Final Report for Project Number 05-DD-01:
Evaluating dust generation from nut harvesting equipment

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Abstract: An established measurement tool for determining relative dust intensity during harvesting practices was used to evaluate differences in sweeper header settings and general harvester operating conditions. Results found that a conventional sweeper head height setting decreased relative dust intensity during nut pick-up operations. Conventional versus deep sweeping operations decreased relative dust intensity by 46 % and 32 % when harvesting at 1.5 and 3.0 mph, respectively. Harvester operating conditions were evaluated; results found that decreasing ground speed from 3.0 to 1.5 mph decreased relative dust intensity during pick-up operations by 52 %. Generally, regardless of harvest machine operating conditions, a 1.5 mph ground speed resulted in lower dust intensity during harvesting. A low separation fan speed during harvesting at 3.0 mph decreased relative dust intensity 49 % when compared to conventional operating conditions. Preliminary results from gravimetric analyses indicate there may be in-field variability during harvesting. The measurement tools developed in this work can be used for evaluating differences in machine design and operating conditions, in addition to orchard management practices and can provide rapid feedback to growers, operators and other stake holders.

Introduction

Initial work, funded by the Almond Board, established that an in-line monitoring system can be used on harvesters to compare relative dust intensity during nut pick-up operations. The measurement system developed for this on-going study has been used to establish differences in machine design, harvester operating conditions and orchard management practices.

Regulatory methods for assessing dust during agricultural operations are based on filter deposition measurements of airborne particulate matter. While there is debate over the absolute accuracy of some gravimetric sampling devices, the technique remains the most common method for airborne particulate measurements. Preliminary measurements from the 2005 season used a gravimetric sampler (MiniVol™ Portable Air Sampler, Airmetrics, Eugene, OR) during several field test runs. The device is recognized and used by the California Air Resources Board for PM10 and PM2.5 measurements at high particulate concentrations. The intent of the preliminary measurements during this past year was to establish the feasibility of the gravimetric measurement method to be used concurrently with the opacity measurement system.

The primary goal of this project was to use an established measurement tool, mounted on or near machine during harvest operations and developed specifically for measuring dust intensity, to instantaneously estimate the dust intensity generated and discharged by almond harvesting equipment. The project established that an opacity monitoring system can be used to compare relative dust intensity during nut pick-up operations and results indicated that dust intensity was related to sweeper settings for windrow preparation and harvester operating conditions (ground speed, separation fan speed and cleaning chain speed). The measurement systems developed for this on-going study provide an efficient tool to assess field operating conditions and changes in management or cultural practices that can minimize dust intensity. Additionally, the tool provides results from tested conditions immediately, that is, during the actual test run and can be used for immediate feedback of in-field operations.

Objectives

1. Purchase and calibrate an additional commercial opacity measurement system for use during the 2005 harvest season.
2. Establish the limits of the measurement system with respect to particle sizes from known test dusts and field sampled test dusts.
3. Continue opacity measurements of dust intensity from different harvest machines.
4. Measure effects of orchard management treatments, including irrigation timing and application of polyacrylamide (PAM), on opacity and in-orchard dust measurements
5. Design and construct a trailer mounted measurement system that can be used for opacity measurements off-harvest row during typical harvesting practices.
6. Coordinate and compare opacity and dust intensity measurements with established filter deposition methods used by projects associated with PI Cassel.

Results

Objective 1: A new opacity monitor for measuring relative dust intensity during harvesting operations was purchased this past year for use during the 2005 harvest season. The device was mounted on a small truck bed and used for off-harvest-row dust intensity measurements based on modifications in machine design. The results are discussed in Objective 5.

Objective 2: Preliminary measurements this past year were made with a MiniVol™ gravimetric sampler (Airmetrics, Eugene, OR). The sampler (figure 1) is capable of measuring PM2.5 and PM10. The device is not a Federal Reference Method sampler, however, it is generally acknowledged as providing results comparable to federal reference method samplers at high particulate matter concentrations.

Windrow materials were sampled during the 2005 season, prior to and after pick-up operations. All samples were pretreated prior to soil size analysis by sifting through a Number 4 sieve with 4850 µm openings. Samples were analyzed by Powder Technology, Inc., (PTI) and gave a break-down in terms of percentage of material less than specified size ranges (samples were analyzed using an Horiba LA-930 laser diffraction analyzer with particulate measuring capabilities ranging from 0.02 to 2000 µm).

Figure 1. MiniVol™ sampler with PM2.5 inlet located within the dust plume one row away from harvest row.

Several tests were completed that measured opacity and gravimetric particulate matter concentrations simultaneously during conventional harvester operations versus a modified harvester. The gravimetric sampler was placed mid-row, two rows away from the harvest row. The row adjacent to the harvest row was used to measure opacity during harvest pick-up operations with a truck-bed mounted measurement system (discussed later). The modified harvester had a nylon bag attached to the separation fan outlet. The bag had 2 mm square openings with approximately 121 openings per square inch. Three replicates for each test condition (conventional versus modified harvester) were measured and both harvesters were operated under similar operating conditions.

