Final Report for Project Number 04-DD-01: Engineering an In-line Monitor for Evaluating Dust Generation from Nut Harvesting Equipment

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Abstract: A commercial dust measurement instrument was mounted onto a nut harvester. Field testing determined that real time measurements of dust intensity from fan exhaust could be made and used to study the effects of grower-controller variables on dust generation. Test measurements indicated machine operation may have an effect on dust generated during harvesting. Additionally, differences may exist with soil type and relative dust concentration as measured with the instrument. Initial calibration of the dust measurement instrument under static conditions found good correlation between dust concentration and opacity measurements.

Introduction

Dust generation during nut harvest operations is a researchable topic for the industry as the desire to reduce dust discharge increases. Air quality in certain areas of California is a current issue with respect to suspended ambient particulate matter (PM) and human respiratory concerns. Agricultural operations such as livestock and poultry are increasingly subject to discharge guidelines for PM and there is concern that methods developed to monitor and regulate urban PM sources that are subsequently used to regulate agricultural sources may be biased (Buser *et al.*, 2001; Buser *et al.*, 2003).

Filter deposition measurements, using air samplers and sensitive gravimetric analysis for PM are time consuming and potentially limited in scope, since results are typically averaged over long time periods and large geographic regions. Ambient gravimetric PM measurements using PM10 and PM2.5 instruments are labor intensive. Filters can become overloaded if dust plumes become too dense, filters are required to be equilibrated under specific conditions prior to monitoring, and care must be taken when transporting filters back to the laboratory to minimize particle deposition loss. This methodology is time consuming and requires meticulous attention to details, in addition to requiring a climate controlled room for filter equilibration and analysis.

For the equipment industry to develop improved nut harvesting equipment and for growers to understand how cultural practices they can control would help mitigate dust generation, a more rapid and focused - in both time and space - measurement would be very useful. The goal of this project was to select and mount a commercial smokestack monitoring instrument on a nut harvester and determine the feasibility of using the instrument for estimating dust intensity. Using a light measurement instrument may reduce laboratory work associated with gravimetric analyses; however, it is unlikely to replace the accuracy and precision associated with precise gravimetric methodologies.

Objectives

1. Investigate commercially-available sensors used for particulate emission measurement in other industries and determine potential for use on mobile agricultural equipment.
2. Select and acquire a commercial sensor for further testing; if no commercial unit appears acceptable, design and develop a potential design for a prototype unit.
3. Develop a calibration method to compare in-line sensing of generated dust with established filter methods.
4. Adapt the sensor (commercial or prototype) onto harvest equipment and interface the measurement system with GPS recording systems.
5. Conduct preliminary testing on harvest machines.
6. Cooperate with existing dust measurement groups to coordinate field tests.

Results

Objectives 1 and 2 were addressed in the Final Report for Project Number 03-DD-01 based on funding received in July 2004. Briefly, an FW300 dust concentration monitor, manufactured by Sick-Maihak (Minneapolis, MN) was purchased. Figure 1 shows the FW300 instrument and conceptual mounting for an industrial application.

