

**A SCIENCE BASED EMISSION FACTOR FOR PARTICULATE MATTER  
EMITTED FROM COTTON HARVESTING**

A Dissertation

by

JOHN DAVID WANJURA

Submitted to the Office of Graduate Studies of  
Texas A&M University  
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

May 2008

Major Subject: Biological and Agricultural Engineering

**A SCIENCE BASED EMISSION FACTOR FOR PARTICULATE MATTER  
EMITTED FROM COTTON HARVESTING**

A Dissertation

by

JOHN DAVID WANJURA

Submitted to the Office of Graduate Studies of  
Texas A&M University  
in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

Approved by:

Chair of Committee,	Calvin B. Parnell, Jr.
Committee Members,	Bryan W. Shaw
	Sergio C. Capareda
	Dennis L. O'Neal
Head of Department,	Gerald L. Riskowski

May 2008

Major Subject: Biological and Agricultural Engineering

## ABSTRACT

A Science Based Emission Factor for Particulate Matter Emitted from Cotton  
Harvesting. (May 2008)

John David Wanjura, B.S., Texas A&M University;

M.S. Texas A&M University

Chair of Advisory Committee: Dr. Calvin B. Parnell, Jr.

Poor regional air quality in some states across the US cotton belt has resulted in increased pressure on agricultural sources of particulate matter (PM) from air pollution regulators. Moreover, inaccurate emission factors used in the calculation of annual emissions inventories led to the identification of cotton harvesting as a significant source of PM<sub>10</sub> in California and Arizona. As a result, cotton growers in these states are now required to obtain air quality permits and submit management practice plans detailing the actions taken by the producer to reduce fugitive PM emissions from field operations. The objective of this work was to develop accurate PM emission factors for cotton harvesting in terms of total suspended particulate (TSP), PM<sub>10</sub>, and PM<sub>2.5</sub>.

Two protocols were developed and used to develop PM emission factors from cotton harvesting operations on three farms in Texas during 2006 and 2007. Protocol one utilized TSP concentrations measured downwind of harvesting operations with meteorological data measured onsite in a dispersion model to back-calculate TSP emission flux values. Flux values, determined with the regulatory dispersion models ISCST3 and AERMOD, were converted to emission factors and corrected with results from particle size distribution (PSD) analyses to report emission factors in terms of PM<sub>10</sub> and PM<sub>2.5</sub>. Emission factors were developed for two-row (John Deere 9910) and six-row (John Deere 9996) cotton pickers with protocol one. The uncertainty associated with the emission factors developed through protocol one resulted in no significant difference between the emission factors for the two machines.

Under the second protocol, emission concentrations were measured onboard the six-row cotton picker as the machine harvested cotton.  $PM_{10}$  and  $PM_{2.5}$  emission factors were developed from TSP emission concentration measurements converted to emission rates using the results of PSD analysis. The total TSP,  $PM_{10}$ , and  $PM_{2.5}$  emission factors resulting from the source measurement protocol are  $1.64 \pm 0.37$ ,  $0.55 \pm 0.12$ , and  $1.58E-03 \pm 4.5E-04$  kg/ha, respectively. These emission factors contain the lowest uncertainty and highest level of precision of any cotton harvesting PM emission factors ever developed. Thus, the emission factors developed through the source sampling protocol are recommended for regulatory use.

## ACKNOWLEDGEMENTS

This research effort has been very challenging, trying, and rewarding. The success of this work is in no way due to the sole efforts of one person, but through the extraordinary efforts of a wonderful group of people, this project has experienced great success. It is my intention to thank each and every person involved in this work from the bottom of my heart.

First I would like to thank God for his continuing graces and blessings in my life. I owe everything to Him for providing me the opportunity of life. I pray that my life may be lived by His will and as a gift back to Him.

To my wife, Karen, your love and encouragement through this journey has made the experience a joy for me. I love you and I thank God for you each and every day. I look forward to what the future holds for us.

To my family, thank you for your love, support, and encouragement. I would like to thank my mother and father for their love and guidance through out my life. Mom, your love and care continues to support me through everyday. Dad, you are a great role model and thank you for your wisdom and ability to help me put things in perspective.

To Vic, Amy, Eric, and Christine, thank you for your encouragement during my time at A&M. I look forward to working and living in Lubbock and to all of the time we will be able to spend together. There really is nothing like going home!

The extraordinary efforts of “Parnell’s Crew” have made the execution of this project not only possible, but a joy. Without you all we couldn’t have done this! One problem with spending ten years of your life in a place like Texas A&M is that you have a hard time remembering everyone who has helped you along your way. Nonetheless, I’ll give it a try. Brock, Bonz, Barry, Clay, Craig, Brad, Mike, Amber, Ling, Amy, Lee, Sergio, Ryan, “Tree”, Jackie, Shay, Jing, Mark, Nathaniel, Cale, Shane, Clint, Atila, “Stanley”, Toni, Scott, Lee, Stewart, Jen, Kaela, Mary, Froi, Joan, Yufeng, Sam, “Monkey Man” Shane Morgan, Josh, Kyle, Russ, Matt, Britt, Mark, Dustin, you guys

are great friends and I wish the best for all of you in the future. I can't thank you enough for your help.

To Dr. Parnell, thank you for your support and help throughout my experience at A&M. I am leaving A&M with that grin we spoke about. Your example of what an engineer, scientist, role model, mentor and friend has made an everlasting impression on me. Thank you for all of this!

I would like to thank my committee members, Drs. Parnell, Shaw, Capareda, and O'Neal, for their help and encouragement through this process. Thank you for giving me the chance to further develop my skills as an engineer through this Ph. D. program. Also, a big word of thanks is due to Dr. Lacey for having an open ear and the willingness to help me in this effort. Thank you also to the staff of the BAEN department for your help in this process.

I would also like to thank Mr. Tim Deutsch, Dr. Ed Barnes, and Dr. Bill Norman, from John Deere, Cotton Incorporated, and The Cotton Foundation, respectively, for providing the financial assistance needed to conduct this research. Further thanks are due to John Deere for providing the 9996 cotton picker used in the project. Thank you for your help and I look forward to working with you again in the future.

A special word of thanks goes to all of the people working on my behalf within USDA-ARS to give me the opportunity to pursue further education in agricultural engineering. I would especially like to thank Dr. Alan Brashears, Dr. Jeff Carroll, Dr. Michael Buser, Dr. Dan Upchurch, Wanda Robertson, and all of the folks at the Cotton Production and Processing Research Unit for helping to make this a success. Further thanks go to the Cotton Production and Processing Research Unit for allowing us the use of the 9910 model cotton picker over these past two years.

## TABLE OF CONTENTS

	Page
ABSTRACT .....	iii
ACKNOWLEDGEMENTS .....	v
TABLE OF CONTENTS .....	vii
LIST OF FIGURES.....	ix
LIST OF TABLES .....	xii
CHAPTER	
I INTRODUCTION.....	1
Objective .....	6
II FIELD SITE CHARACTERIZATION.....	8
Introduction .....	8
Sampling Site Descriptions .....	8
Sampling Site Characterization Methods .....	18
Results .....	21
III EMISSION FACTOR DEVELOPMENT PROTOCOL I: UPWIND/DOWNWIND SAMPLING WITH DISPERSION MODELING .....	26
Introduction .....	26
Particulate Matter Concentration Measurements .....	29
Dispersion Modeling.....	34
Results .....	52
IV EMISSION FACTOR DEVELOPMENT PROTOCOL II: SOURCE MEASUREMENT OF EMISSION CONCENTRATIONS.....	71
Introduction .....	71
Prototype Development and First Year Testing .....	72
Seed Cotton Separation System Design Modification and Evaluation .....	78
System Development and Evaluation Results.....	94
Source Measurement of Cotton Picker PM Emissions .....	107

CHAPTER	Page
V	PARTICLE SIZE DISTRIBUTION AND PARTICLE DENSITY ANALYSIS OF PARTICULATE MATTER SAMPLES ..... 119
	Introduction ..... 119
	Methods ..... 120
	Results ..... 122
VI	SUMMARY AND CONCLUSIONS ..... 142
	Future Work ..... 145
	REFERENCES ..... 146
APPENDIX A	SOIL SIEVING PROCEDURE ..... 152
APPENDIX B	METEOROLOGICAL DATA DEVELOPED FOR USE IN AERMOD FROM 3D SONIC ANEMOMETER MEASUREMENTS ..... 156
APPENDIX C	TSP AND PM10 CONCENTRATION MEASUREMENTS TAKEN DURING THE SAMPLING EVENTS DURING 2006 AND 2007 ..... 163
APPENDIX D	SYSTEMATIC UNCERTAINTY ANALYSIS FOR THE SOURCE SAMPLING SYSTEM ..... 186
APPENDIX E	ASH ANALYSIS RESULTS FOR PARTICULATE MATTER LESS THAN 100 MICROMETERS CAPTURED IN THE SOURCE SAMPLER CYCLONE BUCKET ..... 192
APPENDIX F	TEST SUMMARY SHEETS FOR THE SOURCE SAMPLING TESTS CONDUCTED DURING 2007 ..... 195
APPENDIX G	PARTICLE SIZE DISTRIBUTION RESULT STATISTICS FOR THE TSP SAMPLER FILTERS AND PM CAPTURED BY THE SOURCE SAMPLER ..... 206
VITA	..... 212



## LIST OF FIGURES

	Page
Figure 1 United States cotton yield between 1977 and 2007 .....	4
Figure 2 Layout of the test plots used in the testing at farm 1.....	9
Figure 3 Layout of the test plots used in the tests conducted on farm 2.....	11
Figure 4 Layout of test plots on farm 3 .....	13
Figure 5 Aerial image of farm 3 showing the test plot layout used in 2007....	16
Figure 6 Image of air washing system shown with seed cotton sample.....	19
Figure 7 Typical arrangement of collocated TSP/PM <sub>10</sub> samplers around the test plots.....	30
Figure 8 Modified sampler arrangement used during tests 1 – 5 at farm 2. ....	31
Figure 9 Schematic diagram of the separation system designed to separate the seed cotton from the air stream from duct 3 of the six-row harvester. ....	73
Figure 10 Detail drawing of separator box design 1 showing interior curved baffle (side view).....	74
Figure 11 Schematic drawing of separator box design 1 with general dimensions shown (isometric view).....	75
Figure 12 Photo of seed cotton separation system mounted in the testing frame configured with the seed cotton feeder and fan system .....	79
Figure 13 Schematic drawing of separator box design 2 illustrating the straight back wall design with the brush wheel moved to the rear of the separator box. ....	81
Figure 14 Detail drawing of separator box design 2 shown with interior baffle design 5 (side view) .....	82
Figure 15 Schematic drawing of separator box design 2 showing general dimensions (isometric view) .....	83
Figure 16 Schematic showing curved baffle dimensions for baffles 1, 2, 3, and 4 .....	85
Figure 17 Schematic showing straight baffle dimensions for baffles 5, 6, and 7 .....	85

	Page
Figure 18 Schematic diagram of air velocity probe locations across the exit duct (numbers inside the equal area squares represent probe locations) .....	87
Figure 19 Schematic diagram of concentration sampling locations in the exit duct (numbers represent sampling locations).....	89
Figure 20 Linear motion dust feeding system used to feed corn starch into the testing system at 12 g/min. ....	90
Figure 21 Photograph of the source sampling system mounted on the test frame.....	94
Figure 22 Seed cotton penetration test results for separation box design 1 tested with baffles 1, 2, and 3 at seed cotton feeding rates of 22.7, 45.4, and 68.1 kg/min.....	95
Figure 23 Seed cotton penetration test results for separation box design 2 tested with baffles 1 - 7 at seed cotton feeding rates of 22.7, 45.4, and 68.1 kg/min. ....	97
Figure 24 Normalized velocity measurements at nine coplanar points across the cross section of the exit duct .....	99
Figure 25 Comparison of the duct mean concentration to the center point concentration by test.....	102
Figure 26 Center point, mass weighted average, and input corn starch PSDs measured during test 4.....	106
Figure 27 Photograph of the six row harvester traveling down rows of cotton (average plant height 41 – 51 cm) with the row units and fan not engaged in order to measure the concentration of PM generated by the interaction of the harvester wheels and the soil surface (samplers located to the left of the harvester) .....	116
Figure 28 Percent volume vs. ESD particle diameter PSDs for the air wash PM <100 $\mu\text{m}$ (Air Wash Material), PM on the TSP sampler filter (Ambient TSP Sampler Filter), soil material < 75 $\mu\text{m}$ (Soil Material), source sampler cyclone bucket material <100 $\mu\text{m}$ (SS Cyclone Bucket Material), and PM on the source sampler filters (Source Sampler Filter) from test 7 on farm 1 during 2006.....	125

	Page
Figure 29 Percent volume vs. ESD particle diameter PSDs for the air wash PM <100 $\mu\text{m}$ (Air Wash Material), PM on the TSP sampler filter (Ambient TSP Sampler Filter), soil material < 75 $\mu\text{m}$ (Soil Material), source sampler cyclone bucket material <100 $\mu\text{m}$ (SS Cyclone Bucket Material), and PM on the source sampler filters (Source Sampler Filter) from test 7 on farm 2 during 2006.....	126
Figure 30 Percent volume vs. ESD particle diameter PSDs for the air wash PM <100 $\mu\text{m}$ (Air Wash Material), PM on the TSP sampler filter (Ambient TSP Sampler Filter), and soil material < 75 $\mu\text{m}$ (Soil Material) from test 1 on farm 3 during 2006.....	127
Figure 31 Average PSD results for the soil material <75 $\mu\text{m}$ from farm 1, 2, and 3 .....	128
Figure 32 Average PSD results of the air wash material from farm 1, 2, and 3 .....	129
Figure 33 Composite source sampler PSDs for the four source sampling tests conducted at farm 1 and farm 2.....	131
Figure 34 PSD of a downwind TSP sampler from test 20 at farm 3 during 2007 shown with the farm average lognormal PSD of the TSP sampler filters (MMD = 14.7, GSD = 2.23).....	135
Figure 35 Average PSD for the soil material < 75 $\mu\text{m}$ collected from farm 3 during 2007 .....	136
Figure 36 Average PSD of the core samples cut from the source sampler filters obtained during the tests conducted at farm 3 during 2007. ....	137
Figure 37 Average PSD of the PM < 100 $\mu\text{m}$ air washed from the source sampler cyclone bucket from the tests conducted on farm 3 during 2007. ....	139
Figure 38 Average PSDs for the source sampler filters, PM < 100 $\mu\text{m}$ captured in the source sampler cyclone bucket, and the mass weighted average composite PSD for the tests conducted on farm 3 during 2007 .....	140

## LIST OF TABLES

	Page
Table 1	Experimental design of the sampling tests conducted at farm 1 ..... 10
Table 2	Design of the experiments conducted at farm 2 ..... 12
Table 3	Order of the experiments conducted at farm 3 in 2006..... 14
Table 4	Order of experiments conducted on farm 3 during 2007. .... 17
Table 5	Moisture content analysis results of the hand harvested seed cotton samples taken during the tests at farms 1, 2, and 3 during 2006 and 2007. .... 22
Table 6	Sieve analysis results for soil samples collected from farms 1, 2, and 3 during 2006 and 2007. The values presented in the table represent the percent of the total material processed remaining within the size range..... 24
Table 7	Surface soil moisture content measurements from farm 3 during 2007 ..... 25
Table 8	Key to Solar Radiation Delta – T method for estimating day time Pasquill-Gifford stability categories (EPA, 2000) ..... 37
Table 9	Key to Solar Radiation Delta – T method for estimating night time Pasquill-Gifford stability categories (EPA, 2000) ..... 37
Table 10	Concentration measurement results and average sampler PM <sub>10</sub> /TSP concentration ratios from the sampling conducted at farm 1 during 2006..... 52
Table 11	Concentration measurement results and average sampler PM <sub>10</sub> /TSP concentration ratios from the sampling conducted at farm 2 during 2006..... 53
Table 12	Concentration measurement results and average sampler PM <sub>10</sub> /TSP concentration ratios from the sampling conducted at farm 3 during 2006..... 53
Table 13	Concentration measurement results and average sampler PM <sub>10</sub> /TSP concentration ratios from the sampling conducted at farm 3 during 2007..... 54

	Page
Table 14 Emission factor results from the dispersion modeling procedure using ISCST3 for farm 1 during 2006.....	56
Table 15 Emission factor results from the dispersion modeling procedure using ISCST3 for farm 2 during 2006.....	57
Table 16 Emission factor results from the dispersion modeling procedure using ISCST3 for farm 3 during 2006.....	58
Table 17 Emission factor results from the dispersion modeling procedure using ISCST3 for farm 3 during 2007.....	59
Table 18 Summary of ISCST3 emission factor results combining the data from farms 1, 2, and 3 (2006) and farm 3 (2007).....	60
Table 19 Emission factor results from the dispersion modeling procedure using AERMOD for farm 3 during 2007 .....	62
Table 20 Correlation analysis results using the emission factor results produced with ISCST3 .....	64
Table 21 Correlation analysis results using the emission factor results produced with AERMOD.....	65
Table 22 Description of the baffles tested in separator box designs 1 and 2 .....	84
Table 23 Mass of seed cotton penetrating (g) separator box design 1 with baffles 1, 2, and 3 (see Table 22) at three seed cotton feed rates.....	95
Table 24 Mass of seed cotton penetrating (g) separator box design 2 with baffles 1 - 7 (see Table 22) at three seed cotton feed rates. ....	97
Table 25 Mean normalized air velocity measurements (% of maximum duct velocity) from five replicated tests at three seed cotton feed rates ...	98
Table 26 Concentration data collected at five coplanar locations across the cross section of the exit duct of the seed cotton separation system .....	101
Table 27 Summary statistics for the ratio of the air velocity entering the sampling probe to the air velocity passing the probe calculated for five samplers during five concentration tests .....	104

	Page
Table 28 AED PSD analysis results of each isokinetic sampling location within the exit duct of the seed cotton separation system .....	106
Table 29 Source sampling system total deposition test results at 5 and 10 g/min nominal inlet dust feeding rate.....	107
Table 30 Six-row harvester emission concentration results for the 10 tests conducted with the source sampling system on farm 3 during 2007 .....	109
Table 31 Six-row harvester emission rates for ten tests conducted with the source sampling system on farm 3 during 2007.....	110
Table 32 Six-row harvester emission factors from ten tests performed with the source sampling system on farm 3 during 2007.....	111
Table 33 Correlation results of the source sampler emission rate data with area, yield, test duration, soil mass % < 75 $\mu$ m, soil mass % < 106 $\mu$ m, seed cotton moisture content, and soil surface moisture content .....	112
Table 34 Emission factors developed using measured TSP concentrations and ISCST3 for tests conducted to quantify the PM emissions generated by the interaction between the harvester wheels and the soil surface.....	118
Table 35 Average particle density measurements on soil material less than 75 $\mu$ m taken from farms 1, 2, and 3 during 2006 and 2007 .....	122
Table 36 Particle density analysis results for particulate matter less than 100 $\mu$ m air washed from seed cotton samples taken during 2006.....	123
Table 37 Particle density results of PM <100 $\mu$ m air washed from material captured in the bucket of the source sampler cyclone during 2007 ..	124
Table 38 MMD (ESD) and GSD of the best fit lognormal curves for the data shown in Figures 28, 29, and 30 .....	127
Table 39 MMD and GSD values for the best fit lognormal distributions for the average air wash PSDs from farm 1, 2, 3 .....	129
Table 40 MMD and GSD values for the best fit lognormal distributions for the composite source sampler PSDs. Also shown are the mass percentages of PM <sub>10</sub> and PM <sub>2.5</sub> of the best fit lognormal distributions and PSD data measured by the Coulter Counter .....	132
Table 41 PSD analysis results of the PM on the TSP filters from farms 1, 2, and 3 .....	133

	Page
Table 42 TSP sampler filter PSD analysis result statistics for samples taken on farm 3 during 2007. The particle density used to convert ESD to AED was 1.59 g/cm <sup>3</sup> .....	134
Table 43 Soil material < 75µm PSD result statistics from samples collected on farm 3 during 2007 .....	136
Table 44 PSD analysis result statistics for the source sampler filters collected during the tests conducted on farm 3 during 2007.....	138
Table 45 PSD results for the PM < 100 µm air washed from the material captured in the source sampler cyclone bucket from the tests conducted on farm 3 during 2007 .....	138
Table 46 Result statistics for the mass weighted average composite PSDs developed from the PSDs of the source sampler filters and PM < 100 µm captured in the source sampler cyclone bucket during 2007 .....	141

## CHAPTER I

### INTRODUCTION

Air pollution regulation across the US is implemented and enforced by state air pollution regulatory agencies (SAPRA). This authority is granted to the SAPRA by the federal EPA upon approval of the state implementation plan (SIP). The SIP outlines the steps that a state will take to ensure that the air quality within the state meets federal air quality standards (CFR, 1996). The National Ambient Air Quality Standards (NAAQS) are established for six criteria pollutants including  $\text{SO}_x$ ,  $\text{NO}_x$ , CO, ozone,  $\text{PM}_{10}$ , and  $\text{PM}_{2.5}$ . An area within a state may be classified as a non-attainment area if the ambient concentration of a criteria pollutant is shown to exceed the NAAQS by measurement or through dispersion modeling.

On September 21, 2006, EPA finished the five year cyclical review of the PM NAAQS and published “the most protective suite of national air quality standards for particle pollution ever” (EPA, 2006). Included in these revisions to the PM NAAQS were the removal of the annual  $\text{PM}_{10}$  standard of  $50 \mu\text{g}/\text{m}^3$  and the lowering of the 24 hour average  $\text{PM}_{2.5}$  standard from 65 to  $35 \mu\text{g}/\text{m}^3$ . The EPA based the decision to implement these NAAQS revisions on an in depth review of the most current and up-to-date scientific studies which investigated the health related impacts of PM pollution on certain sensitive populations.

The primary criteria pollutant of interest to the cotton industry is  $\text{PM}_{10}$ .  $\text{PM}_{10}$  refers to the fraction of particulate matter (PM) with aerodynamic equivalent diameter (AED) less than or equal to 10 micrometers ( $\mu\text{m}$ ). The 24-hour average NAAQS concentration limit for  $\text{PM}_{10}$  is  $150 \mu\text{g}/\text{m}^3$  (Federal Register, 2006).  $\text{PM}_{2.5}$  refers to particles (liquid or solid) that have an AED less than or equal to 2.5  $\mu\text{m}$ . The NAAQS limits the 24 hour average concentration of  $\text{PM}_{2.5}$  to  $35 \mu\text{g}/\text{m}^3$ . The annual average

---

This dissertation follows the format and style of *Transactions of the ASAE*.



NAAQS concentration limit for PM<sub>2.5</sub> is 15 µg/m<sup>3</sup> (Federal Register, 2006).

Historically, the PM<sub>2.5</sub> NAAQS has been of little concern to agricultural producers. Agricultural operations (including cotton production and processing) typically emit PM with larger particle sizes than urban sources (Wanjura, 2005) and which contain very few particles smaller than 2.5 µm

Cotton producers in some states across the cotton belt are facing increased regulatory pressure from SAPRAs due to poor regional air quality (PM<sub>10</sub> and PM<sub>2.5</sub> NAAQS non-attainment status). Further, cotton producers in California have been identified as a significant source of PM<sub>10</sub> due to the use of a flawed emission factor. As a result, agricultural producers are required to obtain operating permits from the SAPRA (CARB, 2003) and submit Conservation Management Practice (CMP) plans detailing the actions to be taken by the producer to reduce fugitive PM emissions (SJVAPCD, 2004 a and b). Further, the reduction of the PM<sub>2.5</sub> NAAQS accomplished during the five year review of the NAAQS by EPA in 2006 will present cotton producers with new air quality regulation challenges due to the lack of accurate emission factors.

Emission factors are estimates of the amount of a pollutant emitted by an operation per unit of production (i.e. lbs. PM<sub>10</sub> per acre of cotton harvested). Emission factors are used by air pollution regulators to determine annual emissions inventories and in dispersion models to predict downwind concentrations resulting from the pollutant emissions from a source.

A limited amount of research has been conducted to quantify the PM<sub>10</sub> emissions from cotton harvesting. A study conducted under contract with the USEPA by Snyder and Blackwood (1977) reported emissions of particulate matter less than 7 µm (mean aerodynamic diameter) on the order of 0.96 kg/km<sup>2</sup> (8.4\*10<sup>-3</sup> lbs/acre) for harvesting operations using cotton pickers. This emission factor represented the total emission factor from harvesting operations including emissions from the harvesting machine, trailer loading operations, and trailer transporting operations. It was reported by Snyder and Blackwood (1977) that particulate matter samplers followed the harvesting machine at a fixed distance within the plume to collect particulate matter concentrations. The

authors stated further that particulate matter concentrations downwind of trailer loading operations were taken by placing samplers at a fixed downwind distance. It is stated in AP-42 (EPA, 1995a) that the emission factors reported are based on the following assumptions:

1. The average speed of the picking machine was 1.34 m/s (3.0 mph),
2. The basket capacity of the picking machine was 109 kg (240 lbs),
3. The capacity of the transport trailers were 6 baskets each, and
4. The average cotton lint yield was 1.17 bales/acre for pickers.

The information given in AP-42 (EPA, 1995a) is based on antiquated harvesting technology and a flawed protocol. No detail was given as to how the researchers used measured concentrations to determine the emissions from the harvesting machine. The same was true for the method used to determine the emission rate from the trailer loading operation. Did the researchers use a dispersion model to back-calculate the emission rates from these operations, and if so, which one? Further, the emission factors reported are based on concentrations of particulate matter less than 7  $\mu\text{m}$  mean aerodynamic diameter. This size range of particulate matter represents only part of the regulated size fraction of dust in the US.  $\text{PM}_{10}$  concentrations include the mass of all particles less than 10  $\mu\text{m}$  in aerodynamic diameter.

The harvesting machinery used to develop the emission factors in AP-42 (EPA, 1995a) does not represent the technology that is used today. Today's machinery can harvest up to six rows of cotton per pass with basket capacities in the range of 4086 kg (9000 lbs) (basket volume: 40  $\text{m}^3$  or 1400  $\text{ft}^3$ ). Clearly, the machines used to harvest the US cotton crop today are significantly different from the machines used in the 1970's, when the Snyder and Blackwood study was conducted.

Farming practices have also changed resulting in increased yields and field efficiencies since the 1970's. In particular, US cotton production has increased from approximately 10 million bales to around 20 million bales over the last 30 years while the total production area has remained the same (USDA, 2007). The increase in yield is due primarily to improved plant varieties producing higher yields and farming practices

that optimize the use of input resources to produce maximum yields. Average annual yields (Figure 1) have increased from around 2.47 bales/ha to around 4.45 bales/ha in 2007 (USDA, 2007).

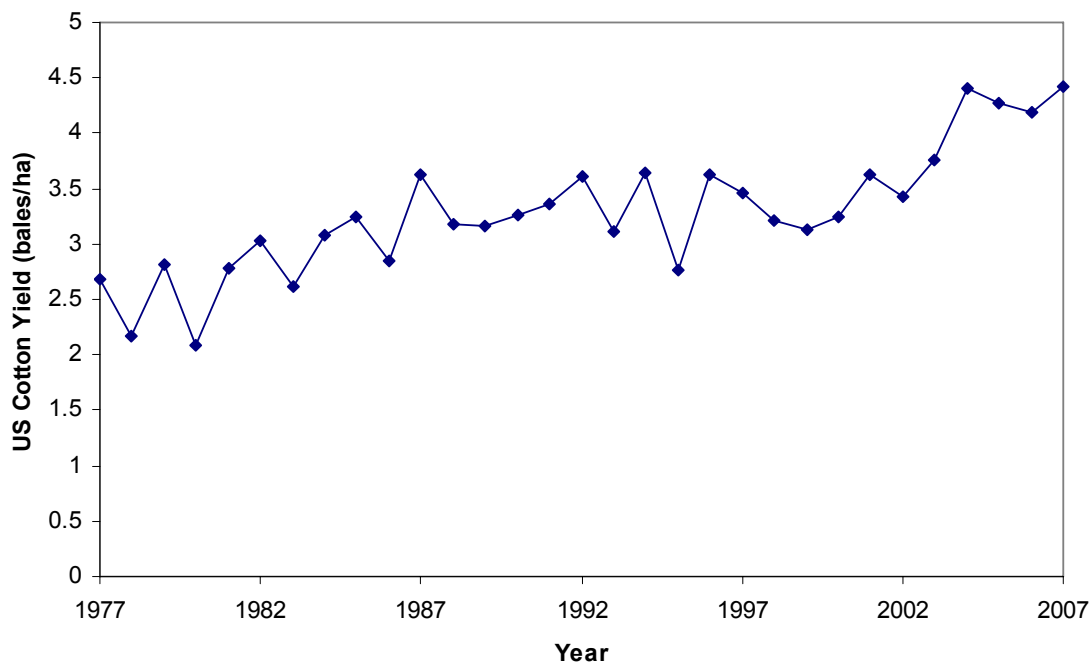


Figure 1. United States cotton yield between 1977 and 2007.

In an effort to quantify the  $PM_{10}$  emissions from modern cotton harvesting operations, Flocchini et al. (2001) conducted a study to measure the emissions from cotton harvesting operations using two to five row equipment. The results of the study by Flocchini et al. (2001) indicate that the  $PM_{10}$  emissions from cotton picking machines in the San Joaquin valley of California are on the order of 1.9 kg/ha (1.7 lbs/acre). The protocol used by Flocchini et al. (2001) is summarized as follows:

1. Ambient  $PM_{10}$  samplers (Sierra Anderson Model 246b) were used to measure  $PM_{10}$  concentrations both upwind and downwind of the harvesting operation.

2. The vertical concentration profile of the dust plume downwind of the operation was quantified using a series of three mobile towers with PM<sub>10</sub> samplers and anemometers mounted at several heights.
3. A LIDAR instrument was also used to help describe the shape of the plume downwind of the harvesting operation. The results of the LIDAR instrument give insight as to the shape of the plume as it travels downwind, but it does not give any reliable indication of the concentration or size of the particulate matter within the plume.
4. A mass balance box model was used with the concentration data to determine the area source emission rate from the operation. Several different methods to describe the shape of the plume were used within the box model to assess the influence of the plume shape on the estimated emission factors.

The work by Flocchini et al. (2001) represents the most up-to-date information regarding PM<sub>10</sub> emissions from cotton harvesting operations. However, the sampling protocol used by Flocchini et al. (2001) contained several components that introduced significant levels of uncertainty, including:

1. The federal reference method PM<sub>10</sub> samplers have been shown to exhibit substantial over-sampling errors when sampling agricultural dusts. Buser et al. (2001) indicated that the Federal Reference Method (FRM) PM<sub>10</sub> sampler could theoretically overstate PM<sub>10</sub> concentrations by as much as 340% when sampling a dust with mass median diameter (MMD) and geometric standard deviation (GSD) of 20µm and 2.0, respectively. The over-sampling errors reported by Buser et al. (2001) have been observed in field work conducted by several sources including Wanjura et al. (2005a) and Capareda et al. (2005).
2. The box model used to estimate the area source emission rate from the harvesting operation relies on several assumptions pertaining to the height of the plume and depth of the emitting area. In addition, the emission rates

determined using the box model are specific to the box model and may not be appropriate to use with another dispersion model. In other words, an emission rate developed with the box model and subsequently used in the box model will return the same measured concentrations initially used to develop the emission rate. However, if the same emission rate is used in another dispersion model, such as those utilized by SAPRAs, it is likely that the model will not return the measured concentration values. This is important from a regulatory standpoint.

For agricultural sources to be equitably regulated, accurate emissions inventories must be calculated by air pollution regulators using accurate, science-based emission factors. Along with facilitating the equitable regulation of agricultural sources, accurate emissions inventories will help regulators and agricultural producers focus their emissions reduction efforts on the operations or processes that produce the highest level of emissions.

## **OBJECTIVE**

The main objective of this work was to develop accurate emission factors for PM emissions originating from modern cotton harvesting operations in terms of PM<sub>10</sub>, PM<sub>2.5</sub>, and TSP. The PM emission factors currently available for use by air pollution regulators were developed using antiquated harvesting machinery with respect to throughput capacity and machine size. Two protocols were used to develop PM emission factors from cotton harvesting operations using machines of two different harvesting capacities. Emission factors for a two-row John Deere model 9910 and six-row John Deere model 9996 were developed with a protocol employing two dispersion models to back calculate emission flux values from downwind concentrations and meteorological data measured onsite. The dispersion models used are Industrial Source Complex Short Term version 3 (ISCST3) and American Meteorological Society/Environmental Protection Agency Regulatory Model (AERMOD). The second protocol employed a novel source sampling system designed for use onboard the six-row machine. Source sampling of field

operations to develop emission factors has not been performed due to the difficulty encountered in collecting representative emissions data from agricultural machinery operating under field conditions. It was anticipated that the emission factors developed using the source sampling protocol would be the most accurate ever developed. The emission factors developed under the source sampling protocol allowed for in depth analysis of the relationship between PM emission rates and crop yield and land area. Particle size distribution (PSD) analyses were conducted on the PM collected under both protocols and used to determine  $PM_{10}$  and  $PM_{2.5}$  emission factors from TSP measurements.

## **CHAPTER II**

### **FIELD SITE CHARACTERIZATION**

#### **INTRODUCTION**

Field work was conducted at three locations during 2006 and one location during 2007. Three sites were selected for use during the 2006 season to ensure that sufficient data were collected and that any necessary modifications to the measurement protocols could be properly evaluated. Such modifications included changes in experimental design, sampler placement, and test plot size/configuration. A total of twenty three tests were conducted during 2006 while twenty one were conducted during 2007. The available area used for testing on farm 3 was increased significantly between 2006 and 2007 allowing for all of the tests conducted in 2007 to be performed at farm 3.

In addition to the PM concentration measurements taken at each location, additional samples were taken to quantify 1) the moisture content of the seed cotton during harvest, 2) the soil moisture content during harvest (2007 only), 3) the mass fraction of soil less than 75 and 104  $\mu\text{m}$ , and 4) the particle density and PSD of the PM contained in the harvested seed cotton. While the primary focus of the work at each farm was to collect PM concentration data for emission factor development, these additional data were taken to help characterize the source of the PM emissions as well as investigate the relationships between source characteristics and the magnitude of PM emissions. The protocols used and the results from these analyses are discussed here and used in further analyses in later sections. All statistical analyses were conducted using the General Linear Model in SPSS (SPSS 12.0.1, SPSS Inc., Chicago, IL) with  $\alpha = 0.05$  unless specified otherwise.

#### **SAMPLING SITE DESCRIPTIONS**

Farm 1 is located approximately 8 km south of El Campo, TX. The dark, clay soil was fairly wet at the beginning of the four day sampling event but dried out by the end. The 28.3 ha (70 ac) rectangular field was planted with a 96.5 cm (38 in) row

spacing oriented in a north – south pattern. The field was divided into two sections (16.2 ha to the south and 12.1 ha to the north) by a house and grazing area (see Figure 2). The southern section of the field was subdivided into eight 1.6 ha (4 acre approximate size) test plots (450 m row length). The northern section was subdivided into four 2.4 ha (6 acre approximate size) test plots (245 m row length). A conventional picker variety of cotton was grown and the crop was defoliated with one application of Ginstar® (Bayer Crop Science, Research Triangle Park, NC).

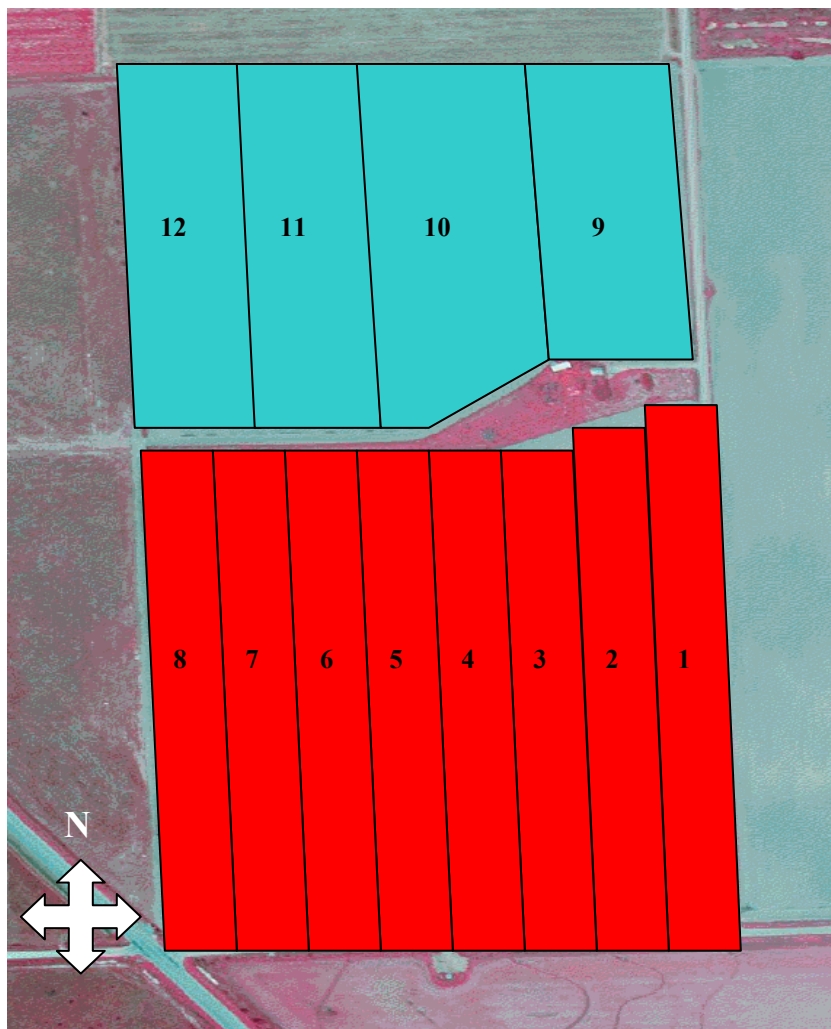


Figure 2. Layout of the test plots used in the testing at farm 1.