Table 1 gives results comparing the two harvester designs. These data are preliminary and must be replicated for statistical validity (elevated background gravimetric samples were a point of statistical concern). However, the preliminary results from table 1 indicate that there was in-orchard variability of PM2.5 concentrations (for this orchard) in addition to showing that the modified harvester decreased PM2.5 by 90 % on the eastern side of the orchard and 80 % on the western section of the orchard. Inferences from this table should be cautionary since this was one point measurement within the orchard canopy during harvesting of one row (i.e., one gravimetric sampler placed mid-row, two rows away from the harvest row).

Table 2 gives results of pre- and post-harvest windrows analyzed for particle sizes using the PTI measurement device. The post-harvest window was sampled after a conventional harvest. One replicate was analyzed for each windrow. Future work will analyze multiple windrow replicates for particle sizes and potential for air entrainment.

Table 1. Single point PM2.5 dust concentrations measured during conventional and modified harvesting in a Stanislaus County test field; rows were oriented N-S; gravimetric samples were collected at a single point mid-row, two rows away from harvest row during harvest of one row within side of orchard indicated (east/west); opacity measurements were simultaneously made with the truck-bed opacity system one row from harvest row and results averaged for each condition; no overt wind conditions were obvious.

Treatment condition	Side of orchard	PM2.5 µg/m3	Average opacity %
Conventional harvester	East	3458.8	34.5
	West	353.0	
Modification 1	East	305.9	12.7
	West	73.3	

Table 2. Pre-harvest and post-harvest windrow samples (one replicate) for test orchard in Stanislaus County.

	Percent of particle sizes less than given diameters					
	5 %	10 %	20 %	30 %	40 %	60 %
Pre-harvest:						
Diameter, µm	9.6	17.8	42.8	75.3	109.8	213.7
Median particle size: 152.9 µm.						
Post-harvest:						
Diameter, µm	7.9	14.5	33.9	63.2	92.0	171.6
Median particle size: 125.3 µm.						

Objective 3: The monitoring system developed from the initial study in 2004 was used to measure dust intensity for several different harvesting conditions. The device, mounted on a nut harvester, is shown in figure 2. This past 2005 season, the system was used to evaluate the effect of sweeper depth on harvest dust intensity and harvest machine operating conditions of ground speed, dust/nut separation fan speed and cleaning chain speed. As in the earlier study, opacity is a relative indicator of dust intensity during harvest, where 0 % opacity indicates relatively clean air and 100 % opacity indicates dust laden air.

Two sweeper machine settings were evaluated with respect to the resultant effect on dust intensity from the harvest machine during pick-up operations; a conventional sweeper head height setting and the sweeper head height set for a deep sweep operation. In addition to the sweeper settings, the harvester was operated at several ground speeds. Three independent windrows were produced for each sweeper setting and harvester ground speed. Results from opacity measurements during harvest of each of the three independent rows for each sweeper setting and harvest ground speed were averaged and are given in table 3. In-row opacity measurements from harvesting after conventional sweeping operations are shown in figure 3. Opacity measurements indicated that harvesting at 1.5 mph ground speed reduced relative dust intensity by approximately 52 % when compared to the 3 and 4 mph harvester ground speeds, respectively. There was no significant difference between the 3 mph and 4 mph harvesting speeds on relative dust intensity from the conventionally swept windrows. In-row opacity measurements while harvesting at 1.5 and 3.0 mph, after conventional versus deep sweep operations, are shown in figures 4 and 5. These results show that the conventional sweeper head setting decreased relative dust intensity during harvest; average opacities for each replicated condition indicate these reductions are on the order of 46 % and 32 % for 1.5 and 3 mph harvester ground speeds, respectively.