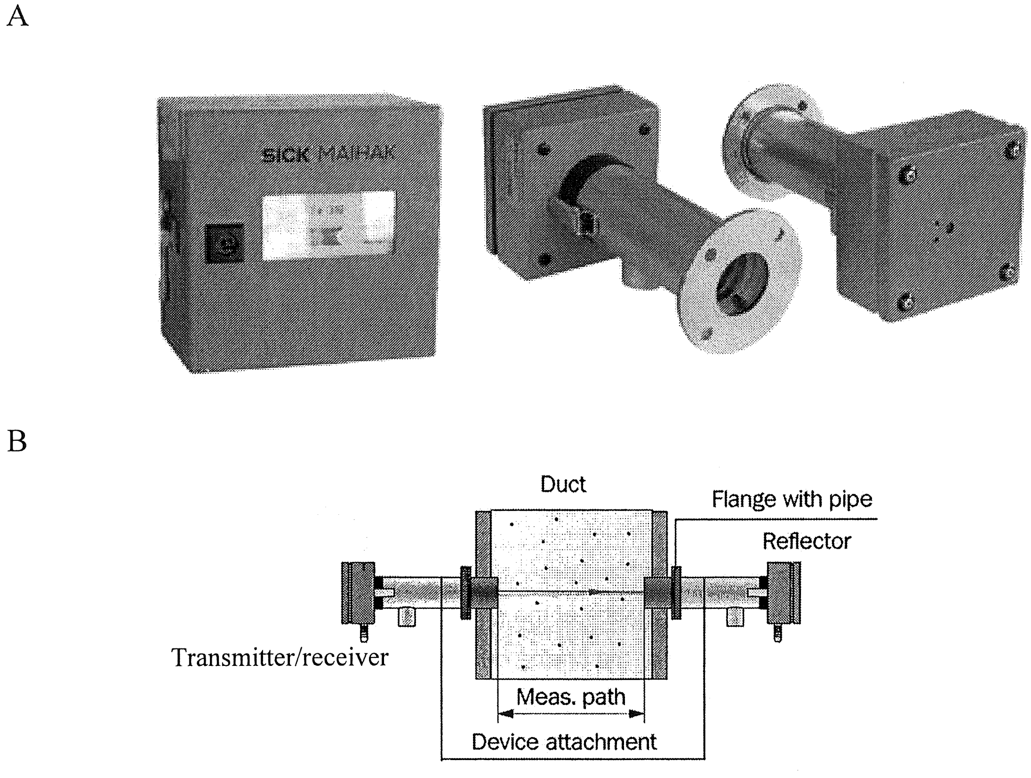

Figure 1. FW300 opacity monitor (A) and conceptual setup (B) for industry stack emission measurements.

Objective 3: Dust concentration measurements with the FW300 were evaluated in the laboratory. Figure 2 shows the chamber used to measure static dust concentrations. Coarse, medium, fine and ultra fine grade tests dusts were used (Powder Technology, Inc, Burnsville, MN). The test dusts were rated by SAE (Society of Automotive Engineers) and are NIST (National Institute of Standards and Testing) traceable. Mean particle sizes were 4.1, 9.0, 12.4, and 25.5 μm for the ultra fine, fine, medium and coarse test dusts respectively. Several massed quantities of each dust grade were suspended within the dust chamber (0.10, 0.25, 0.50, 0.75, 1.0, 1.5, 2.0 grams). Each mass was suspended with an air/dust interface entrainment nozzle (Venturi-Induction model, ExAir Corp., Cincinnati, OH) as shown in Figure 2. Each dust sample was suspended with a controlled burst of air for approximately 3 s using a direct acting solenoid valve (Model 359014-0861, KIP, Inc., Farmington, CT).

The FW300 was interfaced to a laptop computer to monitor each dust suspension event. Depending on the test grade of dust, data were collected between 8 (coarse dust) - 20 minutes (ultra fine dust). The test dust samples were entrained randomly; the FW300 was monitored to ensure the instrument response returned to that expected for clean air (approximately 98 -99 % transmission). Data were collected at 1 s intervals and a moving 15 s arithmetic average was calculated for each event to determine the minimum response for each mass entrainment event for each test dust. This minimum response is the equivalent dust concentration suspended. Note that 0 % opacity (100 % transmission) is dust free air, while 100 % opacity (0 % transmission) would indicate zero light is able to pass through a dust sample.

Plotting opacity or transmission can be a misleading way to view concentration data due to the non-linear relationship between opacity, transmission and dust generation. Figure 3 shows a typical response for a 1 g sample of fine test dust suspended in the dust chamber. This response was typical for all the test dust events measured. The data were arithmetically averaged for 15 s to establish a representative minimum response of transmission due to suspended dust concentration. The extended time on these graphs is effectively the residence time of the suspended dust in the chamber and represents a relative settling time of the suspended dust particle sizes. However, the minimum transmission is effectively the entrained dust concentration.

Extinction is also used to view concentration data, and provides a linear response with regards to dust concentration. The data are transformed using:

$$\text{Extinction} = \log(1/T) \qquad (1),$$

Note that in this equation transmission is represented in decimal format (1 T is equivalent to 100 % transmission, 0.5 T is equivalent to 50% transmission, 0.1 T is equivalent to 10% transmission). Additionally, note that opacity is represented as 1-T.