Three treatments were tested in a randomized complete block design (blocked by day/replication). The three treatments included 1) upwind/downwind sampling of the PM emissions from the two-row harvester (“2 row”), 2) upwind/downwind sampling of the PM emissions from the six-row harvester without the source sampling system (“6 row”), and 3) source sampling in conjunction with upwind/downwind sampling of the six-row harvester emissions (“6 row w/SS”). The experimental design for the tests conducted at farm 1 is shown in Table 1.

Ten of the original twelve planned sampling tests were conducted at farm 1 due to unexpected delays caused by equipment failures and the labor intensive nature of the sampling work. Approximately 6 man hours of labor were required to install and remove the source sampling system between tests. Moving and resetting the collocated TSP and PM<sub>10</sub> samplers between tests required approximately three to four man hours. Ten to fourteen hour working days became common place over the duration of the sampling work conducted at farm 1.

All of the planned tests on days one and two were not carried out due to equipment failures and the labor intensive nature of the sampling work. Thus, analysis of the data collected at farm 1 according to the randomized complete block design became problematic due to the incomplete blocks from days one and two. The emission factor data were analyzed for differences between treatment means using analysis of variance in SPSS.

Table 1. Experimental design of the sampling tests conducted at farm 1.

<b>Test Order</b>	<b>Day 1</b>	<b>Day 2</b>	<b>Day 3</b>	<b>Day 4</b>
1	2 Row	6 row w/SS	2 Row	6 Row
2	6 Row	6 Row	6 Row	2 Row
3			6 row w/SS	6 row w/SS

Farm 2 is located approximately 21 km south-southwest of College Station, TX. The soils varied across the farm from clay to sandy clay loam. The soil was dry during the four day sampling event. The rectangular 32.4 ha (80 ac) field is oriented in a northeast-southwest manner with rows oriented northwest-southeast (96.5 cm row spacing). The field was subdivided into nine 1.9 ha (4.7 ac) test plots, each with 366 m row length (figure 3). DP555 BG/RR (Delta and Pine Land Company, Scott, MS) was grown on farm 2 and Def® and Prep® (Bayer Crop Science, Research Triangle Park, NC) were used to defoliate the crop and open the bolls.



Figure 3. Layout of the test plots used in the tests conducted on farm 2.

Nine total tests were planned for farm 2. Equipment malfunctions and the labor intensive nature of the work again caused a reduction in the number of tests conducted to eight. The experimental design was modified from that used at farm 1 to a randomized complete block design with blocks on location within the field. This change in the experimental design was made to account for differences in soil type within the field and to reduce the labor involved with installing and removing the source sampling equipment between tests. The test plots were ordered sequentially from northeast to southwest and three groups of adjacent test plots were formed (area 1 = plots 1-3, area 2 = plots 4-6, area 3 = plots 7-9). The treatments were randomly assigned to one plot within each area of the field and all of the plots for one treatment were harvested before proceeding to the next treatment. The design of the experiments conducted at farm 2 is shown in Table 2.

The experimental design to block by location within the field was modified due to equipment failures and the labor intensive nature of the work. Again, the emission factor results from farm 2 were analyzed for differences by treatment mean in SPSS.

Table 2. Design of the experiments conducted at farm 2.

<b>Test No.</b>	<b>Treatment</b>	<b>Plot No.</b>	<b>Area No. (Experimental Block)</b>	<b>Day of Test</b>
1	6 Row	1	1	1
2	6 Row	5	2	1
3	6 Row	7	3	2
4	2 Row	2	1	2
5	2 Row	4	2	2
6	2 Row	8	3	3
7	6 Row w/SS	3	1	3
8	6 Row w/SS	6	2	3

Farm 3 is located approximately 12.5 km southwest of College Station, TX. The northeastern edge of the field is bordered by the Brazos River. The soil varies across the field from clay to sand and remained dry during the 2006 sampling event. The rows were spaced 101.6 cm (40 in) apart and oriented northeast to southwest. In 2006, the 13.8 ha (35 ac) field was subdivided into six test plots with areas ranging from 2 to 2.6 ha (4.9 to 6.9 ac) (see Figure 4). The row lengths of the test plots ranged from 184 to 300 m. FM988 LL/B2 was grown and defoliated with one treatment of Ginstar® and Dropp® (Bayer Crop Science, Research Triangle Park, NC).



Figure 4. Layout of test plots on farm 3.

Since only six test plots were available for use on farm 3 during 2006, the decision was made to reduce the number of treatments tested to two. Source sampling of

the six-row harvester was not conducted at farm 3 during 2006. The experiments were designed as a randomized complete block design with a block on replication (similar to that used at farm 1). The soil texture varied consistently across the field from well drained sand (plot 1) to a clay soil (plot 6). Thus the plots were harvested in sequential order (2 plots per day) with the order of the treatments randomized. A problem in the right side picking unit on the two-row machine caused a fire during test 3. Only 84 of 108 rows were harvested during test 3 prior to the fire and the others were not harvested that day to avoid the further risk of fire. Due to the fire, the test on plot four was not conducted. Thus, five of six tests were conducted at farm 3 during 2006. The emission factor data were analyzed for differences by treatment means in SPSS. The design of the experiments conducted at farm 3 is shown in Table 3.

Table 3. Order of the experiments conducted at farm 3 in 2006.

<b>Test No.</b>	<b>Treatment</b>	<b>Day</b>
1	2 Row	1
2	6 Row	1
3*	2 Row	2
4	6 Row	3
5	2 Row	3

\*Fire during test

The area available for testing on farm 3 in 2007 was more than double the area available during 2006. Approximately 36 ha (90 ac) were planted to DP 455 BG/RR (Delta and Pine Land Company, Scott, MS) and defoliated with one application of Prep® and Ginstar® (Bayer Crop Science, Research Triangle Park, NC). The field was planted with the same orientation and spacing as the 2006 crop. Twenty one test plots were setup on farm 3 during 2007 as shown in Figure 5 and all three machine configuration treatments were tested. To accommodate the research needs of other scientists, the field was harvested in two phases. In phase one the 6-Row and 6-Row w/SS treatments were randomly assigned to plots 1 – 15 and each of the plots assigned to one treatment were harvested in sequential order before moving to the next treatment. Weather conditions (rain) delayed the tests conducted with the two-row machine (phase 2) by approximately one week from the end of the five day sampling event with the six-row machine. The two-row harvester tests were conducted in sequential order by plot number on plots 16 – 21 over a three day period. The order of the experiments conducted on farm 3 during 2007 is shown in Table 4. Heavy rainfall during the growing season and limited applications of plant growth regulator resulted in extremely tall and rank crop conditions at harvest. Thus more plant and organic material was processed through the picking units during the harvest tests conducted on farm 3 during 2007.

The emission factor data collected from farm 3 during 2007 were analyzed for treatment means in SPSS using ANOVA.





Figure 5. Aerial image of farm 3 showing the test plot layout used in 2007.

Table 4. Order of experiments conducted on farm 3 during 2007.

<b>Test</b>	<b>Treatment</b>	<b>Plot</b>	<b>Day</b>
1	6 Row	1	1
2	6 Row	4	2
3	6 Row	8	2
4	6 Row	9	2
5	6 Row	15	2
6	6 Row w/SS	2	3
7	6 Row w/SS	3	3
8	6 Row w/SS	5	4
9	6 Row w/SS	6	4
10	6 Row w/SS	7	4
11	6 Row w/SS	10	4
12	6 Row w/SS	11	4
13	6 Row w/SS	12	5
14	6 Row w/SS	13	5
15	6 Row w/SS	14	5
16	2 Row	16	6
17	2 Row	17	7
18	2 Row	18	7
19	2 Row	19	8
20	2 Row	20	8
21	2 Row	21	8



## **SAMPLING SITE CHARACTERIZATION METHODS**

### ***Seed Cotton Moisture Content Analysis***

Seed cotton samples were hand harvested from each plot during each test conducted in 2006 and 2007. The 100 g samples (approximate mass) were collected from the plants and placed immediately in an air tight container for shipment back to the laboratory for analysis. Each sample was analyzed to determine the moisture content at harvest using the 10 hour oven method described by USDA (1972). The samples were pre- and post-weighed on an analytical laboratory balance with 0.01 g resolution (PB1502, Mettler-Toledo, Greifensee Switzerland). Accounting for the mass of the sample container, the moisture content of each sample was determined by dividing the net change in seed cotton mass by the initial mass of the seed cotton sample.

### ***Seed Cotton Air Wash Analysis***

Samples of harvested seed cotton were collected from the basket of the harvester during each test in 2006 and 2007. Approximately 3 – 5 kg samples were collected and placed in plastic bags for storage. The samples were collected for use in later air wash analysis to provide PM samples for particle density analyses. Typically, the mass of PM material collected on the filters used in the ground level TSP and PM<sub>10</sub> samplers is not sufficient to allow for particle density analysis. Approximately 1 g of material is needed to perform an accurate particle density analysis on a sample of dust. The procedures used to perform particle density analysis will be discussed in a later section.

The air washing process essentially removes PM from a sample of seed cotton by pulling airflow through a sample container rotating inside a sealed enclosure. The rotation of the sample container helps to separate the PM from the sample before it passes through the mesh covering on the sample container and finally onto a collection filter. The air washing machine used is shown in Figure 6. During each run with the air wash machine, approximately 400 g of seed cotton was loaded into the inner sample container and rotated at approximately 60 rpm. The side length dimension of the cubic sample container is 0.304 m (1 ft) and each side was covered with 100  $\mu$ m (nominal

opening size) mesh. Approximately  $1.1 \text{ m}^3/\text{m}$  ( $40 \text{ ft}^3/\text{min}$ ) was pulled through the rotating sample container during the 20 m processing period. The PM passing through the  $100 \text{ }\mu\text{m}$  mesh was collected on a 20.3 by 25.4 cm borosilicate glass microfiber filter (Pall Corp., Pallflex Emfab filter material, East Hills, NY). The filters used in the air washing procedure were pre and post weighed using a high precision analytical balance (AG245, Mettler-Toledo, Greifensee Switzerland). One filter was used for each sample and the PM was allowed to buildup to the point where it could be removed by lightly tapping the back of the filter after post-weighing.



Figure 6. Image of air washing system shown with seed cotton sample.

The air washing process was used on the seed cotton samples collected in 2006 to provide material samples for particle density analysis. The resulting particle density measurements were used to convert the PSD analysis results of the ground level TSP sampler filters from an equivalent spherical diameter (ESD) basis to an aerodynamic equivalent diameter (AED) basis. During 2007, the particle density samples used to convert the PSD analysis results of the ground level TSP sampler filters from an ESD basis to an AED basis were obtained by air washing the material captured in the source sampler cyclone bucket.

### ***Soil Sampling***

Soil samples were collected from each test plot during 2006 and 2007. The samples collected during 2006 were collected at the time the harvesting tests were conducted and each sample consisted of approximately four to six 200 g sub-samples collected from random points within each plot. During 2007, 31 samples were taken across the 36 ha (90 ac) field in an evenly spaced grid pattern with approximately one sampling point per ha. The 2007 samples were collected several weeks before harvest to allow for ample processing time at the lab.

The soil samples collected in 2006 and 2007 were sieved to determine the mass percent of soil less than 106  $\mu\text{m}$  (#75 sieve) and less than 75  $\mu\text{m}$  (#200 sieve). These mass fractions were used for later correlation analysis with emission factor data to investigate relationships by soil texture.

Each soil sample was processed through two sets of sieves for 20 min per set. The designation of the sieves used are; set 1: 22.4 mm (7/8 in), 16 mm (5/8 in), 9.5 mm (3/8 in), 8 mm (5/16 in), 2 mm (#10); and set 2: 1.4 mm (#14), 710  $\mu\text{m}$  (#25), 180  $\mu\text{m}$  (#80), 106  $\mu\text{m}$  (#140), and 75  $\mu\text{m}$  (#200). The sieves were arranged in decreasing opening size from top to bottom. The net material mass remaining in each sieve was used to determine the mass percent of the original soil sample mass within each size range. The procedure used to sieve the soil samples is described in greater detail in Appendix A.

### ***Soil Moisture Content Measurements***

Surface soil moisture content measurements (top 10 cm) were conducted on farm 3 during the 2007 sampling events. Ten sampling sites were randomly located within each test plot and the measurements were taken during the time of each test. Volumetric soil moisture content measurements were taken using a hand held moisture meter (HH2, Delta-T Devices, Cambridge England) with integrated soil probe (Theta Probe type ML2x, Delta-T Devices, Cambridge England). Volumetric soil moisture content is equivalent to the volume of water present in the sample divided by the total volume of the sample (soil + water) expressed as a percentage. The average soil moisture content readings from each test were used in later correlation analysis with emission factor data.

## **RESULTS**

### ***Seed Cotton Moisture Content Analysis***

The moisture content analysis results of the hand harvested seed cotton samples taken during the tests conducted at farms 1, 2, and 3 in 2006 and 2007 are shown in Table 5. Combining the data for both years, means by farm and harvesting treatment were compared using analysis of variance (ANOVA) with Fisher's Least Significant Difference (LSD) post hoc procedure (due to unequal sample sizes) with  $\alpha = 0.05$ .

The results of the analysis indicate that there was no significant difference between the seed cotton moisture content values by harvester treatment (p value = 0.467). However, significant differences were observed between the farm average moisture content values (p value = 0.001). The mean seed cotton moisture content values for farm 1 and farm 3 (2007) were significantly higher than the means for farm 2 and farm 3 (2006) as indicated in Table 5. This result is likely a consequence of the high relative humidity encountered during the sampling events at farm 1 and also due to the rank condition of the cotton at farm 3 during 2007.

Table 5. Moisture content analysis results of the hand harvested seed cotton samples taken during the tests at farms 1, 2, and 3 during 2006 and 2007.

<b>Seed Cotton Moisture Content (%)</b>				
<b>Test No.</b>	<b>Farm 1 (2006)</b>	<b>Farm 2 (2006)</b>	<b>Farm 3 (2006)</b>	<b>Farm 3 (2007)</b>
1	8.11	5.51	4.97	10.08
2	10.59	5.07	4.6	17.40
3	8.71	6.03	6.04	8.64
4	10.28	n/a	8.72	7.79
5	8.08	n/a	6.53	7.97
6	7.58	5.57		7.77
7	8.3	5.15		6.88
8	9.47	5.68		8.45
9	8.15			7.03
10	14.59			6.99
11				7.64
12				8.30
13				8.22
14				8.20
15				8.16
16				7.50
17				9.84
18				7.46
19				9.87
20				7.54
21				7.51
<b>Means</b>	<b>9.39<sup>a</sup></b>	<b>5.50<sup>b</sup></b>	<b>6.17<sup>b</sup></b>	<b>8.53<sup>a</sup></b>

\*Means with the same letter are not significantly different at the 0.05 level of significance.

### ***Soil Sampling***

The results of the sieve analysis on the soil samples collected during 2006 and 2007 from farms 1, 2, and 3 are shown in Table 6. An ANOVA indicated significant differences in the farm means for both particle size ranges (p values < 0.001). The results indicate that the soils from farm 1 and farm 3 (2006) are not significantly different at the 0.05 level of significance when comparing the means of the 106 to 75  $\mu\text{m}$  (p value = 0.666) and <75 $\mu\text{m}$  (p value = 0.907) size ranges (Fisher's LSD post hoc procedure). However, the means of the same size ranges for the soil samples taken from farm 2 and farm 3 (2007) are significantly different from each other and from those of

farm 1 and 3 (2006) at the 0.05 level of significance. Further analysis indicates that significant differences exist between the harvesting treatment means within the 106 to 75  $\mu\text{m}$  (p value = 0.666) and  $<75\mu\text{m}$  (p value = 0.907) size ranges (Fisher's LSD post hoc procedure).

### ***Soil Moisture Content Measurements***

Soil moisture content measurements were conducted during 2007 at farm 3 to investigate potential trends of increasing PM emissions with decreasing surface soil moisture content. An ANOVA on the soil moisture content data indicates that significant differences did exist between the mean soil moisture content values of the plots by harvesting treatment (p value = 0.009). LSD post hoc tests indicate that the mean plot soil moisture content for the 6-row and 2-row harvesting treatments were not significantly different (p value = 0.764). However, there was a significant difference in the mean soil moisture content between the 6-row w/SS and 6-row treatments (p value = 0.025) and between the 6-row w/SS and 2-row treatments (p value = 0.005). These results were expected as the 6-row w/SS tests were conducted one day after the 6-row harvesting treatment tests. A rain event occurred the same day that the 6-row w/SS tests were finished and the 2-row tests were not conducted for approximately one week to allow for sufficient drying time. The results of the surface soil content measurements are presented in Table 7.

Table 6. Sieve analysis results for soil samples collected from farms 1, 2, and 3 during 2006 and 2007. The values presented in the table represent the percent of the total material processed remaining within the size range.

Test No.	Farm 1 (2006)		Farm 2 (2006)		Farm 3 (2006)		Farm 3 (2007)	
	#200 Sieve 106 $\mu$ m > %	< #200 Sieve % <75 $\mu$ m	#200 Sieve 106 $\mu$ m > %	< #200 Sieve % <75 $\mu$ m	#200 Sieve 106 $\mu$ m > % > 75 $\mu$ m	< #200 Sieve % <75 $\mu$ m	#200 Sieve 106 $\mu$ m > % > 75 $\mu$ m	< #200 Sieve % <75 $\mu$ m
	> 75 $\mu$ m	% <75 $\mu$ m	> 75 $\mu$ m	% <75 $\mu$ m	75 $\mu$ m	% <75 $\mu$ m	75 $\mu$ m	% <75 $\mu$ m
1	10.9	20.2	1.3	5.1	11.4	31.1	0.98	7.2
2	11.0	21.0	1.5	2.4	16.2	28.2	2.17	9.1
3	6.0	12.7	0.7	1.3	2.2	8.6	2.13	7.0
4	9.1	18.3	n/a	n/a	6.0	23.0	1.51	4.5
5	10.7	26.2	n/a	n/a	3.3	12.0	4.42	34.5
6	5.9	16.1	0.9	1.5			0.98	7.2
7	7.6	19.7	0.6	1.5			1.29	6.5
8	7.0	21.8	0.6	1.3			3.20	9.7
9	7.9	22.5					3.20	9.7
10	8.0	23.3					2.13	7.0
11							1.51	4.5
12							1.08	4.8
13							1.08	4.8
14							4.53	9.1
15							4.53	9.1
16							6.73	16.7
17							7.77	16.9
18							13.41	27.0
19							12.75	22.4
20							8.47	27.6
21							8.47	27.6
<b>Mean*</b>	<b>8.4<sup>a</sup></b>	<b>20.2<sup>d</sup></b>	<b>0.9<sup>b</sup></b>	<b>2.2<sup>e</sup></b>	<b>7.8<sup>a</sup></b>	<b>20.6<sup>d</sup></b>	<b>4.4<sup>c</sup></b>	<b>13<sup>f</sup></b>

\*Means with the same letter are not significantly different at the 0.05 level of significance using the LSD post hoc procedure.

Table 7. Surface soil moisture content measurements from farm 3 during 2007.

Test No.	Treatment	Soil Moisture Content (%)	Std. Dev. (%)
1	6 Row	14.9	6.68
2	6 Row	17.5	4.99
3	6 Row	20.3	3.52
4	6 Row	22.3	5.48
5	6 Row	n/a	n/a
	<b>Mean*</b>	<b>18.7<sup>a</sup></b>	
6	6 Row w/SS	16.3	5.37
7	6 Row w/SS	16.8	3.78
8	6 Row w/SS	14.1	4.41
9	6 Row w/SS	14.1	1.94
10	6 Row w/SS	14.2	2.84
11	6 Row w/SS	16.3	3.83
12	6 Row w/SS	16.5	2.65
13	6 Row w/SS	16.6	3.76
14	6 Row w/SS	16.9	2.56
15	6 Row w/SS	16.2	3.51
	<b>Mean*</b>	<b>15.8<sup>b</sup></b>	
16	2 Row	23.2	4.28
17	2 Row	18.7	3.01
18	2 Row	17.2	3.12
19	2 Row	17.3	2.18
20	2 Row	20.1	4.21
21	2 Row	18.4	4.38
	<b>Mean*</b>	<b>19.1<sup>a</sup></b>	

\*Means with the same letter are not significantly different at the 0.05 level of significance (Fisher's LSD test).



### CHAPTER III

#### EMISSION FACTOR DEVELOPMENT PROTOCOL I: UPWIND/DOWNWIND SAMPLING WITH DISPERSION MODELING

#### INTRODUCTION

Emission factors for most stationary sources can be developed through source measurement techniques. Often times these source measurements are conducted using EPA approved sampling devices and methods such as the EPA method 5, EPA method 201a, or CTM-039 stack samplers for measuring TSP, PM<sub>10</sub>, or PM<sub>2.5</sub> emission concentrations, respectively (CFR, 2007). The resulting emission concentrations can be converted to emission rates by multiplying by the gas flow rate in the exhaust stream and finally to emission factors by normalizing the emission rates to a production unit basis. However, agricultural operations such as feedlots, dairies, and many field operations are not stationary sources with common points of pollutant emission which can be easily measured on a source basis. Emission factors for these fugitive sources have been developed through back-calculating emission fluxes with a dispersion model and simultaneously collected concentration and meteorological data (Goodrich, 2006; Parnell, 1994; Wanjura et. al. 2004).

The EPA recommended dispersion model for regulatory use was ISCST3 until 2006 when EPA began promoting the use of AERMOD (Federal Register, 2005). According to EPA (Federal Register, 2005), all state air pollution regulatory agencies had a one year transition period during 2007 in which to make the switch from ISCST3 to AERMOD. The EPA regulatory platform for near-field modeling has remained fundamentally unchanged over the last 25 years with ISCST3 selected as the workhorse model for regulatory use (EPA, 2004).

*“The objective of the AMS/EPA Regulatory Model Improvement Committee (AERMIC) was to develop a replacement for the ISC3 model by: 1) adopting ISCST3’s input/output computer architecture, 2) updating, where practical, antiquated ISC3 model algorithms with newly developed or current state-of-the-art modeling techniques, and 3) insuring that the source and atmospheric*

*processes presently modeled by ISC3 will continue to be handled by the AERMIC Model (AERMOD), albeit in an improved manner”.* (EPA, 2004)

Dispersion models are used in the air pollution regulatory process to predict downwind concentrations from a source with a given emission factor and meteorological data. These concentration results are used in the preparation of State Implementation Plans (SIP), new source permits, risk assessments and exposure analysis for toxic air pollutants (EPA, 2004). Thus, appropriate emission factors must be used in the modeling process to estimate downwind concentration impacts of a source so to not preclude the equitable regulation of the source. Moreover, an emission factor appropriate for ISCST3 may not be appropriate for use in AERMOD. Powell et al. (2006) showed that fugitive emissions from an area source may be over-estimated by AERMOD compared to ISCST3 when using the same emission factor and meteorological conditions.

The methods presented in this protocol employ both ISCST3 and AERMOD to produce emission factor estimates from the ground level concentration and meteorological data collected during the 2006 and 2007 sampling events. The following general steps are used to develop an emission factor according to this protocol:

1. Meteorological data measured onsite during each test is processed into the proper formats required by the dispersion model and input to the model-user interface program. The model-user interfaces used for ISCST3 and AERMOD were BREEZE ISC GIS Pro (BREEZE ISC GIS Pro v. 5.2.1, Trinity Consultants, Dallas, TX) and BREEZE AERMOD 6 (BREEZE AERMOD v. 6.1.37, Trinity Consultants, Dallas, TX), respectively.
2. The user defines model setup parameters such as the size and orientation of the area source, the emission release height, and receptor locations and heights in the user-interface program. An area source release height of 4 m and receptor heights of 2 m were used to model the harvesting operations with flat terrain conditions. At this point the user also specifies an initial source emission flux ( $Q_1$ ). The initial emission flux used in this work was 0.002569

g/m<sup>2</sup>-s. This value is equivalent to the PM<sub>10</sub> emission factor used in California of 1.9 kg/ha (1.7 lb/ac) under the following assumptions: 1) 101.6 cm (40 in) row spacing, 2) 6.4 km/hr (4 mph) harvester speed, 3) harvester width of six rows, and 4) the mass fraction of TSP that is PM<sub>10</sub> is 20%.

3. The user then runs the model to produce a set of model predicted concentrations ( $C_1$ ) at each receptor location.
4. The Gaussian dispersion equation defines the relationship between downwind concentration and source emission rate (flux) to be directly proportional such that an increase in emission flux will produce a proportional increase in estimated concentration. Thus, the initial area source flux ( $Q_1$ ), initial model predicted concentration, and measured concentration ( $C_2$ ) for a particular receptor location are used in equation 1 to determine the area source flux ( $Q_2$ ) required by the dispersion model to predict the measured concentration value. This process is repeated for each receptor location and the average of the  $Q_2$  values for the downwind receptor locations is reported as the test average.

$$\frac{C_1}{C_2} = \frac{Q_1}{Q_2} \quad (1)$$

5. Upwind samplers were used during 2006 and 2007 to measure background PM concentrations at each site. In many cases, the upwind sampler concentrations from 2006 were significantly influenced by outside sources thus invalidating the background concentration measurement. Therefore, the measured concentrations used in the dispersion modeling process for 2006 were not corrected to a net basis by subtracting the background concentration. In effect, this provides a level of conservatism to the resulting emission factors from 2006. This was not the case for 2007 as valid upwind concentration measurements were used to correct the downwind concentrations to a net basis.
6. The test average flux values are then converted to emission factors for size range X (X indicating TSP, PM<sub>10</sub>, or PM<sub>2.5</sub>) according to equation 2.

$$EF_{PM,X} = Q_{avg} * D_t * MF_{PM,X} * C \quad (2)$$

where:

$EF_{PM,X}$  = PM emission factor for size range X, kg/ha (lb/ac),

$Q_{avg}$  = test average flux, g/m<sup>2</sup>-s,

$D_t$  = test duration, min,

$MF_{PM,X}$  = mass fraction of PM<sub>X</sub> from PSD analysis (decimal), and

$C$  = unit conversion constant, 600 for EF in kg/ha (535 for EF in lb/ac).

The concentrations used in the dispersion modeling process are TSP measurements. PM<sub>10</sub> and PM<sub>2.5</sub> emission factors were determined by multiplying the TSP emission factors by the respective mass fractions from PSD analysis. Buser et al. (2001) showed that FRM PM<sub>10</sub> and PM<sub>2.5</sub> samplers report concentrations far in excess of true concentrations when sampling PM with a mass median diameter larger than the cutpoint of the sampler. Therefore, concentration measurement error imparted by the sampler propagates directly through to emission factors developed through dispersion modeling.

## PARTICULATE MATTER CONCENTRATION MEASUREMENTS

Six sets of collocated low volume TSP and PM<sub>10</sub> samplers were used to measure the PM concentrations upwind and down wind of the harvesting operation during each test during 2006. Five sets of collocated samplers were arranged around the test plots to measure the PM concentrations downwind of the harvesting operation. One set of collocated samplers was placed at a distance (100 – 200 m approximately) away from the test plot to measure the background PM concentrations in the area. The common sampler arrangement around the test plots is shown in Figure 7. This arrangement was modified during tests 1 – 5 of farm 2 where the downwind samplers were all placed inline along the downwind side of the test plot (Figure 8). This modification was made to increase the number of samplers measuring the highest downwind concentrations from the operation. The arrangement shown in Figure 4 was used to ensure that a

reliable downwind concentration would be measured from the harvesting operation in times of meandering wind direction.

The sampler arrangement shown in Figure 7 was used again in 2007. However, only four sets of collocated samplers were used along the east and west sides of each plot. The northern most sampler location shown in Figure 4 was not used during 2007.

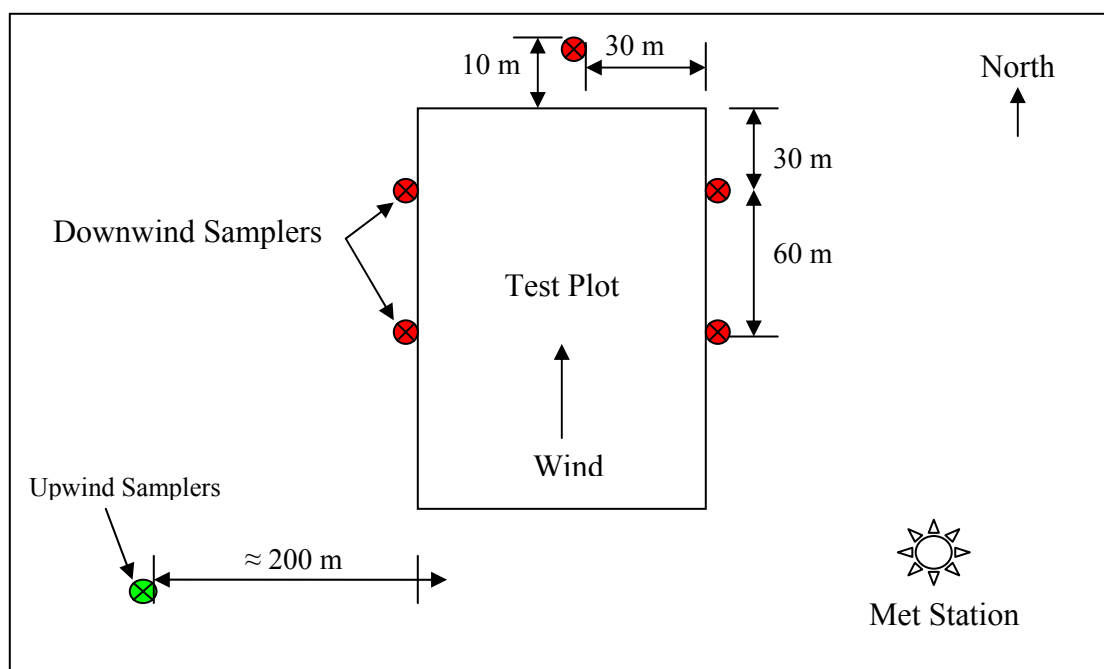


Figure 7. Typical arrangement of collocated TSP/PM<sub>10</sub> samplers around the test plots.

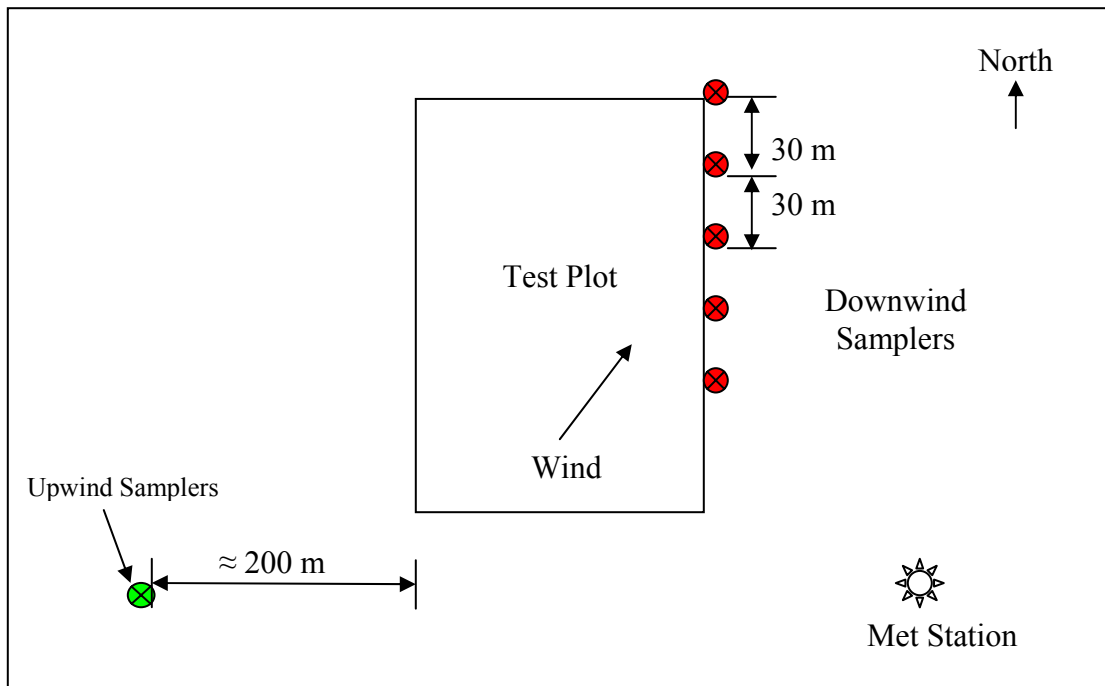


Figure 8. Modified sampler arrangement used during tests 1 – 5 at farm 2.

The TSP and PM<sub>10</sub> samplers used to measure PM concentrations upwind and downwind of the harvesting operations both operated with an air flow rate of 16.7 l/min (Wanjura et. al., 2005b). The flow rate of the samplers used in this study is approximately 85 times less than the flow rate of a comparable “high volume” federal reference method (FRM) TSP or PM<sub>10</sub> sampler (1.42 m<sup>3</sup>/min). Thus the term low volume is used to describe the sampler air flow rate of the samplers used in this study.

The TSP inlet head used in this study was designed and evaluated by Wanjura et. al. (2005b). TSP concentration measurements represent the concentration of a broad range of inhaleable particles. The cutpoint of the TSP sampler was reported to be around 45 µm with a slope of 1.5 by McFarland and Ortiz (1983). Thus the TSP sampler concentration represents the concentration of airborne particles with diameters up to 100 µm. The results of subsequent PSD analysis of the PM captured on the TSP sampler

filter was used to determine the true concentration of PM less than a given particle diameter (i.e. true PM<sub>10</sub> or PM<sub>2.5</sub> concentrations) (Buser, 2004).

The PM<sub>10</sub> samplers used the Graseby-Andersen FRM PM<sub>10</sub> inlet. The concentrations measured by the PM<sub>10</sub> samplers are intended to represent the concentration of PM less than 10 µm. However, the concentrations measured by the FRM PM<sub>10</sub> samplers do not accurately represent true PM<sub>10</sub> concentrations when sampling PM from agricultural operations due to the interaction between the sampler performance characteristics and the PSD of the sampled PM (Buser, 2004). PM<sub>10</sub> concentration measurements were made in this study using FRM PM<sub>10</sub> samplers to investigate this sampling error phenomenon in the presence of dust emitted from cotton harvesting operations.

The systems used to establish and control the flow rate of the TSP and PM<sub>10</sub> samplers were identical. The flow system used a 0.09 kW (1/8 hp) diaphragm pump (917CA18-59, Thomas Industries, Sheboygan, WI) to draw the 16.7 l/min sample flow rate through the sampler inlet head. Electrical power for the samplers was supplied by gasoline powered generators located between the samplers. The air flow rate was measured using a sharp edge orifice meter. The diameter of the orifice was 4.76 mm (3/16 inch). The pressure drop across the orifice plate was measured by a Magnehelic gauge (as a visual check) and also by a differential pressure transducer (PX274, Omega Engineering, Inc., Stamford, Conn.). The differential pressure transducer converted the differential pressure readings into a current (ma) signal that was recorded by a data logger (HOBO H8 RH/Temp/2x External, Onset Computer Corp, Pocasset, MA). Pressure drop readings were recorded for each sampler at the beginning and end of each test. The relationship shown in equation 3 was used to calculate the sampler flow rate using the pressure drop across the orifice plate recorded on the log sheets (from the Magnehelic gauge) and recorded by the data loggers.

$$Q = 3.478 * K * D_o^2 * \sqrt{\frac{\Delta P}{\rho_a}} \quad (3)$$

where,

$Q$  = air flow rate through the orifice meter ( $\text{m}^3/\text{s}$ ),  
 $K$  = flow coefficient (dimensionless),  
 $D_o$  = orifice diameter (m),  
 $\Delta P$  = pressure drop across the orifice ( $\text{mm H}_2\text{O}$ ), and  
 $\rho_a$  = air density ( $\text{kg}/\text{m}^3$ ).

Meteorological data was collected during each test by an onsite weather station. The weather station recorded air temperature, relative humidity, barometric pressure, wind direction, wind speed, and solar radiation (Temp/RH Sensor: Model S-THB-M002; Barometric Pressure Sensor: Model S-BPA-CM10; Wind Direction/Speed Sensor: S-WCA-M003; Silicon Pyranometer: S-LIB-M003, Onset Computer Corporation, Pocasset, MA). The density of air used in (3) was calculated using the air properties recorded by the weather station in equation 4.

$$\rho_a = \frac{P_b - \phi P_s}{0.0028 * (t_{db} + 273)} + \frac{\phi P_s}{0.0046 * (t_{db} + 273)} \quad (4)$$

where:

$P_b$  = Barometric pressure (atm),  
 $\phi$  = relative humidity (decimal),  
 $P_s$  = Saturation vapor pressure (atm), and  
 $t_{db}$  = Dry bulb temperature, ( $^{\circ}\text{C}$ ).