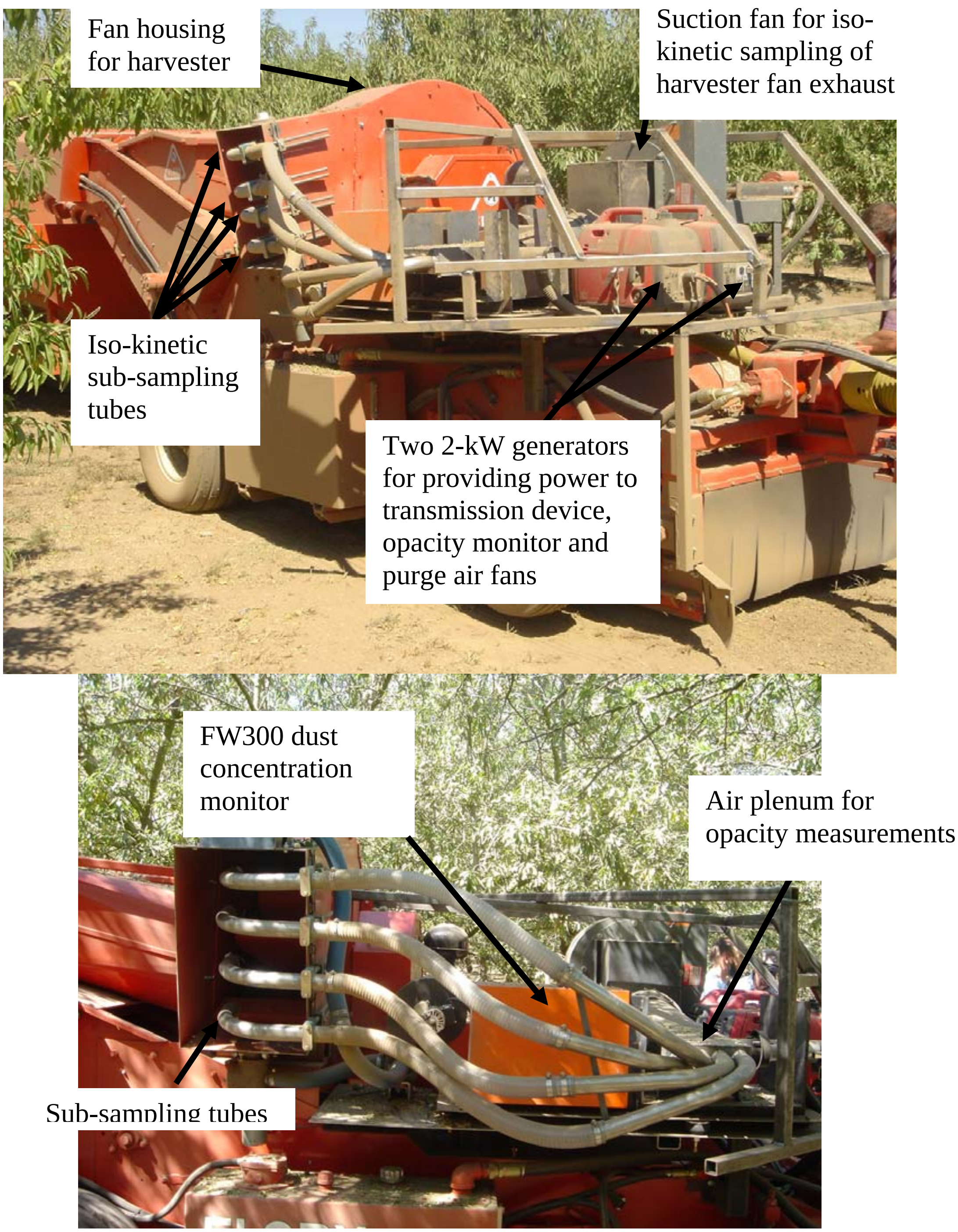

Figure 2. Dust intensity measurement system mounted on nut harvester (initial testing and fabrication completed during 2004).

Table 3. Opacity results from conventional harvesting operations in Stanislaus County after normal and deep sweeping for windrow preparations; opacity measurements were based on sub-samples from harvester fan outlet.

Ground speed mph	Comments	Average opacity for row Percent
1.5	Standard sweeper settings	24.5
3.0	Standard sweeper settings	51.2
4.0	Standard sweeper settings	50.8
1.5	Deep sweeper settings	45.2
3.0	Deep sweeper settings	75.3