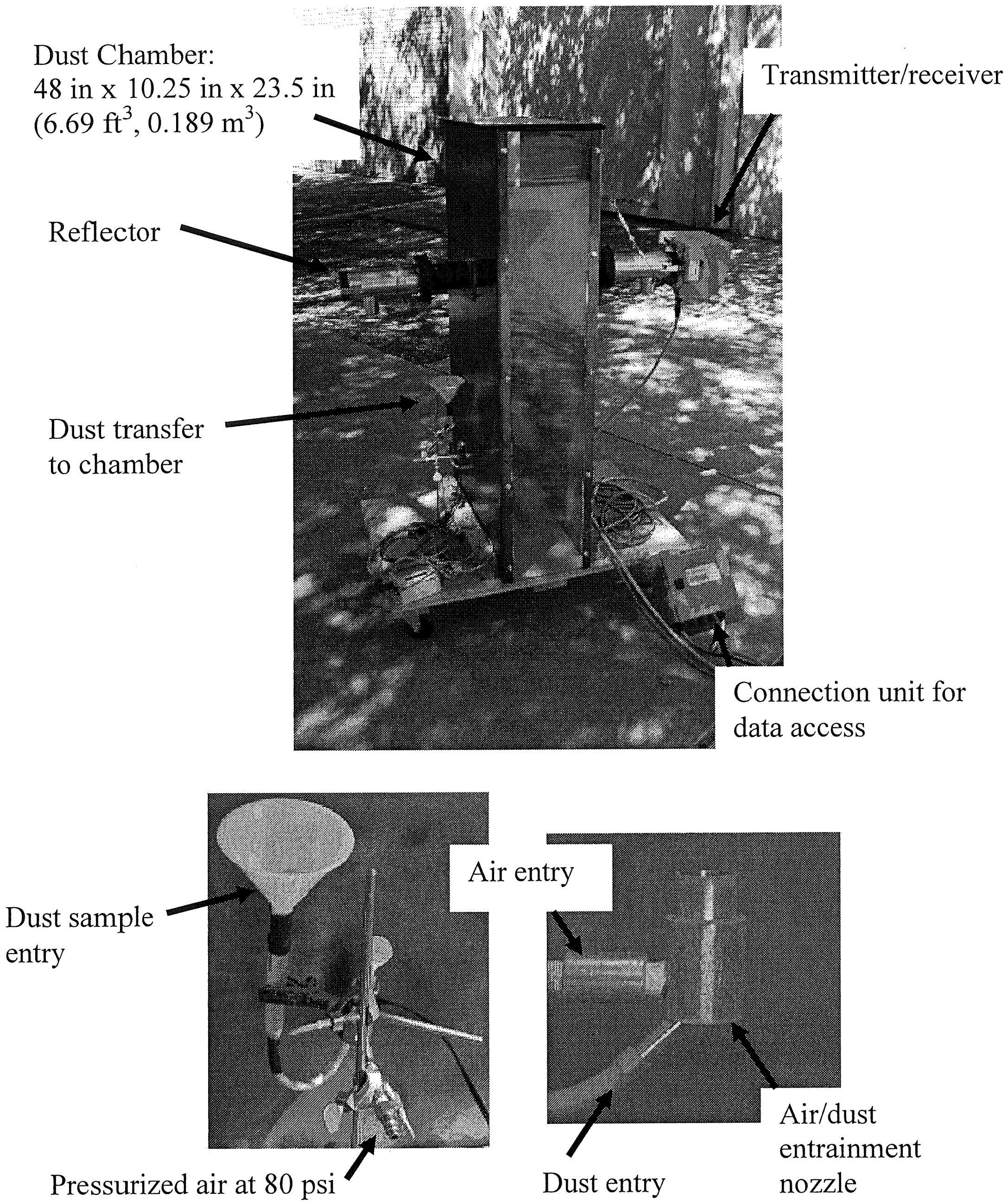

Figure 2. Dust chamber for static dust concentration tests.