The PM collected by the TSP and  $\text{PM}_{10}$  samplers was deposited on 47 mm diameter polytetrafluoroethylene (PTFE) filters (2  $\mu\text{m}$  pore size Zefluor Membrane Filters, Pall Corp., East Hills, NY). These filters were pre and post weighed using a high precision analytical balance (XS205, Mettler-Toledo, Greifensee Switzerland). Each filter was weighed three times during the pre and post weighing processes. Afterwards, the mean of the three pre weights was subtracted from the mean of the three post weights to determine the net PM mass collected on the filter. The pre and post processing of the filters is described in detail by Wanjura (2005). The PM concentrations were determined using the relationship shown in (5).



$$C = \frac{\Delta M}{\sum_i Q_i t_i} \quad (5)$$

where:

$C$  = average concentration of PM measured over the test duration ( $\mu\text{g}/\text{m}^3$ ),

$\Delta M$  = change in mass of the filter due to PM loading ( $\mu\text{g}$ ),

$Q_i$  = average air flow rate over the  $i^{\text{th}}$  time interval, and

$t_i$  =  $i^{\text{th}}$  time interval duration (s).

The logging intervals ( $t_i$ ) used by the data loggers was 12 s during 2006 and 1 min during 2007. However, when determining the total flow volume measured during the test period using the beginning and ending pressure drop readings from the log sheets, the time interval duration ( $t_i$ ) was the total duration of the test.

The total uncertainty due to systematic effects of the low volume sampling systems was determined to be 11.85% by Price (2004) using the method described by Kline and McClintock (1953).

## **DISPERSION MODELING**

### ***Industrial Source Complex Short Term Version 3***

ISCST3 is a Gaussian dispersion model that uses the normal (Gaussian) distribution to describe the horizontal and vertical dispersion of a pollutant downwind from the source (Wanjura et. al., 2005c). The pollutant concentration estimated by ISCST3 at a downwind receptor is influenced by meteorological factors (wind direction, wind speed, temperature, etc.), source emission characteristics (emission height, emission temperature, emission velocity, etc.), and receptor characteristics (receptor height and distance from source to receptor). ISCST3 is an EPA approved dispersion model for evaluating the impact of emissions from a source on downwind concentrations. SAPRAs have used ISCST3 in New Source Review permitting processes to determine off property concentrations resulting from emissions from the facility seeking the permit.

The Gaussian dispersion equation for a single point source is shown in equation 6.

$$C_M = \frac{ER_{TSP}}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{1}{2} \frac{y^2}{\sigma_y^2}\right) \left\{ \exp\left(-\frac{1}{2} \frac{(z-H)^2}{\sigma_z^2}\right) + \exp\left(-\frac{1}{2} \frac{(z+H)^2}{\sigma_z^2}\right) \right\} \quad (6)$$

where:

$C_M$  = time average steady state concentration at a point (x, y, z) ( $\mu\text{g}/\text{m}^3$ );

$u$  = average wind speed at stack height (m/s);

$y$  = horizontal distance from plume centerline (m);

$z$  = height of receptor with respect to ground (m);

$H$  = effective stack height ( $H=h+\Delta h$ , where  $h$  = physical stack height and  $\Delta h$  = plume rise)(m);

$\sigma_y, \sigma_z$  = horizontal and vertical plume dispersion coefficients, m.

The area source algorithm in ISCST3 utilizes a numerical integration of (6) in the upwind and crosswind directions to determine receptor concentrations. In this case, (6) takes the form shown in (7) and the sum of the concentration contribution from all line sources used to model the source equal the predicted concentration at the receptor.

$$C_M = \frac{q}{2\pi u \sigma_y \sigma_z} \left\{ \exp\left(-\frac{1}{2} \frac{(z-H)^2}{\sigma_z^2}\right) + \exp\left(-\frac{1}{2} \frac{(z+H)^2}{\sigma_z^2}\right) \right\} \int_{y_1}^{y_2} \exp\left(-\frac{1}{2} \frac{y^2}{\sigma_y^2}\right) dy \quad (7)$$

where  $q$  is the area source flux ( $\text{g}/\text{m}^2\text{-s}$ ). ISCST3 solves the equation shown in (7) using a trapezoidal approximation. The number of trapezoidal regions approximating the source ( $N$ ) doubles with each iteration of the algorithm. The algorithm discontinues execution and the previous estimate of the integral is used when any of the following three conditions is met (EPA, 1995b):

1. The number of “halving intervals” ( $N$ ) in the trapezoidal approximation of the integral has reached 10 (where the number of individual elements in the approximation is given by  $1 + 2^{N-1} = 513$  for  $N$  of 10),
2. The extrapolated estimate of the real integral (Romberg approximation) has converged to within a tolerance of 0.0001 (i.e. 0.01%), and at least 4 halving intervals have been completed, or

3. the extrapolated estimate of the real integral is less than  $1.0 \text{ E-}10$ , and at least 4 halving intervals have been completed.

The horizontal and vertical plume dispersion parameters,  $\sigma_y$  and  $\sigma_z$ , respectively, are estimated in ISCST3 by the Pasquill-Gifford atmospheric stability parameter estimates (Wanjura et al., 2005c). Beychok (1996) indicates that there is much disagreement over the time period for which  $C_M$  (equation 6) is the average concentration when using Pasquill's dispersion coefficients. He states further that some argue that  $C_M$  represents a 3 min concentration while others argue that  $C$  represents a 30 min concentration, but most will agree on a range of 10 – 15 min (Beychok, 1996). When used for regulatory purposes, one hour average meteorological data is used in ISCST3 to estimate downwind concentrations (EPA, 2000). Beychok (1996) indicates that using one hour average meteorological data in ISCST3 can result in the over-estimation of downwind concentrations by as much as 250%. Variations in wind direction within a one hour period are not adequately accounted for in the use of hourly average meteorological data (Fritz, 2002). Thus, the meteorological data collected during each test was averaged using 15 – 20 minute intervals for use in ISCST3.

The meteorological data collected onsite during the tests was processed according to the guidelines given by EPA (EPA, 2000).

- The meteorological data were processed using 15-20 minute averaging times. 15 minute average meteorological data were used for the short averaging period from farm 1 due to a weather station malfunction whereas 20 minute average data were used for farms 2 and 3. It was assumed that differences in the emission factors developed using the short time average meteorological data (15 – 20 minute averages) would not be a consequence of the 5 minute discrepancy in the averaging periods.
- The wind direction was processed using the unit vector averaging procedure described by EPA (2000).

- The wind speed data were scalar averaged over the two time periods according to EPA recommendations.
- The Solar Radiation Delta-T (SRDT) method was used to define the atmospheric stability classes during the tests. Solar radiation and wind speed are the criteria used to define the atmospheric stability class according to the SRDT method (EPA, 2000). Using these two criteria, one can easily determine the day time atmospheric stability class using the data in Table 8. Similarly, the wind speed and vertical temperature gradient are used to classify night time atmospheric stability as presented in Table 9.

Table 8. Key to Solar Radiation Delta – T method for estimating day time Pasquill-Gifford stability categories (EPA, 2000).

<b>Wind Speed (m/s)</b>	<b>Day Time</b>			
		<b>Solar Radiation (W/m<sup>2</sup>)</b>		
	<b>≥925</b>	<b>925 - 675</b>	<b>675 - 175</b>	<b>&lt;175</b>
<b>&lt;2</b>	1	1	2	4
<b>2 - 3</b>	1	2	3	4
<b>3 - 5</b>	2	2	3	4
<b>5 - 6</b>	3	3	4	4
<b>≥6</b>	3	4	4	4

Table 9. Key to Solar Radiation Delta – T method for estimating night time Pasquill-Gifford stability categories (EPA, 2000).

<b>Wind Speed (m/s)</b>	<b>Night Time</b>	
	<b>Vertical Temperature Gradient</b>	
	<b>&lt;0</b>	<b>≥0</b>
<b>&lt;2.0</b>	5	6
<b>2.0 - 2.5</b>	4	5
<b>≥2.5</b>	4	4

Emission flux values were calculated for each downwind sampler location for each test. However, not all of the downwind sampler locations yielded reliable emission flux values due to the orientation of the receptor to the source. For example, if the wind direction were to shift such that the wind is blowing toward the northeast in Figure 4, the northern and eastern samplers would become the downwind samplers. ISCST3 would estimate the highest concentrations at the receptors located on the east side of the plot. This is a consequence of the area within the source that is available to contribute to the receptor concentration. If the concentrations measured during the test at the samplers located along the north and eastern sides of the plot were approximately equal (this was the situation in most cases), the resulting emission flux calculated for the sampler located along the north side of the plot would be substantially larger than the fluxes calculated for the samplers located on the east side of the plot. Said differently, the emission flux from the small area contributing to the concentration at the sampler located on the north side of the plot would have to be much larger than the flux from the larger areas contributing to the concentrations measured by the samplers on the east side of the plot in order to calculate the same concentration at all three receptor locations. In this situation, only two of the fluxes calculated from the downwind sampler concentrations (the two located on the east side of the plot) would be used to determine the average test flux.

#### ***AMS/EPA Regulatory Model: AERMOD***

AERMOD is a steady state Gaussian dispersion model developed to model near field dispersion of pollutants from stationary industrial sources. EPA (2004) states that the major improvement in AERMOD over ISCST3 (which AERMOD is intended to replace as the recommended regulatory model) is found in the incorporation of state-of-the-art relationships for flow over complex terrain and in the ability to characterize the planetary boundary layer (PBL) under both stable and convective conditions. For air quality purposes, one is concerned with dispersion in the PBL. Garratt (1992) defines the PBL as:

*... the layer of air directly above the Earth's surface in which the effects of the surface (friction, heating, and cooling) are felt directly on time scales less than a day, and in which significant fluxes of momentum, heat or matter are carried by turbulent motions on a scale of the order of the depth of the boundary layer or less.*

The AERMOD model architecture is comprised of two preprocessors, AERMET and AERMAP, which process standard meteorological data and terrain data, respectively, and the AERMOD dispersion model. AERMAP is used to describe the physical configuration of the model domain with regard to source-receptor orientation (i.e. source elevation and release height and receptor elevation and height above grade). AERMET is used to develop meteorological data files for use in AERMOD containing standard meteorological data (surface measurements of wind speed, wind direction, temperature, and cloud cover) as well as parameters to characterize the PBL such as friction velocity ( $u_*$ ), Monin-Obukhov length ( $L$ ), convective velocity scale ( $w_*$ ), temperature scale ( $\theta_*$ ), mixing height ( $z_i$ ), and surface heat flux ( $H$ ). Estimates for albedo, surface roughness, and Bowen ratio are also input to AERMET to help calculate the PBL stability parameters. Similarity relationships are used in AERMOD with meteorological data input files from AERMET to develop vertical profiles for wind speed, lateral and turbulent fluctuations ( $\sigma_v$ , and  $\sigma_w$  respectively), potential temperature, and potential temperature gradient (EPA, 2004). Detailed discussion on the methods used in this work to develop the meteorological input files for AERMOD is given in the following section.

The AERMOD dispersion model assumes the distributions of lateral and vertical pollutant dispersion in the stable PBL (SBL) to be Gaussian. Further, the model assumes that, in the convective PBL (CBL), the lateral distribution is Gaussian but the vertical becomes a bi-Gaussian distribution (EPA, 2004). The vertical distribution of pollutant dispersion in the CBL is skewed toward higher elevations above the ground surface; meaning that higher pollutant concentrations are closer to the ground. While a scrupulous description of the model formulation may be outside the scope of this work, an abbreviated attempt will be made to describe the general formulation for stable and

convective conditions. A more in depth discussion of the model formulation is given in EPA (2004).

Under both stable and convective conditions, the general form of the concentration prediction equation is shown in (8). In both cases (convective and stable conditions indicated by the c and s subscripts, respectively) the plume is contained in two plume types; 1) the horizontal plume and 2) the terrain responding plume.

$$C_t \{x_r, y_r, z_r\} = f C_{c,s} \{x_r, y_r, z_r\} + (1 - f) C_{c,s} \{x_r, y_r, z_p\} \quad (8)$$

where  $C_t \{x_r, y_r, z_r\}$  represents the total concentration predicted at receptor location  $x_r, y_r, z_r$  from the horizontal plume,  $C_{c,s} \{x_r, y_r, z_r\}$ , and terrain following plume,  $C_{c,s} \{x_r, y_r, z_p\}$ . The horizontal and terrain following plumes are divided by a receptor specific dividing streamline height,  $H_c$ .  $H_c$  is calculated for each receptor based on the receptor height scale,  $h_c$ , which describes the height of local terrain features which most dominate flow in the region (EPA, 2004). The portion of the plume below  $H_c$  tends to remain in horizontal flow (i.e. the horizontal plume) and is modeled such that when the plume encounters a terrain feature such as a hill, it will either impact the hill surface or divide and go around. The portion of the plume in the flow above  $H_c$  has sufficient kinetic energy to sustain entrainment above the terrain surface; thus allowing the plume to follow the terrain (EPA, 2004). The plume state weighting function,  $f$ , is the portion of the total concentration from each plume type. The receptor height,  $z_r$ , is referenced to the stack base elevation and in cases of flat terrain,  $z_r = z_p$  and the equation reduces to a single plume model dominated by the horizontal plume. Further, under convective conditions,  $f = 0.5$  and the concentration at a receptor with elevation above stack base elevation is the average of the horizontal and terrain following plume concentrations (EPA, 2004).

Under stable conditions, the point source dispersion equation takes the Gaussian form shown in (9).

$$C_s \{x_r, y_r, z\} = \frac{Q}{\sqrt{2\pi}u\sigma_{zs}} F_y \sum_{m=-\infty}^{\infty} \left[ \exp\left(-\frac{(z - h_{es} - 2mz_{ieff})^2}{2\sigma_{zs}^2}\right) + \exp\left(-\frac{(z + h_{es} + 2mz_{ieff})^2}{2\sigma_{zs}^2}\right) \right] \quad (9)$$

where  $Q$  is the emission rate,  $u$  is the wind speed,  $\sigma_{zs}$  is the total vertical dispersion coefficient (under stable conditions – s subscript),  $h_{es}$  is the plume height, and  $z_{ieff}$  is the effective mechanical mixing height.  $F_y$  accounts for the lateral meander of the plume and has the form shown in (10).

$$F_y = \frac{1}{\sqrt{2\pi}\sigma_y} \exp\left(-\frac{1}{2} \frac{y^2}{\sigma_y^2}\right) \quad (10)$$

where  $\sigma_y$  is the lateral plume spread parameter evaluated at crosswind distance  $y$ . EPA (2004) states that  $\sigma_y$  and  $\sigma_z$  result from the combination of dispersion resulting from ambient turbulence as well as turbulence due to plume buoyancy.

The contributions from the horizontal and terrain following plumes used to calculate the total predicted concentration as shown in (8) in the CBL are a consequence of three source components: the direct source, the indirect source, and the penetrated source contributions. The sum of these source contributions are used to calculate the horizontal and terrain following plume contributions as shown by (11) (EPA, 2004).

$$C_c \{x_r, y_r, z_r\} = C_d \{x_r, y_r, z_r\} + C_r \{x_r, y_r, z_r\} + C_p \{x_r, y_r, z_r\} \quad (11)$$

where  $C_d$ ,  $C_r$ , and  $C_p$  are the direct, indirect, and penetrated source contributions. To calculate  $C_c$  for the terrain following plume state, the substitution of  $z_p$  is made for  $z_r$ .

The direct source contribution ( $C_d$ ), found by (12), accounts for pollutant emissions that are directly dispersed in the convective boundary layer and are subsequently transported toward ground based receptors.

$$C_d \{x_r, y_r, z\} = \frac{Qf}{\sqrt{2\pi}u} F_y \sum_{j=1}^2 \sum_{m=0}^{\infty} \frac{\lambda_j}{\sigma_{z,j}} \left[ \exp\left(-\frac{(z + \psi_{dj} - 2mz_i)^2}{2\sigma_{zj}^2}\right) + \exp\left(-\frac{(z - \psi_{dj} + 2mz_i)^2}{2\sigma_{zj}^2}\right) \right] \quad (12)$$

where  $\lambda$  is the distribution weighting coefficient and  $\psi$  is the effective source height.

The indirect source contribution ( $C_r$ ), found by (13), is the portion of the plume reflected by the surface between the stable upper boundary layer and the mixed boundary layer at the mixing height of the convective boundary layer. The portion of



the indirect plume not reflected back toward the ground is assumed to penetrate to the stable upper layer.

$$C_r\{x_r, y_r, z\} = \frac{Qf}{\sqrt{2\pi}u} F_y \sum_{j=1}^2 \sum_{m=1}^{\infty} \frac{\lambda_j}{\sigma_{z,j}} \left[ \exp\left(-\frac{(z + \psi_{rj} - 2mz_i)^2}{2\sigma_{zj}^2}\right) + \exp\left(-\frac{(z - \psi_{rj} + 2mz_i)^2}{2\sigma_{zj}^2}\right) \right] \quad (13)$$

The penetrated source contribution ( $C_p$ ), found by (14), accounts for the portion of the plume that initially penetrates the CBL above  $z_i$ , and is subsequently re-entrained by and dispersed in the CBL.

$$C_p\{x_r, y_r, z\} = \frac{Q(1-f)}{\sqrt{2\pi}u\sigma_{zp}} F_y \sum_{m=-\infty}^{\infty} \left[ \exp\left(-\frac{(z - h_{ep} - 2mz_{ieff})^2}{2\sigma_{zp}^2}\right) + \exp\left(-\frac{(z + h_{ep} + 2mz_{ieff})^2}{2\sigma_{zp}^2}\right) \right] \quad (14)$$

### *Meteorological Data Processing in AERMOD*

The following discussions describe the methods used to calculate the meteorological parameters used in AERMOD from meteorological data measured onsite at farm 3 during 2007. Typically when creating the meteorological files for use in AERMOD, one would obtain NWS or ADMS meteorological data files and process them through the AERMOD meteorological data preprocessor AERMET. AERMET calculates surface layer parameters from meteorological data collected from a particular surface station location and user supplied surface estimates of albedo ( $\alpha$ ), surface roughness ( $z_o$ ), and Bowen ratio ( $B_o$ ). Empirical relationships encoded into the program architecture of AERMET are then used to provide estimates for the variables required by the dispersion relationships in AERMOD such as the Monin-Obukhov Length ( $L$ ), surface friction velocity ( $u_*$ ), surface sensible heat flux ( $H$ ), and the convective scaling velocity ( $w_*$ ). The final function of AERMET is to compile all of the measured, user defined, and estimated meteorological data into the specific file formats required by AERMOD. AERMOD requires two data files (which are output from the AERMET preprocessor) to characterize the PBL conditions of the modeling domain: the surface meteorological data file and the profile data file. The profile data file contains

information on the wind speed, direction, and temperature at a specified reference height. While all of the data input to the AERMET preprocessor is passed through to AERMOD, not all of the data is used by AERMOD. Specifically, the albedo, surface sensible heat flux, and Bowen ratio are not used in any calculation performed by AERMOD (Trinity Consultants, 2007).

AERMET was not used to develop the meteorological files used in AERMOD for this work. Rather, the parameters estimated by AERMET were derived from meteorological data measurements collected by an onsite weather station equipped with 3D and 2D sonic anemometers. These measurement derived parameters were then incorporated into surface and profile files prepared by TCEQ for Burleson county from 1988 (TCEQ, 2007). These files were used to simplify the process of developing the hourly meteorological files required by AERMOD. The 2D sonic anemometer (WindSonic1, Gill Instruments Ltd., Lymington Hampshire) was used to measure the wind speed and direction 3 m above the ground surface while the 3D sonic anemometer (Model 81000, R.M. Young Co., Traverse City, MI) collected data for use in defining the stability of the surface layer at 2m. Both the 2D and 3D sonic anemometers operated with a sampling frequency of 4 Hz. Barometric pressure was measured by the weather station with a barometric pressure sensor (Model 278, Setra Systems Inc., Boxborough, MA) and temperature and relative humidity were measured by a T/RH probe mounted in a solar radiation shield at 2 m (HMP50, Campbell Scientific Inc., Logan, UT). Net radiation was also measured using two pyranometers, one mounted face up (CMP 22, Kipp and Zonen, Delft, The Netherlands) and one mounted face down (CMP 6, Kipp and Zonen, Delft, The Netherlands). The weather station sensor data was recorded by a data logger (CR1000, Campbell Scientific Inc., Logan, UT) and stored on a removable compact flash memory disk. The disk was changed between tests to simplify the data processing work.

The data contained in the profile file from TCEQ (2007) was collected at a reference height of 10 m. Wind data was not collected at 10 m during the 2007 tests on farm 3. Rather, the information in the file from TCEQ was modified to reflect the wind

direction measured at 2 m and the wind speed was calculated according to the procedure described by Manwell et al. (2002) using the power law relationship shown in equation 15.

$$\frac{U(z)}{U(z_r)} = \left( \frac{z}{z_r} \right)^\alpha \quad (15)$$

where  $U(z)$  and  $U(z_r)$  are the wind speeds at height  $z$  and reference height,  $z_r$  ( $z_r = 2$  m). The power law exponent  $\alpha$  is a function of the surface roughness length,  $z_o$  (m), as shown in equation 16. A surface roughness value of 0.05 m was used.

$$\alpha = 0.096 \log_{10}(z_o) + 0.016 (\log_{10}(z_o))^2 + 0.24 \quad (16)$$

Several primary parameters used by AERMOD contained in the surface file to characterize the PBL can be calculated from wind speed and temperature measurements taken by the sonic 3D anemometer used during 2007. A sonic anemometer measures the transit times of ultrasonic sound pulses to compute the wind vector and the sonic virtual temperature (Van Boxel et al., 2004). An average of these high frequency readings (taken at 4 Hz) will give a measure of the mean wind speed and direction relative to the fixed coordinate system of the instrument. The accuracy of the measurements can be impacted by interference with solid or liquid particles in the measured air stream.

Kaimal and Finnigan (1994) state that in surface modeling of the PBL, the surface friction velocity ( $u_*$ , m/s) is an important scaling factor and is defined as the square root of the Reynolds' Stress (RS) divided by the air density ( $\rho$ , kg/m<sup>3</sup>). A direct measure of RS is found by the covariance between the horizontal and vertical wind speed (Van Boxel et al., 2004). Reynolds (1895) states that the principal orthogonal components of the wind vector ( $u$ ,  $v$ , and  $w$  [m/s]) are made up by average (indicated by an overbar) and fluctuating (indicated by a prime) components. Further, Van Boxel et al. (2004) states that the temperature ( $T$ , °K) is also made up of mean and fluctuating components. These decompositions are shown in equations 17 - 20.

$$u = \bar{u} + u' \quad (17)$$

$$v = \bar{v} + v' \quad (18)$$

$$w = \bar{w} + w' \quad (19)$$

$$T = \bar{T} + T' \quad (20)$$

The Reynolds' stress and surface friction velocity are then calculated according to equations 21 and 22, respectively.

$$RS = -\rho \overline{u'w'} \quad (21)$$

$$u_*^2 = \sqrt{(\overline{u'w'})^2 + (\overline{v'w'})^2} \quad (22)$$

The friction velocity represents the horizontal shear stress exerted by the wind vector on a horizontal surface (Van Boxel et al., 2004) and can be affected by misalignment of the sonic anemometer with respect to a stream-wise coordinate system. Slight misalignment of the instrument with respect to the vertical axis of the wind flow vector can result in significant errors being introduced in to the calculation of the covariance between the horizontal and vertical wind components (RS). The wind vector changes slightly from one second to another while the anemometer is fixed to the reference coordinate system it was configured to. If the wind vector tilts slightly downward with respect to the instrument coordinate system, the slight perturbations in the u and v directions will be interpreted as fluctuations in the w direction. While these misinterpretations are small, they can contribute significantly to  $u'w'$  and  $v'w'$  (correlation between the horizontal and vertical wind speeds) (Van Boxel et al., 2004). These errors can be precluded by performing a sequential three stage post measurement rotation on the wind speed data collected by the sonic anemometer into a stream-wise coordinate system. In this new reference frame, u is in the direction of the wind stream lines (wind direction), v is in the plane of the wind stream lines and perpendicular to u, and w is orthogonal to both u and v.

The first rotation ( $\theta$  = yaw rotation angle, degrees) focuses the u direction of the instrument into the wind direction. The second rotation ( $\phi$  = pitch rotation, degrees) orients u into the direction of the sloping stream lines and w perpendicular to u. The final rotation orients v perpendicular to the surfaces of the wind streamlines and w perpendicular to the streamline surfaces. A more detailed description of these rotations is given by Van Boxel et al. (2004) with the mathematical rotations as shown here.

Rotation 1 is calculated by equations 23 – 26.

$$\theta = \arctan\left(\frac{\overline{v_m}}{\overline{u_m}}\right) \quad (23)$$

$$u_1 = u_m \cos \theta + v_m \sin \theta \quad (24)$$

$$v_1 = -u_m \sin \theta + v_m \cos \theta \quad (25)$$

$$w_1 = w_m \quad (26)$$

where:

$\theta$  = yaw angle (degrees),

$u_m, v_m, w_m = u, v,$  and  $w$  components of the wind speed as measured by the sonic anemometer (m/s), and

$u_1, v_1, w_1 = u, v,$  and  $w$  components after the first rotation.

Rotation 2 is calculated according to equations 27 – 30.

$$\phi = \arctan\left(\frac{\overline{w_1}}{\overline{u_1}}\right) \quad (27)$$

$$u_2 = u_1 \cos \phi + w_1 \sin \phi \quad (28)$$

$$v_2 = v_1 \quad (29)$$

$$w_2 = -u_1 \sin \phi + w_1 \cos \phi \quad (30)$$

where:

$\phi$  = pitch angle required to align  $u$  with the sloping of the streamlines (degrees),

and

$u_2, v_2, w_2 = u, v,$  and  $w$  components after the second rotation.

Rotation 3 is calculated according to equations 31 – 34.

$$\psi = 0.5 \arctan\left(\frac{2\overline{v_2 w_2}}{\overline{v_2^2 - w_2^2}}\right) \quad (31)$$

$$u_3 = u_2 \quad (32)$$

$$v_3 = v_2 \cos \psi + w_2 \sin \psi \quad (33)$$

$$w_3 = -v_2 \sin \psi + w_2 \cos \psi \quad (34)$$

where:

$\psi$  = rotation angle (degrees) required to orient  $v$  along the wind stream line surfaces and  $w$  orthogonal to  $v$  and  $u$ , and

$u_3, v_3, w_3$  =  $u, v$ , and  $w$  components after the third rotation.

The values for  $u, v$ , and  $w$  after the third rotation were used to calculate the mean and fluctuating components of the wind vectors (equations 17 - 20) as well as the correlations for calculating  $u_*$ . The relationship for  $u_*$  can be simplified to that shown in equation 35 when the previous rotation is used to transform the measured data (Garratt, 1992).

$$u_* = \sqrt{-\overline{(u'w')}} \quad (35)$$

Along with the surface friction velocity, an estimate of the surface sensible heat flux ( $H, W/m^2$ ) is needed to help characterize the PBL. The sensible heat flux can be calculated using the correlation between the rotated vertical wind speed and temperature (equation 36) (Etling, 1996).

$$H = \rho c_p \overline{w'T'} \quad (36)$$

where  $c_p$  is the specific heat of the air (J/kg-K). The PBL transitions from convective (CBL) to stable conditions (SBL) when the sign of  $H$  changes from positive to negative.

The Monin-Obukhov length ( $L, m$ ) is used to help define the thermal stability of the PBL. The thermal stability parameter ( $\zeta$ ) is defined as  $\zeta = -z/L$  where  $z$  is the measurement height of the sonic anemometer. The thermal stability parameter is essentially a ratio of the thermal turbulence production to mechanical turbulence production normalized by the dimensionless wind stress profile (Stull, 1988). The Monin-Obukhov length was calculated by Hiscox et al. (2006) as shown in (37):

$$L = \frac{-\rho c_p \overline{T} u_*^3}{kgH} = \frac{-\overline{T} u_*^3}{kg \overline{w'T'}} \quad (37)$$

where  $k$  is the dimensionless von Karman constant (0.4) and  $g$  is the acceleration due to gravity ( $9.81 m/s^2$ ).

The convective portion of turbulence in the PBL under convective conditions is characterized in AERMOD by the convective velocity scale ( $w_*$ , m/s). The convective velocity scale is calculated as shown in equation 38.

$$w_* = \left( \frac{gH z_{ic}}{\rho c_p \bar{T}} \right)^{1/3} \quad (38)$$

where  $z_{ic}$  is the convective mixing height (m).

Each hour of meteorological data input to AERMOD contains values for both the convective and mechanical mixing height of the PBL. Ideally, the values for both the convective and mechanical mixing heights ( $z_{im}$ ) would result from measurements taken by upper air stations but can be calculated using the procedures described by EPA (2004). The total depth of the PBL in AERMOD is determined based on the stability of the atmosphere. In the CBL, the total depth of the PBL ( $z_i$ ) is taken as the maximum of the mechanical or convective mixing heights. In the SBL,  $z_i$  is defined by the mechanical mixing height. Stability of the PBL is determined in AERMOD by the sign of  $L$ ; stable when  $L \geq 0$  and convective when  $L < 0$ .

The vertical potential temperature gradient in the 500 m above the PBL is required by AERMOD to evaluate the potential for a buoyant plume to penetrate through the PBL. Similar to the convective and mechanical mixing heights, measurements of the vertical potential temperature gradient can be obtained from radiosondes of the upper atmosphere. The values for the vertical potential temperature gradient were not expected to significantly impact the near-field modeling results of this work and thus were assumed to be equal to the values obtained in the meteorological data files from TCEQ. Similarly, due to the lack of radiosonde data, the mechanical and convective mixing heights used in this work were the historical data contained within the files obtained from TCEQ.

The TCEQ recommends values for albedo, Bowen ratio, and surface roughness for specific areas of the state to use in preparing meteorological data for use in AERMOD (TCEQ, 2005). These values are included in the data input to AERMET to use in the calculation of PBL stability parameters (EPA, 2004). However, in this case

the PBL parameters estimated using albedo and Bowen ratio values have been derived from measured data. Thus, assumptions for albedo and Bowen ratio were not necessary but a brief description of the parameters and recommended estimates is included.

The albedo value for an area describes the amount of incident solar radiation that is reflected back from a surface (i.e. how bright the surface looks from above). The albedo value required by AERMET is the noon day average. Typical values range from 0.1 for thick dense forest cover to 0.9 for a surface covered with fresh snow (TCEQ, 2005). A typical range albedo values recommended for the area of Texas near Burleson county is 0.15 – 0.2 (TCEQ, 2005).

The Bowen ratio is another surface parameter used in the characterization of the PBL to describe the amount of latent heat flux relative to the sensible heat flux at the surface. Generally, the less moisture there is available for evaporation on a surface, the higher the Bowen ratio. A moist surface typically has a low Bowen ratio. Typical Bowen Ratio values recommended for the Burleson county area of Texas are on the order of 0.6 (TCEQ, 2005). Both albedo and Bowen ratio are not used during night time hours because of the lack of solar energy to drive CBL conditions at the surface of the Earth.

Surface roughness varies with land use and terrain features. Typical values range from 0.001 m over calm water to over 1 meter (or more) over a forest or urban area (EPA, 2004). The TCEQ (2005) recommends that users select one of three ranges of surface roughness values to use in AERMOD: low = 0.05 m, medium = 0.5 m, and high = 1 m. The selection of the roughness parameter is dependent not only on the surface characteristics of the source but also on the surrounding area. The medium surface roughness value ( $z_0 = 0.5$  m) was chosen since the source was made up by agricultural crop land with medium sized plants and there was a line of trees approximately 10 m to the north of the field with open flat fields to the south, east, and west.

The meteorological data collected onsite was processed to give hourly average estimates of PBL parameters for use in AERMOD. Scalar averaging of surface wind speed and unit vector averaging of surface wind direction measurements from the 2D



sonic anemometer were calculated according to the procedures described by EPA (2000). The hourly met data calculated from the meteorological data collected during the tests conducted at farm 3 during 2007 and used to modify the files obtained from TCEQ is included in Appendix B.

### ***Emission Factor Validation***

Emission factors were calculated for each receptor location using ISCST3 with the 2006 concentration data and both ISCST3 and AERMOD with the 2007 data. The resulting emission factors spanned a wide range of values due to changing meteorological conditions and the amount of relative source exposure at the receptor. Thus it was necessary to validate the emission factors to exclude nonsensical values from test average emission factor estimates. It is imperative at this point that objective means are used to validate emission factors so not to bias the resulting emission factor estimates. Therefore, the following process was used to identify receptors from which reliable emission factor estimates could be obtained.

The first step in the validation process was to identify the downwind receptor locations through the initial concentrations predicted by the dispersion model. The downwind receptors are those which exhibit the highest net concentration predicted by the dispersion model using the initial flux value and the meteorological data measured onsite. Once the downwind receptors were identified, the following criteria were used to ensure that 1) the sampling devices were operating appropriately, 2) the samplers were not significantly influenced by an outside source of PM, and 3) the model algorithms closely approximate the observed dispersion from the source as observed in the measured concentration data.

1. Measured downwind sampler concentrations must be greater than the concentrations measured by non-downwind samplers. Non-downwind samplers are those which were intended to measure downwind concentrations from the source but the wind direction precluded them from this measurement. These are different from the upwind sampler in that the non-

downwind samplers could still measure a net positive concentration due to other activity around the source generating PM (e.g. boll buggies, tractors, small personnel vehicles, etc).

2. The ratio of the measured concentration for a receptor location to the sum of the measured concentrations from all downwind receptors must approximate the ratio of the predicted concentration at the receptor location to the sum of the predicted concentrations at all downwind receptor locations. This relationship is explained mathematically in equation 39.

$$\frac{C_{S,DW,i}}{\sum_i C_{S,DW,i}} \approx \frac{C_{M,DW,i}}{\sum_i C_{M,DW,i}} \quad (39)$$

where  $C_{S,DW,i}$  is the concentration measured by a downwind (DW) sampler (S) at location  $i$  and  $C_{M,DW,i}$  is the concentration predicted by the dispersion model (M) at downwind receptor location  $i$ . The emission factor from a particular sampler/receptor location was considered suspect if the difference between the measured and modeled ratios exceeded 0.25.

3. The ratio of the measured  $PM_{10}$  concentration to the measured TSP concentration at a downwind sampler location must approximate the same ratio for each downwind sampler location. This relationship is shown in equation 40.

$$\frac{C_{DW,PM10,i}}{C_{DW,TSP,i}} \approx \frac{C_{DW,PM10,j}}{C_{DW,TSP,j}} \quad (40)$$

for all  $i \neq j$  where  $C_{DW,PM10,i}$  is the measured  $PM_{10}$  concentration at downwind receptor  $i$ . The calculated ratios for each downwind location were ranked and a sampler concentration/emission factor was considered suspect if the receptor ratio fell outside  $\pm 0.15$  of the median ratio value. This ratio was also calculated for the upwind samplers during each test to determine the ambient  $PM_{10}$ /TSP ratio. Thus the downwind sampler ratios were expected to be less than the upwind sampler ratio as the PSD of the PM emitted from the

harvesting operation was anticipated to contain much larger particle diameters than the ambient PSD.

## RESULTS

### *Upwind/Downwind Particulate Matter Concentration Measurements*

The upwind and downwind, collocated TSP and PM<sub>10</sub> concentration measurement results for farms 1, 2, and 3 from 2006 and 2007 are summarized in Tables 10, 11, 12, and 13 respectively. The mean ratio of the collocated PM<sub>10</sub>/TSP sampler concentrations for the downwind samples used to develop the emission factors for each test is also presented in the tables. These ratios were used in the process of determining which TSP sampler concentrations would yield valid emission factor estimates through the dispersion modeling process.

Table 10. Concentration measurement results and average sampler PM<sub>10</sub>/TSP concentration ratios from the sampling conducted at farm 1 during 2006.

Test	Treatment	TSP Sampler Concentration ( $\mu\text{g}/\text{m}^3$ )			PM <sub>10</sub> Sampler Concentrations ( $\mu\text{g}/\text{m}^3$ )			Upwind Concentrations ( $\mu\text{g}/\text{m}^3$ )		Avg. DW PM <sub>10</sub> / TSP Ratio
		Mean	Max	Min	Mean	Max	Min	TSP	PM <sub>10</sub>	
1	2 Row	83	109	71	47	56	22	65	52	0.62
2	6 Row	219	354	121	40	71	13	147	100	0.20
3	6 Row w/ss	80	118	45	26	42	12	86	88	0.40
4	6 Row	331	882	120	103	179	42	62	16	0.64
5	2 Row	118	307	37	37	117	7	69	n/a	0.23
6	6 Row	232	330	120	81	145	44	n/a	67	0.40
7	6 Row w/ss	123	171	16	34	57	12	21	n/a	0.67
8	6 Row	61	121	9	19	31	7	n/a	40	0.73
9	2 Row	52	107	7	15	18	10	39	9	0.20
10	6 Row w/ss	97	133	77	32	45	27	25	54	0.35

Table 11. Concentration measurement results and average sampler PM<sub>10</sub>/TSP concentration ratios from the sampling conducted at farm 2 during 2006.