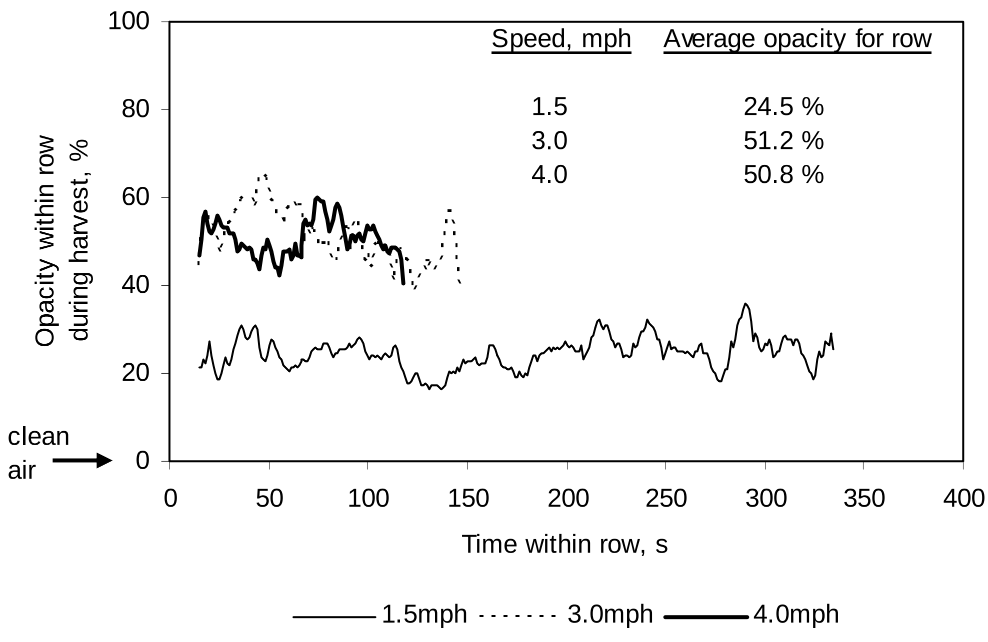

Figure 3. In-row opacity as a function of harvester ground speed after conventional sweeping operations.

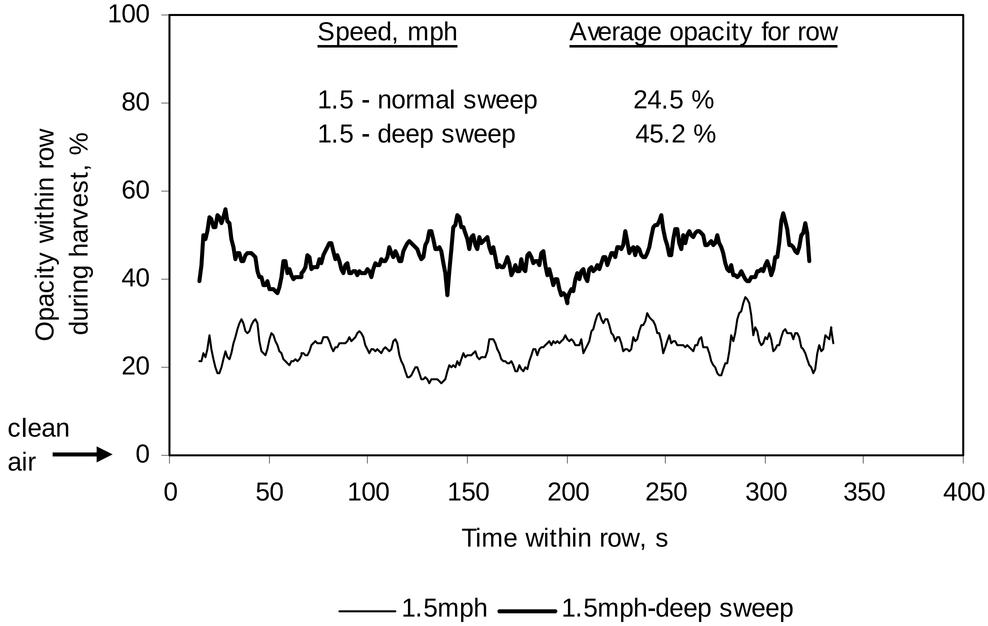

Figure 4. In-row opacity during harvesting at 1.5 mph based on sweeper settings.

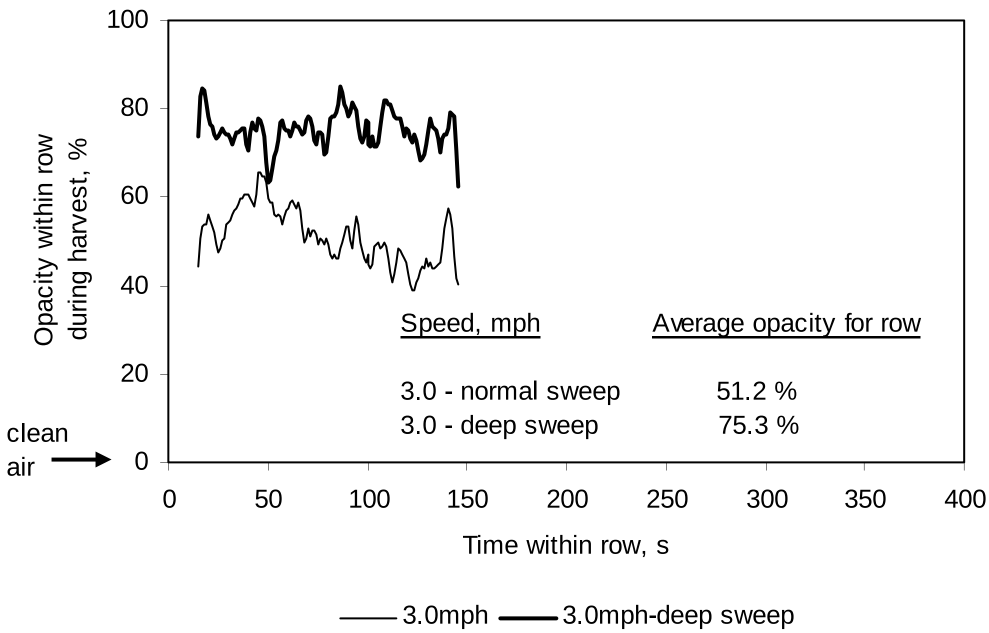

Figure 5. In-row opacity during harvesting at 3.0 mph based on sweeper settings.

