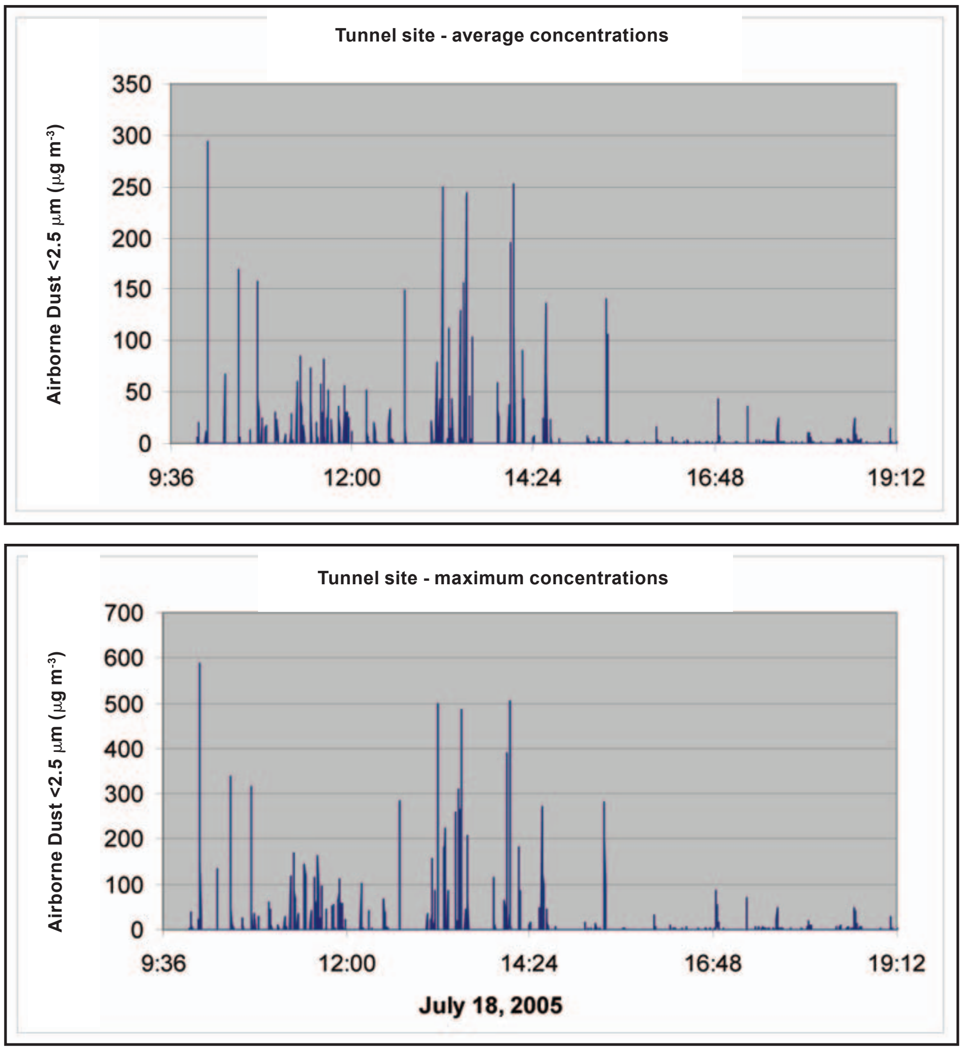


Figure 5—Ambient concentrations of particle measuring less than 2.5μm.

Total particulate loads estimated by the passive monitors deployed at the riders' head height (about 4 feet off the ground) was 0.433 mg cm^2, or roughly 4.33 g of dust per meter of trail over the 10 hour sampling period.

Ambient particulate loading and human health

The EPA has shifted from an absolute concentration metric for determining concern levels for human health to an index system. The index is based on a 24-hour average concentration and has a scale of 0 to 500 for all criteria pollutants (those that EPA has established health risks for). Above 100 is considered unhealthy for sensitive groups. An index of 100 is equivalent to 40-μg m^{-3} PM 2.5. An index of 150 is unhealthy for all individuals and corresponds to 65.4-μg m^{-3}. A calculator to converting concentration to index and visa-a-versa can be found at:
http://cfpub.epa.gov/airnow/index.cfm?action=aqi.aqi_conc_calc

The current EPA method does not account for very high, but short acute exposures. On the day of the experiment the air quality at both sites was good with short episodes of very unhealthful air.