Test	Treatment	TSP Sampler Concentration (µg/m <sup>3</sup> )			PM <sub>10</sub> Sampler Concentrations (µg/m <sup>3</sup> )			Upwind Concentrations (µg/m <sup>3</sup> )		Avg. DW PM <sub>10</sub> / TSP Ratio
		Mean	Max	Min	Mean	Max	Min	TSP	PM <sub>10</sub>	
1	6 Row	66	133	45	35	51	18	46	46	0.61
2	6 Row	57	70	45	59	123	10	n/a	n/a	0.89
3	6 Row	36	51	19	40	46	34	52	3	0.05
4	2 Row	58	66	49	34	49	7	44	12	0.58
5	2 Row	189	205	170	114	125	91	94	n/a	0.58
6	2 Row	48	59	42	29	40	9	54	n/a	0.80
7	6 Row w/ss	116	190	65	39	60	19	26	19	0.40
8	6 Row w/ss	104	154	34	46	49	44	146	42	0.37

Table 12. Concentration measurement results and average sampler PM<sub>10</sub>/TSP concentration ratios from the sampling conducted at farm 3 during 2006.

Test	Treatment	TSP Sampler Concentration (µg/m <sup>3</sup> )			PM <sub>10</sub> Sampler Concentrations (µg/m <sup>3</sup> )			Upwind Concentrations (µg/m <sup>3</sup> )		Avg. DW PM <sub>10</sub> / TSP Ratio
		Mean	Max	Min	Mean	Max	Min	TSP	PM <sub>10</sub>	
1	2 Row	242	297	170	75	102	60	33	36	0.26
2	6 Row	164	232	95	89	135	70	20	75	0.44
3	2 Row	76	90	57	28	41	16	112	29	0.43
4	6 Row	105	190	37	165	574	23	2	2	0.21
5	2 Row	237	704	50	37	57	22	49	18	0.48

Table 13. Concentration measurement results and average sampler PM<sub>10</sub>/TSP concentration ratios from the sampling conducted at farm 3 during 2007.

Test	Treatment	TSP Sampler Concentration (µg/m <sup>3</sup> )			PM <sub>10</sub> Sampler Concentrations (µg/m <sup>3</sup> )			Upwind Concentrations (µg/m <sup>3</sup> )		Avg. DW PM <sub>10</sub> / TSP Ratio
		Mean	Max	Min	Mean	Max	Min	TSP	PM <sub>10</sub>	
1	6 Row	136	160	94	100	122	61	58	32	0.73
2	6 Row	135	183	65	106	133	94	25	18	0.78
3	6 Row	159	229	51	108	227	15	25	18	0.24
4	6 Row	209	346	138	115	168	54	25	18	0.60
5	6 Row	103	164	64	57	90	34	25	18	0.68
6	6 Row w/SS	130	198	95	67	81	53	35	12	0.44
7	6 Row w/SS	115	221	54	51	80	27	35	12	0.29
8	6 Row w/SS	103	191	38	38	68	12	17	27	0.39
9	6 Row w/SS	79	164	7	38	70	31	17	27	0.46
10	6 Row w/SS	143	259	32	37	111	3	17	27	0.33
11	6 Row w/SS	226	368	73	93	186	35	17	27	0.49
12	6 Row w/SS	150	310	34	89	171	19	17	27	0.53
13	6 Row w/SS	143	230	55	100	146	70	27	27	0.62
14	6 Row w/SS	273	574	110	117	185	53	27	27	0.68
15	6 Row w/SS	157	431	28	74	146	10	27	27	0.60
16	2 Row	156	282	14	61	94	18	38	34	0.33
17	2 Row	73	98	49	36	47	33	37	32	0.56
18	2 Row	57	76	34	28	47	8	37	32	0.43
19	2 Row	96	133	51	49	80	49	70	37	0.49
20	2 Row	332	389	308	102	116	87	70	37	0.33
21	2 Row	221	418	74	125	217	41	70	37	0.66

The concentration results presented in Tables 10 - 13 were developed from the average concentrations measured over the duration of each test. The test durations ranged from 3 – 5 hours for the two-row harvester and from 1 – 2 hours for the six-row harvester. The TSP and PM<sub>10</sub> concentrations measured during each test at farms 1, 2, and 3 during 2006 and 2007 are included in Appendix C.

### ***PM<sub>10</sub> Sampling Errors***

The ratio of the concentration measured by the PM<sub>10</sub> sampler to the true PM<sub>10</sub> concentration (measured/true PM<sub>10</sub> concentration ratio) was calculated for each TSP sampler filter used in the PSD analysis using the concentration from the corresponding collocated PM<sub>10</sub> sampler. The true PM<sub>10</sub> concentrations were calculated by multiplying the TSP concentration (of the filters used in the PSD analysis) by the PM mass %  $\leq 10$   $\mu\text{m}$  from the Coulter Counter PSD analysis. The measured/true PM<sub>10</sub> concentration ratio was in the following ranges for each farm:

- 44% to 122% for farm 1 (2006),
- 70% to 130% for farm 2 (2006),
- 70% to 300% for farm 3 (2006), and
- 34% to 271% for farm 3 (2007).

A measured/true PM<sub>10</sub> concentration ratio less than 100% indicates that the PM<sub>10</sub> sampler measured a concentration less than the true PM<sub>10</sub> concentration calculated from the TSP concentration. A possible explanation is that the loading on the PM<sub>10</sub> sampler filters was too light to give an accurate PM<sub>10</sub> concentration. However, these results also indicate that it is possible for an FRM PM<sub>10</sub> sampler to measure a PM<sub>10</sub> concentration three times greater than the true concentration of PM<sub>10</sub> present. These results are similar to those found by Buser (2004).

### ***ISCST3 Emission Factor Results***

The emission factor results from the dispersion modeling procedure using ISCST3 for farm 1 from 2006 are shown in Table 14. An ANOVA on the emission

factor data by harvester treatment indicated no significant difference for any of the harvester treatments (all p values > 0.3). The overall and treatment emission factor means in terms of kg/ha and kg/bale are shown in Table 14. The mass %PM<sub>10</sub> and PM<sub>2.5</sub> used to convert the TSP emission factors to a PM<sub>10</sub> and PM<sub>2.5</sub> basis were 35.8 and 0.2%, respectively. Detailed results of PSD analyses on the TSP samples are discussed later.

Table 14. Emission factor results from the dispersion modeling procedure using ISCST3 for farm 1 during 2006.

Test	Treatment	PM <sub>10</sub> Emission Factors		PM <sub>2.5</sub> Emission Factors		TSP Emission Factors	
		(kg/ha)	(kg/bale)	(kg/ha)	(kg/bale)	(kg/ha)	(kg/bale)
1	2 row	0.48	0.15	2.68E-03	8.56E-04	1.34	0.43
2	6 row	0.99	0.31	5.53E-03	1.71E-03	2.77	0.85
3	6 row w/ss <sup>+</sup>	0.18	0.05	1.02E-03	2.67E-04	0.51	0.13
4	6 row	0.41	0.09	2.28E-03	5.10E-04	1.14	0.25
5	2 row	0.65	0.15	3.65E-03	8.38E-04	1.83	0.42
6	6 row	0.56	0.14	3.11E-03	7.61E-04	1.55	0.38
7	6 row w/ss	0.65	0.18	3.64E-03	1.03E-03	1.82	0.51
8	6 row	0.99	0.20	5.51E-03	1.10E-03	2.75	0.55
9	2 row	0.87	0.19	4.88E-03	1.07E-03	2.44	0.54
10	6 row w/ss	0.32	0.09	1.80E-03	4.82E-04	0.90	0.24
<b>Overall Means</b>		<b>0.61</b>	<b>0.15</b>	<b>3.41E-03</b>	<b>8.62E-04</b>	<b>1.70</b>	<b>0.43</b>
2 Row Means*		0.67 <sup>a</sup>	0.17 <sup>d</sup>	3.74E-03 <sup>b</sup>	9.22E-04 <sup>e</sup>	1.87 <sup>c</sup>	0.46 <sup>f</sup>
6 Row Means*		0.73 <sup>a</sup>	0.18 <sup>d</sup>	4.10E-03 <sup>b</sup>	1.02E-03 <sup>e</sup>	2.05 <sup>c</sup>	0.51 <sup>f</sup>
6 Row w/ss Means*		0.39 <sup>a</sup>	0.11 <sup>d</sup>	2.15E-03 <sup>b</sup>	5.92E-04 <sup>e</sup>	1.08 <sup>c</sup>	0.30 <sup>f</sup>

<sup>+</sup>Emission factors reported for the 6 row w/ss treatment were developed from the methods described in protocol I using the upwind/downwind measured concentrations and not by the source sampling protocol.

\*Means with the same letter are not significantly different at the 0.05 level of significance by Fisher's LSD test.

The emission factor results from ISCST3 in terms of kg/ha and kg/bale for farm 2 during 2006 are shown in Table 15. Similar to the data presented for farm 1, an ANOVA on the farm 2 emission factor data indicated no significant differences by harvesting treatment within any PM size range (i.e. PM<sub>10</sub>, PM<sub>2.5</sub>, TSP) for either emission factor basis (all p values > 0.286). The mass %PM<sub>10</sub> and PM<sub>2.5</sub> used to convert the TSP emission factors to a PM<sub>10</sub> and PM<sub>2.5</sub> basis were 48.8 and 0.2%, respectively.

Table 15. Emission factor results from the dispersion modeling procedure using ISCST3 for farm 2 during 2006.

Test	Treatment	PM <sub>10</sub> Emission Factors		PM <sub>2.5</sub> Emission Factors		TSP Emission Factors	
		(kg/ha)	(kg/bale)	(kg/ha)	(kg/bale)	(kg/ha)	(kg/bale)
1	6 row	0.49	0.13	2.02E-03	5.35E-04	1.01	0.27
2	6 row	1.11	0.23	4.54E-03	9.47E-04	2.27	0.47
3	6 row	1.20	0.30	4.92E-03	1.21E-03	2.46	0.61
4	2 row	0.91	0.25	3.71E-03	1.04E-03	1.86	0.52
5	2 row	1.17	0.31	4.81E-03	1.26E-03	2.41	0.63
6	2 row	0.70	0.19	2.86E-03	7.69E-04	1.43	0.38
7	6 row w/ss <sup>+</sup>	0.71	0.18	2.90E-03	7.24E-04	1.45	0.36
8	6 row w/ss	0.38	0.10	1.56E-03	3.96E-04	0.78	0.20
<b>Overall Means</b>		<b>0.83</b>	<b>0.21</b>	<b>3.42E-03</b>	<b>8.60E-04</b>	<b>1.71</b>	<b>0.43</b>
2 Row Means*		0.93 <sup>a</sup>	0.25 <sup>d</sup>	3.80E-03 <sup>b</sup>	1.02E-03 <sup>e</sup>	1.90 <sup>c</sup>	0.51 <sup>f</sup>
6 Row Means*		0.93 <sup>a</sup>	0.22 <sup>d</sup>	3.83E-03 <sup>b</sup>	8.98E-04 <sup>e</sup>	1.91 <sup>c</sup>	0.45 <sup>f</sup>
6 Row w/ss Means*		0.54 <sup>a</sup>	0.14 <sup>d</sup>	2.23E-03 <sup>b</sup>	5.60E-04 <sup>e</sup>	1.11 <sup>c</sup>	0.28 <sup>f</sup>

<sup>+</sup>Emission factors reported for the 6 row w/ss treatment were developed from the methods described in protocol I using the upwind/downwind measured concentrations and not by the source sampling protocol.

\*Means with the same letter are not significantly different at the 0.05 level of significance by Fisher's LSD test.

The emission factor results from the dispersion modeling process using ISCST3 for farm 3 during 2006 are shown in Table 16. The 2-row and 6-Row harvesting treatments were significantly different (by ANOVA) when comparing the emission factors on a kg/ha basis within the PM<sub>10</sub> (p value = 0.30), PM<sub>2.5</sub> (p value = 0.29), and TSP (p value = 0.29) size indicators. The 2-Row harvesting treatment yielded higher emission factors in terms of kg/ha than the 6-Row treatment. However, no significant differences were observed in the emission factors between harvesting treatments within any PM size range for the kg/bale emission factors (all p values > 0.075). The mass %PM<sub>10</sub> and PM<sub>2.5</sub> used to convert the TSP emission factors to a PM<sub>10</sub> and PM<sub>2.5</sub> basis were 30.3 and 0.1%, respectively.



Table 16. Emission factor results from the dispersion modeling procedure using ISCST3 for farm 3 during 2006.

Test	Treatment	PM <sub>10</sub> Emission Factors		PM <sub>2.5</sub> Emission Factors		TSP Emission Factors	
		(kg/ha)	(kg/bale)	(kg/ha)	(kg/bale)	(kg/ha)	(kg/bale)
1	2 Row	1.07	0.50	3.24E-02	1.50E-02	3.60	1.67
2	6 Row	0.30	0.06	9.11E-03	1.90E-03	1.01	0.21
3	2 Row	1.30	0.37	3.93E-02	1.11E-02	4.37	1.23
4	6 row	0.53	0.10	1.60E-02	2.97E-03	1.78	0.33
5	2 Row	0.90	0.22	2.73E-02	6.59E-03	3.04	0.73
<b>Overall Means</b>		<b>0.82</b>	<b>0.25</b>	<b>2.48E-02</b>	<b>7.52E-03</b>	<b>2.76</b>	<b>0.84</b>
2 Row Means*		1.09 <sup>a</sup>	0.36 <sup>g</sup>	3.30E-02 <sup>c</sup>	1.09E-02 <sup>h</sup>	3.67 <sup>e</sup>	1.21 <sup>i</sup>
6 Row Means*		0.41 <sup>b</sup>	0.08 <sup>g</sup>	1.25E-02 <sup>d</sup>	2.44E-03 <sup>h</sup>	1.39 <sup>f</sup>	0.27 <sup>i</sup>

\*Means with the same letter are not significantly different at the 0.05 level of significance.

The emission factors from the dispersion modeling procedure using ISCST3 for farm 3 during 2007 are shown in Table 17. Significant differences in the emission factor data by harvesting treatment were observed for emission factors reported in terms of kg/ha and kg/bale through ANOVA. A p value of 0.044 was observed for the ANOVA tests performed on the PM<sub>10</sub>, PM<sub>2.5</sub>, and TSP emission factors reported in kg/ha. LSD post hoc tests indicate that the 6-row treatment emission factors were lower than both the 2-row and 6-row w/ss treatments. Similarly, a p value of 0.008 was observed for the ANOVA tests performed on the emission factor data reported in terms of kg/bale. The common p value for all the ANOVA tests within an emission factor unit basis was expected as the PM<sub>10</sub> and PM<sub>2.5</sub> emission factors are simply a constant fraction of the TSP emission factor equal to the respective mass percent from the PSD analysis. Yield data was not available for the 2-Row harvesting tests conducted during 2007; therefore emission factors are not reported in terms of kg/bale.

Table 17. Emission factor results from the dispersion modeling procedure using ISCST3 for farm 3 during 2007.

Test	Treatment	PM <sub>10</sub> Emission Factors		PM <sub>2.5</sub> Emission Factors		TSP Emission Factors	
		(kg/ha)	(kg/bale)	(kg/ha)	(kg/bale)	(kg/ha)	(kg/bale)
1	6 Row	0.51	0.11	1.42E-03	2.99E-04	1.47	0.31
2	6 Row	0.89	0.20	2.47E-03	5.41E-04	2.57	0.56
3	6 Row	0.54	0.06	1.49E-03	1.73E-04	1.55	0.18
4	6 Row	0.96	0.11	2.67E-03	3.03E-04	2.77	0.31
5	6 Row	0.44	0.06	1.23E-03	1.67E-04	1.28	0.17
6	6 Row w/ss <sup>†</sup>	1.21	0.19	3.36E-03	5.31E-04	3.49	0.55
7	6 Row w/ss	1.17	0.20	3.23E-03	5.43E-04	3.36	0.56
8	6 Row w/ss	3.12	0.53	8.65E-03	1.46E-03	8.99	1.52
9	6 Row w/ss	1.49	0.22	4.12E-03	6.00E-04	4.28	0.62
10	6 Row w/ss	4.06	0.45	1.12E-02	1.24E-03	11.68	1.29
11	6 Row w/ss	6.98	0.75	1.93E-02	2.09E-03	20.10	2.17
12	6 Row w/ss	4.27	0.51	1.18E-02	1.42E-03	12.30	1.47
13	6 Row w/ss	6.67	0.81	1.85E-02	2.25E-03	19.19	2.34
14	6 Row w/ss	5.19	0.77	1.44E-02	2.14E-03	14.95	2.23
15	6 Row w/ss	1.89	0.25	5.25E-03	6.95E-04	5.46	0.72
16	2 Row	5.02	n/a	1.39E-02	n/a	14.47	n/a
17	2 Row	0.68	n/a	1.87E-03	n/a	1.95	n/a
18	2 Row	0.65	n/a	1.81E-03	n/a	1.88	n/a
19	2 Row	1.74	n/a	4.81E-03	n/a	5.00	n/a
20	2 Row	5.95	n/a	1.65E-02	n/a	17.14	n/a
21	2 Row	4.70	n/a	1.30E-02	n/a	13.52	n/a
<b>Overall Means</b>		<b>2.77</b>	<b>0.35</b>	<b>7.67E-03</b>	<b>9.63E-04</b>	<b>7.97</b>	<b>1.00</b>
2 Row Means*, §		3.12 <sup>a, b</sup>	n/a	8.65E-03 <sup>c, d</sup>	n/a	8.99 <sup>e, f</sup>	n/a
6 Row Means*		0.67 <sup>a</sup>	0.11 <sup>g</sup>	1.85E-03 <sup>c</sup>	2.96E-04 <sup>i</sup>	1.93 <sup>e</sup>	0.31 <sup>k</sup>
6 Row w/ss Means*		3.60 <sup>b</sup>	0.47 <sup>h</sup>	9.99E-03 <sup>d</sup>	1.30E-03 <sup>j</sup>	10.37 <sup>f</sup>	1.35 <sup>l</sup>

<sup>†</sup>Emission factors reported for the 6 row w/ss treatment were developed from the methods described in protocol I using the upwind/downwind measured concentrations and not by the source sampling protocol.

\* Means with the same letter are not significantly different at the 0.05 level of significance.

§ Yield data was not available for the 2 row harvesting treatment from 2007.

ANOVA tests were performed on a combined data set made up of the emission factor data reported for each farm from both 2006 and 2007 (see Table 18). The ANOVA tests on the emission factors for each size indicator reported in terms of kg/ha indicated significant differences by farm (4 farms) (p values < 0.008). Significant differences were observed in the kg/ha emission factor data by harvesting treatment for the TSP and PM<sub>10</sub> size indicators (TSP p value = 0.023, PM<sub>10</sub> p value = 0.024). Significant differences in the PM<sub>2.5</sub> emission factor data by harvesting treatment, reported in terms of kg/ha, were not observed (p value = 0.080).

Table 18. Summary of ISCST3 emission factor results combining the data from farms 1, 2, and 3 (2006) and farm 3 (2007).

Year	Means For	PM <sub>10</sub> Emission Factors		PM <sub>2.5</sub> Emission Factors		TSP Emission Factors	
		(kg/ha)	(kg/bale)	(kg/ha)	(kg/bale)	(kg/ha)	(kg/bale)
2006	Farm 1*	0.61 <sup>a</sup>	0.15 <sup>d</sup>	3.41E-03 <sup>g</sup>	8.62E-04 <sup>i</sup>	1.70 <sup>k</sup>	0.43 <sup>n</sup>
2006	Farm 2*	0.83 <sup>a</sup>	0.21 <sup>d</sup>	3.42E-03 <sup>g</sup>	8.60E-04 <sup>i</sup>	1.71 <sup>k</sup>	0.43 <sup>n</sup>
2006	Farm 3*	0.82 <sup>a</sup>	0.25 <sup>d</sup>	2.48E-02	7.52E-03	2.76 <sup>k</sup>	0.84 <sup>no</sup>
2007	Farm 3*	2.77	0.35 <sup>d</sup>	7.67E-03	9.63E-04 <sup>i</sup>	7.97	1.00 <sup>o</sup>
		<b>1.79<sup>bc</sup></b>	<b>0.26<sup>e</sup></b>	<b>1.16E-02<sup>h</sup></b>	<b>4.28E-03</b>	<b>5.09<sup>LM</sup></b>	<b>0.73<sup>pq</sup></b>
	2 Row*	± 0.92	± 0.08	± 6.18E-3	± 3.52E-3	± 2.68	± 0.29
		<b>0.71<sup>b</sup></b>	<b>0.15<sup>e</sup></b>	<b>4.45E-03<sup>h</sup></b>	<b>9.38E-04<sup>j</sup></b>	<b>1.88<sup>L</sup></b>	<b>0.39<sup>p</sup></b>
	6 Row*	± 0.16	± 0.04	± 2.08E-3	± 4.18E-4	± 0.36	± 0.1
		<b>2.55<sup>c</sup></b>	<b>0.35<sup>f</sup></b>	<b>7.38E-03<sup>h</sup></b>	<b>1.06E-03<sup>j</sup></b>	<b>7.28<sup>M</sup></b>	<b>0.99<sup>q</sup></b>
	6 Row w/ss* <sup>+</sup>	± 1.18	± 0.13	± 3.14E-3	± 3.42E-4	± 3.44	± 0.39

Treatment means are shown with 95% confidence intervals.

\* Means with the same letter are not significantly different at the 0.05 level of significance.

<sup>+</sup>Emission factors reported for the 6 row w/ss treatment were developed from the methods described in protocol I using the upwind/downwind measured concentrations and not by the source sampling protocol.

Significant differences by farm were observed within the TSP and PM<sub>2.5</sub> emission factor data reported in terms of kg/bale (TSP p value = 0.043, PM<sub>2.5</sub> p value < 0.001). Overall, significant differences were observed in the TSP emission factor data (kg/bale) by harvester treatment (p value = 0.020). However, significant differences by harvester treatment were observed in the PM<sub>2.5</sub> emission factor data (p value = 0.01). The combined PM<sub>10</sub> emission factor data, in terms of kg/bale, indicated no significant differences by farm (p value = 0.121) but significant differences were observed by harvesting treatment (p value = 0.019).

### ***AERMOD Emission Factor Results***

The emission factors developed for the harvesting tests conducted at farm 3 during 2007 are shown in Table 19. Significant differences were observed in the mean emission factors by harvesting treatment for the emission factors reported in terms of kg/ha (p value = 0.046). Fisher's LSD test indicates that the 2-row and 6-row treatment means for PM<sub>10</sub>, PM<sub>2.5</sub>, and TSP are significantly different (p value = 0.014) with the 2-row treatment mean larger than the 6-row harvesting treatment. ANOVA tests on the emission factor data in terms of kg/bale indicate a significant difference (p value = 0.018) between the 6-row and 6-row w/ss treatment means for PM<sub>10</sub>, PM<sub>2.5</sub>, and TSP. Inspection of the data shows the treatment means for the 6-row w/ss to be higher than the 6-row treatment means. Yield data was not available for the 2-row tests during 2007. The mass %PM<sub>10</sub> and PM<sub>2.5</sub> used to convert the TSP emission factors to a PM<sub>10</sub> and PM<sub>2.5</sub> basis were 34.7 and 0.1%, respectively. Detailed results of PSD analyses on the TSP samples is discussed later.

Table 19. Emission factor results from the dispersion modeling procedure using AERMOD for farm 3 during 2007.

Test	Treatment	PM <sub>10</sub> Emission Factors		PM <sub>2.5</sub> Emission Factors		TSP Emission Factors	
		(kg/ha)	(kg/bale)	(kg/ha)	(kg/bale)	(kg/ha)	(kg/bale)
1	6 Row	0.87	0.18	2.42E-03	5.10E-04	2.52	0.53
2	6 Row	1.32	0.29	3.67E-03	8.04E-01	3.81	0.84
3	6 Row	1.65	0.19	4.57E-03	5.31E-01	4.75	0.55
4	6 Row	1.39	0.16	3.85E-03	4.37E-01	4.00	0.45
5	6 Row	0.30	0.04	8.43E-04	1.14E-01	0.88	0.12
6	6 Row w/ss <sup>+</sup>	1.69	0.27	4.67E-03	7.39E-01	4.86	0.77
7	6 Row w/ss	1.28	0.21	3.54E-03	5.95E-01	3.68	0.62
8	6 Row w/ss	2.93	0.49	8.11E-03	1.37E+00	8.43	1.42
9	6 Row w/ss	1.62	0.24	4.50E-03	6.55E-01	4.68	0.68
10	6 Row w/ss	3.93	0.43	1.09E-02	1.20E+00	11.31	1.25
11	6 Row w/ss	4.98	0.54	1.38E-02	1.49E+00	14.34	1.55
12	6 Row w/ss	2.77	0.33	7.68E-03	9.18E-01	7.98	0.95
13	6 Row w/ss	5.22	0.64	1.45E-02	1.76E+00	15.02	1.83
14	6 Row w/ss	3.83	0.57	1.06E-02	1.58E+00	11.03	1.65
15	6 Row w/ss	1.35	0.18	3.73E-03	4.95E-01	3.88	0.51
16	2 Row	5.64	n/a	1.56E-02	n/a	16.23	n/a
17	2 Row	1.16	n/a	3.22E-03	n/a	3.35	n/a
18	2 Row	0.81	n/a	2.25E-03	n/a	2.34	n/a
19	2 Row	9.22	n/a	2.55E-02	n/a	26.55	n/a
20	2 Row	8.50	n/a	2.35E-02	n/a	24.46	n/a
21	2 Row	2.97	n/a	8.22E-03	n/a	8.54	n/a
<b>Overall Means</b>		<b>3.02</b>	<b>0.32</b>	<b>8.37E-03</b>	<b>8.46E-01</b>	<b>8.70</b>	<b>0.92</b>
2 Row Means* <sup>§</sup>		<b>4.72<sup>a</sup></b> ± 2.92	n/a	<b>1.31E-02<sup>c</sup></b> ± 0.0081	n/a	<b>13.58<sup>e</sup></b> ± 8.39	n/a
6 Row Means*		<b>1.11<sup>b</sup></b> ± 0.47	<b>0.17<sup>g</sup></b> ± 0.08	<b>3.07E-03<sup>d</sup></b> ± 0.0013	<b>4.78E-4<sup>i</sup></b> ± 2.17E-4	<b>3.19<sup>f</sup></b> ± 1.33	<b>0.50<sup>k</sup></b> ± 0.22
6 Row w/ss Means*		<b>2.96<sup>ab</sup></b> ± 0.92	<b>0.39<sup>h</sup></b> ± 0.10	<b>8.20E-03<sup>cd</sup></b> ± 0.0026	<b>1.08E-3<sup>j</sup></b> ± 2.84E-4	<b>8.52<sup>ef</sup></b> ± 2.64	<b>1.12<sup>L</sup></b> ± 0.29

<sup>+</sup>Emission factors reported for the 6 row w/ss treatment were developed from the methods described in protocol I using the upwind/downwind measured concentrations and not by the source sampling protocol.

\* Means with the same letter are not significantly different at the 0.05 level of significance.

<sup>§</sup> Yield data was not available for the 2 row harvesting treatment from 2007.

Treatment means are displayed with 95% confidence intervals.

### *Emission Factor Analysis Summary*

The emission factor data presented previously exhibits wide variation due to meandering wind direction, source-to-receptor configuration, and low net mass on the

TSP filters used in the analysis. Thus, statistical differences by harvesting treatment were not readily observed for the ISCST3 emission factor data for the two year combined data. Uncertainty in the determination of emission factors through dispersion modeling has not been addressed from an objective standpoint other than to say that the reported systematic uncertainty in the measured TSP sampler concentrations is on the order of 12% (Price, 2004).

Statistical differences were observed in the emission factor data produced with AERMOD between the 2-row and 6-row harvesting treatments with the mean 2-row emission factors being approximately four times greater than the 6-row treatment. Wide variation in the emission factor data from AERMOD was also observed.

In an effort to further investigate the trends in the emission factor data produced with both ISCST3 and AERMOD, correlation analyses were conducted on the emission factor variables (i.e.  $PM_{10}$ ,  $PM_{2.5}$ , and TSP emission factors in terms of kg/ha and kg/bale). The emission factor variables were correlated with crop yield (lint bales/ha), test plot area (ha), test duration (min), soil mass % < 75  $\mu m$ , soil mass % < 106  $\mu m$ , seed cotton moisture content (%), and soil surface moisture content (%). The results of the correlation analysis using the ISCST3 and AERMOD emission factor data are shown in Tables 20 and 21, respectively.

Table 20. Correlation analysis results using the emission factor results produced with ISCST3. (significant correlations at the 0.01 level are highlighted)

		ISCST3 Emission Factors					
		TSP (kg/ha)	PM <sub>10</sub> (kg/ha)	PM <sub>2.5</sub> (kg/ha)	TSP (kg/bale)	PM <sub>10</sub> (kg/bale)	PM <sub>2.5</sub> (kg/bale)
Yield (bales/ha)	R	0.64	0.79	0.00	0.38	0.37	-0.29
	p value	<0.001	<0.001	0.995	0.019	0.022	0.080
Area (ha)	R	-0.60	-0.74	-0.07	-0.43	-0.46	0.17
	p value	<0.001	<0.001	0.653	0.008	0.003	0.318
Test Duration (min)	R	-0.32	-0.26	0.20	-0.13	-0.14	0.41
	p value	0.033	0.089	0.194	0.437	0.395	0.011
Soil Mass % < 75 $\mu$ m	R	-0.10	0.13	0.08	-0.18	-0.26	0.24
	p value	0.522	0.410	0.598	0.284	0.123	0.158
Soil Mass % < 106 $\mu$ m	R	-0.12	0.14	0.06	-0.18	-0.26	0.24
	p value	0.456	0.384	0.698	0.294	0.133	0.167
Seed Cotton Moisture Content (%)	R	-0.05	0.03	-0.28	-0.07	-0.09	-0.28
	p value	0.743	0.860	0.068	0.665	0.597	0.092
Soil Surface Moisture Content (%)	R	0.04	0.18	0.04	-0.31	-0.32	-0.31
	p value	0.878	0.440	0.878	0.278	0.271	0.278

The correlation results shown in Table 20 for the ISCST3 emission factors indicate that the TSP and PM<sub>10</sub> emission factors in terms of kg/ha are significantly correlated with yield at the 0.01 level of significance. Similarly, the TSP and PM<sub>10</sub> emission factors (for both kg/ha and kg/bale) are significantly correlated with the test plot area at the 0.01 level of significance. The correlation values with regard to test plot area are negative while those for yield are positive and slightly higher.

Significant correlations between yield and PM emission factors is logical in that as the machines process more total material, so should PM emissions increase proportionally. However, significant correlations with area seem not to follow intuition as well. The observed negative correlations indicate that as the test plot area increases, the emission factors on a mass/unit area and mass/bale basis decrease.

Table 21. Correlation analysis results using the emission factor results produced with AERMOD.

		<b>AERMOD Emission Factors</b>					
		<b>TSP (kg/ha)</b>	<b>PM<sub>10</sub> (kg/ha)</b>	<b>PM<sub>2.5</sub> (kg/ha)</b>	<b>TSP (kg/bale)</b>	<b>PM<sub>10</sub> (kg/bale)</b>	<b>PM<sub>2.5</sub> (kg/bale)</b>
<b>Yield (bales/ha)</b>	R	0.48	0.48	0.48	0.19	0.19	0.29
	p value	0.070	0.069	0.069	0.492	0.490	0.296
<b>Area (ha)</b>	R	-0.44	-0.44	-0.44	-0.29	-0.29	-0.42
	p value	0.045	0.045	0.045	0.290	0.289	0.118
<b>Test Duration (min)</b>	R	0.24	0.24	0.24	0.11	0.11	0.02
	p value	0.292	0.293	0.293	0.689	0.690	0.942
<b>Soil Mass % &lt; 75 <math>\mu</math>m</b>	R	0.18	0.18	0.17	-0.45	-0.45	-0.39
	p value	0.446	0.447	0.449	0.096	0.095	0.148
<b>Soil Mass % &lt; 106 <math>\mu</math>m</b>	R	0.24	0.24	0.24	-0.42	-0.42	-0.36
	p value	0.286	0.287	0.288	0.123	0.123	0.193
<b>Seed Cotton Moisture Content (%)</b>	R	-0.12	-0.12	-0.12	-0.06	-0.06	-0.10
	p value	0.609	0.608	0.608	0.828	0.828	0.736
<b>Soil Surface Moisture Content (%)</b>	R	0.20	0.20	0.19	-0.33	-0.33	-0.24
	p value	0.409	0.408	0.410	0.242	0.243	0.406

The correlation analysis using the AERMOD emission factor data indicate no significant correlations at the 0.01 level of significance. Although reduced in magnitude, the correlation coefficients between the emission factor data and test plot area maintain the previously observed indirect nature.

The correlation results between the emission factor data and the test plot area may be an indication of fallacy in the steady state area source assumption in the dispersion modeling process. In reality, the emissions generated by the cotton harvester moving through the field is best described as a mobile point source.

The following general findings were observed from the emission factors developed using Protocol I:



- As indicated by previous research, ISCST3 over estimates downwind concentrations when used to predict hourly concentrations. Thus, sub-hourly variations in wind direction and speed can be accounted for more appropriately in downwind concentration predictions using meteorological data averaged over shorter time periods on the order of 15 to 20 minutes.
- The amount of meteorological input data required by AERMOD is substantially greater than the data required by ISCST3. Thus, the meteorological data processing time is significantly increased for AERMOD.
- The majority of the additional meteorological input parameters required by AERMOD (surface friction velocity, surface sensible heat flux, Monin-Obukhov length, and convective velocity scale) can be calculated from wind vector and temperature measurements taken by a 3D sonic anemometer. The remaining parameters (temperature scale and potential temperature gradient) can be obtained from radiosonde data of the upper atmosphere or through the empirical relationships described by EPA (2004).
- AERMOD, the dispersion model recommended by EPA for regulatory purposes after 2007, characterizes dispersion within the planetary boundary layer under stable and convective conditions by a mass weighted average, two plume state model. The first plume state accounts for pollutants contained in the horizontal flow near the surface of the Earth which do not possess sufficient kinetic energy to pass over or around complex terrain features. The second plume state accounts for the mass of pollutants in the turbulent flow region above the horizontal plume (state one) which have sufficient kinetic energy to maintain entrainment when flowing around or over complex terrain features.
- The emission factors calculated through the dispersion modeling process are greatly dependent upon the source to receptor configuration. Variation in wind direction and speed can exacerbate the variation incorporated in emission flux values determined through the dispersion modeling process. An objective validation process was used to identify receptor locations which would likely yield unreliable emission flux

estimates due to improper sampler operation, significant influence from outside sources of PM, and the inability for the dispersion model to closely approximate the dispersion of PM emissions from the source as observed through the concentrations measured downwind.

- Errors were observed in the FRM PM<sub>10</sub> sampler concentrations measured downwind of the harvesting operations. The ratio of the true PM<sub>10</sub> concentration to the measured PM<sub>10</sub> concentration varied by farm but ranged from 34 to 300%. True PM<sub>10</sub> concentrations were determined by multiplying the measured collocated TSP concentration by the mass fraction of PM<sub>10</sub> from PSD analysis.
- The treatment mean TSP emission factors in terms of kg/ha (lb/ac) from the 2006 and 2007 combined data set resulting from the dispersion modeling procedure using ISCST3 are:
  - 2-Row:  $5.09 \pm 2.68$  kg/ha ( $4.54 \pm 2.39$  lb/ac),
  - 6-Row:  $1.88 \pm 0.36$  kg/ha ( $1.68 \pm 0.32$  lb/ac), and
  - 6-Row w/SS:  $7.28 \pm 3.44$  kg/ha ( $6.49 \pm 3.07$  lb/ac).

Emission factors reported for the 6 row w/ss treatment were developed from the methods described in protocol I using the upwind/downwind measured concentrations and not by the source sampling protocol.
- The treatment mean PM<sub>10</sub> emission factors in terms of kg/ha (lb/ac) from the 2006 and 2007 combined data set resulting from the dispersion modeling procedure using ISCST3 are:
  - 2-Row:  $1.79 \pm 0.92$  kg/ha ( $1.6 \pm 0.82$  lb/ac),
  - 6-Row:  $0.71 \pm 0.16$  kg/ha ( $0.63 \pm 0.14$  lb/ac), and
  - 6-Row w/SS:  $2.55 \pm 1.18$  kg/ha ( $2.27 \pm 1.05$  lb/ac).
- The treatment mean PM<sub>2.5</sub> emission factors in terms of kg/ha (lb/ac) from the 2006 and 2007 combined data set resulting from the dispersion modeling procedure using ISCST3 are:
  - 2-Row:  $1.16\text{E-}2 \pm 6.18\text{E-}3$  kg/ha ( $1.03\text{E-}2 \pm 5.51\text{E-}3$  lb/ac),
  - 6-Row:  $4.45\text{E-}3 \pm 2.08\text{E-}3$  kg/ha ( $3.97\text{E-}3 \pm 1.86\text{E-}3$  lb/ac), and

- 6-Row w/SS:  $7.38\text{E-}3 \pm 3.14\text{E-}3$  kg/ha ( $6.58\text{E-}3 \pm 2.8\text{E-}3$  lb/ac).
- The treatment mean TSP emission factors in terms of kg/bale (lb/bale) from the 2006 and 2007 combined data set resulting from the dispersion modeling procedure using ISCST3 are:
  - 2-Row:  $0.73 \pm 0.29$  kg/bale ( $1.61 \pm .64$  lb/bale),
  - 6-Row:  $0.39 \pm 0.1$  kg/bale ( $0.86 \pm 0.22$  lb/bale), and
  - 6-Row w/SS:  $0.99 \pm 0.39$  kg/bale ( $2.18 \pm 0.86$  lb/bale).
- The treatment mean PM<sub>10</sub> emission factors in terms of kg/bale (lb/bale) from the 2006 and 2007 combined data set resulting from the dispersion modeling procedure using ISCST3 are:
  - 2-Row:  $0.26 \pm 0.08$  kg/bale ( $0.57 \pm 0.18$  lb/bale),
  - 6-Row:  $0.15 \pm 0.04$  kg/bale ( $0.33 \pm 0.09$  lb/bale), and
  - 6-Row w/SS:  $0.35 \pm 0.13$  kg/bale ( $0.77 \pm 0.29$  lb/bale).
- The treatment mean PM<sub>2.5</sub> emission factors in terms of kg/bale (lb/bale) from the 2006 and 2007 combined data set resulting from the dispersion modeling procedure using ISCST3 are:
  - 2-Row:  $4.28\text{E-}3 \pm 3.52\text{E-}3$  kg/bale ( $9.43\text{E-}3 \pm 7.75\text{E-}3$  lb/bale),
  - 6-Row:  $9.38\text{E-}4 \pm 4.18\text{E-}4$  kg/bale ( $2.07\text{E-}3 \pm 9.21\text{E-}4$  lb/bale), and
  - 6-Row w/SS:  $1.06\text{E-}3 \pm 3.42\text{E-}4$  kg/bale ( $2.34\text{E-}3 \pm 7.53\text{E-}4$  lb/bale).
- The combined ISCST3 emission factor data from 2006 and 2007 indicates that there is not a significant difference in PM emission factors for any size indicator for the two-row and six-row harvesting treatments (kg/ha emission factor basis). Similarly, significant differences were not observed between the two-row and six-row machines for the kg/bale data with the exception of the PM<sub>2.5</sub> data. Although significant differences were not observed, there is a substantial difference in the mean emission factors for the two-row and six-row harvesting treatments. This result is likely due to the great amount of variability introduced in the emission factors from wind direction/speed variation.