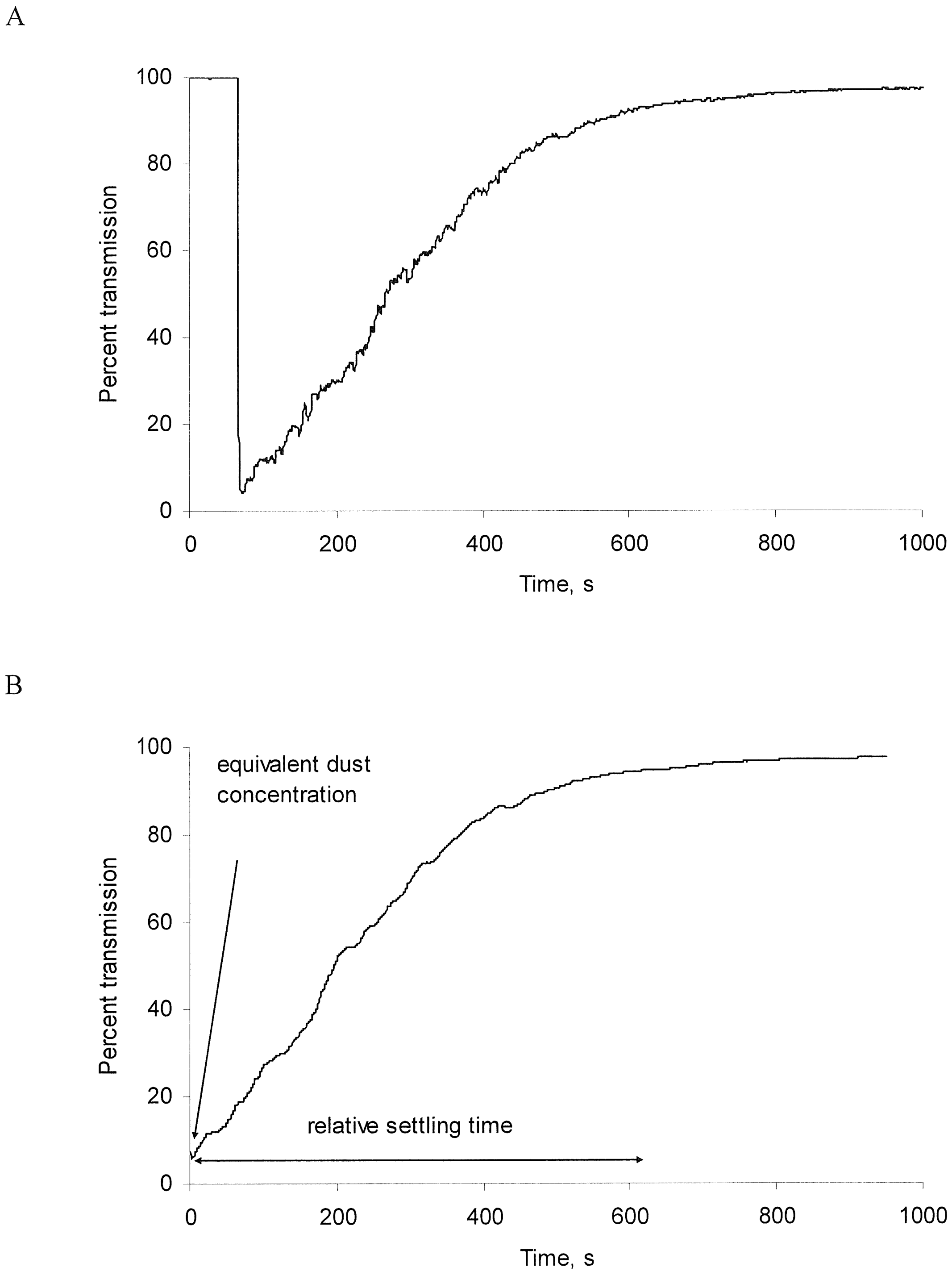

Figure 3. FW300 response after suspending 1 g of fine dust in the dust chamber: (A) shows actual response, (B) shows 15 s averaged data used to estimate the minimum transmission, or equivalent dust concentration.