Although dust was visible for longer periods than were recorded by the particulate monitors, based on images of particulates accumulating on leaf surfaces, most of the dust particles generated by OHVs are larger than 2.5μm (fig. 6). Based on this limited information and the current EPA interpretation, particles sent airborne by OHV traffic do not pose any long-term health concerns at the rider densities encountered on June 18, 2005.

Vegetation

Leaf samples from autumn olive (*Eleaganus umbellata*), staghorn sumac (*Rhus typhina*), sycamore (*Platanus occidentalis*), and wild grape (*Virtis spp*) were collected next to the main trail and 25 meters away from the trail. The sampling day followed several days of heavy rain so only small amounts or dust was visible to the naked eye. Dust deposition assessments were made using a JEOL-T-330 scanning electron microscope. Images were assessed for:

1. Physical damage such as abrasions, broken trichomes and punctures.
2. Percent surface area occupied by dust particles.
3. Blocked stomata.
4. Estimated size of particles.

In comparing samples on and off the trail, the leaves collected along the trail did have a higher number of particles on the surface, but there was no observed difference in lesions or superficial damage. Particles were observed on both sides of the leaves (fig. 6). All four of the species examined had stomata on the underside of the leaves exclusively, which is common for temperate zone plants, and important for dust interference with leaf respiration. A few examples of particles blocking stomata were observed and captured in images, but there were no consistent patterns of stomatal blockage due to dust deposition (figs. 6 and 7).

Based on a visual assessment, it does not appear that plants growing along the roads and trails are severely impacted by dust generated by OHVs, as long as heavy traffic is followed by rain. We did not do a physiological assessment where photosynthesis and respiration were measured, but outside of a biochemical assimilation of nutrient elements from dust, it seems unlikely that a physiological assessment would change the conclusion.

The scanning electron microscope images also allow an estimate of typical dust size – at least particles that remained after rain. For the most part, particles were larger that 2.5μm, but examples of fine particles were captured at higher magnification (figs 6,7,8).

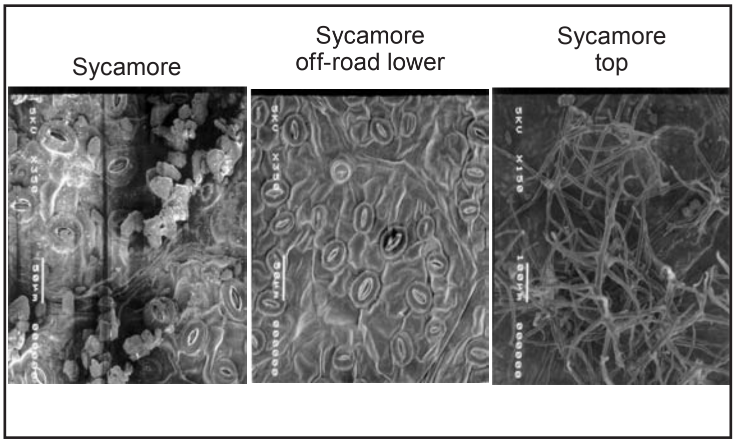


Figure 6—Sycamore

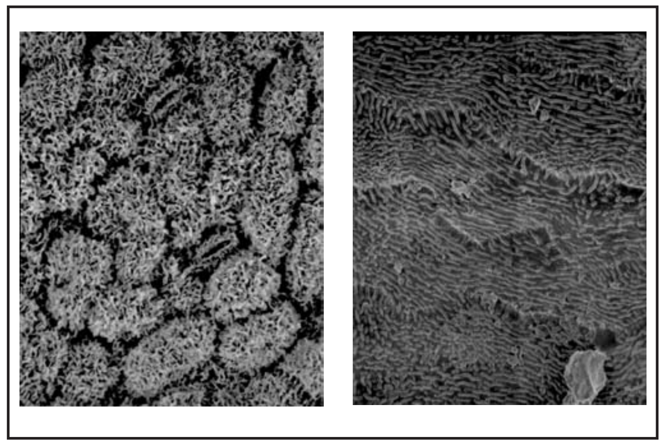


Figure 7—Grape lower and top.