- The TSP emission factors for farm 3 during 2007 in terms of kg/ha (lb/ac) from the dispersion modeling process using AERMOD are:
  - 2-Row:  $13.58 \pm 8.39$  kg/ha ( $12.1 \pm 7.48$  lb/ac),
  - 6-Row:  $3.19 \pm 1.33$  kg/ha ( $2.84 \pm 1.19$  lb/ac), and
  - 6-Row w/SS:  $8.52 \pm 2.64$  kg/ha ( $7.59 \pm 2.35$  lb/ac).
- The PM<sub>10</sub> emission factors for farm 3 during 2007 in terms of kg/ha (lb/ac) from the dispersion modeling process using AERMOD are:
  - 2-Row:  $4.72 \pm 2.92$  kg/ha ( $4.21 \pm 2.6$  lb/ac),
  - 6-Row:  $1.11 \pm 0.47$  kg/ha ( $0.99 \pm 0.42$  lb/ac), and
  - 6-Row w/SS:  $2.96 \pm 0.92$  kg/ha ( $2.64 \pm 0.82$  lb/ac).
- The PM<sub>2.5</sub> emission factors for farm 3 during 2007 in terms of kg/ha (lb/ac) from the dispersion modeling process using AERMOD are:
  - 2-Row:  $1.31\text{E-}2 \pm 0.008$  kg/ha ( $0.012 \pm 0.007$  lb/ac),
  - 6-Row:  $3.07\text{E-}3 \pm 0.0013$  kg/ha ( $0.003 \pm 0.0012$  lb/ac), and
  - 6-Row w/SS:  $8.2\text{E-}3 \pm 0.0026$  kg/ha ( $0.073 \pm 0.0023$  lb/ac).
- The mean TSP emission factors in terms of kg/bale (lb/bale) from farm 3 during 2007 resulting from the dispersion modeling procedure using AERMOD are (yield data was not available for the 2-Row treatment):
  - 6-Row:  $0.50 \pm 0.22$  kg/bale ( $1.1 \pm 0.48$  lb/bale), and
  - 6-Row w/SS:  $1.12 \pm 0.29$  kg/bale ( $2.47 \pm 0.64$  lb/bale).
- The mean PM<sub>10</sub> emission factors in terms of kg/bale (lb/bale) from farm 3 during 2007 resulting from the dispersion modeling procedure using AERMOD are:
  - 6-Row:  $0.17 \pm 0.08$  kg/bale ( $0.37 \pm 0.18$  lb/bale), and
  - 6-Row w/SS:  $0.39 \pm 0.1$  kg/bale ( $0.86 \pm 0.22$  lb/bale).
- The mean PM<sub>2.5</sub> emission factors in terms of kg/bale (lb/bale) from farm 3 during 2007 resulting from the dispersion modeling procedure using AERMOD are:
  - 6-Row:  $4.78\text{E-}4 \pm 2.17\text{E-}4$  kg/bale ( $0.001 \pm 0.0005$  lb/bale), and
  - 6-Row w/SS:  $1.08\text{E-}3 \pm 2.84\text{E-}4$  kg/bale ( $0.002 \pm 0.0006$  lb/bale).

- Significant differences were observed in the mean emission factors developed with AERMOD for the two-row and six-row treatments, for all size indicators. The 2-row and 6-row emission factors generated with AERMOD were larger than the emission factors generated with ISCST3 for the tests performed on farm 3 during 2007. However, the 6-row w/SS emission factors generated in ISCST3 were higher than those generated in AERMOD for the farm 3, 2007 data.
- The emission factor data developed in ISCST3 were found to be significantly correlated with crop yield and test plot area. However, significant correlations were not observed between the emission factor data developed in AERMOD and crop yield or test plot area. These results may be indicative of problems in the assumption that the dispersion from the harvesting operation can be closely approximated by an area source model with a constant emission flux.

## **CHAPTER IV**

### **EMISSION FACTOR DEVELOPMENT PROTOCOL II: SOURCE MEASUREMENT OF EMISSION CONCENTRATIONS**

#### **INTRODUCTION**

Little accurate emission factor data exists for agricultural field operations. The data that does exist has been developed through indirect measurement techniques similar to those described in the previous section. The indirect measurement technique used in this work for emission factor development relies on mathematical models with unspecified levels of uncertainty which may vary with meteorological conditions such as wind direction and wind speed, among others. Further, the variation introduced into the predicted emission factors due to the estimation of meteorological parameters through theoretical and empirical relationships is undefined. Nonetheless, dispersion models play a key role in the air pollution regulatory process to protect human health through the estimation of downwind concentrations resulting from source emissions.

Agricultural and industrial sources of PM should be permitted based on accurate emission factors. Ideally, these emission factors would be obtainable through both indirect and direct measurements. A premise of the emission factor development protocol discussed in this section is that the conservative nature of regulatory dispersion models tends to produce emission factor estimates that do not accurately reflect true source emission levels. Although an emission factor developed through this process will result in the close approximation of downwind concentrations from an agricultural source, the emission factor may lead to the inappropriate regulation of an agricultural source when regulations are based on emission inventory levels. It is also a premise of this method that accurate emission factors can be developed through direct source measurement of PM emission rates.

## PROTOTYPE DEVELOPMENT AND FIRST YEAR TESTING

A prototype source sampling system (Figure 9, 10, and 11) was designed and used onboard a John Deere model 9996 cotton picker during the first year of the study. The source sampling system was designed to collect all of the air, seed cotton, and foreign material (plant material, soil, etc.) from one of the ducts on the six-row harvester, separate the seed cotton from the air stream, and exhaust the particulate laden air stream after performing an isokinetic emission concentration measurement.

Pitot tube traverses were performed on the six ducts which transport the seed cotton from the picking units to the basket to determine the average air velocity in each duct. The average air velocities ranged from 1070 to 1525 m/min (3500 – 5000 ft/min) across the six ducts. The maximum average velocity was observed in duct 3 (numbering the ducts from left to right sitting in the operator seat). Thus, the source sampling system was designed for use on duct 3 so that any increase in static pressure loss caused by the source sampler would lower the average duct velocity (in duct 3) to a value closer to that observed for the other ducts. The average air velocity measured at the exit of the source sampler was approximately  $914 \text{ m min}^{-1}$  ( $3000 \text{ ft min}^{-1}$ ) after the source sampler was installed on duct 3. The air flow rate of each duct was calculated by multiplying the average velocities determined by the pitot tube traverse by the cross sectional area of each duct (duct area =  $0.093 \text{ m}^2 = 1 \text{ ft}^2$ ).

Separation of the seed cotton from the air stream was accomplished in the separator section by means of a baffle type separator (see Figures 9, 10, and 11). The inlet duct to the separator section maintained the cross sectional area ( $20.3 \times 45.7 \text{ cm}$ ) of the harvester duct so that the velocity of the seed cotton and air would be approximately the same entering the baffle type separator as it was exiting duct 3. The critical air velocity, as described by Mihalski (1996), used for the design of the baffle separation section was  $305 \text{ m/min}$  ( $1000 \text{ ft/min}$ ). The critical air velocity was provided by increasing the flow area at the edge of the baffle to four times that of the inlet area. It is expected that the actual air velocity at the edge of the baffle was less than the designed critical velocity due to a decrease of the inlet air velocity caused by static pressure loss

in the inlet duct. Once the seed cotton was separated from the air stream, the seed cotton was dropped into the basket of the harvester via a 38 cm (15 in) diameter brush wheel revolving at approximately 85 rpm.

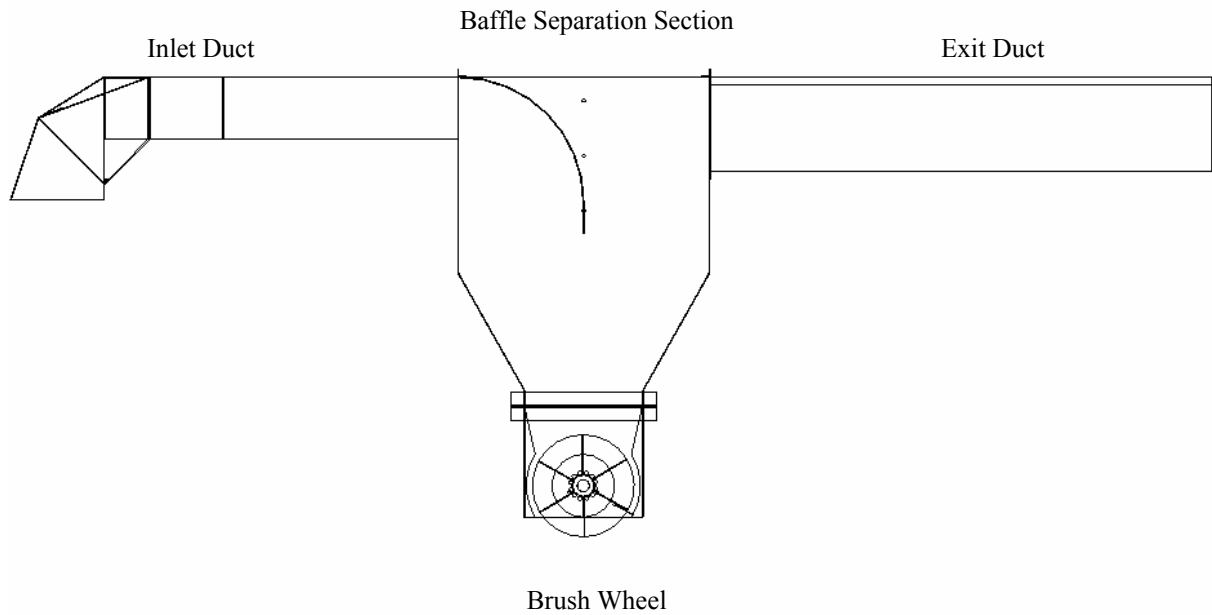


Figure 9. Schematic diagram of the separation system designed to separate the seed cotton from the air stream from duct 3 of the six-row harvester.



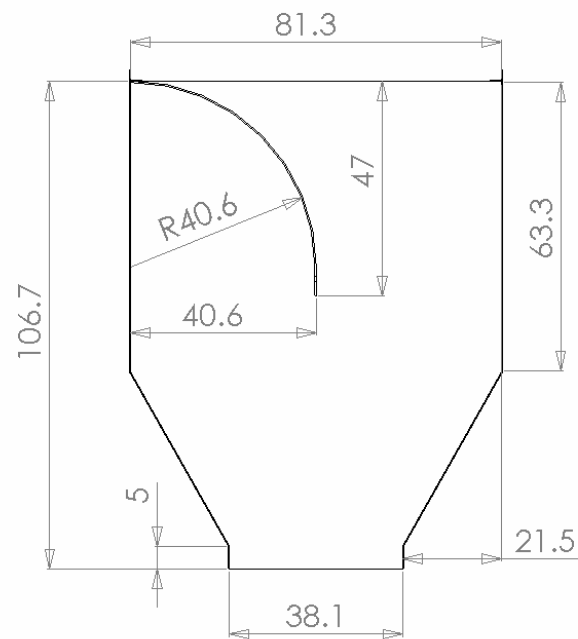


Figure 10. Detail drawing of separator box design 1 showing interior curved baffle (side view). All dimensions are in cm.

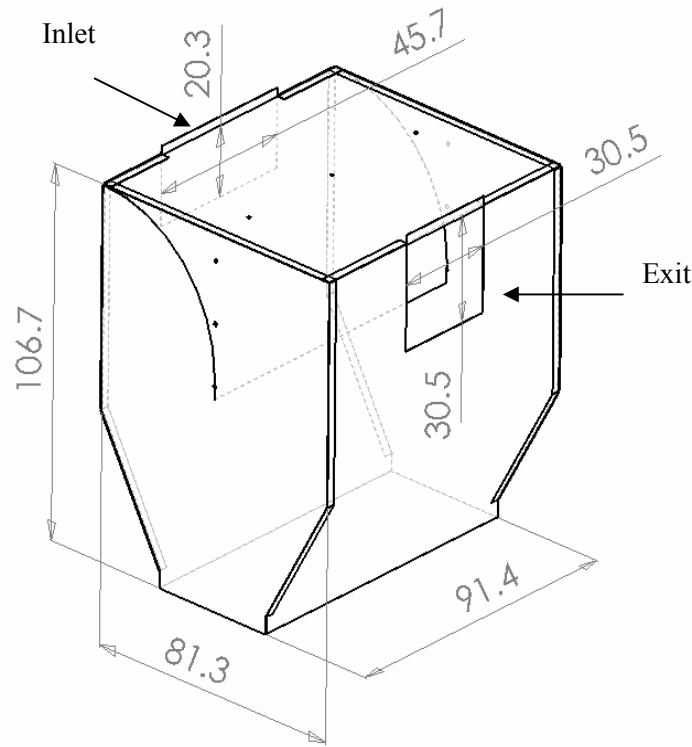


Figure 11. Schematic drawing of separator box design 1 with general dimensions shown (isometric view). All dimensions are in cm.

The particulate laden air was exhausted through a 1.6 m (64 in) exit duct. The cross section dimensions of the exit duct were 30.5 cm x 30.5 cm (1 ft x 1 ft). The velocity pressure of the air in the exit duct was measured by a pitot tube located in the center of the duct approximately 40.6 cm (16 in) from the exit and the air velocity was calculated according to equation 41.

$$V = 14.01 \sqrt{\frac{P_v}{\rho_a}} \quad (41)$$

where  $V$  = air velocity (m/s),  $P_v$  = velocity pressure measured by pitot tube (cm H<sub>2</sub>O), and  $\rho_a$  = air density (kg/m<sup>3</sup>).

An isokinetic emission concentration measurement was taken at the center of the duct approximately 20.3 cm (8 in) from the exit. The PM laden air captured by the isokinetic sampler nozzle was passed through a 15.2 cm (6 in) diameter barrel type

cyclone (Tullis et.al., 1997) to separate the large PM from the air stream. The PM which penetrated the cyclone was captured on a bank of four, 20.3 by 25.4 cm coated borosilicate glass microfiber filters (Pall Corp., Pallflex Emfab filter material 7224, East Hills, NY).

The designed maximum air flow rate of the isokinetic sampler was  $2.12 \text{ m}^3 \text{ min}^{-1}$  ( $75 \text{ ft}^3 \text{ min}^{-1}$ ) and was measured by an orifice meter. The orifice diameter of 53.64 mm (2.112 in) was specified such that the pressure drop across the orifice plate would be equal to the velocity pressure of the duct (measured by the pitot tube) when the velocity of the air entering the sampler nozzle was equal to the velocity of the air in the exit duct (thus producing an isokinetic sample of the air exiting the harvester). This was done to simplify the operation of the sampler control system. The system operator (sitting inside the cab of the harvester) maintained the isokinetic sampling condition by controlling the speed of the fans using a variable transformer (Dayton E165942, Dayton Electric Manufacturing Co., Niles, IL). The sampler air flow was provided by two fans (Model HP-33, Clements National Company, Chicago, IL) installed in series mounted on top of the harvester and the diameter of the sampling nozzle was 47 mm (1.85 in). Pressure transducers (PX274, Omega Engineering, Inc., Stamford, Conn.) were used to measure the velocity pressure from the pitot tube in the exit duct, the pressure drop across the orifice plate, and the pressure drop across the filter housings (to give a measure of the filter loading). Data loggers (HOBO H8 RH/Temp/2x External, Onset Computer Corp, Pocasset, Mass) were used to record the differential pressure readings from the pressure transducers over the duration of the test.

The emission concentration measured by the source sampler was calculated according to equation 42.

$$EC = \frac{M_F + M_B}{\sum_i Q_i t_i} \quad (42)$$

where EC = emission concentration ( $\text{g}/\text{m}^3$ ),  $M_F$  = PM mass on the four filters used in the source sampler (g),  $M_B$  = PM mass <  $100\mu\text{m}$  captured in the cyclone bucket (g),  $Q_i$  = air flow rate during the  $i^{\text{th}}$  logging interval ( $\text{m}^3/\text{s}$ ), and  $t_i$  =  $i^{\text{th}}$  logging interval (6 sec).

The cyclone bucket contained all of the material separated from the sampled air stream by the cyclone. This material was primarily plant and soil material with small amounts of lint fiber and PM. The material taken from the cyclone bucket was air washed for 15 minutes ( $1.1 \text{ m}^3 \text{ min}^{-1}$  air flow rate, 60 rpm tumbler rotation speed) to remove the PM  $<100 \text{ }\mu\text{m}$  (Wanjura et al., 2007). The air wash tumbler was covered with  $100 \text{ }\mu\text{m}$  stainless steel mesh and the extracted PM was collected on a 20.3 by 25.4 cm borosilicate glass microfiber filter (Pall Corp., Pallflex Emfab filter material, East Hills, NY). All of the filters used in the source sampler and in the air washing process of the cyclone bucket material were pre and post weighed according to the procedure described by Wanjura et al. (2005b).

The total mass of PM emitted from duct 3 during the test was calculated by multiplying the emission concentration (equation 42) by the total volume of air passing through the duct. The total mass of PM emitted from the harvester was estimated by multiplying the total PM mass emission from duct 3 by 6 (the number of picking units/seed cotton transport ducts on the harvester). It was assumed that the total mass of PM emitted from one duct was constant across all of the ducts. TSP emission factors were calculated by dividing the total mass of PM emitted by the harvester by either the area harvested or the number of 218 kg (480 lb) bales harvested to obtain emission factors in units of mass of TSP per area harvested or per bale harvested, respectively. The total mass of lint harvested (bales) was estimated by multiplying the weight of seed cotton harvested during each test by an estimated 34% lint turnout and dividing by 218 kg/bale (480 lb/bale). Seed cotton weights were obtained from a boll buggy equipped with load cells.  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  emission factors were obtained by multiplying the TSP emission factors by the respective mass fractions from the results of PSD analyses on the filters.

Wanjura et al. (2007) reported overall average TSP,  $\text{PM}_{10}$ , and  $\text{PM}_{2.5}$  source sampler emission factors of 114, 45, and 0.15 g/ha, respectively. They also reported overall average TSP,  $\text{PM}_{10}$ , and  $\text{PM}_{2.5}$  source sampler emission factors of 10, 4, and 0.01 g/bale, respectively. The authors stated that the emission factors developed by the

source sampling system exhibited much higher precision than the comparable emission factors developed using a protocol employing ground level samplers downwind of the harvesting operation. However, the reported emission factors developed by the source sampling system were developed from four tests conducted at two locations during the 2006 south Texas cotton harvest season.

## SEED COTTON SEPARATION SYSTEM DESIGN MODIFICATION AND EVALUATION

### *Separator Box Design and Evaluation*

The system designed to separate seed cotton from the air stream on the six-row picker was mounted on a test frame to facilitate testing and evaluation (Figure 12). Two centrifugal fans (PB-18, Cincinnati Fan, Mason, OH) connected in parallel provided the air flow to transport seed cotton from the feeder through the system. The fans were operated on a hydraulic circuit powered by a 37.3 kW (50 hp) pressure compensated pump (Eaton PVB45, Eaton Hydraulics, Eden Prairie, MN). Fan speed was controlled through a flow control valve which regulated the high pressure fluid flow to the hydraulic motor (Parker PGM315, Parker Hannifin, Youngstown, OH). The hydraulic motor was connected to the fan rotors via a belt drive with a speed increasing ratio of 2:1. The total air flow through the system was maintained at  $85 \pm 0.85 \text{ m}^3 \text{ min}^{-1}$  ( $3000 \pm 30 \text{ ft}^3 \text{ min}^{-1}$ ). The air flow rate from each fan was determined using equation 43 and center point velocity pressure measurements taken in the 12.7 cm (5 in) diameter ducts located between the discharge of each fan and the inlet to the seed cotton feeder.

$$Q_i = 210.15 \pi d^2 \sqrt{\frac{P_{V,CP}(F)}{\rho_a}} \quad (43)$$

where  $Q_i$  = air flow rate from fan  $i$  ( $\text{m}^3/\text{min}$ ),  $d$  = duct diameter (m),  $P_{V,CP}$  = center point velocity pressure (cm  $\text{H}_2\text{O}$ ),  $F$  = center point correction factor, and  $\rho_a$  = air density ( $\text{kg}/\text{m}^3$ ).

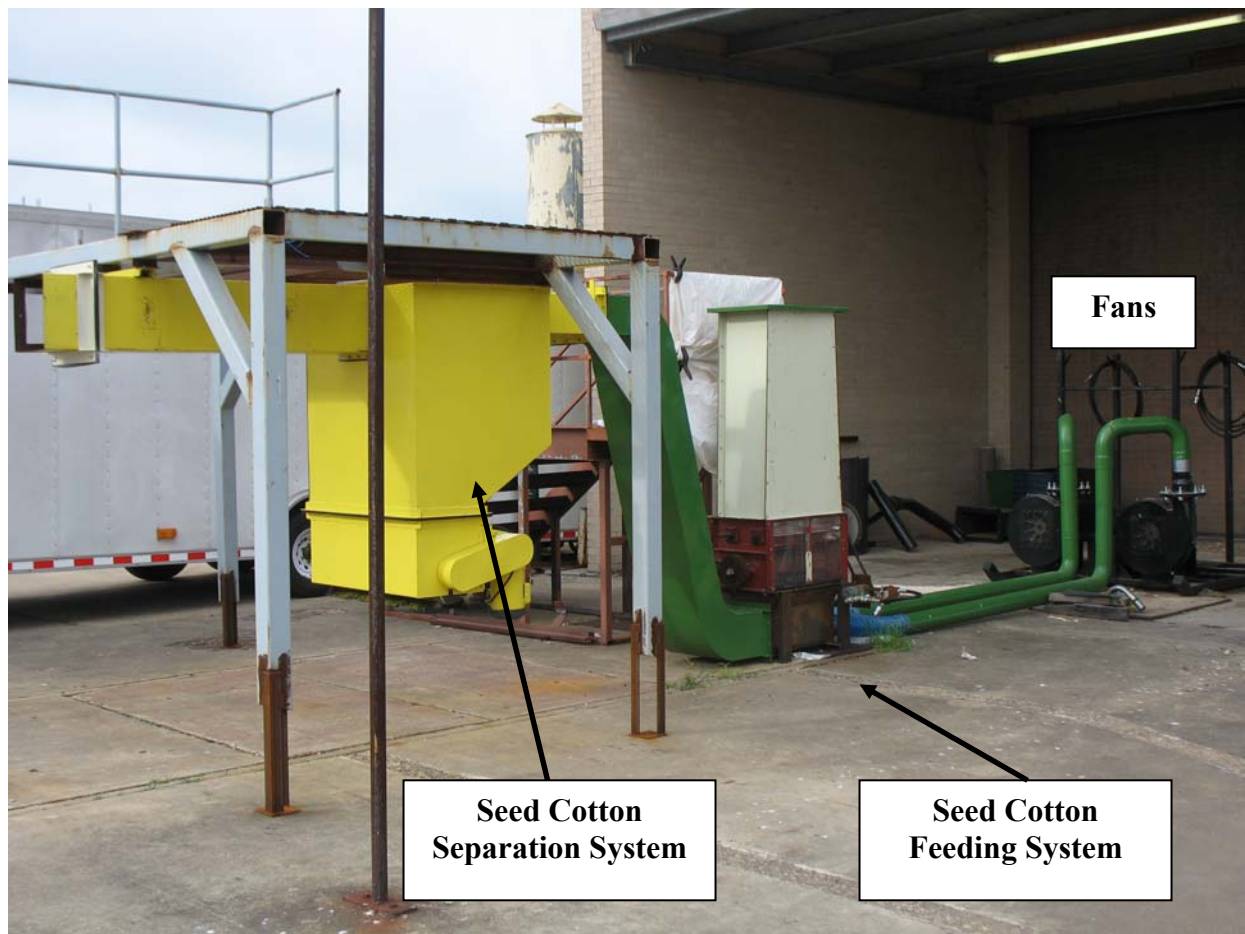


Figure 12. Photo of seed cotton separation system mounted in the testing frame configured with the seed cotton feeder and fan system.

Velocity pressure measurements were taken at 20 locations along 2 perpendicular diameters of the fan ducts to determine the average velocity pressure in each duct. The center point correction factor ( $F$ ) was calculated for each duct as the ratio of the duct average velocity pressure to the center point velocity pressure. Thus, the center point velocity pressure measurements taken prior to each test were corrected to the duct average velocity pressure using the center point correction factor in order to determine the flow rate from each fan. All velocity pressure measurements were taken using a pitot tube (Model 166-12, W.E. Anderson, Michigan City, IN) and digital magnehelic gage (475-1-FM, Dwyer Instruments, Inc., Michigan City, IN).

Air dry bulb temperature, relative humidity, and barometric pressure were measured during each test using a weather station (Temp/RH Sensor: Model S-THB-M002; Barometric Pressure Sensor: Model S-BPA-CM10, Onset Computer Corporation, Pocasset, MA). These measurements were used to calculate the density of the air as shown in equation 4.

The feeder used to introduce seed cotton into the air stream (figure 13) consisted of a set of upper paddle rollers rotating inward in opposite directions to pull the seed cotton from the hopper onto a set of spiked rollers rotating at approximately twice the speed of the upper rollers. The lower spiked rollers helped to open clumped masses of seed cotton pressed together by the paddle rollers and provide more uniform feeding of the seed cotton into the air stream. The seed cotton feeder was operated by a hydraulic motor (Char-Lynn H Series 101-1008, Eaton Hydraulics, Eden Prairie, MN) powered by a 22.4 kW (30 hp) pressure compensated pump (Eaton PVB29, Eaton Hydraulics, Eden Prairie, MN). The feed rate of seed cotton into the system was controlled by regulating the speed of the upper rollers of the feeder. Thus a flow control valve was used to control the speed of the hydraulic motor. During each test, 18.2 kg (40 lb) lots of seed cotton were fed through the system at nominal feed rates of 22.7, 45.4, and 68.1 kg/min (50, 100, and 150 lbs/min). These feed rates are approximately equivalent to the harvesting rate of a single row unit gathering seed cotton in yields of 1, 2, and 3 bales per acre, respectively (assuming: 101.6 cm row spacing, 681 kg of seed cotton per bale, and 6.4 km h<sup>-1</sup> picking speed).

Two separator box designs were evaluated with several different baffle configurations to determine the separator box/baffle configuration which resulted in the lowest mass of seed cotton penetrating the exit duct. The first separator box design was tested with three curved baffle configurations with overall lengths of 30.5, 40.6, and 47 cm (12, 16, and 18.5 in). Each baffle was positioned so that the lower edge of the baffle was 40.6 cm (16 in) from the front wall of the separator box. Clear polycarbonate material was placed on one side wall of both separator box designs so that visual observations of the cotton flowing through the system could be made. During testing of

separator box design 1 it was observed that seed cotton accumulated on the inclined back wall of the box before falling into the brush wheel. It was further observed that the seed cotton which accumulated in this area was easily re-entrained in the air stream allowing it to penetrate to the exit duct. Therefore, the design of separator box 2 (Figures 13, 14, and 15) included a straight back wall so to minimize the accumulation of seed cotton before the brush wheel. This design modification resulted in the movement of the brush wheel to the back wall of the separator box where as it was located at the center of separator box design 1.

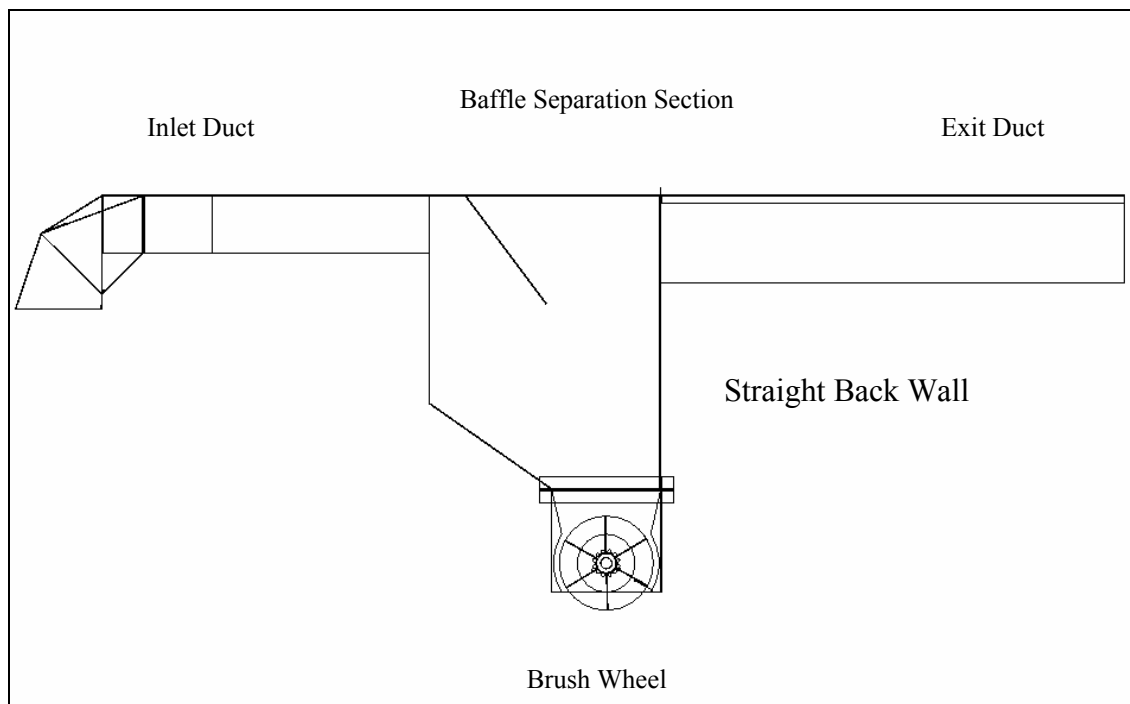


Figure 13. Schematic drawing of separator box design 2 illustrating the straight back wall design with the brush wheel moved to the rear of the separator box.



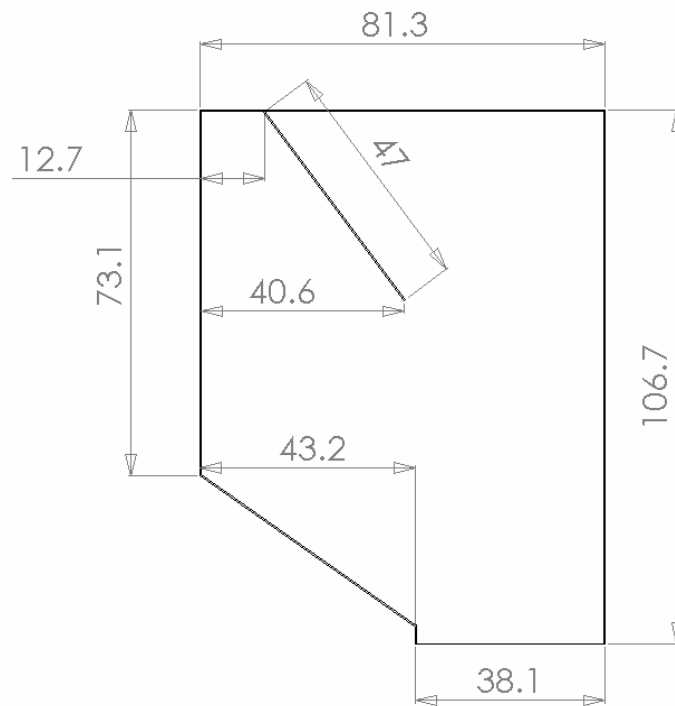


Figure 14. Detail drawing of separator box design 2 shown with interior baffle design 5 (side view). All dimensions are in cm.

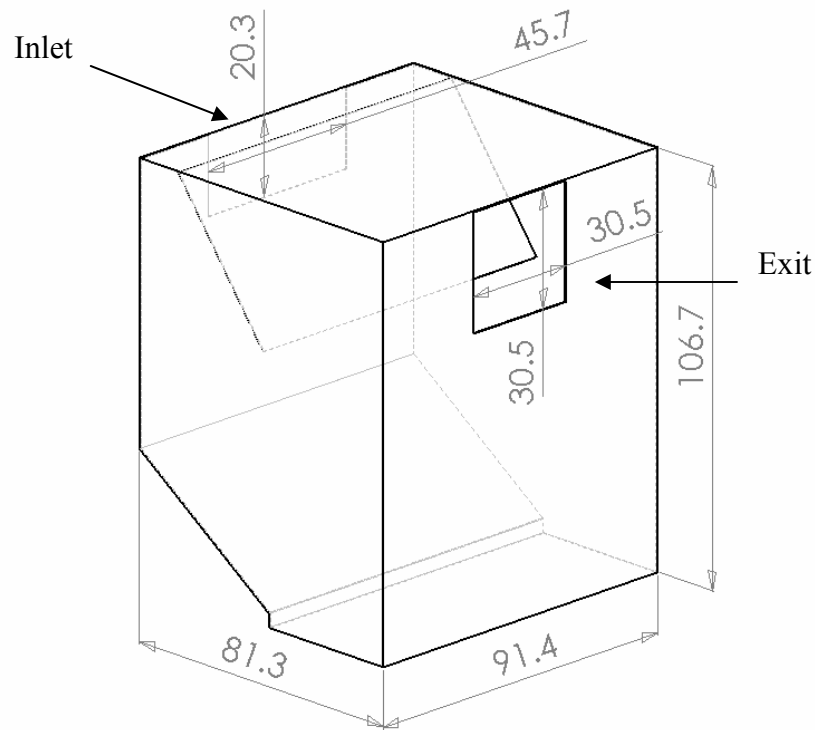


Figure 15. Schematic drawing of separator box design 2 showing general dimensions (isometric view). All dimensions are in cm.

Separator box design 2 (Figures 13, 14, and 15) was tested with four curved and three straight baffle configurations. The three baffles tested in separator box design 1 with an additional 30.5 cm (12 in) radius curved baffle with bottom edge located at 30.5 cm (12 in) from the front wall were tested. Also, a 47 cm (18.5 in) straight baffle was tested in three different positions including:

1. slanted with top edge located 12.7 cm (5 in) from the front wall and bottom edge located 40.6 cm (16 in) from the front wall (figure 3b),
2. slanted with top edge located 25.4 cm (10 in) from the front wall and bottom edge located 40.6 cm (16 in) from the front wall, and
3. vertical, located at 40.6 cm (16 in) from the front wall,

The dimensions of each baffle tested in separator box design 2 are shown in Table 22 with reference to Figures 16 and 17.

Each separator box/baffle configuration was tested at three nominal seed cotton feed rates of 22.7, 45.4, and 68.1 kg/min (50, 100, and 150 lbs/min) with three replications per feed rate. Actual feed rates were calculated for each test by dividing the lot mass of seed cotton by the duration of the test. Each configuration was evaluated based on the mass of seed cotton that penetrated the exit duct of the separator system. The seed cotton penetrating the system was collected in a wire mesh bin attached to the discharge end of the exit duct. The collection bin was weighed before and after each test using a laboratory balance (Mettler-Toledo PM30, Mettler-Toledo, Inc., Columbus, OH). Analysis of variance (ANOVA) and Tukey's HSD tests were performed using the general linear model in SPSS to determine differences in the separator box design/baffle configurations.