Figure 4 shows dust concentrations as measured by the FW300 for different test dust grades. The results show the distinctive nature of the different test dust grades, and these are in some respects, directly related to particle sizes. The linear prediction variables are given in Table 1; Table 2 shows volumetric percentages of the test dust particle size ranges. These results are promising with regards to several concepts. The instrument response was in accordance with the theory of optical measurements of dust concentration. In these initial calibrations, measurements were taken with only one size range of dust at a time, the effect of multiple ranges is under investigation.

Table 1. Linear response variables for Figure 4 representations of coarse, medium, fine and ultra fine dust extinction-concentration prediction lines.

	Coarse	Medium	Fine	Ultra Fine
Slope	13126	7432	4772	4889
Intercept	-639	-562	-369	-112
R^2	0.98	0.99	0.97	0.98

Table 2. MSDS (Powder Technology, Inc.) data of volumetric statistics (geometric) for the different test dust particle size ranges.

	Percent of particles greater than listed sizes				
Test dust grade (mean size, µm)	10 %	25 %	50 %	75 %	90 %
	------------------Particle size, µm	------------------------			
Ultra fine (4.1 µm)	7.3	5.9	4.5	3.2	2.1
Fine (9.0 µm)	41.3	23.0	8.9	3.8	2.0
Medium (12.4 µm)	43.0	25.9	12.9	6.6	3.5
Coarse (25.5 µm)	82.8	56.2	31.8	14.0	5.2