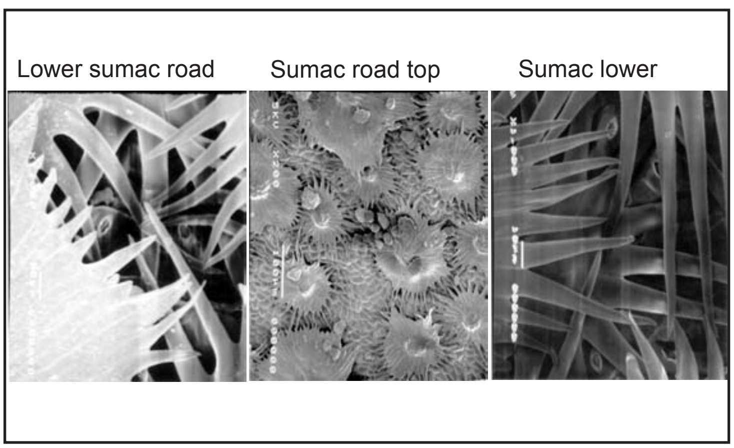


Figure 8—Sumac lower road, road top, lower.

Passive dust collectors

Both the "laboratory controls" and the "field controls" indicated a small but consistent loss of mass from the initial weights to the final weights. The weights of the collectors deployed were adjusted to compensate for losses. The collectors deployed closest to the dust source at the edges of the trails captured the majority of the dust in the lower 6 feet (fig. 9). The mass collected was variable along the transects, as expected, with variances up to ± 50 percent. In all cases, accumulation of dust in the 4-foot and 6-foot samplers was significantly greater than accumulation in the upper 10-foot and 15-foot collectors for samplers in the front row.

Wind direction had a significant effect on dust collection in the front field and woods sites. Wind direction was generally to the west-northwest, and the collectors on the north side (fig 9B) of the road accumulated nearly 10 times more mass than did the southside collectors (fig 9A). Along the tunnel site, winds were generally calmer because of dense vegetation. This probably contributed to the reduced variability along sampling points of the transect and no significant differences between the two sides of the trail (fig. 9 C and D).