Table 22. Description of the baffles tested in separator box designs 1 and 2. (see Figures 16 and 17)

	<b>Tested in Separator Box Design</b>		<b>R</b>	<b>D</b>	<b>X</b>	<b>T</b>	<b>L</b>
<b>Baffle No.</b>	<b>Numbers</b>	<b>Shape</b>	<b>cm (in)</b>	<b>cm (in)</b>	<b>cm (in)</b>	<b>cm (in)</b>	<b>cm (in)</b>
1	1 and 2	Curved	30.5 (12)	40.6 (16)	0	-	-
2	1 and 2	Curved	40.6 (16)	40.6 (16)	0	-	-
3	1 and 2	Curved	40.6 (16)	40.6 (16)	6.4 (2.5)	-	-
4	2 only	Curved	30.5 (12)	30.5 (12)	0	-	-
5	2 only	Straight	-	40.6 (16)	-	12.7 (5)	47 (18.5)
6	2 only	Straight	-	40.6 (16)	-	25.4 (10)	47 (18.5)
7	2 only	Straight	-	40.6 (16)	-	40.6 (16)	47 (18.5)

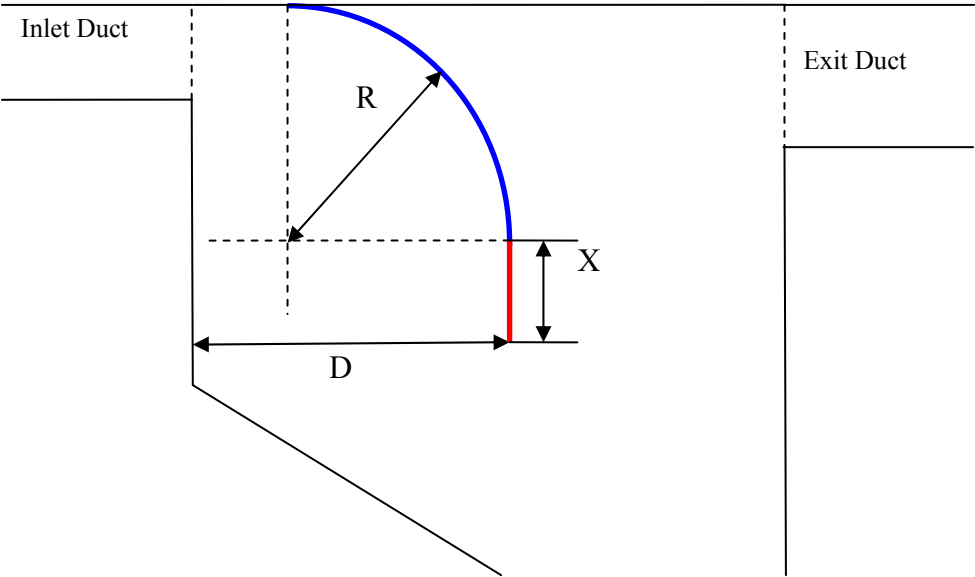


Figure 16. Schematic showing curved baffle dimensions for baffles 1, 2, 3, and 4 (see Table 22).

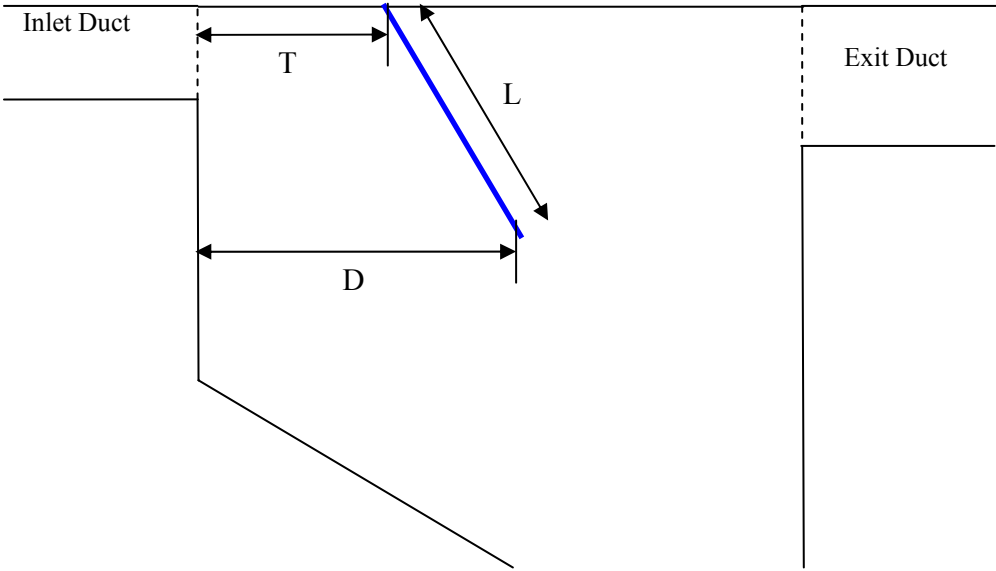


Figure 17. Schematic showing straight baffle dimensions for baffles 5, 6, and 7 (see Table 22).

### ***Velocity Profile Testing***

Air velocity measurements were taken at nine points across the cross section of the exit duct to determine if consistent air flow patterns exist in the exit duct. The logic was used that if consistent air flow patterns were present in the exit duct, it is likely that a concentration profile also exists in the exit duct. Thus the air velocity profile was investigated by dividing the cross section of the exit duct into nine equal area sections and locating air velocity probes (641RM-12, Dwyer Instruments, Inc., Michigan City, IN) at the centroid of each equal area region (see Figure 18). The velocity probes were installed coplanar to one another at 20.3 cm (8 in) from the end of the exit duct. Air velocity profile testing was only performed on separator box design 2 with the top and bottom edges of the straight baffle located at 12.7 and 40.6 cm (5 and 16 in), respectively (baffle 5, see Table 22).

The air velocity profile was measured at seed cotton feed rates of 0, 22.7, and 45.4 kg/min (0, 50, and 100 lb/min). Five replications at each seed cotton feed rate were performed. During each test the system air flow rate (measured using a pitot tube in the ducts on the exit side of the fans) was maintained at 85 m<sup>3</sup>/min (3000 ft<sup>3</sup>/min). Air velocity readings at the nine locations in the exit duct were taken simultaneously using a data acquisition system (cFP-AI-110, National Instruments, Austin, TX) controlled by a laptop computer. The data acquisition system measured and recorded air velocity readings on a 1 Hz frequency. Air temperature, relative humidity, and barometric pressure were measured inside the exit duct using a temperature/RH sensor (HX94A, Omega Engineering, Stamford, CN) and barometric pressure transducer (PX2760, Omega Engineering, Stamford, CN). These readings were used to calculate the density of the air (equation 4) in the exit duct in order to convert the sensor air velocity readings to actual conditions according to equation 44.

$$V_{act} = V_{cal} \left( \frac{\rho_{cal}}{\rho_a} \right) \quad (44)$$

where  $V_{act}$  = air velocity at actual air density (m/s),  $V_{cal}$  = air velocity at calibration air density (m/s), and  $\rho_{cal}$  = air density at calibration conditions (1.202 kg/m<sup>3</sup>).

The duration of the tests varied by seed cotton feed rate due to the collection of lint fiber on the velocity sensors. The tests run without seed cotton were conducted for 60 s while the tests at 22.7 and 45.4 kg/min were considerably shorter. During the tests performed with seed cotton in the system, the technicians started feeding the seed cotton into the system before the data acquisition system began recording air velocity readings. Data recording was discontinued once lint fiber had accumulated on any one of the nine sensors. The system would typically record air velocity measurements for 5 to 10 s before the sensors were occluded by lint fiber.

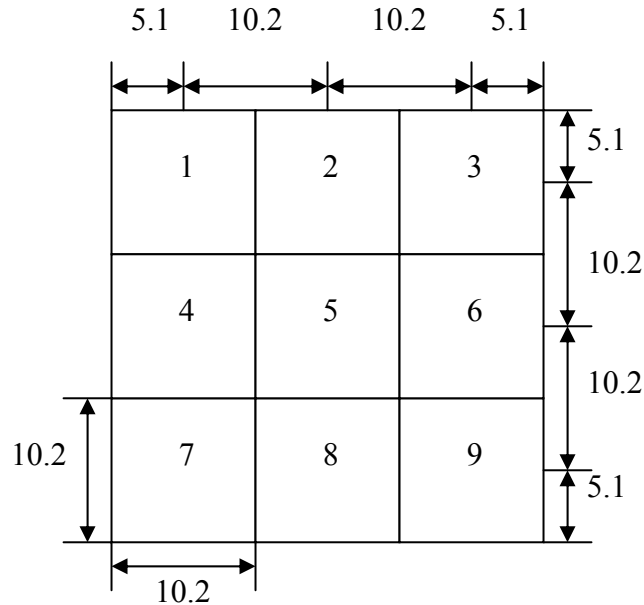


Figure 18. Schematic diagram of air velocity probe locations across the exit duct (numbers inside the equal area squares represent probe locations). All dimensions are in cm.

The air velocity measurements at each location in the exit duct were analyzed relative to the other sensor locations by normalizing the data to the maximum velocity (equation 45). This procedure was used to circumvent any apparent differences in the air

flow patterns between seed cotton feed rates due to the uncertainty associated with measuring and controlling the system air flow rate.

$$V_{n,i} = \left( \frac{V_i}{V_{\max}} \right) 100 \quad (45)$$

where  $V_{n,i}$  = normalized velocity of position  $i$  represented as a percentage of the maximum velocity (%),  $V_i$  = air velocity measurement of sensor position  $i$  (m/s), and  $V_{\max}$  = maximum air velocity measurement of the nine sensor positions in the exit duct (m/s).

The normalized velocity data were analyzed in SPSS using the multivariate analysis of variance (MANOVA) procedure in the General Linear Model algorithm to test for overall differences in the air velocity patterns between seed cotton feed rates. The test statistic used to evaluate the significance of the MANOVA test was Wilks'  $\lambda$  (Johnson and Wichern, 2002).

### ***Concentration Profile Testing***

Concentration profile testing in the exit duct was conducted using a five point sampling grid with sampling locations as shown in Figure 19. The goal of this effort was to determine the magnitude of an isokinetic emission concentration measured at the center of the exit duct relative to the duct average concentration. The results of this evaluation would then be used to correct center point concentration measurements to duct average concentrations for use in calculating emission rates and subsequent emission factors. The four sampling locations surrounding the center sampling location were used to determine the average emission concentration in the exit duct.

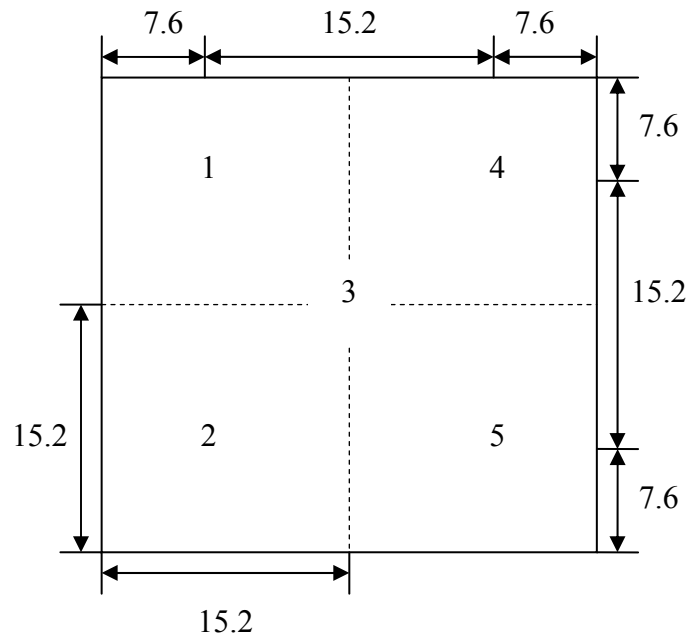


Figure 19. Schematic diagram of concentration sampling locations in the exit duct (numbers represent sampling locations). All dimensions are in cm.

A dust feeder was used to feed corn starch into the air stream at 12 g/min. The dust feeding system was operated by a linear drive system powered by a 0.187 kW (1/4 hp) DC motor with an 80:1 speed reducing gear box. The linear drive system consisted of a 1.8 m long, 2.54 cm diameter, 5 pitch Acme threaded shaft with two traveler nuts attached to the 20.3 cm x 1.8 m dust table. The dust was spread out in a uniform depth pattern (approximately 138 cm long by 5 cm wide) on top of the dust table. As the threaded shaft was rotated by the motor (27 rpm), the dust table advanced passed a venturi nozzle which pulled the dust from the table and introduced it into the air stream passing into the inlet of the seed cotton feeding system (Figure 20).





Figure 20. Linear motion dust feeding system used to feed corn starch into the testing system at 12 g/min.

The isokinetic sampling nozzles were constructed from 7.04 mm (0.277 in) inner diameter seamless steel tubing with 1.24 mm (0.049 in) wall thickness. The sampling nozzles were installed coplanar to one another at 20.3 cm (8 in) from the end of the exit duct. The air flow rate through each sampling nozzle was measured with an orifice meter and controlled using a manually operated ball valve. The pressure drop across each orifice meter was monitored by a magnehelic gage and differential pressure transducer (PX274, Omega Engineering, Inc., Stamford, Conn.) The flow rate through each orifice meter was calculated using equation 3 and the differential pressure measured across the orifice (orifice diameter = 4.763 mm = 0.1875 in).

The velocity of the air entering each of the sampling nozzles was calculated by dividing the flow rate measured by the orifice meter by the inlet area of the nozzle ( $0.389 \text{ cm}^2$ ). The velocity of the air passing each nozzle was measured using an air velocity probe (641RM-12, Dwyer Instruments, Inc., Michigan City, IN). Isokinetic sampling conditions were maintained by regulating the sampler nozzle flow rate with the manually operated ball valve. These two velocities were recorded along with air temperature, relative humidity, and barometric pressure readings by the data acquisition system used to record the air velocity profile data. Post test analysis of the air velocity

readings was conducted to determine how precisely isokinetic conditions were maintained at the sampling nozzles using the EPA Method 5 (CFR, 1999) criteria. These criteria state that the ratio of the air velocity entering the nozzle to the air velocity passing the nozzle should be within 0.9 to 1.1 (CFR, 1999).

The airflow through each sampling nozzle was provided by a rotary vane vacuum pump (1023-V131Q, Gast Mfg., Inc., Benton Harbor, MI). The sampled air was pulled through the sampling nozzle and 47 mm diameter filter (2  $\mu\text{m}$  pore size Zefluor Membrane Filters, Pall Corp., East Hills, NY) where the particulate matter was separated from the air stream. The filters were pre and post weighed using a high precision analytical balance (AG245, Mettler-Toledo, Greifensee Switzerland). The pre and post processing of the filters is described by Wanjura et al. (2005b). The concentration measured at each location was calculated by dividing the net mass of accumulated PM on the filter by the total air volume pulled through the filter during the test.

The system air flow rate was monitored and maintained at 85  $\text{m}^3/\text{min}$  (3000  $\text{ft}^3/\text{min}$ ) during each of the tests. The system air flow rate was measured using a pitot tube in the 12.7 cm (5 in) diameter ducts on the exit side of each fan. Five tests were conducted at the 12 g/min nominal feed rate and the duration of each test was approximately 10 min.

The concentration data was normalized using the maximum concentration measured during each test to help identify concentration profile patterns. The ratio of the duct average concentration to the center point concentration was calculated and used in the concentration profile analysis. The univariate ANOVA procedure in the General Linear Model algorithm in SPSS was used to analyze the normalized concentration data. Particle size distribution (PSD) analyses of the raw corn starch and PM collected on the filters were conducted on a Coulter Counter Multisizer3 according to the procedure described by Faulkner and Shaw (2006). A particle density of 1.5  $\text{g}/\text{cm}^3$ , measured by an AccuPyc 1330 Pycnometer (AccuPyc 1330 Pycnometer, Micromeritics Instrument Corp., Norcross, GA), was used to convert the Equivalent Spherical Diameter PSDs

from the Coulter to an AED basis. The PSD data were analyzed to investigate differences in PSD by sampling location within the exit duct.

### ***Total System Deposition Testing***

The source sampling system designed for use onboard the harvesting system was mounted on the test frame along with the seed cotton separation system (see Figure 21) to evaluate the total mass of dust lost to deposition within the system. The isokinetic sampling system was modified from the 2006 design to include an automated control system as well as improved sampling train duct work to minimize dust losses and prevent plugging by locks of seed cotton penetrating the exit duct. The isokinetic nozzle (diameter = 59.563 mm) mounted inside the exit duct was designed for a sampling velocity of  $732 \pm 122$  m/min based on onboard duct measurements from 2006. The sampling flow rate (passing through the nozzle), based on the design inlet velocity of the barrel cyclone, was specified at  $2.124 \text{ m}^3/\text{min}$  ( $75 \text{ ft}^3/\text{min}$ ). The airflow through the system was provided for by two fans mounted in series (Model HP-33, Clements National Company, Chicago, IL) and controlled by an automated ball valve (PBVPV1206, Dwyer Instruments Inc., Michigan City, IN). The pressure drop across the orifice meter and the velocity pressure measured by a pitot tube (Model 160-8, Dwyer Instruments Inc., Michigan City, IN) mounted in the duct were measured by pressure transducers (Series 677, Dwyer Instruments Inc., Michigan City, IN). Air temperature and relative humidity as well as barometric pressure were measured inside the duct using a T/RH probe (HX94A, Omega Engineering Inc., Stamford, CT) and barometric pressure transmitter (Model 278, Setra Systems Inc., Boxborough, MA). The measurement and control system (cFP-AI-110 input module, cFP-AO-200 output module, National Instruments, Austin, TX) used with the source sampling system was operated by a laptop computer running LabView 8.0 (LabView v. 8.0, National Instruments, Austin, TX). The measurement and control system monitored and recorded the readings from the pressure transducers, T/RH probe, and barometric pressure

transmitter and performed the calculations on a real-time basis for controlling the airflow rate through the system on a 1 Hz frequency.

The particulate matter penetrating the cyclone was captured on a set of two, 20.3 by 25.4 cm coated borosilicate glass microfiber filters (Pall Corp., Pallflex Emfab filter material 7224, East Hills, NY). The filters were pre and post weighed according to the process described previously for the 47 mm diameter Teflon filters using a high precision analytical balance (AG245, Mettler-Toledo, Greifensee Switzerland). The cyclone bucket was pre and post weighed with a laboratory balance (PB1502, Mettler-Toledo, Greifensee Switzerland).

Five replications at each of two dust feed rates (5 and 10 g/min) were conducted with a target duct velocity of 732 m/min (2500 ft/min). Corn starch was used as the dust in the tests. The total system deposition was calculated as shown in equation 46.

$$D = \left( 1 - \frac{ER}{m_{in}} \right) * 100 \quad (46)$$

where D is the total system deposition (%),  $m_{in}$  is the calculated feeding rate of the dust into the system (g/min), and ER is the total emission rate of dust from the exit duct as calculated by the emission concentration measured by the source sampler multiplied by the total duct flow rate (g/min).



Figure 21. Photograph of the source sampling system mounted on the test frame.

## SYSTEM DEVELOPMENT AND EVALUATION RESULTS

### *Seed Cotton Separation System Evaluation*

The seed cotton penetration test results for separator box design 1 with baffles 1, 2, and 3 (see Table 22) are shown in Table 23 and Figure 22. No significant interaction was observed between the baffle and seed cotton feed rate factors ( $p$  value = 0.734). However, an ANOVA on the seed cotton penetration data indicated significant differences by baffle design ( $p$  value = 0.016) and by nominal seed cotton feed rate ( $p$  value < 0.001). Significant differences ( $\alpha = 0.05$ ) were observed between the baffles at the 45.4 and 68.1 kg/min feed rates according to Tukey's HSD test (Table 23). Although significant differences between the mass of seed cotton penetrating the system was not observed between the 22.7 and 45.4 kg/min feed rates, the mean mass of seed cotton penetrating the system at the 68.1 kg/min feed rate was significantly higher than

either of the other two feed rates according to Tukey's HSD test ( $\alpha = 0.05$ ). The results indicate that the mass of seed cotton penetrating the exit duct increased with the length of the baffle as well as seed cotton feed rate.

Table 23. Mass of seed cotton penetrating (g) separator box design 1 with baffles 1, 2, and 3 (see Table 22) at three seed cotton feed rates. During each test, an 18.2 kg lot of seed cotton was fed through the system.

Baffle	Nominal Feed Rate (kg/min)		
	22.7	45.4	68.1
1	115.0 <sup>a</sup>	129.7 <sup>a</sup>	181.3 <sup>a</sup>
2	129.3 <sup>a</sup>	147.0 <sup>a</sup>	216.5 <sup>a,b</sup>
3	166.0 <sup>a</sup>	192.0 <sup>b</sup>	275.0 <sup>b</sup>

Means within a column with the same letter are not significantly different according to Tukey's HSD test ( $\alpha = 0.05$ ).

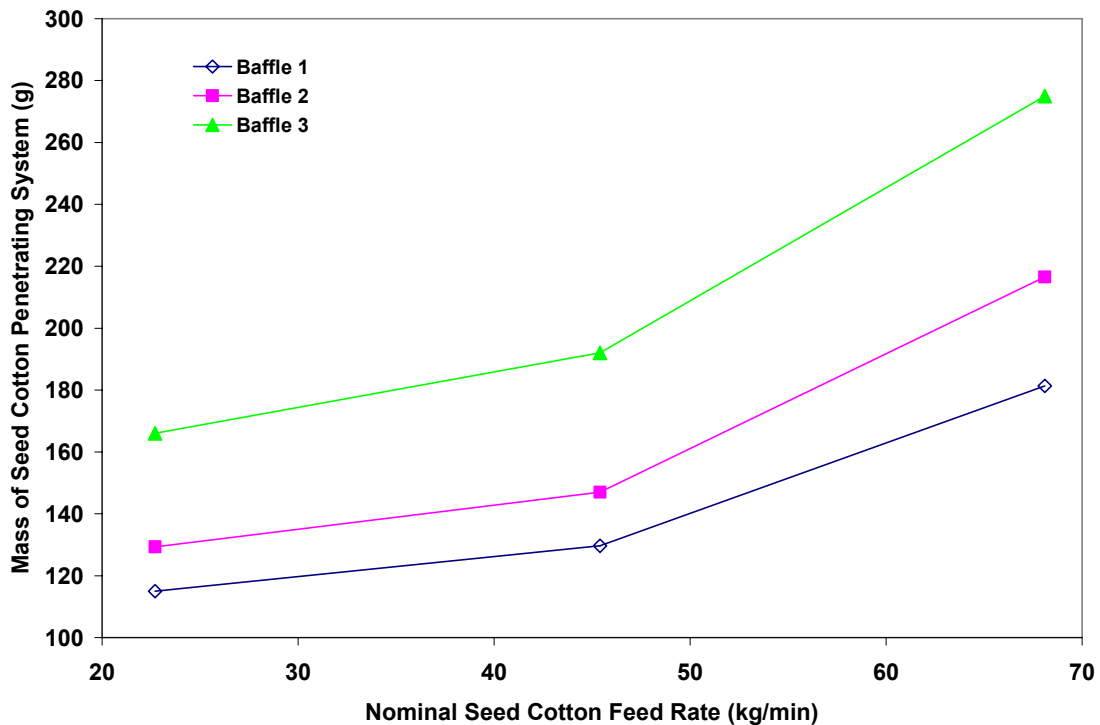


Figure 22. Seed cotton penetration test results for separation box design 1 tested with baffles 1, 2, and 3 at seed cotton feeding rates of 22.7, 45.4, and 68.1 kg/min.

Over all seed cotton feed rates, separator box design 1 configured with baffle 1 resulted in the lowest mass of seed cotton penetrating the exit duct. However, it was hypothesized that the mass of seed cotton penetrating the system could be reduced by incorporating the design changes included in separator box design 2.

The results of the seed cotton penetration tests conducted with separator box design 2 are shown in Table 24 and Figure 23. In general, the mass of seed cotton penetrating the exit duct was lower for all of the baffles tested in separator box design 1 when tested in design 2 (baffles 1, 2, and 3). An ANOVA on the seed cotton penetration data for all seven baffles tested in separator box design 2 indicated significant differences by baffle design ( $p$  value  $< 0.001$ ) and by seed cotton feed rate ( $p$  value = 0.022). However, a significant interaction was observed between the baffle and seed cotton feed rate factors ( $p$  value  $< 0.001$ ). Therefore, the interpretation of significant differences observed in the seed cotton penetration data by seed cotton feed rate and baffle design is problematic. However, the seed cotton penetration means for the two straight baffles installed at an angle (baffles 5 and 6) were significantly lower than the other baffles tested at 45.4 and 68.1 kg/min according to Tukey's HSD test with  $\alpha = 0.05$  (see Table 24). Although the means for baffles 5 and 6 are not significantly different at any seed cotton feed rate, baffle 5 tended to produce the lowest mass of seed cotton penetrating the exit duct. Therefore, baffle 5 was selected for use in separator box design 2 onboard the six row harvester.

Table 24. Mass of seed cotton penetrating (g) separator box design 2 with baffles 1 - 7 (see Table 22) at three seed cotton feed rates. During each test, an 18.2 kg lot of seed cotton was fed through the system.

Baffle	Shape	Seed Cotton Feed Rate (kg min <sup>-1</sup> )		
		22.7	45.4	68.1
1	Curved	47.0 <sup>a,b</sup>	79.3 <sup>a</sup>	91.0 <sup>a</sup>
2	Curved	34.3 <sup>a,c</sup>	78.7 <sup>a</sup>	106.3 <sup>a</sup>
3	Curved	129.3	200.3	208.3
4	Curved	55.0 <sup>b</sup>	80.7 <sup>a</sup>	104.3 <sup>a</sup>
5	Straight	20.7 <sup>c</sup>	24.0 <sup>b</sup>	35.7 <sup>b</sup>
6	Straight	27.3 <sup>c</sup>	41.7 <sup>b</sup>	52.0 <sup>b</sup>
7	Straight	105.0	119.7	125.3 <sup>a</sup>

Means within a column with the same letter are not significantly different according to Tukey's HSD test ( $\alpha = 0.05$ ).

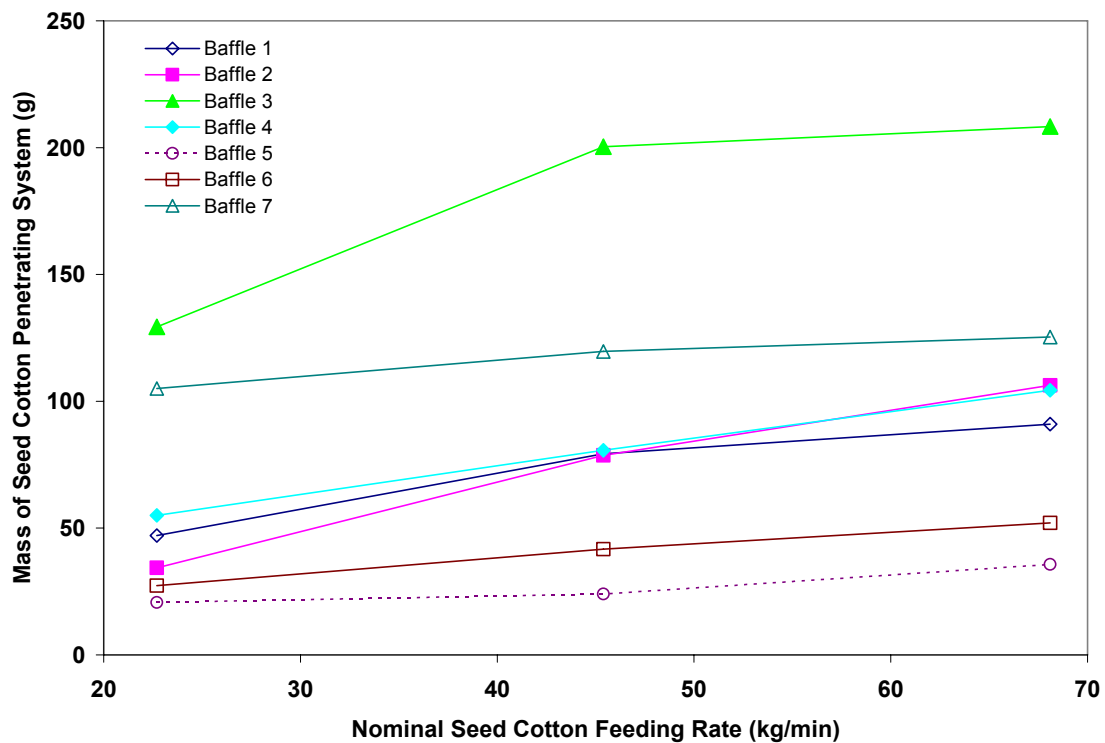


Figure 23. Seed cotton penetration test results for separation box design 2 tested with baffles 1 - 7 at seed cotton feeding rates of 22.7, 45.4, and 68.1 kg/min.



### *Velocity Profile Testing*

A MANOVA test performed on the normalized velocity data indicates that there is no significant difference in the air velocity patterns between any of the seed cotton feed rates ( $\alpha = 0.05$ ). The value of Wilks'  $\lambda$  calculated in SPSS was 0.077 with an F statistic value of 1.625 (p value = 0.220). An individual comparison of the normalized velocities by sensor location (shown in Table 25) also indicate that there is little difference in the air velocity patterns by seed cotton feed rate. Only probes three and seven indicated significant differences between mean normalized air velocities between seed cotton feed rates. However, these differences should be interpreted with caution due to the insignificance of the MANOVA test. The results of the velocity profile tests are shown in Table 25 and Figure 24.

Table 25. Mean normalized air velocity measurements (% of maximum duct velocity) from five replicated tests at three seed cotton feed rates. The probes were located coplanar to one another at nine evenly spaced points across the cross section of the exit duct (see Figure 18).

Probe No.	Seed Cotton Feed Rate (kg/min)		
	0	22.7	45.4
1	82.6 <sup>a</sup>	82.6 <sup>a</sup>	82.6 <sup>a</sup>
2	90.9 <sup>a</sup>	90.7 <sup>a</sup>	91.3 <sup>a</sup>
3	82.2 <sup>a</sup>	82.5 <sup>a,b</sup>	83.3 <sup>b</sup>
4	83.2 <sup>a</sup>	84.1 <sup>a</sup>	83.6 <sup>a</sup>
5	100.0 <sup>a</sup>	100.0 <sup>a</sup>	100.0 <sup>a</sup>
6	93.6 <sup>a</sup>	94.0 <sup>a</sup>	94.4 <sup>a</sup>
7	87.4 <sup>a</sup>	88.5 <sup>b</sup>	88.2 <sup>a,b</sup>
8	98.4 <sup>a</sup>	98.5 <sup>a</sup>	98.5 <sup>a</sup>
9	94.6 <sup>a</sup>	94.3 <sup>a</sup>	94.3 <sup>a</sup>
<b>Maximum Air Velocity (m/min)</b>	<b>1078.8</b>	<b>1077.5</b>	<b>1077.7</b>

Means within a row with the same letter are not significantly different according to Tukey's HSD test ( $\alpha = 0.05$ ).

An ANOVA test on the normalized velocity data indicated significant differences between the sensors for the 0 (p value < 0.001), 22.7 (p value < 0.001), and 45.4 kg/min feed rates (p value < 0.001). Tukey's HSD test indicated that the center point normalized velocity was significantly different than at all other sensor locations for the 0 and 22.7 kg min<sup>-1</sup> feed rates ( $\alpha = 0.05$ ). However, the same test indicated that the normalized velocity at sensor locations five (center point) and eight were not significantly different at the 45.4 kg/min feed rate. The air velocity profiles shown in Figure 24 consistently indicate that the maximum air velocity in the exit duct is at the center point (probe location 5). In addition, the velocity of the air in the exit duct generally increases from the top to the bottom side.

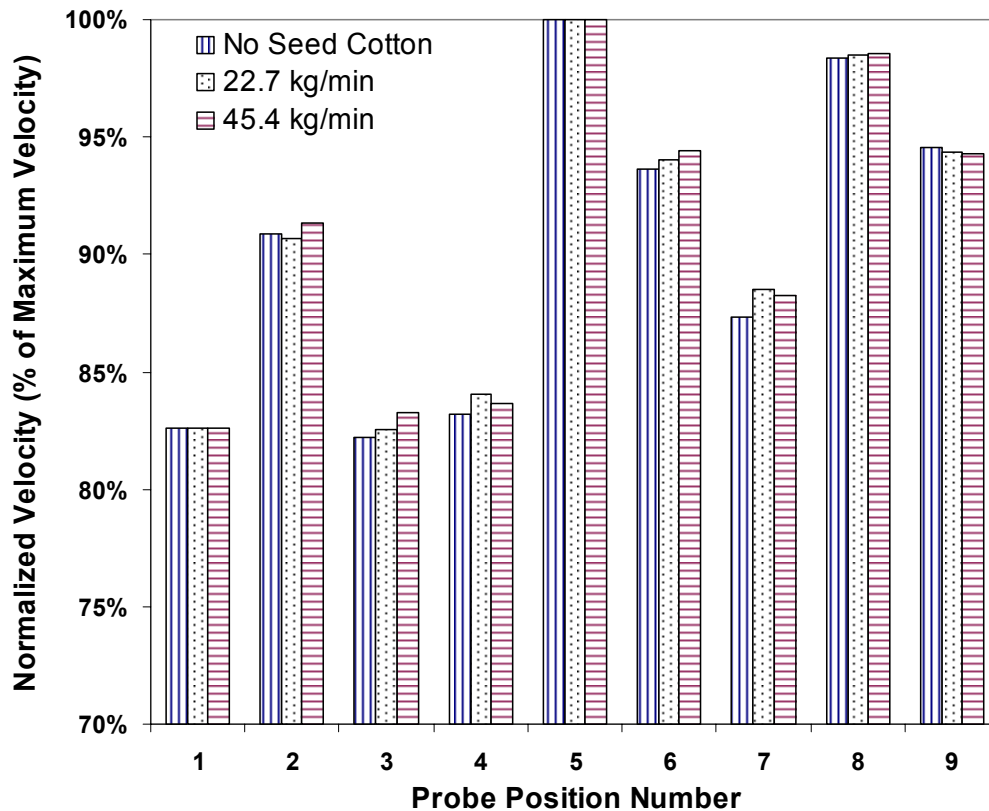


Figure 24. Normalized velocity measurements at nine coplanar points across the cross section of the exit duct.

### ***Concentration Profile Testing***

The results of the concentration tests performed on the exit duct of the seed cotton separation system are shown in Table 26 and Figure 25. An ANOVA test indicated significant differences between mean concentrations by probe location (p value = 0.005). The mean center point correction factor, calculated as the ratio of the duct average concentration to the center point concentration, for all five tests was 93%. An ANOVA test on the concentration data indicate that there is no significant difference between the duct mean concentration and center point (probe location 3) concentration measurements (p value = 0.248). Thus, an isokinetic concentration measurement taken at the center point of the exit duct is likely to adequately represent the duct average emission concentration.

Isokinetic sampling conditions were evaluated for each sampling probe using the ratio of the air velocity entering the sampling probe to the air velocity passing the probe. A summary of this ratio for each sampling probe during each test is shown in Table 27. In general, isokinetic sampling conditions were consistently maintained for each sampler during each test. However, during the first test, isokinetic sampling conditions were not maintained for probe five for 93 s due to an equipment malfunction. An equipment malfunction also resulted in the decreased sampling time for sampling probe one during test one. Hinds (1999) describes the ratio of the probe concentration ( $C_p$ ) to the free stream concentration ( $C_o$ ) in the duct under anisokinetic sampling conditions as shown in equation 47.

Table 26. Concentration data collected at five coplanar locations across the cross section of the exit duct of the seed cotton separation system.

Test	Probe Location	Concentration	Relative Concentration	Center Point Correction Factor	Duct Mean Concentration
		(mg m <sup>-3</sup> )	(% of Max Concentration)	(%)	(mg m <sup>-3</sup> )
1	1	71.9	76.3%	87.5%	76.1
	2	84.8	90.0%		
	3*	87.1	92.4%		
	4	94.2	100.0%		
	5	53.6	56.9%		
2	1	67.9	86.7%	97.1%	70.6
	2	73.5	93.9%		
	3*	72.8	93.0%		
	4	78.3	100.0%		
	5	62.9	80.3%		
3	1	79.3	100.0%	87.4%	68.3
	2	66.9	84.3%		
	3*	78.2	98.5%		
	4	73.7	92.9%		
	5	53.4	67.3%		
4	1	69.4	87.1%	110.0%	69.5
	2	67.0	84.1%		
	3*	63.2	79.3%		
	4	79.7	100.0%		
	5	61.8	77.6%		
5	1	66.5	88.1%	87.2%	65.8
	2	69.2	91.7%		
	3*	75.4	100.0%		
	4	66.4	88.0%		
	5	61.0	80.9%		
<b>Means</b>	<b>1</b>	<b>71.0<sup>a,b</sup></b>	<b>90.5%</b>	<b>93.0%</b>	<b>70.1</b>
	<b>2</b>	<b>72.3<sup>a,b</sup></b>	<b>92.1%</b>		
	<b>3*</b>	<b>75.3<sup>b</sup></b>	<b>96.0%</b>		
	<b>4</b>	<b>78.5<sup>b</sup></b>	<b>100.0%</b>		
	<b>5</b>	<b>58.5<sup>a</sup></b>	<b>74.6%</b>		

\* Indicates center point probe location.

Mean concentrations with the same letter are not significantly different according to Tukey's HSD test ( $\alpha = 0.05$ ).