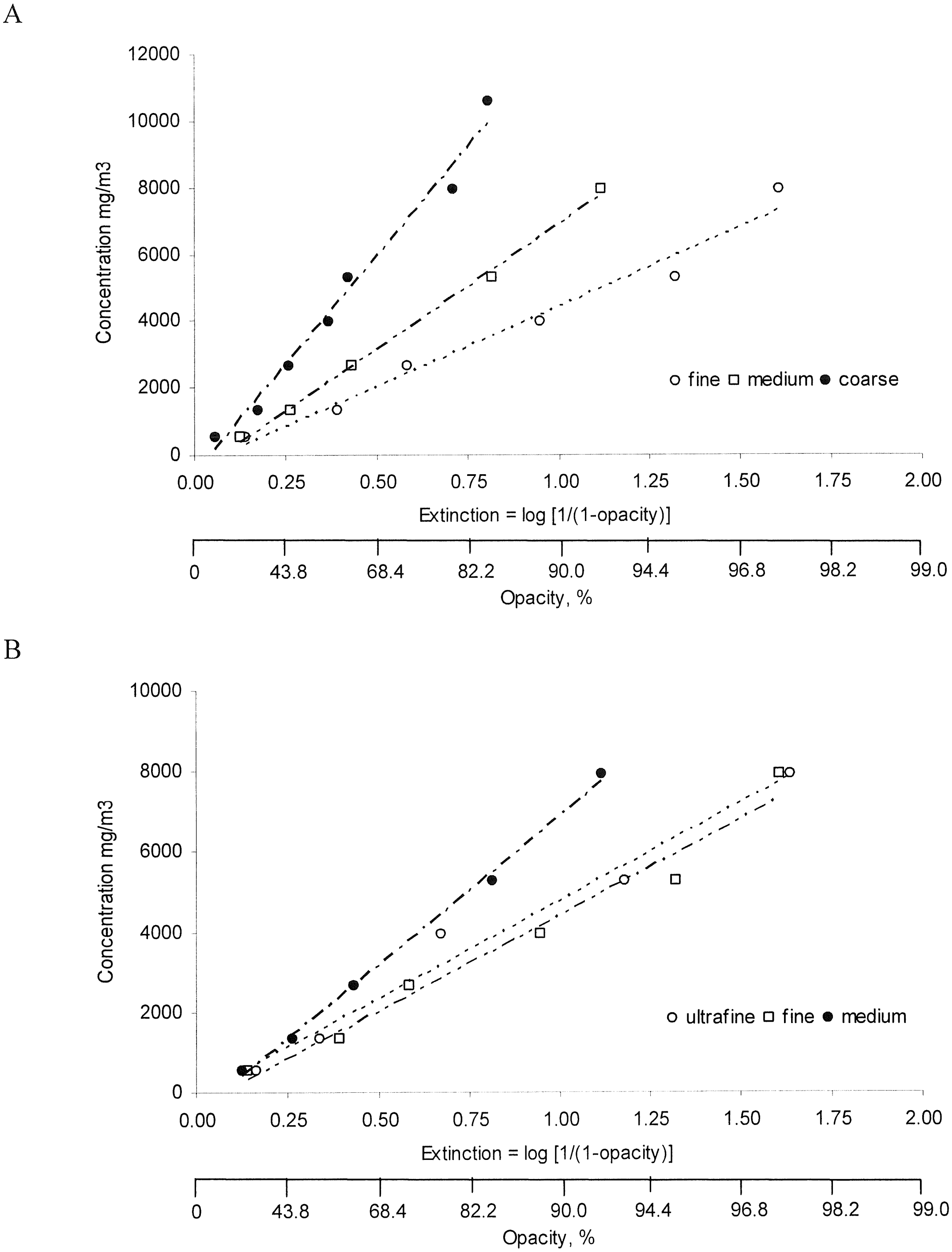

Figure 4. Dust concentration response as a function of opacity (transformed to extinction) for (A) coarse, medium and fine test dusts and (B) medium, fine and ultra fine test dusts: note that lines shown are prediction lines with response coefficients given in Table 1.

Objective 4: A platform (Figure 5) was fabricated for mounting the instrument on a harvester (Model 850, Flory Industries, Salida, CA). The Research and Development Section of Flory Industries fabricated and mounted this platform to the harvester.