The effects of harvest machine operating conditions were measured. The test conditions were ground speed (1.5 mph and 3.0 mph), dust/nut separation fan speed (low, mid and standard rpm settings) and adjustments to the cleaning chain speed (standard settings and optimal settings to match forward travel of the harvester). Each condition was replicated three times, results were averaged and are given in table 4 and figure 6. The results indicated that the lowest travel speed of the harvester, 1.5 mph, generally resulted in less dust intensity during harvest, regardless of harvester operating conditions. Opacity measurements averaged approximately 30% for all of the 1.5 mph harvester ground speed test conditions. In general, relative dust intensity measurements at 3.0 mph ground speed for the different machine settings were similar. Average opacities ranged from 51.2 % to 56.8 %, except for two conditions. These two conditions showing the lowest averaged measured opacity during harvesting at 3 mph ground speed occurred when the separation fan speed was set to the lowest test condition (900 rpm, versus the standard fan speed of 1080 rpm or a mid range of 1012 rpm). A comparison of the relative dust intensity during standard operating conditions for the harvester versus the harvester operated with a lower separation fan speed is shown in figure 6. Average opacity results indicated that lowering the separation fan speed decreased relative dust intensity by 49 %.

Table 4. Opacity results from harvesting in Stanislaus County based on changes in machine operating conditions; opacity measurements were based on sub-samples from harvester fan outlet.

Ground speed mph	Fan speed†	Machine Drive‡	Average opacity for row Percent
1.5	Standard	Standard	24.5
1.5	Standard	Optimal	30.5
3.0	Standard	Standard	51.2
3.0	Standard	Optimal	56.8
1.5	Mid	Standard	34.4
3.0	Mid	Standard	52.1
3.0	Mid	Optimal	51.6
1.5	Low	Standard	30.0
1.5	Low	Optimal	30.1
3.0	***Low***	***Standard***	***26.1***
3.0	Low	Optimal	40.1

† Standard fan speed setting was 1080 rpm, mid setting was 1012 rpm, low was 900 rpm.
‡ Standard machine drive settings for the primary shaft driving the cleaning chain were based on manufacturer recommendations; optimal settings matched forward speed of harvester.

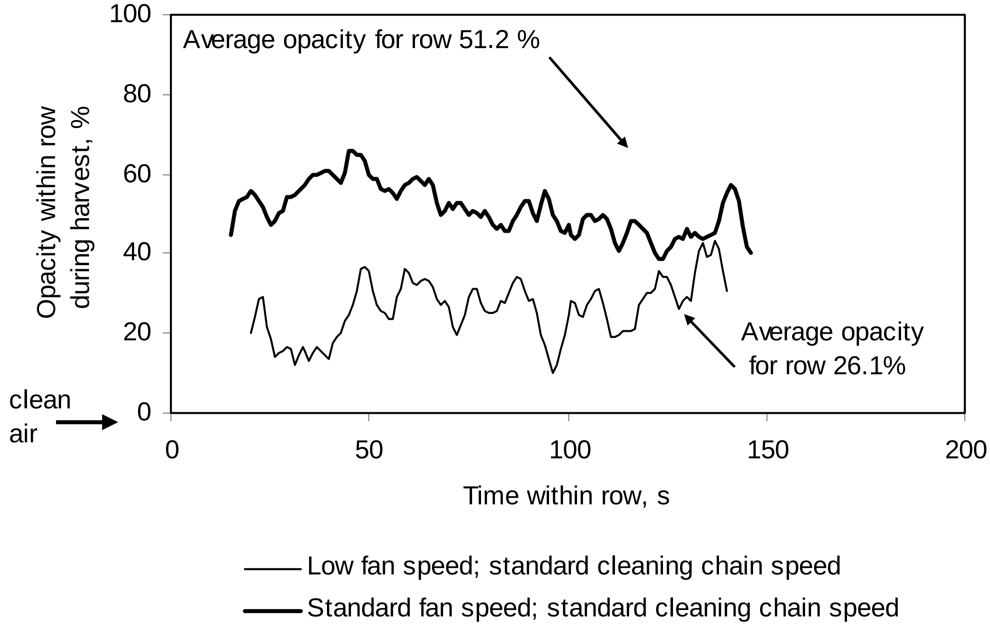

Figure 6. Comparison of opacity measurements during harvest at 3.0 mph ground speed, standard cleaning chain speed and fan speed of 900 rpm (low separation fan speed) versus 1080 rpm (standard separation fan speed).