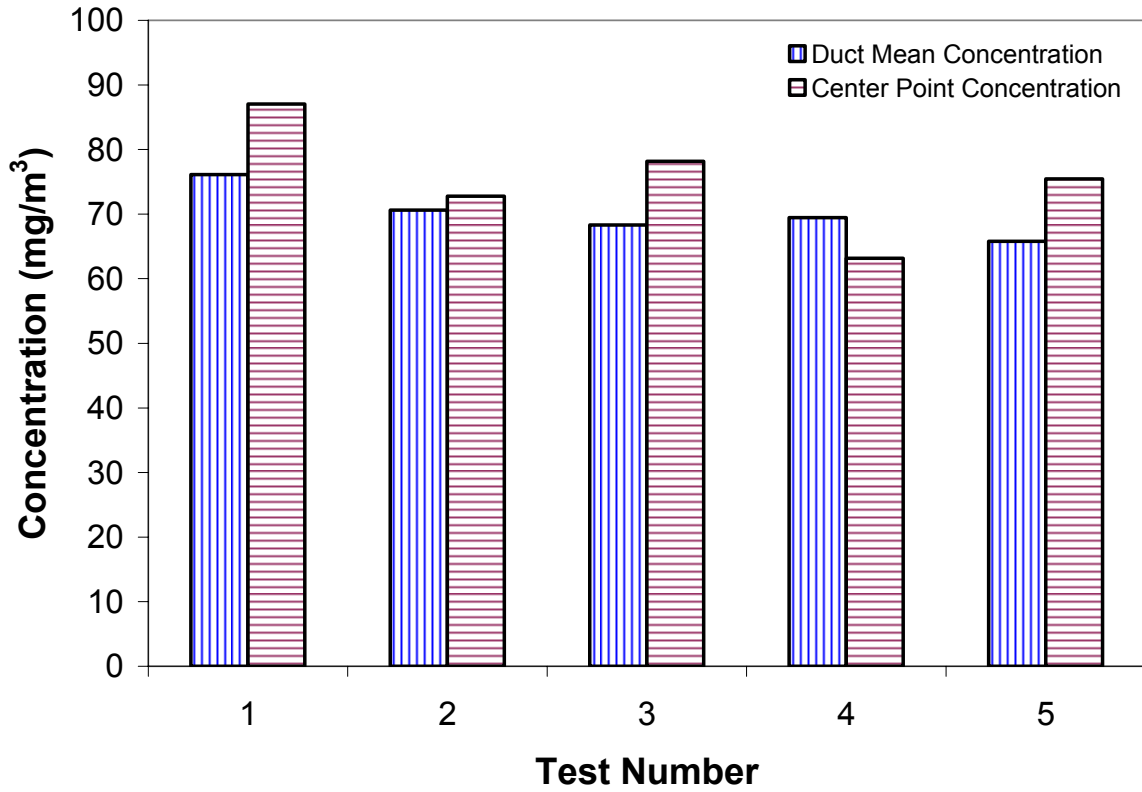


Figure 25. Comparison of the duct mean concentration to the center point concentration by test.

$$\frac{C_P}{C_o} = 1 + \left( \frac{U_o}{U} - 1 \right) \left( 1 - \frac{1}{1 + (2 + 0.62 U/U_o) S} \right) \quad (47)$$

where  $U_o$  = free stream air velocity in the duct (m/s),  $U$  = velocity of the air entering the sampling nozzle (m/s), and  $S$  = Stokes number. The unitless Stokes number for the inlet of the sampling nozzle is given by equation 48.

$$S = \frac{\tau U_o}{D_s} \quad (48)$$

where  $\tau$  = particle relaxation time (s), and  $D_s$  = sampling nozzle diameter. Hinds (1999) defines  $\tau$  in terms of particle diameter ( $d$ ) as shown in equation 49.

$$\tau = \frac{\rho_p d^2 C_c}{18\eta} \quad (49)$$

where  $\rho_p$  = particle density (kg/m),  $C_c$  = Cunningham correction factor, and  $\eta$  = absolute viscosity (Pa – s).

The procedure described by Hinds (1999) was used on a time weighted average basis (equation 50) with the PSD of the PM captured by sampling probe five during test one to estimate the error in the concentration measurement resulting from the anisokinetic sampling conditions. This analysis indicated that the measured concentration was 3% greater than the free stream concentration in the duct at the location of probe 5. Thus, the measurement error resulting from the anisokinetic sampling conditions was considered to be negligible and the measured concentration from probe five was used as reported for all analyses.

$$F_a C + F_i C_o = C_m \quad (50)$$

where  $F_a$  = fraction of sampling time when conditions were anisokinetic,  $F_i$  = fraction of sampling time when conditions were isokinetic, and  $C_m$  = measured concentration ( $\mu\text{g}/\text{m}^3$ ).

Table 27. Summary statistics for the ratio of the air velocity entering the sampling probe to the air velocity passing the probe calculated for five samplers during five concentration tests.

Test	Location	I = Nozzle Velocity / Probe Velocity				N (s)	Anisokinetic Time (s)
		Mean	St. Dev.	Min	Max		
1	1	0.985	0.041	0.856	1.177	589	8
1	2	1.003	0.021	0.814	1.071	641	9
1	3	0.992	0.010	0.968	1.056	641	0
1	4	0.997	0.025	0.934	1.043	641	0
1	5	0.941	0.036	0.839	1.004	547	93
2	1	1.017	0.016	0.989	1.162	666	6
2	2	0.993	0.013	0.957	1.061	666	0
2	3	0.993	0.012	0.966	1.056	666	0
2	4	0.995	0.018	0.941	1.041	666	0
2	5	0.988	0.011	0.943	1.029	666	0
3	1	1.015	0.018	0.985	1.200	643	4
3	2	0.987	0.012	0.944	1.024	643	0
3	3	0.990	0.015	0.945	1.079	643	0
3	4	0.989	0.017	0.942	1.039	643	0
3	5	0.982	0.015	0.938	1.009	643	0
4	1	1.015	0.015	0.972	1.113	649	3
4	2	0.995	0.009	0.970	1.048	649	0
4	3	0.999	0.010	0.969	1.032	649	0
4	4	0.994	0.008	0.967	1.018	649	0
4	5	0.994	0.008	0.975	1.024	649	0
5	1	1.014	0.018	0.965	1.245	649	3
5	2	1.002	0.007	0.958	1.041	649	0
5	3	0.999	0.012	0.965	1.038	649	0
5	4	0.992	0.011	0.967	1.068	649	0
5	5	0.991	0.011	0.956	1.019	649	0

### ***Particle Size Distribution Analysis***

The AED MMD and GSD of the best fit lognormal distribution for each isokinetic sampling probe location are shown in Table 28 along with the mass weighed average PSD representing the duct average PSD. Also shown in Table 28 are the PSD analysis results of the corn starch fed into the system during each test. The mass

weighted average PSD was calculated using the PSDs and net filter masses from the sampling probes at locations 1, 2, 4, and 5 (see Figure 26). No significant differences ( $\alpha = 0.05$ ) were observed between the MMD or GSD values for any of the sampling locations (MMD p value = 0.749, GSD p value = 0.054). Further analysis indicated no significant difference between the MMD of the mass weighted average PSD and the center point location PSD (p value = 0.780). However, a significant difference between the GSD values for the mass weighted average PSD and the center point location PSD was observed (p value = 0.038). The difference in mean GSD values for the mass weighted average and center point location PSDs is 0.06 ( $1.45 - 1.39 = 0.06$ ). Although this difference is significant, no appreciable difference between the duct mean and center point PSDs was observed. The center point, mass weighted average, and inlet corn starch PSDs measured for test 4 are shown in Figure 26. The overlapping of the three PSDs shown in Figure 26 was typical of all the tests. The mean AED MMD and GSD of the PSD for the corn starch used in the tests were  $18.4 \mu\text{m}$  and 1.36, respectively. No significant difference was observed between the mean MMD values for the inlet corn starch, center point sampling location, and mass weighted average PSDs (p value = 0.109). However, significant differences in the GSD values from these PSDs were observed (p value = 0.008). Further analysis using Tukey's HSD test indicated that two homogeneous subsets exist in the GSD values using the data taken from the inlet corn starch, center point sampling location, and mass weighted average PSDs. The constituents within each homogeneous subset are not significantly different while significant differences exist between subsets. The constituents of subset one were the inlet cornstarch and center point sampling location GSDs (p value = 0.494) while the second subset was made up by the GSD values from the center point sampling location and mass weighted average PSDs (p value = 0.059). These results indicate that the PSD of the inlet dust was not substantially altered between the feeding point and exit of the seed cotton separation system.



Table 28. AED PSD analysis results of each isokinetic sampling location within the exit duct of the seed cotton separation system. The inlet corn starch and mass weighted average PSD characteristics calculated from the net filter mass and PSD of probe locations 1, 2, 4, and 5 are also shown for each test.

	Test 1		Test 2		Test 3		Test 4		Test 5	
Location	MMD	GSD	MMD	GSD	MMD	GSD	MMD	GSD	MMD	GSD
Inlet Corn Starch	18.6	1.42	18.0	1.34	18.4	1.35	19.1	1.35	18.0	1.36
1	15.5	1.56	19.7	1.51	17.4	1.45	18.6	1.50	18.9	1.39
2	17.4	1.34	18.2	1.47	17.6	1.40	15.0	1.44	17.2	1.38
3	<b>19.1</b>	<b>1.31</b>	<b>16.5</b>	<b>1.42</b>	<b>16.8</b>	<b>1.40</b>	<b>18.0</b>	<b>1.42</b>	<b>16.6</b>	<b>1.40</b>
4	18.4	1.37	17.8	1.45	16.6	1.50	17.6	1.37	18.0	1.41
5	15.7	1.45	17.2	1.44	18.0	1.53	17.2	1.41	18.4	1.51
Mass Wt. Avg.	<b>17.2</b>	<b>1.43</b>	<b>18.2</b>	<b>1.47</b>	<b>17.4</b>	<b>1.46</b>	<b>17.0</b>	<b>1.45</b>	<b>18.0</b>	<b>1.42</b>

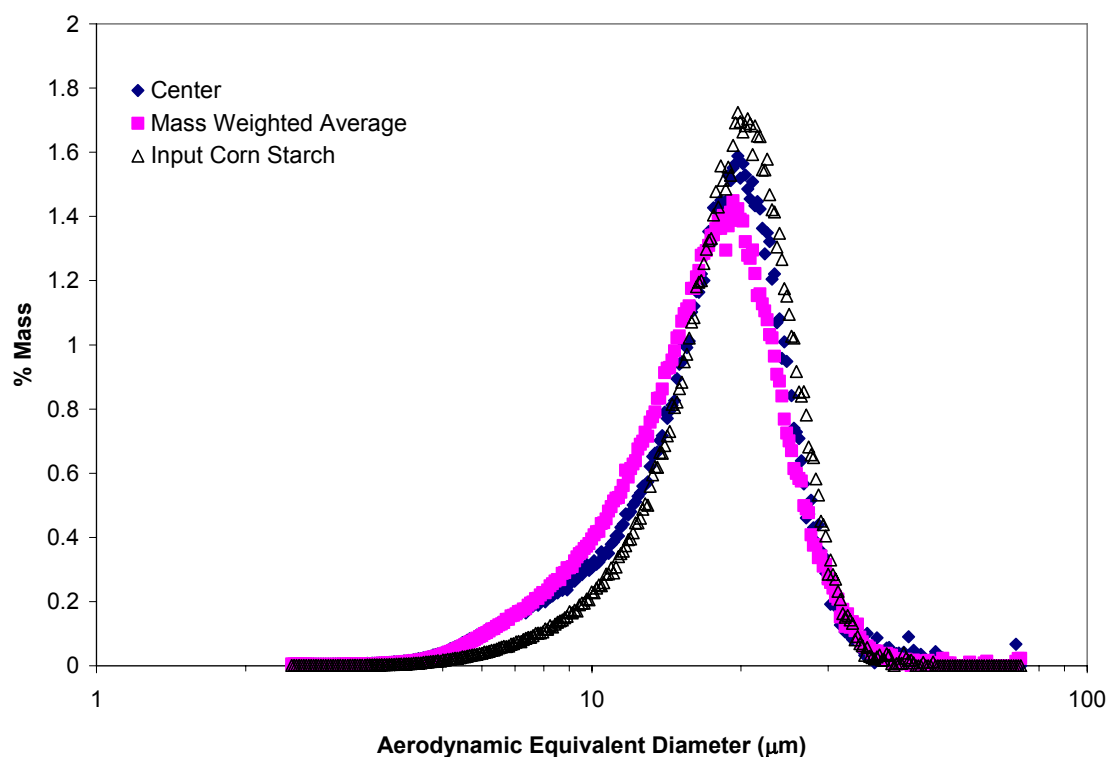


Figure 26. Center point, mass weighted average, and input corn starch PSDs measured during test 4.

### ***Total System Deposition Test Results***

The system deposition test results for the 5 and 10 g/min dust feeding rates are shown in Table 29. The mean deposition at 10 and 5 g/min was 76.0 and 63.6 %, respectively. The mean deposition values by feed rate were not statistically different by the results of an ANOVA test ( $p$  value = 0.225). These values are expected to represent worst case deposition values due to the nature of the cornstarch, and therefore substantially overestimate the deposition values likely to be observed under field conditions. Corn starch is an organic dust that tends to easily adhere to a clean surface but was chosen for use in the tests due to its abundant availability and well known PSD characteristics. Isokinetic ratio statistics calculated for each test indicated that there was a negligible amount of error introduced in the concentration measurements due to anisokinetic sampling conditions.

Table 29. Source sampling system total deposition test results at 5 and 10 g/min nominal inlet dust feeding rate.

<b>Test</b>	<b>Total System Deposition (%)</b>	
	<b>10 g/min</b>	<b>5 g/min</b>
1	74.6	81.8
2	73.6	68.6
3	78.2	64.2
4	83.4	83.4
5	70.0	20.3
<b>Mean</b>	<b>76.0<sup>a</sup></b>	<b>63.6<sup>a</sup></b>

\*Means with the same letter are not statistically different at the 0.05 level of significance.

## **SOURCE MEASUREMENT OF COTTON PICKER PM EMISSIONS**

### ***Field Testing***

Source testing of the PM emissions generated by a John Deere 9996 cotton picker were conducted during the sampling events conducted at farm 3 during 2007. Ten source measurement tests were conducted in conjunction with upwind/downwind sampling to measure the PM emissions generated by the harvester. The source sampling

system was installed on the harvester on duct 3 in the same configuration in which it was tested (see previous discussion of source sampling system testing and evaluation). Each test plot was setup so that the harvester made a total of eight passes in the field (4 rounds) covering 48 rows per test. The test plots ranged in size from 2.3 to 1.01 ha and the test durations ranged from 128 to 49 min. The 20.3 x 25.4 cm filters used in the source sampler (Pall Corp., Pallflex Emfab filter material 7224, East Hills, NY) were pre and post weighed according to the previously discussed procedure for weighing 47 mm diameter filters for the low volume TSP samplers. A total of four filters were used during each test at farm 3. The two filters initially installed in the source sampling filter bank were replaced half way through each test to prevent overloading. The cyclone bucket was weighed prior to and after each test using a laboratory balance (PB1502, Mettler-Toledo, Greifensee Switzerland).

Prior to entering the field, the system operator would start the fan on the harvester and run the picker engine at full throttle to allow the system to stabilize before entering the field. Once the harvester fan was running at full speed, the operator switched on the source sampler fans through the laptop computer and allowed the source sampling system to equilibrate with the harvester air system before entering the field. Typically this warm-up process would last approximately 10-15 s. The harvester speed was held approximately constant in the field at 6.44 km/h. Thus the load on the harvester would vary by yield and plant density resulting in fluctuations in the harvester fan speed. Typically, these fluctuations were brief in nature only lasting a few seconds. Therefore, the control algorithm used in the source sampler control system was configured to modulate the valve position based on a 7 second running average for both the exit duct velocity and source sampler nozzle velocity. The duct velocity was measured by a pitot tube (Model 160-8, Dwyer Instruments Inc., Michigan City, IN) mounted 2.5 cm to the side of the sampling nozzle mounted in the center of the duct. The velocity of the air entering the sampler nozzle was calculated by dividing the flow rate through the orifice meter by the cross sectional area of the nozzle. The tip of the sampling nozzle and pitot tube were mounted at the same distance inward from the exit

of the duct to prevent errors in duct velocity measurements resulting from changes in air flow patterns around the sampling nozzle. After each pass in the field, the harvester basket was emptied to keep cotton from building up under and plugging the source sampler dropper wheel and the sampler nozzle and pitot tube were checked to make sure no cotton fiber was blocking either orifice. Isokinetic sampling ratios were calculated from the duct and nozzle velocities during each test.

### ***2007 Field Testing Results***

The emission concentration results for the ten tests performed with the source sampling system on farm 3 during 2007 are shown in Table 30. The mean TSP, PM<sub>10</sub>, and PM<sub>2.5</sub> emission concentrations were 158.8, 53.7, and 9.7E-02 mg/m<sup>3</sup>, respectively.

Table 30. Six-row harvester emission concentration results for the 10 tests conducted with the source sampling system on farm 3 during 2007.

<b>Rep</b>	<b>Emission Concentration (mg/m<sup>3</sup>)</b>		
	<b>TSP</b>	<b>PM<sub>10</sub></b>	<b>PM<sub>2.5</sub></b>
1	116.8	41.8	7.2E-02
2	111.0	40.6	7.0E-02
3	107.6	38.3	8.0E-02
4	157.9	55.8	1.1E-01
5	214.1	74.8	1.2E-01
6	197.9	69.0	1.2E-01
7	218.2	64.6	1.1E-01
8	155.9	50.1	8.8E-02
9	173.9	62.3	1.1E-01
10	134.2	39.6	9.3E-02
<b>Mean</b>	<b>158.8</b>	<b>53.7</b>	<b>9.7E-02</b>
<b>St. Dev.</b>	<b>41.7</b>	<b>13.5</b>	<b>1.9E-02</b>

Emission rates for each test were calculated by multiplying the measured emission concentrations by the calculated average duct flow rate. The resulting emission rates are shown in Table 31. The emission rate data appear to trend with the emission factor results from the dispersion modeling process using both ISCST3 and AERMOD.

Table 31. Six-row harvester emission rates for ten tests conducted with the source sampling system on farm 3 during 2007.

Rep	Emission Rate (g/min)		
	TSP	PM <sub>10</sub>	PM <sub>2.5</sub>
1	50.9	18.2	0.031
2	43.3	15.8	0.027
3	44.6	15.9	0.033
4	67.4	23.8	0.045
5	88.0	30.8	0.051
6	85.6	29.8	0.051
7	91.5	27.1	0.044
8	66.8	21.5	0.038
9	75.0	26.9	0.050
10	57.7	17.0	0.040
<b>Mean*</b>	<b>67.1 ± 11.05</b>	<b>22.7 ± 3.59</b>	<b>0.041 ± 0.005</b>
<b>St. Dev.</b>	<b>17.8</b>	<b>5.8</b>	<b>0.009</b>

\*Means are shown with 95% confidence intervals.

An analysis of the systematic uncertainty for the source sampling system was conducted according to the procedure described by Kline and McClintock (1953) and used by Price (2004). The average uncertainty due to systematic effects for the source sampler was determined to be 2.78%. A subsequent sensitivity analysis indicated that the majority of the overall systematic uncertainty was due to the measurement of the airflow rate, more specifically in the measurement of pressure drop across the orifice meter in the calibration process. The same sensitivity analysis result was observed by Price (2004) for the low volume TSP samplers. The results of this analysis are presented in Appendix E.

The emission rate data were converted to emission factors in terms of kg/ha and kg/bale by multiplying by the test duration and dividing by either the area harvested or number of lint bales harvested. The emission factor data are presented in Table 32. Summaries of each test with the source sampler during 2007 are included in Appendix F.

Table 32. Six-row harvester emission factors from ten tests performed with the source sampling system on farm 3 during 2007.

Rep	Emission Factors (kg/ha)			Emission Factors (kg/bale)		
	TSP	PM <sub>10</sub>	PM <sub>2.5</sub>	TSP	PM <sub>10</sub>	PM <sub>2.5</sub>
1	0.96	0.34	5.88E-04	0.15	0.05	9.30E-05
2	0.89	0.33	5.60E-04	0.15	0.05	9.40E-05
3	0.97	0.35	7.21E-04	0.16	0.06	1.22E-04
4	1.35	0.48	9.06E-04	0.20	0.07	1.32E-04
5	1.97	0.69	1.13E-03	0.22	0.08	1.25E-04
6	1.90	0.66	1.14E-03	0.20	0.07	1.23E-04
7	1.94	0.57	9.39E-04	0.23	0.07	1.12E-04
8	1.36	0.44	7.64E-04	0.17	0.05	9.31E-05
9	1.52	0.54	1.00E-03	0.23	0.08	1.50E-04
10	1.12	0.33	7.79E-04	0.15	0.04	1.03E-04
	<b>1.40</b>	<b>0.47</b>	<b>8.53E-04</b>	<b>0.19</b>	<b>0.06</b>	<b>1.15E-04</b>
<b>Mean*</b>	<b>± 0.261</b>	<b>± 0.085</b>	<b>± 1.18E-04</b>	<b>± 0.021</b>	<b>± 0.009</b>	<b>± 1.2E-05</b>
<b>St. Dev.</b>	<b>0.42</b>	<b>0.14</b>	<b>2.05E-04</b>	<b>0.03</b>	<b>0.01</b>	<b>1.90E-05</b>

\*Means displayed with 95% confidence intervals.

In an effort to further investigate the trends in the emission rate data, correlation analyses were conducted on the emission rate variables (i.e. PM<sub>10</sub>, PM<sub>2.5</sub>, and TSP emission rates in terms of kg/min). The emission rate variables were correlated with crop yield (lint bales/ha), test plot area (ha), test duration (min), soil mass % < 75 µm, soil mass % < 106 µm, seed cotton moisture content (%), and soil surface moisture content (%). The results of the correlation analysis using the source sampler emission rate data are shown in Table 33.

Table 33. Correlation results of the source sampler emission rate data with area, yield, test duration, soil mass % < 75  $\mu\text{m}$ , soil mass % < 106  $\mu\text{m}$ , seed cotton moisture content, and soil surface moisture content.

		Emission Rate (g/min)		
		TSP	PM <sub>10</sub>	PM <sub>2.5</sub>
Area (ha)	R	-0.503	-0.379	-0.611
	p value	0.1382	0.2795	0.0605
Yield (bales/ha)*	R	0.850	0.775	0.718
	p value	0.0018	0.0085	0.0194
Duration (min)	R	-0.539	-0.425	-0.682
	p value	0.1080	0.2203	0.0298
Soil Mass % < 75 $\mu\text{m}$	R	-0.460	-0.377	-0.086
	p value	0.1815	0.2832	0.8129
Soil Mass % < 106 $\mu\text{m}$	R	-0.334	-0.272	0.070
	p value	0.3458	0.4471	0.8473
Seed Cotton Moisture Content (%)	R	-0.005	-0.168	-0.028
	p value	0.9885	0.6427	0.9384
Soil Surface Moisture Content (%)	R	0.018	-0.071	-0.153
	p value	0.9610	0.8448	0.6725

\*Highlighted correlation coefficients are statistically significant at the 0.01 level of significance.

Significant correlations at the 0.01 level were observed in the relationships between TSP and PM<sub>10</sub> emission rates with yield. The PM<sub>2.5</sub> emission rate correlation with yield is significant at the 0.05 level. Poor correlations with test plot area were observed for the emission rate data for any size indicator. These results indicate that PM emission rates are more closely related with the mass of material processed through the harvester on a unit area basis (i.e. yield) than with land area alone. Therefore it is appropriate to list PM emission factors for cotton harvesting on a mass of PM emitted per lint bale harvested basis.

### *Summary of Source Sampler Emission Factors*

Source measurement of emission concentration onboard a six-row cotton picker was successfully conducted during 2007. However, the novel system and protocol used to develop PM emission factors through direct measurement was initially met with skepticism. Some argued the following points:

- The system initially proposed to separate the seed cotton from the air stream would significantly alter the performance of the harvesting machine in the field and would be problematic from a safety and performance standpoint.
- The system used to measure the emissions from the harvester would alter the normal operating characteristics of the harvester air system and would not be representative of normal operating conditions.
- Source measurements of PM emissions from the harvester basket do not account for PM emissions generated by the interaction of the harvester wheels and the soil surface.

The seed cotton separation system was designed to separate the maximum amount of seed cotton from the air stream while minimizing the total pressure loss added to the harvester air system. Measurements of the system pressure loss were taken during the tests conducted to evaluate the seed cotton separation efficiency, air velocity profile in the exit duct, and concentration profile in the exit duct. The results of these measurements indicate that the system pressure loss at 71 m<sup>3</sup>/min (2500 ft<sup>3</sup>/min) and 85 m<sup>3</sup>/min (3000 ft<sup>3</sup>/min) were 20 cm H<sub>2</sub>O (8 in H<sub>2</sub>O) 23 and cm H<sub>2</sub>O (9 in H<sub>2</sub>O), respectively. The increased pressure loss through the system decreased the velocity of the air in the seed cotton transport duct on the harvester from approximately 1524 m/min (5000 ft/min) to approximately 915 m/min (3000 ft/min). This decrease in air velocity did not result in operational problems with the harvester in terms of plugging of air ducts, decreased picking efficiency, or safety issues.

The seed cotton separation system provided a means by which to remove the seed cotton from the air stream and channel the particulate laden air stream to the back of the harvester, providing a location from which to collect emission concentration measurements. The seed cotton separation system effectively altered the airflow patterns inside the basket in two ways:

1. The presence of the separation system in the basket created an obstacle around which the airflow from the other seed cotton transport ducts must pass.



Anecdotally, this created additional turbulence in the basket potentially increasing the entrainment and emission of PM from the harvester basket. Additionally, the air exiting the exit duct on the seed cotton separation system was directed perpendicular to the back wall of the basket with a separation distance of approximately 30.5 cm (12 in) between the exit of the duct and the back wall. This configuration essentially created a high velocity jet of air at the rear of the harvester basket that normally is not there.

2. The particulate laden air carrying the seed cotton into the basket must normally pass through a set of finger grates or through the screen panels on the side of the basket in order to exit the system. In this process, an unspecified amount of filtration takes place as the air passes through the lint fiber collected on the finger grates and basket screen panels.

Evidence of the increased emissions due to the presence of the source sampler can be seen in the significant differences observed between the mean emission factors for the 6-row and 6-row w/ss treatments developed using both ISCST3 and AERMOD during the sampling at farm 3 in 2007. Thus, the final emission factor for the six row harvester developed through the dispersion modeling procedure with ISCST3 or AERMOD is not inclusive of the emission factors from the 6-row w/ss treatment.

The emissions from duct 3 do not undergo the filtering process before the emission concentrations are measured. Thus emission concentrations measured in the exit duct could be considered higher than emission concentrations on the outside of the harvester basket. Therefore, the PM emission factors developed from the source sampling techniques described here have been developed from the measured emission rates with no correction made to account for deposition. The emission factors from the source sampling technique are not corrected for deposition according to the following logic:

- The deposition values reported here substantially overstate the true deposition in the field because the corn starch used in the tests does not accurately mimic the nature of the primary silica based material

measured in the field. It was not initially anticipated that the corn starch would adhere so readily to the inner surfaces of the separator system. Additionally, vibrations from the harvester preventing deposition to the inner surfaces of the separation system were not accounted for in the deposition tests discussed previously.

- The emission concentrations measured in the exit duct of the source sampling system were not exposed to the filtration action of the seed cotton present on the finger grates and basket screen panels.

The emission concentrations measured by the source sampling system are not inclusive of the emissions generated by the interaction of the harvester wheels traveling over the soil surface. Anecdotally these emissions are considered to be abated through the filtering action provided by the plant canopy as the air flows through. In an effort to quantify these emissions, the harvesters (2-row and 6-row) were operated in the field on farm 3 (without the row units or fans engaged) at three stages of crop growth during 2007. Field conditions during the first set of tests were dry over the unplanted rows. A second set of tests were conducted approximately 2 months later after the crop had reached a height of approximately 30 – 41 cm (12 – 16 in). Finally, a third set of tests were conducted approximately two weeks after the second set of tests when the average plant height was approximately 41 – 51 cm (16 -20 in). The third set of tests were conducted at the stage of growth where the harvester row units could just pass over the top of the plants without touching and the wheels would not cause damage to the sides of the plants as the machines passed through the field (see Figure 27).

Low volume TSP samplers were used to measure the concentrations downwind of the test plot during each test. Three treatments were tested to evaluate the effect of the number of exposure events of the harvester to the samplers (i.e. the number of times the harvester passed the sampler) on the resulting emission factors developed in ISCST3. The same modeling procedure discussed previously was used to develop emission factors in terms of kg/ha from the measured TSP concentrations and meteorological data. The results of the sampling events are shown in Table 34.



Figure 27. Photograph of the six row harvester traveling down rows of cotton (average plant height 41 – 51 cm) with the row units and fan not engaged in order to measure the concentration of PM generated by the interaction of the harvester wheels and the soil surface (samplers located to the left of the harvester).

Replicated tests were not conducted during the first set of tests. The first set of tests was conducted on fallow ground to determine if the emissions generated by the wheel/soil surface interaction could be measured. With positive results from the first tests, the second set of tests were conducted with replication but wind direction variation within the tests resulted in invalid emission factor means for replications two and three, leaving only the emission factors from replication one. The third set of tests was conducted with three replications and the mean emission factors presented are the average of all three replications.  $PM_{10}$  and  $PM_{2.5}$  emission factors were developed by multiplying the respective TSP emission factor by the mass %  $PM_{10}$  and  $PM_{2.5}$  from the

PSD analysis on the soil material  $< 75\mu\text{m}$  from the soil samples collected on farm 3 during 2007. The percent  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  used were 32.2 and 0.3%, respectively.

An analysis of variance on the Growth Stage 3 data indicate no significant difference between treatment means within the TSP,  $\text{PM}_{10}$ , or  $\text{PM}_{2.5}$  size ranges. Thus the average of the emission factors for the six row harvester are used to account for the PM generated by the wheel/soil surface interaction. The resulting TSP,  $\text{PM}_{10}$ , and  $\text{PM}_{2.5}$  emission factors (with 95% confidence intervals) for the PM generated by the wheel/soil surface interaction are  $0.24 \pm 0.11$ ,  $0.08 \pm 0.036$ , and  $7.27\text{E-}04 \pm 3.32\text{E-}04$  kg/ha respectively. These emission factor values are approximately 15% of the total TSP,  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  emission factors when the source sampler emission factors are combined with the emission factors from the wheel/soil surface interaction. The total TSP,  $\text{PM}_{10}$ , and  $\text{PM}_{2.5}$  emission factors resulting from the source measurement protocol are  $1.64 \pm 0.37$ ,  $0.55 \pm 0.12$ , and  $1.58\text{E-}03 \pm 4.5\text{E-}04$  kg/ha, respectively ( $1.46 \pm 0.33$ ,  $0.49 \pm 0.11$ , and  $1.41\text{E-}03 \pm 4.01\text{E-}04$  lb/ac, respectively). In terms of kg/bale, the TSP,  $\text{PM}_{10}$ , and  $\text{PM}_{2.5}$  emission factors from the source measurements of PM emissions from the six row machine were  $0.22 \pm 0.019$ ,  $0.07 \pm 0.007$ , and  $2.15\text{E-}4 \pm 1.49\text{E-}5$  kg/bale, respectively ( $0.48 \pm 0.04$ ,  $0.15 \pm 0.015$ , and  $4.74\text{E-}4 \pm 3.3\text{E-}5$  lb/bale, respectively). These emission factors are inclusive of the PM emissions generated by the harvester wheel/soil surface interaction and represent the average mass per bale emission factors measured over a crop yield range from 5.9 to 9.3 bales/ha (2.4 to 3.8 bales/ac).

Table 34. Emission factors developed using measured TSP concentrations and ISCST3 for tests conducted to quantify the PM emissions generated by the interaction between the harvester wheels and the soil surface.

Treatment	Growth Stage 1* Pre-planting			Growth Stage 2** Plant Height: 30 - 41 cm			Growth Stage 3*** Plant Height: 41 - 51 cm		
	TSP (kg/ha)	PM <sub>10</sub> (kg/ha)	PM <sub>2.5</sub> (kg/ha)	TSP (kg/ha)	PM <sub>10</sub> (kg/ha)	PM <sub>2.5</sub> (kg/ha)	TSP <sup>+</sup> (kg/ha)	PM <sub>10</sub> <sup>+</sup> (kg/ha)	PM <sub>2.5</sub> <sup>+</sup> (kg/ha)
2 Row over 12 rows	5.84	1.88	1.75E-02	n/a	n/a	n/a	0.53 <sup>a</sup>	0.17 <sup>b</sup>	1.58E-03 <sup>c</sup>
2 Row over 24 rows	9.31	3.00	2.79E-02	1.19	0.38	3.58E-03	0.45 <sup>a</sup>	0.15 <sup>b</sup>	1.36E-03 <sup>c</sup>
2 Row over 36 rows	7.81	2.52	2.34E-02	0.57	0.18	1.71E-03	0.43 <sup>a</sup>	0.14 <sup>b</sup>	1.28E-03 <sup>c</sup>
6 Row over 12 rows	4.26	1.37	1.28E-02	0.12	0.04	3.65E-04	0.31 <sup>a</sup>	0.10 <sup>b</sup>	9.43E-04 <sup>c</sup>
6 Row over 24 rows	3.47	1.12	1.04E-02	0.51	0.16	1.52E-03	0.15 <sup>a</sup>	0.05 <sup>b</sup>	4.64E-04 <sup>c</sup>
6 Row over 36 rows	12.54	4.04	3.76E-02	0.52	0.17	1.55E-03	0.26 <sup>a</sup>	0.08 <sup>b</sup>	7.74E-04 <sup>c</sup>

<sup>+</sup>Means with the same letter are not significantly different at the 0.05 level of significance.

\*Replicated tests were not conducted at growth stage one.

\*\*Means displayed for Growth Stage 2 represent the mean emission factor from replication one due to variable wind directions during replications two and three.

\*\*\*Means displayed for Growth Stage 3 represent the average of three replications per treatment.

## **CHAPTER V**

### **PARTICLE SIZE DISTRIBUTION AND PARTICLE DENSITY ANALYSIS OF PARTICULATE MATTER SAMPLES**

#### **INTRODUCTION**

The analysis of particle size in terms of percent mass versus particle diameter plays a key role in understanding both the nature of PM emissions as well as the expected operating performance for sampling devices used to measure PM concentrations. Buser (2004) concluded that significant errors result in PM concentrations measured by FRM PM<sub>10</sub> and PM<sub>2.5</sub> samplers when exposed to PM with aerodynamic mass median diameter larger than the cutpoint of the sampler. The cutpoints of FRM PM<sub>10</sub> and PM<sub>2.5</sub> samplers are 10 and 2.5  $\mu\text{m}$  respectively. Buser (2004) further explains that these errors are a consequence of the interaction between the sampler performance characteristics and the particle size distribution of the sampled PM. The findings of Buser (2004) were based on theoretical simulations assuming that the performance characteristics of the FRM PM<sub>10</sub> and PM<sub>2.5</sub> samplers remain constant within specified performance criteria specified by EPA. Wanjura et al. (2005a) indicate that the errors identified by Buser (2004) may be exacerbated by shifting of the performance characteristics of PM<sub>10</sub> samplers under field conditions.

A more appropriate basis for determining true PM<sub>2.5</sub> and PM<sub>10</sub> concentrations was described by Buser (2004). The procedure described by Buser (2004) determines true PM<sub>10</sub> and PM<sub>2.5</sub> concentrations by multiplying measured TSP concentrations by mass fractions of PM<sub>10</sub> or PM<sub>2.5</sub> from subsequent particle size distribution analyses on the TSP filters. The underlying premise of this procedure is that TSP concentrations accurately represent the total concentration of suspended PM in the atmosphere since the cutpoint of the TSP sampler is much larger than the MMD of the PM suspended in the ambient air. McFarland and Ortiz (1983) indicate that the cutpoint of the TSP sampler is on the order of 45  $\mu\text{m}$  with a slope of 1.5. This procedure was used in this work to determine accurate PM emission factors in terms of PM<sub>10</sub>, and PM<sub>2.5</sub>. The following

discussions describe the methods used to characterize the PM sampled from the cotton harvesting operation with respect to particle density and particle size distribution.

## METHODS

Particle size analyses were conducted on PM and soil samples to determine the distribution of percent mass versus particle diameter. A Coulter Counter Multisizer III (Beckman – Coulter, Coulter Multisizer III, Miami, FL) was used to determine an estimate of the PSD for the different materials in terms of percent volume versus equivalent spherical particle diameter (ESD) according to the procedure described by Buser (2004). Prior to each analysis in the Coulter instrument, the sample was suspended in a 5% LiCl – Methanol electrolyte solution and exposed to ultrasonic vibration for fifteen min. The ultrasonic vibration provided the energy necessary to remove captured PM from filter media as well as to separate agglomerated particles. After the exposure to ultrasonic vibration, the technician transferred (via plastic pipette) the PM/electrolyte solution to a beaker (located inside the Multisizer III) containing approximately 50 ml of clean electrolyte until the concentration in the beaker reached approximately 5%. Once the concentration in the beaker was sufficient, the technician initiated the run. During each run, the instrument drew approximately 300,000 particles through the aperture tube. An aperture tube with measurement range from 2 – 100  $\mu\text{m}$  was used. The effective maximum particle diameter measured by the Coulter is only 60% of the maximum aperture diameter, or in this case 60  $\mu\text{m}$ . The aperture tube contains two electrodes; between which flows a constant electrical current. When a particle enters the aperture orifice, the momentary increase in impedance (due to the presence of the particle) causes the electrical current flowing between the electrodes to decrease. The increased impedance causes the portion of current not passing between the two aperture electrodes to pass to an amplifier which converts the current pulse into a voltage pulse. The Coulter Principle states that the amplitude of this voltage pulse is directly proportional to the volume of the particle (Beckman Coulter, 2002). The

analysis of several hundred thousand particles allows for the development of a relative frequency histogram relating percent volume to ESD.