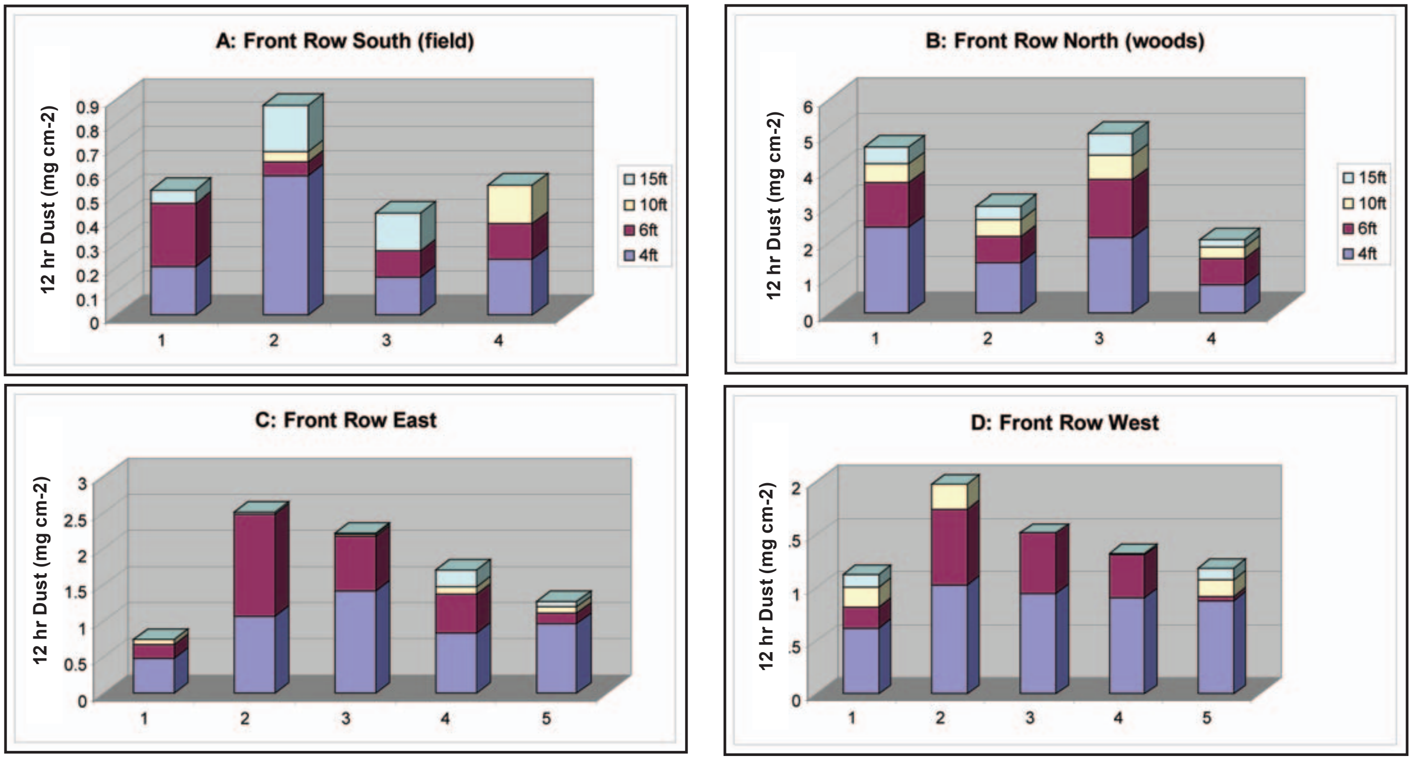
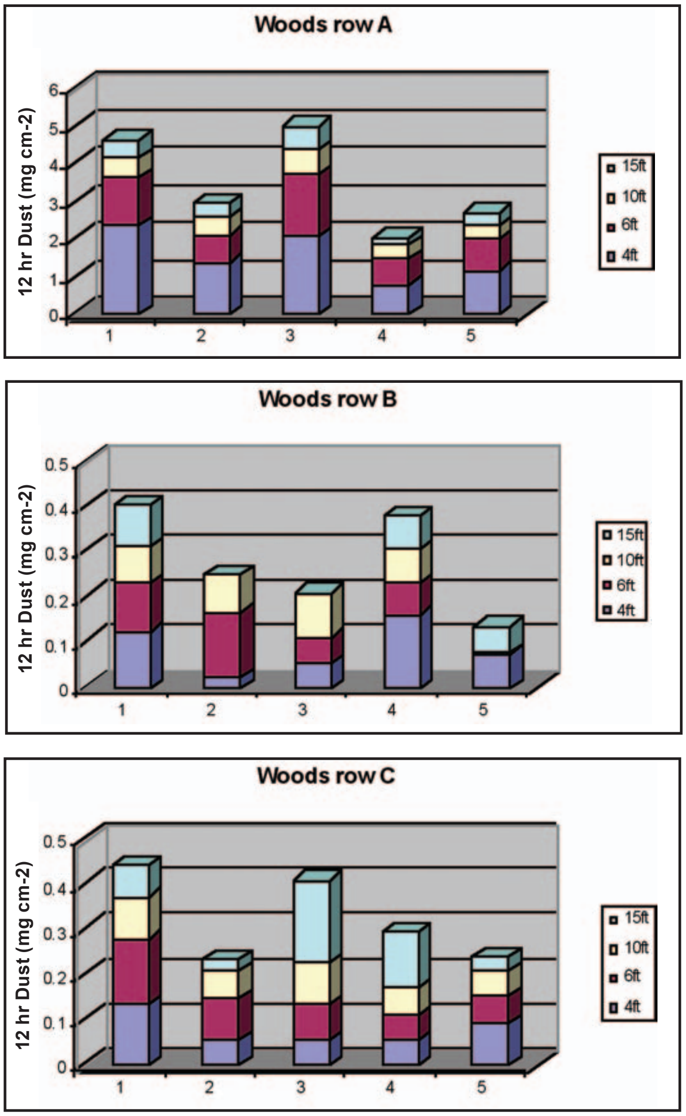


Figure 9—Dust accumulation on passive samplers after 10 hours. Each bar indicates one sampling pole and the divisions indicate the quantity of dust collected at each sampling height.