Objective 4: This goal of this objective was to continue lab-based experiments on the effects of water content and polyacrylamide soil amendments (PAM) on dust production. Field experiments were done to establish the best position of samplers in an orchard so that treatment effects (e.g., harvester speed, irrigation treatments, PAM applications, harvester design and soil properties) could be measured.

Tests for this portion of the project were carried out at the Nickels Soil Laboratory. Tree variety was Carmel; tree spacings were 16 ft x 22 ft. The harvester was a Flory 210 owned and operated by the Nickels Field Lab. Gravimetric samples were collected during pick-up of three rows. PM10 and PM2.5 samplers (developed by the Dept. of Land, Air and Water Resources, UC Davis) were used to collect samples during pick-up operations. Samplers were equipped with pumps and Teflon filters (pre- and post-weighed for gravimetric analysis). Samplers were placed downwind of the harvester, 30 cm above the ground, one row and two rows away from the row being harvested. Three samplers were set-up in each row at 16 ft intervals to measure in-row variation of pick-up measurements. Gravimetric samples from the PM10 and PM2.5 instruments were collected for 6 minutes during the pick-up operations, as the harvester passed the test set-up. Soils were sampled and analyzed for moisture content and texture. Windrows were sampled to measure mass in a uniform scoop to assess variation within row. Wind speed and direction were relatively constant during sampling.

Results for gravimetric measurements from the PM10 and PM2.5 samplers are shown in figures 7 and 8. Three to six times as much PM10 as PM2.5 was measured. PM10 mass dropped off quickly from row 1 to row 2. PM2.5 measurements were more uniform (due to easier transport). There could be potential variation from one row to the next (for example, compare Carmel1 and Carmel2 with Carmel3). Even if soils and windrows were similar it may be more appropriate to sample several rows. Variation within row suggests that at least three samples per row are needed to characterize variation.

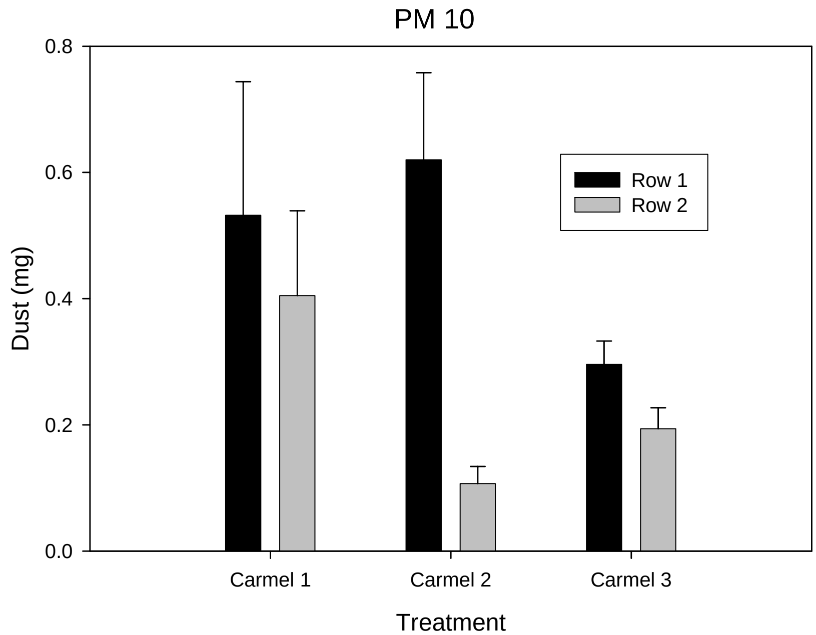

Figure 7. PM10 gravimetric measurements during pick-up operations at the Nickels Soil Lab; Carmel1, Carmel2 and Carmel3 are indicative of the sequence of pick-up operations.