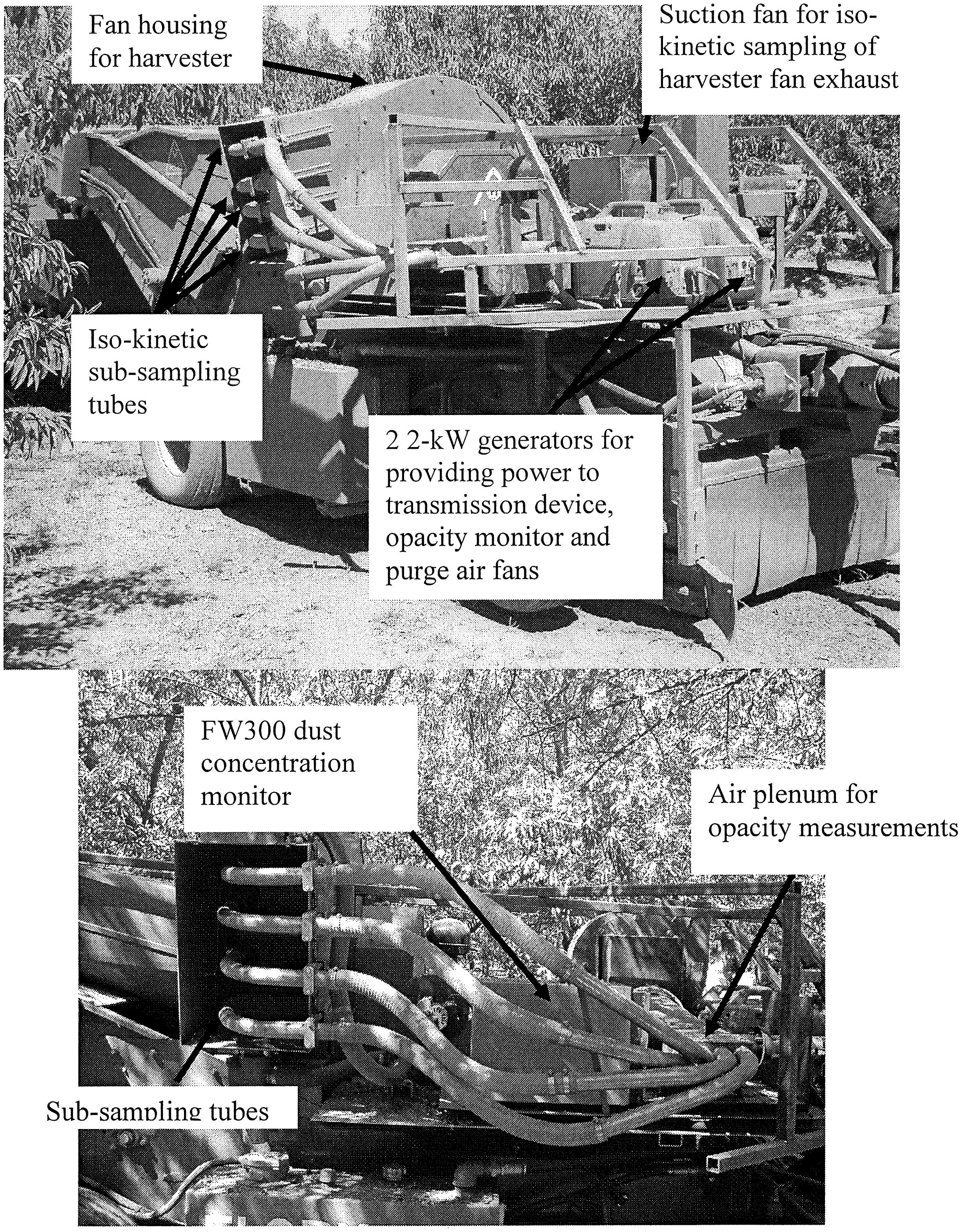

Figure 5. FW300 mounted on a tractor towed harvester.

Velocity measurements through the sub-sampling tubes averaged 70 ft/s. A suction fan (Model 9LS, 9" diameter, 15 5/8" wheel, with outlet area of 0.43 ft^2, Chicago Blowers, Inc., Glendale Heights, IL) provided the sub-sampling flow through the tubes and air plenum for opacity measurements. The sub-sampling tubes were 2" in diameter; entries had elliptical faces and were equipped with mesh screens welded in place. The mesh had nominal open areas of 1/8" x 5/16" for an effective open area of 0.035 ft^2. The mesh face on these tubes prevented large debris from entering the system. Average estimates of velocity profiles along the fan outlet were 75 ft/s, indicating that the sub-sampling tubes provide an iso-kinetic dust flow sample through the air plenum. A handheld GPS was used for speed and position measurements.

Objective 5: Initial field studies were conducted for different regions and harvesting conditions. Results from a typical test run along a row are shown in Figure 6. Basic harvest/pick-up activities are observed in this figure; harvester start-up, initiating movement with fan engaged; harvesting-pick-up-separation; resulting dust intensity; harvester slow down; and disengaging the fan. Preliminary results have indicated that dust intensity (opacity) may vary based on harvester speed, soil texture and soil conditions. Table 3 and Figure 7 show results of in-field harvesting and opacity measurements from the FW300 under actual field conditions. Dust intensity appears to be influenced by harvester operating conditions and soil properties (Table 4).