At 50 m (row B) and 100 m (row C) away from the trails, a higher percentage of particulates was captured at the 10-foot and 15-foot heights (figs. 10 and 11). Although particle sizes on the collectors were not determined, the pattern of capture is consistent with larger particles traveling shorter distances and at lower elevation while smaller particles were launched higher and tended to travel further. Along the tunnel transects, dust movement back into the woods was inhibited by the dense vegetation along the trail, particularly on the west side of the trail where collection rates were very close to zero (fig 12). On the east side, where the boundary vegetation was slightly thinner, a small, but significant, amounts of dust moved horizontally over the landscape.



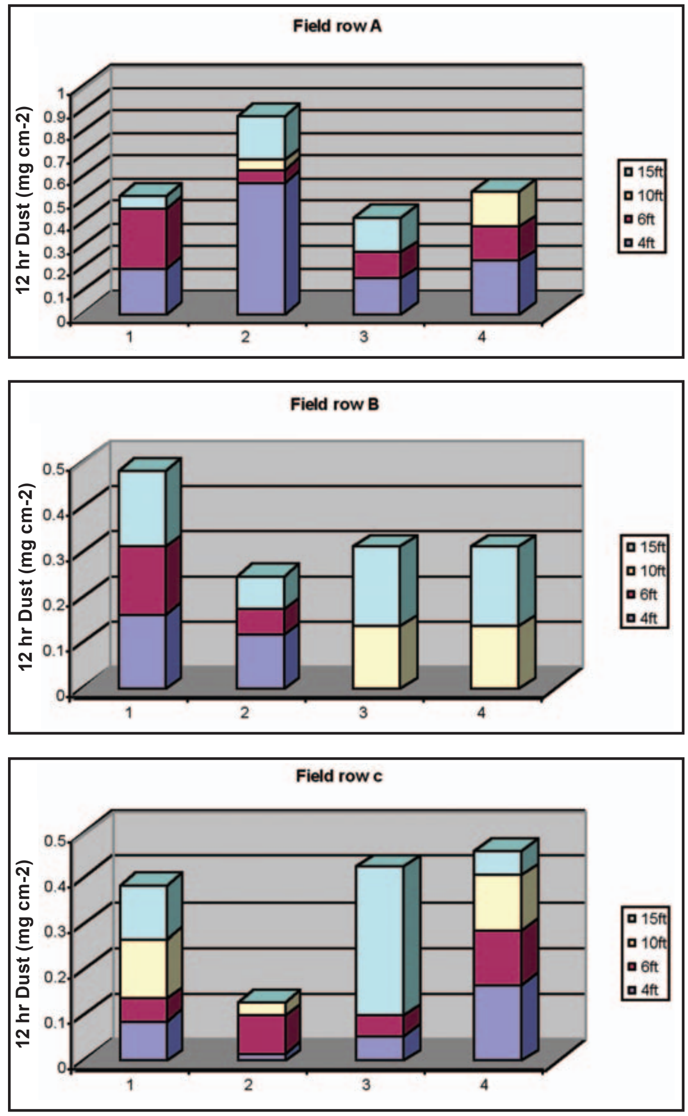


Figure 10 (left – woods) Figure 11 (right – field)—Accumulation of dust particles along a 200m transect and at 50m and 100m away from the source. Note the differences in y-axis scales.