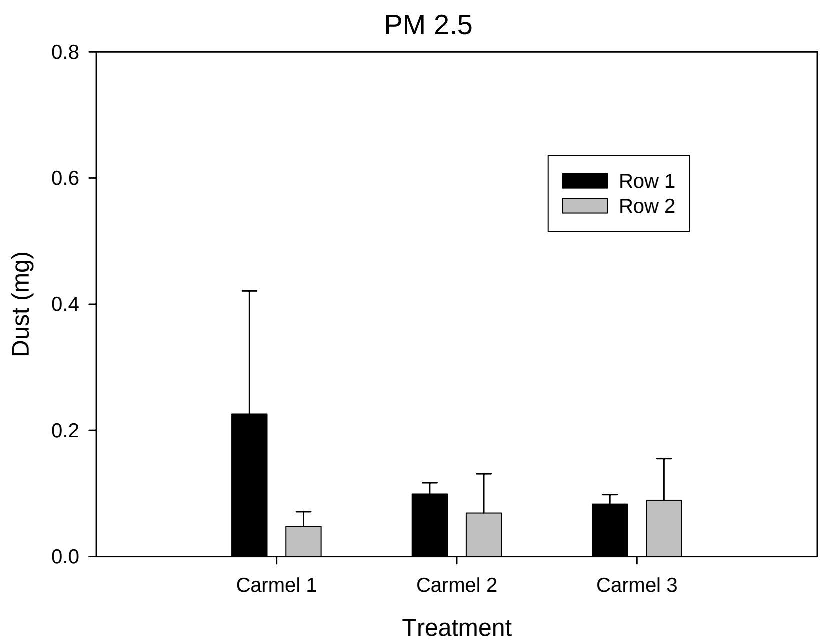

Figure 8. PM2.5 gravimetric measurements during pick-up operations at the Nickels Soil Lab; Carmel1, Carmel2 and Carmel3 are indicative of the sequence of pick-up operations.

Objective 5: A new monitoring system was fabricated for off-harvester measurements of dust intensity. The truck-bed mounted system is shown in figure 9 and was specifically fabricated for measuring dust intensity in adjacent rows during harvesting practices. Additionally, the measuring system was fabricated for evaluating differences in machine designs and soil type and resultant effect on dust intensity due to harvesting and other orchard management conditions. This past season enabled preliminary tests to be completed that evaluated differences in two machine designs; one design being a conventional harvester, the second design was a modified separation fan outlet. The modification was a nylon bag, attached to the separation fan outlet. The bag had 2 mm square openings (approximately 121 openings per square inch), was 10 ft long and fastened along the length of the harvester. Results are shown in table 5 and figure 10. For the specific testing conditions comparing these two designs (a conventional harvester versus a modified harvester), operated under standard conditions, the modified harvester resulted in a 63 % decrease in relative dust intensity. Future use of this measurement system will allow immediate feedback to manufacturers for evaluating differences in machine design.

Objective 6: The instruments and methods developed over the last two years for measuring opacity as an indicator of relative dust intensity during harvesting practices have continued to be available to other manufacturers, Farm Advisors and other air quality groups. The intent and focus of this work has been that opacity measurements with these systems be used for assessing and developing specific machine operating conditions that will minimize relative dust intensity during field operations.