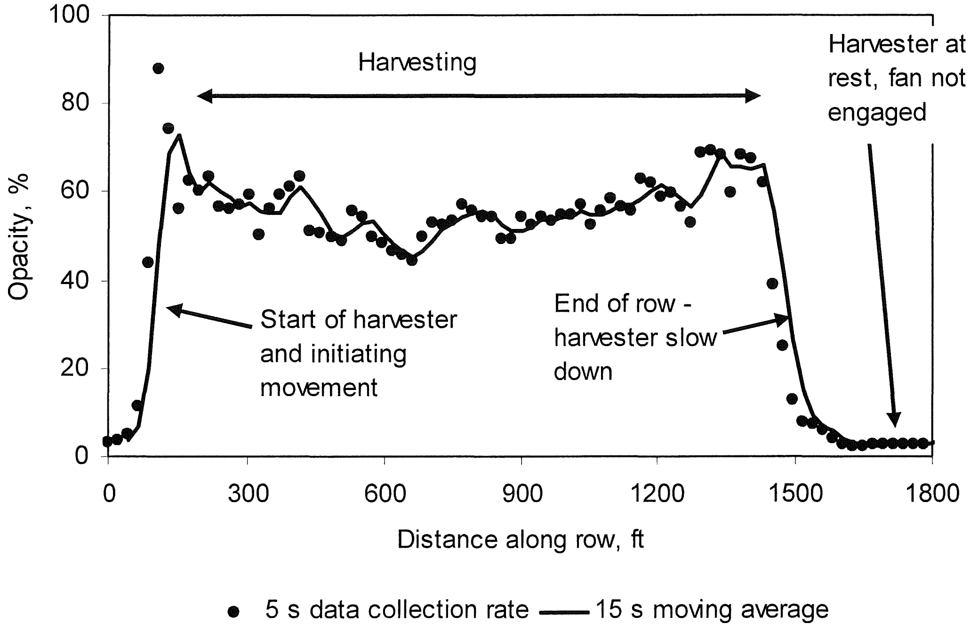

Figure 6. FW300 response during harvest pick-up along an orchard row.

Table 3. Preliminary opacity measurement results from nut harvesting at several locations for the 2004 season.

Location[†]	Opacity,% average	Test speed mph‡	Test comments
Field 1	62.1	3.0	Sandy soil, poor windrow prep
Field 2	67.6	1.9	Sandy soil, more grass than Field 1
	84.5	3.8	"
Field 3	50.0	1.5	Hard clay loam
	77.1	3.0	"
Field 4	19.3	3.0	Hard adobe, with aggregates
	39.5	6.0	"
Field 5	27.6	1.5	Fairly clean, sand/silt soil
	46.6	3.0	"
	65.0	4.5	"
	82.3	5.5	"

† Average results for multiple runs in the field. ‡ Speed determined from hand-held GPS device.

Table 4. Particle size distribution of pre-harvest and post-harvest windrow contents[†].

	Sand %	Silt %	Clay %
Field 3			
Pre	43	30	27
Post	46	32	22
Field 4			
Pre	10	40	50
Post	26	26	48

† Determined on materials passing a 2-mm sieve by standard soil methods of sedimentation and sieving.

A - Field 3, 3 mph, 77.1 % opacity

B - Field 4, 3 mph, 19.3 % opacity

Figure 7. Opacity measurements for two separate fields showing effects of windrow and soil type on dust intensity during harvest operations.

Objective 6: Initial instrument testing, platform fabrication for mounting the FW300, and assessments of the measurement capabilities using the FW300 were the main focus of the 2004 harvest season. This project is cooperating with Farm Advisors and the air quality group at Crocker Nuclear Lab and has made the equipment available for use with the industry and other researchers.

Conclusions

Initial testing was completed for the 2004 season; results showed that differences in orchard location, soil type, and harvest speeds resulted in varying opacity values as determined by a commercial dust measurement instrument. Regarding harvest speed, initial results appeared to show that dust intensity during harvest operation was related to speed, more intense dust, or a higher opacity reading, was found with increased speed during the pick-up operation. However, dust generated, at the harvester, on a per unit time basis must be corrected by the actual time required for harvest in order to develop conclusions on effects of speed and potential dust generation at the machine source per unit land area or per unit of harvested crop.

Initial calibration tests, using test dust grades, for the FW300 determined a strong correlation between dust concentration in a test chamber and opacity readings. Future testing will evaluate flow through dust concentrations and the FW300 opacity response, as it relates to concentration.

Dust intensity measurements during the 2005 season will continue to look at different harvester machines, machine operation conditions, soil type and the response of the FW300 due to different cultural practices, to the extent possible with cooperating harvester manufactures and growers.

References

1. Buser, M.D., Parnell, C.B., Lacey, R.E., Shaw, B.W., Auvermann, B.W. 2001. Inherent biases of PM10 and PM2.5 samplers based on the interaction of particle size and sampler performance. ASAE Paper No. 011167. St. Joseph, MI.:ASAE.
2. Buser, M.D., Parnell, C.B., Shaw, B.W, and Lacey, R.E. 2003b. Particulate matter sampler errors due to the interaction of particle size and sampler performance characteristics: background and theory. Air pollution from agricultural operations III Proceedings of the 12-15 October 2003 Conference, ASAE Pub. No. 701P1403, St. Joseph, MI.:ASAE.