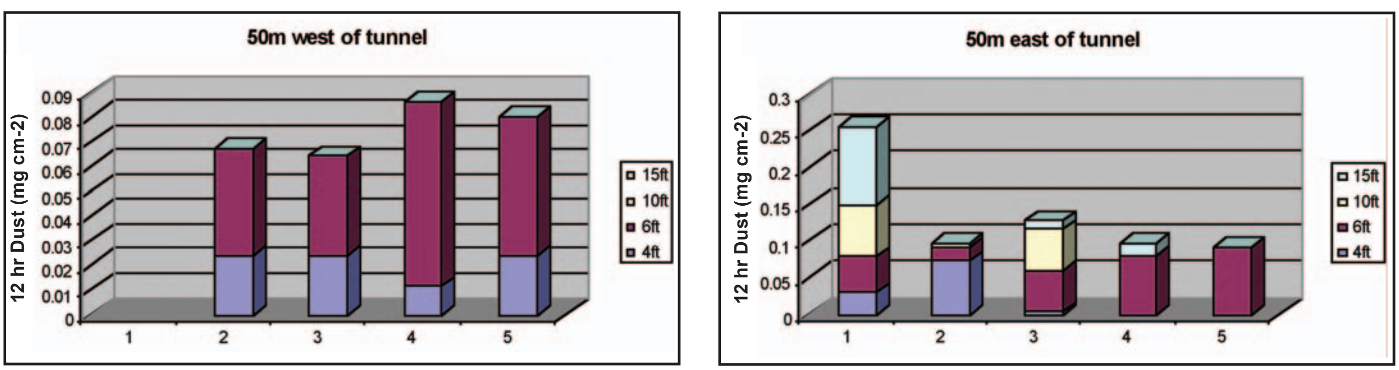


Figure 12—Dust movement off the trail into the forest along the tunnel trail. Note the differences in y-axis.

Estimating aerial displacement

Soil displacement was calculated by integration of the average dust mass for each height over the 15-foot collection pole. The underlying assumption is that the samples taken at four heights are representative of the gradient in dust concentration moving past the poles. An average vertical value of 0.244 grams of particles per square meter was calculated for the woods transect (north of the road) in comparison to 0.125 gram per square meter for the Field transect (south side of the road). The two tunnel transects indicated similar displacement at 0.098 (west side) and 0.113 (east side) grams of dust per vertical square meter. When this value is converted to a linear distance, total displacement for the front field was 1,844 grams of soil per km of trail under a very light riding day, and 1,058 grams of soil per kilometer in the tunnel area. These data only account for dust collected in the first 10 meters. A small percent of the displaced dust was collected 50 meters further away from the road in 3 out of the 4 transects, suggesting that the calculations slightly underestimate the quantity displaced.

Table 1—Displacement of soils particles due to vehicle traffic

		Woods	***Field***	***Tunnel West***	***Tunnel East***
	Collector Height (ft)	**Average dust collected (mg per cm^2)**			
	4	1.575	1.595	0.875	0.949
	6	1.027	0.146	0.383	0.611
	10	0.484	0.045	0.117	0.057
	15	0.398	0.076	0.049	0.067
Displacement	**Unit**	**Integration**			
Particle mass per pole	mg per 450 cm^2	10.979	5.618	4.420	5.106
Particle mass crossing front row	g per m^2	0.244	0.125	0.098	0.113
Soil displacement along transect	g per 5m x 200m	243.98	124.85	98.22	113.47
Linear soil displacement	g per km trail	1219	624	497	567
Soil displaced per trip in 1km	g per trip number	8.19	4.19	3.90	4.50

Summary:

Off highway vehicles cause a significant amount of soil migration by aerial displacement. Most of the soil particles launched during the study period were in size classes greater than 2.5μm and tended to travel less than 50 meters away from the trails.

However, spikes in average particulate loads greater than 150μg per cubic meters were common as vehicles passed the active monitor in the tunnel test site. Given the relatively light ridership during the experiment, when the numbers of riders are substantially higher, air concentrations would be expected well into the unhealthful range where the forested edges of the trails inhibit air circulation. Where the trails are open with adequate air circulation, such as along the main trail by the entrance station, the particulate loads have lower impacts on human health. The passive samplers deployed at head-height confirm a substantial atmospheric loading that could have effects on the rider's respiratory systems.

The evaluation of dust effects on vegetation suggests that OHVs cause only minor perturbations. Some stomatal blockage was observed, and surface accumulations of dust that may periodically inhibit photosynthesis and respiration, but little superficial damage to the cuticle was evident in the images captured by SEM. Because of frequent rainfall, it is unlikely that the effects are long lasting or a cause for serious concern. Vegetation naturally tends to be thickest along the sides trails because of reduced competition for nutrients and water in the trails (this is typically called an edge effect). This density tends to shelter understory plants off the trail from large deposits of dust and any subsequent deleterious effects, and therefore should be maintained or encouraged.

Overall, the results of this study demonstrate the success of using a low-tech particulate trap for determining soil migration and atmospheric loading due to vehicle traffic on unpaved roads.