A

B

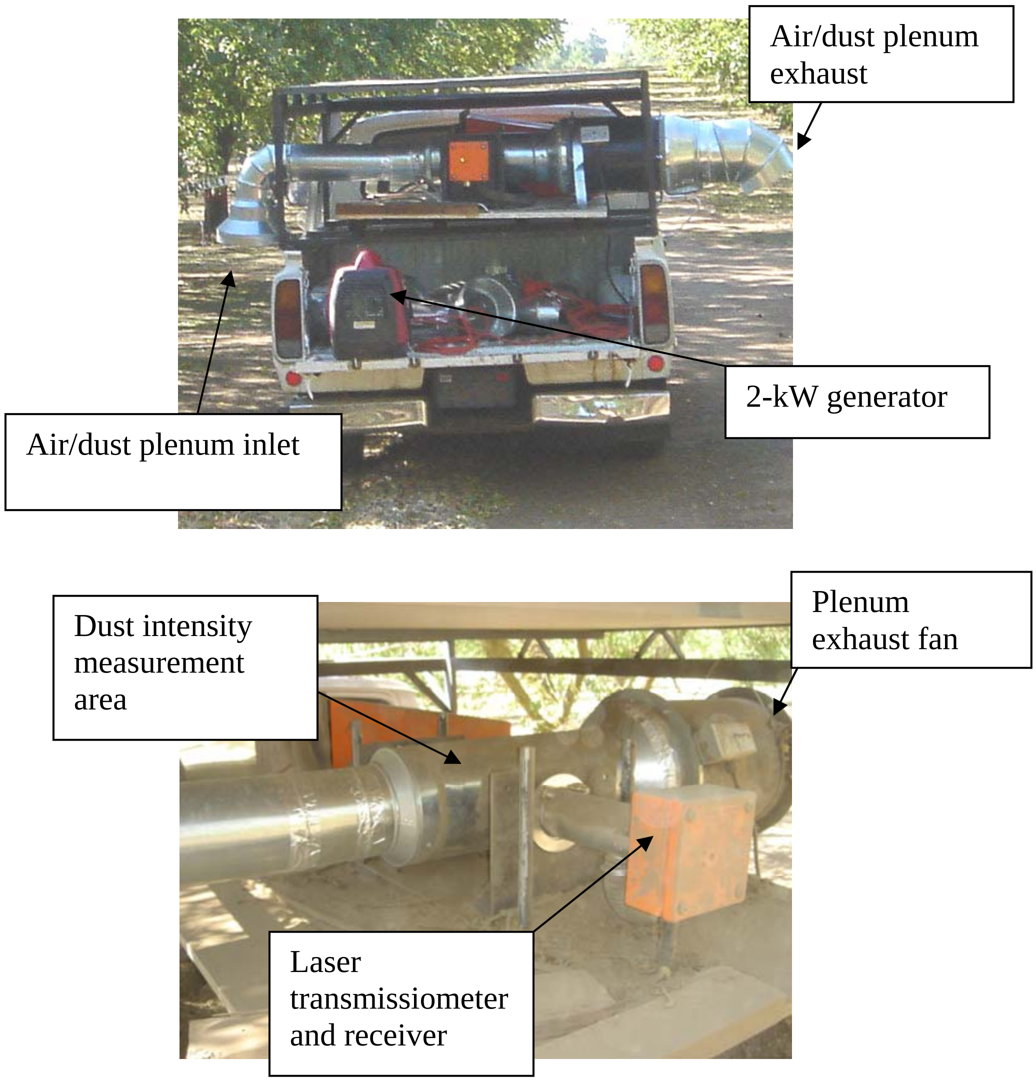

Figure 9. Dust intensity monitoring system mounted on a small truck-bed (A), close- up of measurement system (B).

Table 5. Comparison of a conventional and modified harvester operated under standard conditions in Stanislaus County; measurements were taken one row away from harvest row using the truck-bed mounted opacity measurement system operated at the same ground speed as the harvester.

Ground speed Mph	Comments	Average opacity for row Percent
3.0	Conventional harvester	34.5
3.0†	Modified harvester 1	12.7

† Modification 1 (dust bag mounted at fan output, bag had 2 mm square openings with 121 openings/in^2).

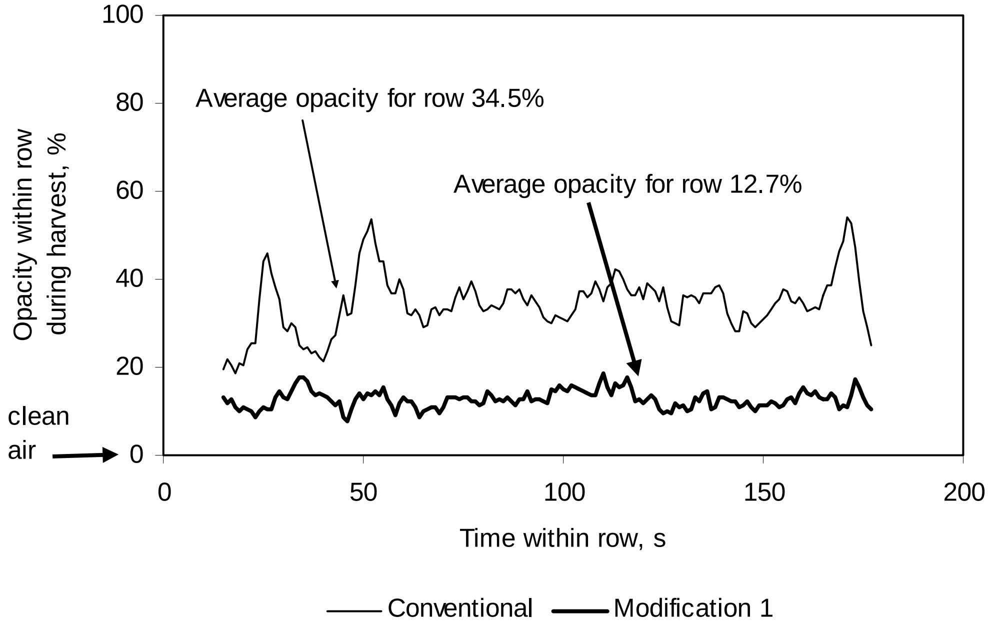

Figure 10. Comparison of in-row opacity for two harvester designs.

Conclusions

This work has established that a rapid and effective measurement tool can be used to determine and evaluate different harvesting practices in the field. The measurement tool was used to evaluate differences in sweeper head height setting and the resultant effect on dust intensity during harvest operations. Results found that relative dust intensity decreased during conventional pick-up operations by 32 % when conventional sweeper settings were used for windrow preparation versus deep sweeping operations. An analysis of harvester operating conditions found that slowing the separation fan speed reduced relative dust intensity by 49 % under conventional operating conditions. Additionally, slowing the ground speed of the harvester resulted in reduced dust intensity, however this may have residual air quality effects by increasing the length of time the harvester remains in the field.

Preliminary work this year indicated that machine design modifications decreased PM2.5 concentrations when measured in an adjacent row during harvest. These results, while preliminary, have enabled comparison methods to be developed between the opacity measurement system and gravimetric sampling. Future work will refine these methods and comparisons. Although opacity measurements provide useful information on total material in the sample stream, the direct relationship of opacity to PM10 and PM2.5 has remained undefined.