A PSD based on percent volume is equivalent to the distribution relating percent mass to ESD under the assumption that the particle density of the PM is constant. The PSDs measured by the Coulter were converted from ESD to aerodynamic equivalent diameter (AED) by equation 51.

$$AED = ESD \sqrt{\rho_p} \quad (51)$$

where:

AED = aerodynamic equivalent diameter ( $\mu\text{m}$ ),

ESD = equivalent spherical diameter ( $\mu\text{m}$ ), and

$\rho_p$  = particle density ( $\text{g}/\text{cm}^3$ ).

PSD analyses were performed on the following samples from 2006:

- 47 mm diameter filters from the TSP samplers,
- soil  $< 75 \mu\text{m}$  (passing the 200 sieve),
- PM  $< 100 \mu\text{m}$  air washed from the bulk seed cotton samples,
- 15 mm diameter cores cut from the source sampler filters, and
- PM  $< 100 \mu\text{m}$  air washed from the material collected in the source sampler cyclone bucket.

PSD analyses were performed on the following samples from 2007:

- 47 mm diameter filters from the TSP samplers,
- soil  $< 75 \mu\text{m}$  (passing the #200 sieve),
- 15 mm diameter cores cut from the source sampler filters, and
- PM  $< 100 \mu\text{m}$  air washed from the material collected in the source sampler cyclone bucket.

Particle density measurements were conducted using a pycnometer (AccuPyc 1330 Pycnometer, Micromeritics, Norcross, GA) according to the procedure described by Wanjura (2005). Approximately one g of material is needed to perform a particle density analysis with the Accupyc 1330 using the  $1 \text{ cm}^3$  sample chamber. The Accupyc 1330 measures the volume of Helium displaced by the solid material in the sample



chamber and calculates the particle density using as the net mass of the sample divided by the volume of solid material contained in the sample chamber. The net mass of the sample is determined prior to the test using a high precision analytical balance (XS205, Mettler-Toledo, Greifensee Switzerland).

Particle density analyses were conducted on the PM < 100 µm air washed from the bulk seed cotton samples and the soil < 75 µm from 2006. Similarly in 2007, particle density analyses were conducted on the soil < 75 µm and the PM < 100 µm air washed from the material collected in the source sampler cyclone bucket.

## RESULTS

### *Particle Size Distribution and Particle Density Analysis Results*

#### *Particle Density Analysis*

The results of the particle density analysis on the soil material less than 75µm from 2006 and 2007 are shown in Table 35. The mean particle densities of the soil samples taken from each sampling location were different by the results of an ANOVA at the 0.05 level of significance (p value < 0.001). This difference was expected due to observed differences in soil structure and texture between sampling locations.

Table 35. Average particle density measurements on soil material less than 75 µm taken from farms 1, 2, and 3 during 2006 and 2007.

	Soil Particle Densities by Harvesting Location (g/cm <sup>3</sup> )			
	Farm 1 (2006)	Farm 2 (2006)	Farm 3 (2006)	Farm 3 (2007)
Average (g/cm <sup>3</sup> )	2.58 <sup>a</sup>	2.53 <sup>b</sup>	2.61 <sup>c</sup>	2.59 <sup>ac</sup>
St. Dev. (g/cm <sup>3</sup> )	0.02	0.03	0.01	0.03

\*Particle density means with the same letter are not significantly different at the 0.05 level of significance (Fisher's LSD).

The results of the particle density analysis on the PM from the air wash procedure on the bulk seed cotton samples taken during 2006 are shown in Table 36. The air wash PM was mixed thoroughly before performing the analysis to help decrease the bias in the particle density measurements due to sampling.

Table 36. Particle density analysis results for particulate matter less than 100  $\mu\text{m}$  air washed from seed cotton samples taken during 2006.

Air Wash PM Particle Density ( $\text{g}/\text{cm}^3$ )	
Farm 1	1.86
Farm 2	1.79
Farm 3	1.97

The particle density results of the air wash PM from the three locations follow the same trend as the soil material particle density results. This trend is likely a consequence of the influence of soil particles as the primary constituent in the air wash material (Wanjura et al., 2006). The other primary constituent of the air wash PM is organic matter from the crop biomass. The presence of organic matter particles in the air wash material results in the decrease in particle density between the soil material and air wash PM. Wanjura et al. (2006) indicated that as much as 79% of the material air washed from seed cotton samples is comprised of by soil material with the remaining 21% made up by plant and organic material.

Particle density results on the PM <75  $\mu\text{m}$  air washed from the material collected in the source sampler cyclone bucket during 2007 are shown in Table 37. Particle density results for the material captured in the source sample cyclone bucket from 2006 were not available due to insufficient sample sizes. The mean particle density of the material captured in the cyclone bucket is 1.59  $\text{g}/\text{cm}^3$ . The particle density of the material in the cyclone bucket is lower than that of the material air washed from the seed cotton samples due to the increased mass of volatile plant material (i.e. lint fiber and pulverized leaf material). The results of an ash analysis on the air washed material from

the cyclone bucket indicated that the average ash content of the samples was 25.4 % (see Appendix E). Wanjura et al. (2006) indicated that the ash content of a sample increases with increasing amounts of soil material and reported average ash content for soil material, PM <100  $\mu\text{m}$  air washed from seed cotton, and ground plant material <75  $\mu\text{m}$  on the order of 94%, 80%, and 37% respectively.

Table 37. Particle density results of PM <100  $\mu\text{m}$  air washed from material captured in the bucket of the source sampler cyclone during 2007.

<b>Test</b>	<b>Particle Density (g/cm<sup>3</sup>)</b>
1	1.62
2	1.60
3	1.60
4	1.59
5	1.57
6	1.56
7	1.56
8	1.57
9	1.61
10	1.63
<b>Mean</b>	<b>1.59</b>
<b>St. Dev.</b>	<b>0.02</b>

#### *2006 Particle Size Distribution Analysis*

PSD analyses were conducted on the PM from 10, 9, and 10 TSP filters from farms 1, 2, and 3, respectively during 2006. Light PM loading resulted in the exclusion of the other TSP filters. Typically, more than 200  $\mu\text{g}$  of PM must be collected on a 47 mm diameter filter in order to conduct a PSD analysis. PSD analyses were conducted on the source sampler filters (16 total filters, four per source sampling test) and the filters containing the PM less than 100  $\mu\text{m}$  from the material captured in the source sampler cyclone bucket. The results of the PSD analyses from test 7 of farm 1, test 7 of farm 2, and test 1 of farm 3 are shown in Figures 28, 29, and 30, respectively. The ESD MMD

and GSD of the best fit lognormal curves for the data shown in Figures 28, 29, and 30 are shown in Table 38.

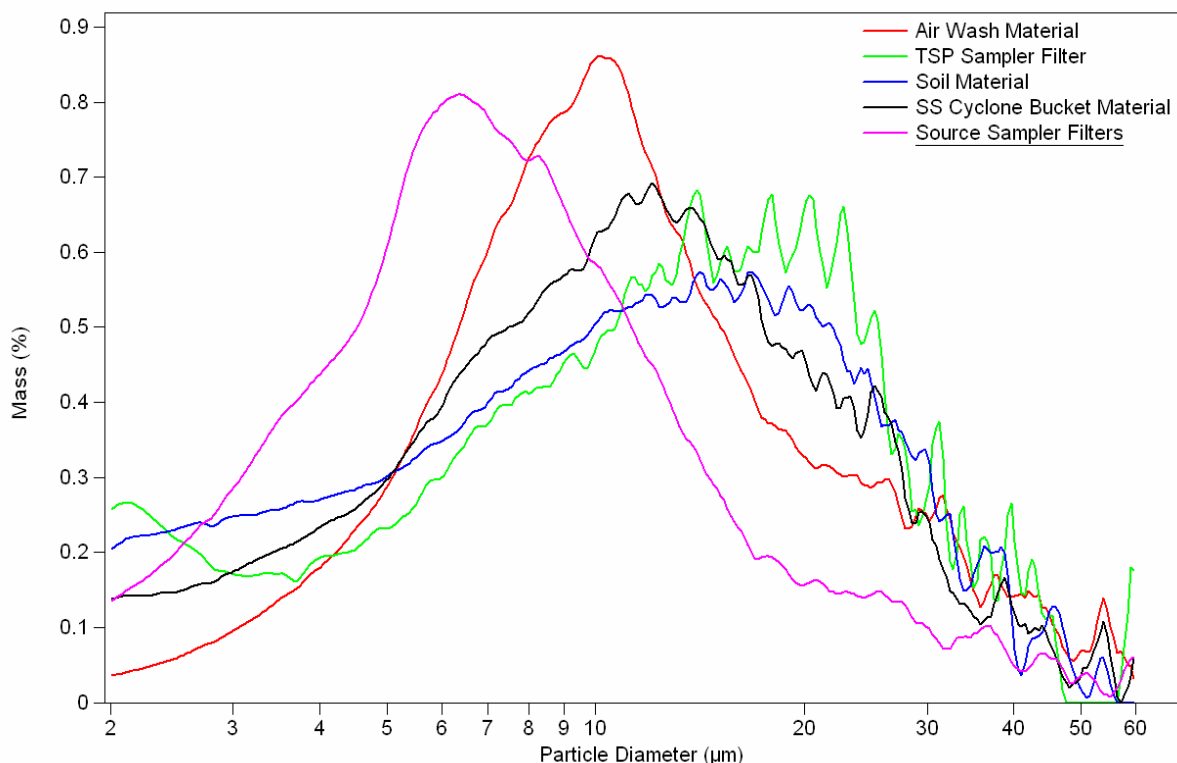


Figure 28. Percent volume vs. ESD particle diameter PSDs for the air wash PM <100  $\mu\text{m}$  (Air Wash Material), PM on the TSP sampler filter (Ambient TSP Sampler Filter), soil material < 75  $\mu\text{m}$  (Soil Material), source sampler cyclone bucket material <100  $\mu\text{m}$  (SS Cyclone Bucket Material), and PM on the source sampler filters (Source Sampler Filter) from test 7 on farm 1 during 2006.

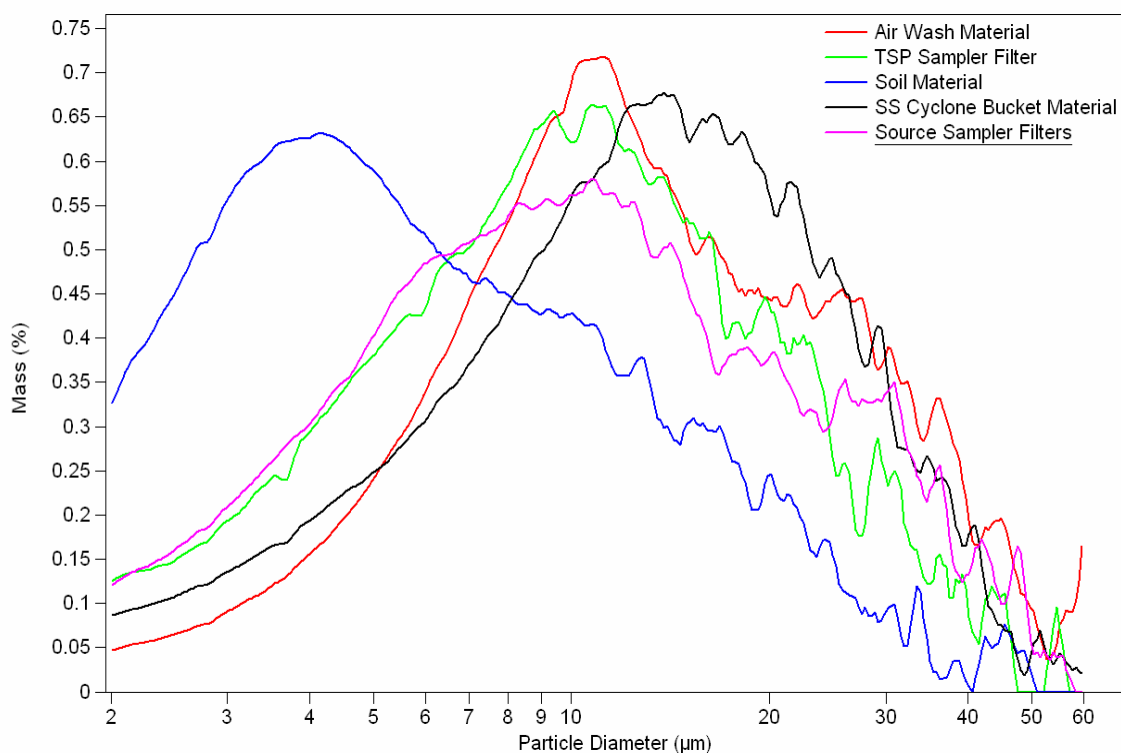


Figure 29. Percent volume vs. ESD particle diameter PSDs for the air wash PM <100 μm (Air Wash Material), PM on the TSP sampler filter (Ambient TSP Sampler Filter), soil material < 75 μm (Soil Material), source sampler cyclone bucket material <100 μm (SS Cyclone Bucket Material), and PM on the source sampler filters (Source Sampler Filter) from test 7 on farm 2 during 2006.

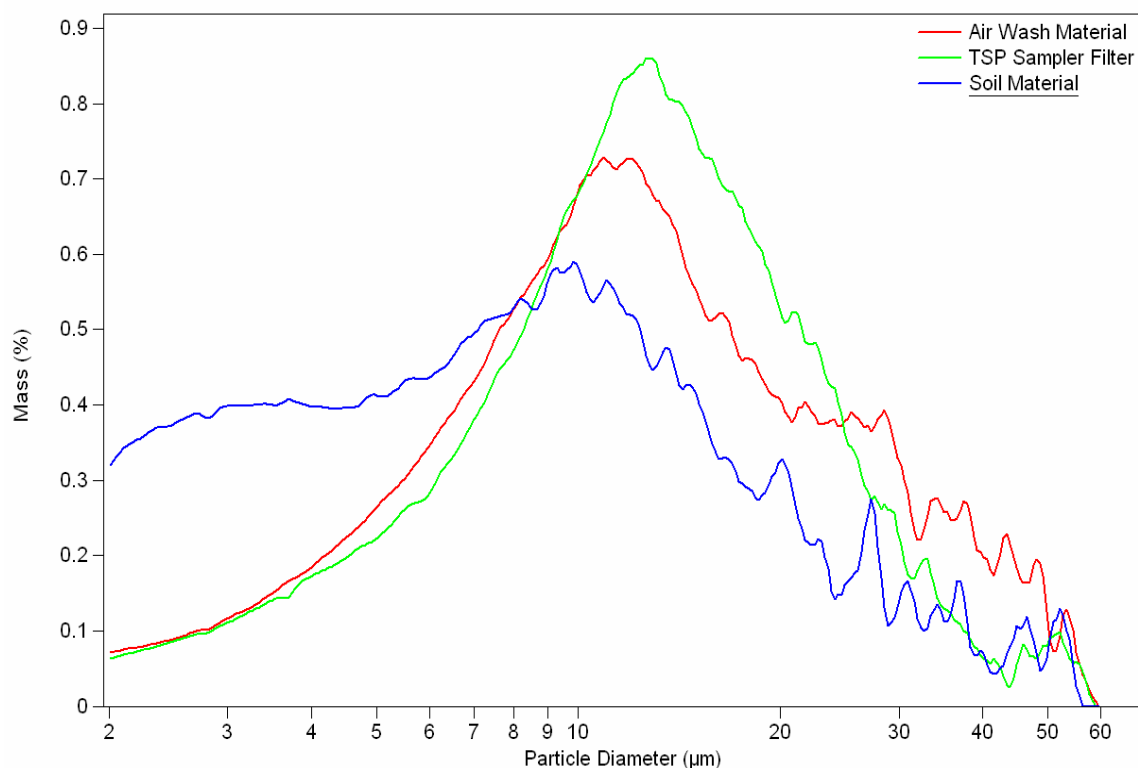


Figure 30. Percent volume vs. ESD particle diameter PSDs for the air wash PM <100  $\mu\text{m}$  (Air Wash Material), PM on the TSP sampler filter (Ambient TSP Sampler Filter), and soil material < 75  $\mu\text{m}$  (Soil Material) from test 1 on farm 3 during 2006.

Table 38. MMD (ESD) and GSD of the best fit lognormal curves for the data shown in Figures 28, 29, and 30.

Sample	Farm 1		Farm 2		Farm 3	
	MMD ( $\mu\text{m}$ )	GSD	MMD ( $\mu\text{m}$ )	GSD	MMD ( $\mu\text{m}$ )	GSD
Air Wash Material	10.5	1.92	12.4	2.06	11.9	2.18
Ambient TSP Sampler Filter	12.7	2.25	10.0	2.19	12.4	1.85
Soil Material	11.2	2.36	5.7	2.1	7.9	2.34
SS Cyclone Bucket Material	11.1	2.08	13.0	2.07	n/a	n/a
Source Sampler Filter	7.4	1.73	10.0	2.28	n/a	n/a

The PSDs shown in Figures 28, 29, and 30 represent the distribution of % mass to ESD particle diameter. Particle densities for the air wash and soil material were measured and subsequently used to convert the ESD PSDs of the respective materials to an AED basis using the relationship shown in (51). The average PSD of the soil material and air wash material from each location are shown in Figures 31 and 32, respectively. The MMD and GSD of the best fit lognormal distributions for the average air wash PSDs are shown in Table 39. The average soil PSDs (shown in Figure 31) for all three farms do not follow the lognormal distribution. Consistently, the left tail of the observed average soil PSDs indicates the presence of a substantial amount of PM with particle diameters less than 10  $\mu\text{m}$ . One possible explanation for this is that the PSD of the soil material  $<75 \mu\text{m}$  is best represented by a multi-mode distribution. This explanation is further substantiated by the observation of two peaks in the average soil PSD shown for farm 2.

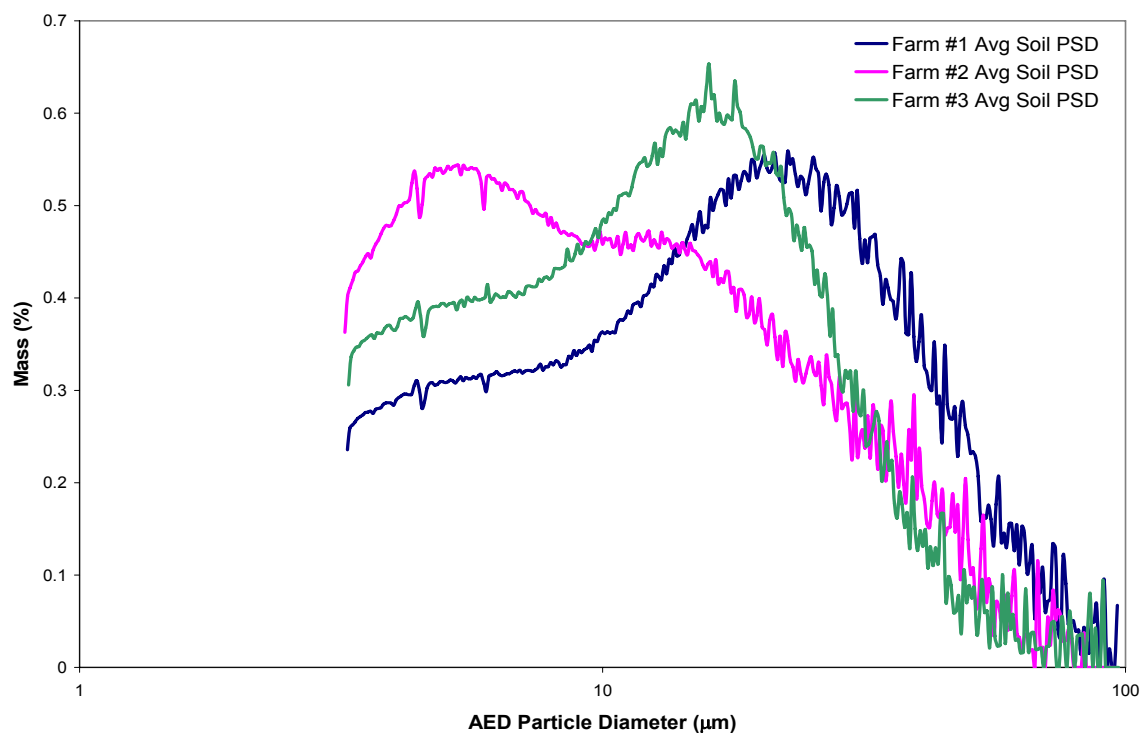


Figure 31. Average PSD results for the soil material  $<75 \mu\text{m}$  from farm 1, 2, and 3.

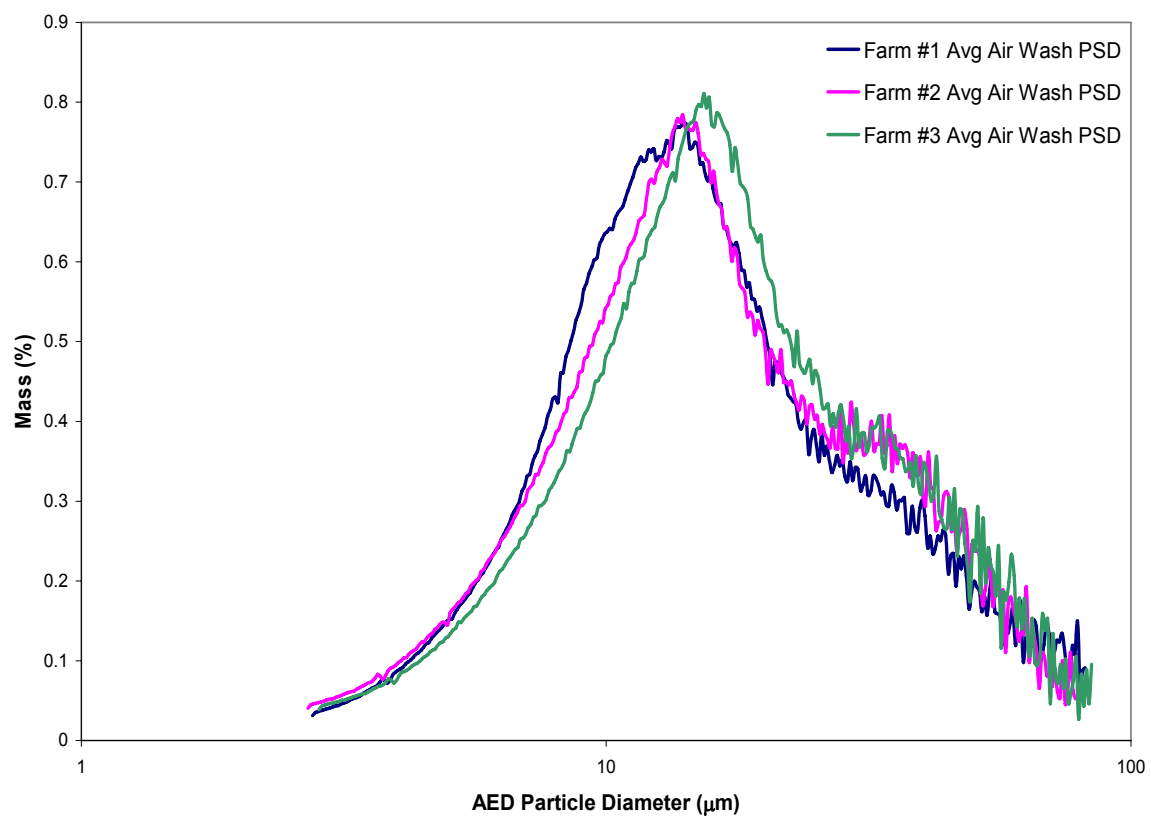


Figure 32. Average PSD results of the air wash material from farm 1, 2, and 3.

Table 39. MMD and GSD values for the best fit lognormal distributions for the average air wash PSDs from farm 1, 2, 3.

	<b>Farm 1</b>	<b>Farm 2</b>	<b>Farm 3</b>
<b>MMD</b>	14.6	15.3	16.4
<b>GSD</b>	2.00	2.05	2.00



The PSD of the air wash material from farm 1 and farm 2 falls between the PSDs of the PM on the source sampler filters and source sampler cyclone bucket material. This result is indicative of the separation of particles that takes place in the source sampling system. PM similar to the air wash material is collected by the source sampling probe and is fed into the barrel cyclone where larger particles are removed from the air stream and accumulated in the cyclone bucket. The PSD of the PM remaining in the sampler air stream (which is deposited on the filters) is then shifted to the left of the PSD of the inlet material.

In order to determine the total mass fraction of a certain size PM sampled by the source sampling system, the PSDs of the PM on the source sampler filters and the cyclone bucket must be considered. Thus, a composite PSD was created for each source sampling test by combining the filter and cyclone bucket PSDs on a mass weighted average basis. The composite PSD matched the PSD of the air wash material more closely than the soil material PSD. Thus, the composite PSD was converted from ESD to AED using the particle density of the air wash material measured for the location of the test. The composite PSDs of the source sampling tests are shown in Figure 33.

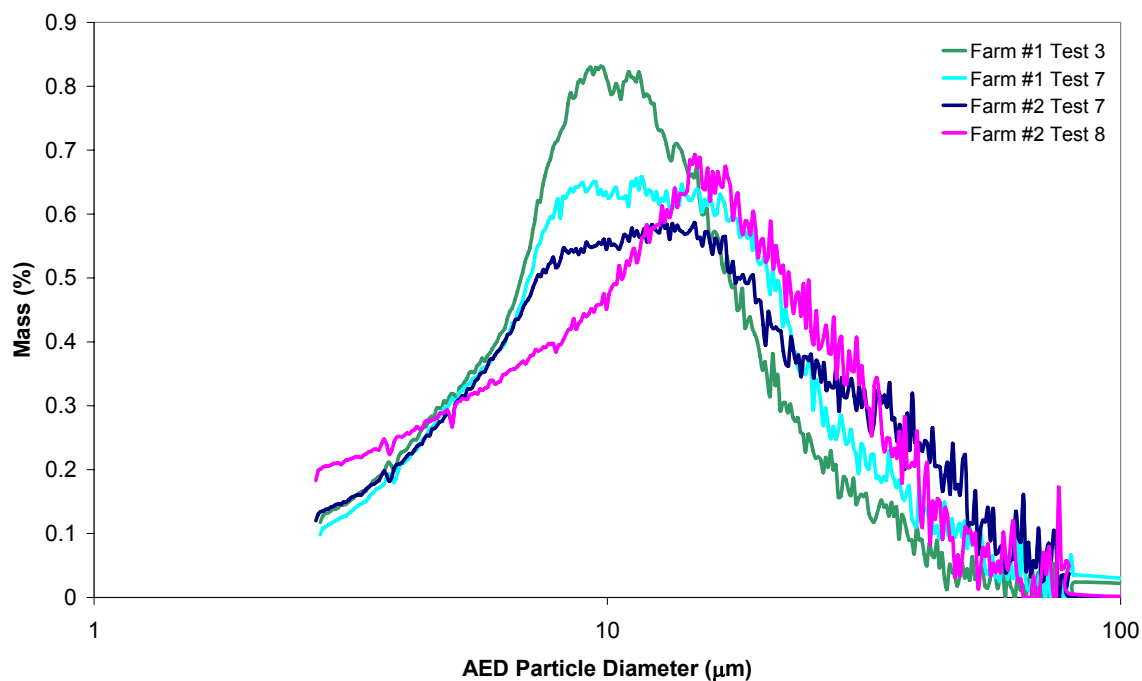


Figure 33. Composite source sampler PSDs for the four source sampling tests conducted at farm 1 and farm 2.

The MMD and GSD of the best fit lognormal distributions for the composite PSD data shown in Figure 33 are presented in Table 40 along with the mass percentage of  $PM_{10}$  and  $PM_{2.5}$  derived from the respective cumulative lognormal functions. Also presented in Table 40 are the mass percentages of  $PM_{10}$  and  $PM_{2.5}$  of the composite source sampler PSDs developed from the Coulter Counter PSD data.

Table 40. MMD and GSD values for the best fit lognormal distributions for the composite source sampler PSDs. Also shown are the mass percentages of PM<sub>10</sub> and PM<sub>2.5</sub> of the best fit lognormal distributions and PSD data measured by the Coulter Counter.

Location	Test	MMD ( $\mu\text{m}$ )	GSD	Lognormal Distribution		Coulter Counter PSD Data	
				% PM <sub>10</sub>	% PM <sub>2.5</sub>	% PM <sub>10</sub>	% PM <sub>2.5</sub>
Farm 1	3	10.5	1.8	46.6	0.7	46	0.1
	7	11.8	1.96	40.4	1.1	40.4	0.1
Farm 2	7	12.5	2.19	38.8	2	38.6	0.1
	8	13.2	2.19	36	1.7	36.3	0.2

Historically, the single mode lognormal distribution has been shown to best represent the distribution of particulate matter dispersed in air (Hinds, 1999). Further, the use of the lognormal distribution to describe the relationship between percent mass and particle size is a simple way to produce an accurate estimate of the percent mass of a regulated particle size range from a TSP sample. The data in Table 40 from the Coulter Counter PSD data indicate that the mass fraction of PM<sub>2.5</sub> in the dust emitted from the harvester is in the range of 0.1 to 0.2% while the same mass fraction from the lognormal distribution is in the range of 0.7 to 2%. This result implies that the mass fraction of PM<sub>2.5</sub> in a TSP concentration sample from a cotton harvesting operation is likely overstated by the use of the lognormal distribution.

The PSDs of the PM on the TSP sampler filters from 2006 were converted from an ESD basis to an AED basis using the particle density of the air wash material under the following logic:

- The PSD of the PM on the TSP filter shown in Figure 28 seems to follow the PSD of the soil material from the test location. However, the MMD (ESD) of the TSP filter is larger than the MMD of the soil material and air wash material. This is likely caused by the settling out of dense soil particles leaving the larger, less dense organic material particles entrained in the air.
- The PSDs of the air wash material, PM on the TSP sampler filter, and soil material shown in Figure 29 indicate that the primary influence on the TSP

sampler filter PSD is from the air wash material. The soil material PSD seems to have very little influence on the PSD of the PM on the TSP sampler filter.

- The PSDs of the PM on the TSP sampler filter, air wash material, and soil material seen in Figure 30 also indicate the same settling phenomena seen in Figure 28. The MMD of the PM shifts to the right as the PM emitted by the harvester travels down wind.

The results of the PSD analyses on the PM on the TSP sampler filters from the three farms are shown in Table 41.

Table 41. PSD analysis results of the PM on the TSP filters from farms 1, 2, and 3. The particle densities used to convert ESD to AED for farms 1, 2, and 3 are 1.86, 1.79, and 1.97 g/cm<sup>3</sup>, respectively.

	<b>Farm 1 (n = 10)</b>			<b>Farm 2 (n = 9)</b>			<b>Farm 3 (n = 11)</b>		
	<b>Mean</b>	<b>Max</b>	<b>Min</b>	<b>Mean</b>	<b>Max</b>	<b>Min</b>	<b>Mean</b>	<b>Max</b>	<b>Min</b>
<b>MMD (μm)</b>	13.2	17.3	9.9	10.4	13.5	7.9	14.9	18.0	12.2
<b>GSD</b>	2.1	2.3	1.9	2.2	2.5	1.9	2.1	2.3	1.8
<b>Lognormal Distribution</b>									
<b>% PM<sub>10</sub></b>	36.0	50.3	22.6	49.3	64.2	34.2	29.7	39.6	18.3
<b>% PM<sub>2.5</sub></b>	1.6	4.0	0.1	4.0	7.2	1.1	0.9	2.0	0.1
<b>Coulter Counter PSD</b>									
<b>% PM<sub>10</sub></b>	35.8	49.6	23.5	48.8	63.3	33.5	30.3	39.5	19.2
<b>% PM<sub>2.5</sub></b>	0.2	0.4	0.1	0.2	0.3	0.1	0.1	0.2	0.1

The mean, minimum, and maximum percentages of PM<sub>10</sub> and PM<sub>2.5</sub> (of the PM on the TSP sampler filters) from the lognormal distribution and Coulter Counter PSD data are also shown in Table 40. The mean percent PM<sub>2.5</sub> is in the range of 0.9 to 4% using the lognormal distribution and in the range of 0.1 to 0.2% for the Coulter Counter PSD data. This result is similar to that observed from the source sampler composite PSD analysis in that the lognormal distribution tends to overstate the percentage of PM<sub>2.5</sub>.

### 2007 Particle Size Distribution Analysis

The TSP samplers used to measure concentrations during 2007 yielded 26 filters with sufficient mass for PSD analysis. The particle density of the material air washed from the source sampler cyclone bucket was used to convert the PSD results on the TSP filters from an ESD to AED basis. The upper tail of the distributions for most of the filters exhibited the spread pattern shown by the PSD in Figure 34. The TSP filter PSD shown in Figure 34 was taken from test 20 at farm 1 during 2007. Also shown in Figure 34 is the overall average lognormal PSD of the TSP filters used in the PSD analysis from 2007 (MMD = 14.7  $\mu\text{m}$ , GSD = 2.23). The statistics of the TSP filter PSD analysis are shown in Table 42.

Table 42. TSP sampler filter PSD analysis result statistics for samples taken on farm 3 during 2007. The particle density used to convert ESD to AED was 1.59 g/cm<sup>3</sup>.

	<b>TSP Sampler PSD Statistics</b>		
	<b>Mean</b>	<b>Max</b>	<b>Min</b>
<b>MMD</b>	14.7	21.1	9.7
<b>GSD</b>	2.2	2.5	2.0
<b>Lognormal Distribution</b>			
<b>% PM<sub>10</sub></b>	33.6	52.0	16.0
<b>% PM<sub>2.5</sub></b>	1.7	4.3	0.2
<b>Coulter Counter PSD</b>			
<b>% PM<sub>10</sub></b>	34.7	50.9	21.7
<b>% PM<sub>2.5</sub></b>	0.1	0.2	0.0

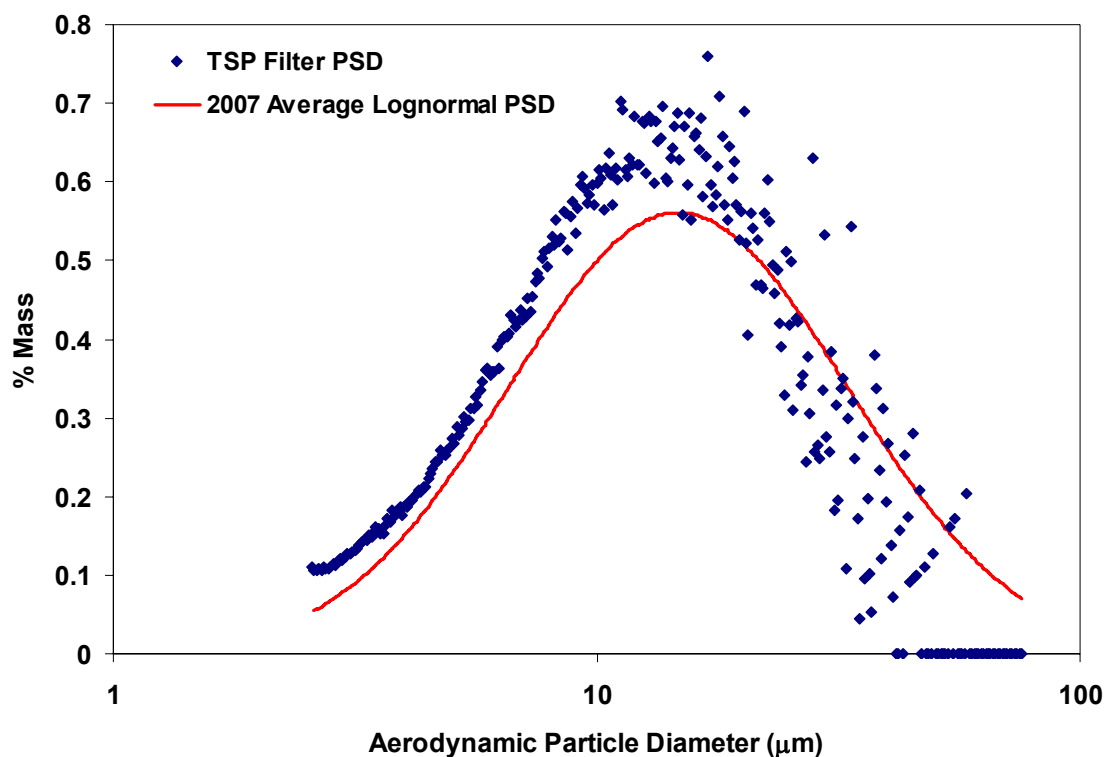


Figure 34. PSD of a downwind TSP sampler from test 20 at farm 3 during 2007 shown with the farm average lognormal PSD of the TSP sampler filters (MMD = 14.7, GSD = 2.23).

The 2007 PSD results of the soil material <75  $\mu\text{m}$  agree well with those observed during 2006. The average soil PSD (see Figure 35) exhibits a left skew with a significant mass of particles with AED less than 10  $\mu\text{m}$ . The mean MMD and GSD of the soil material PSDs are 16.3 and 2.4, respectively. The average statistics of the soil material PSD analyses is shown in Table 43.

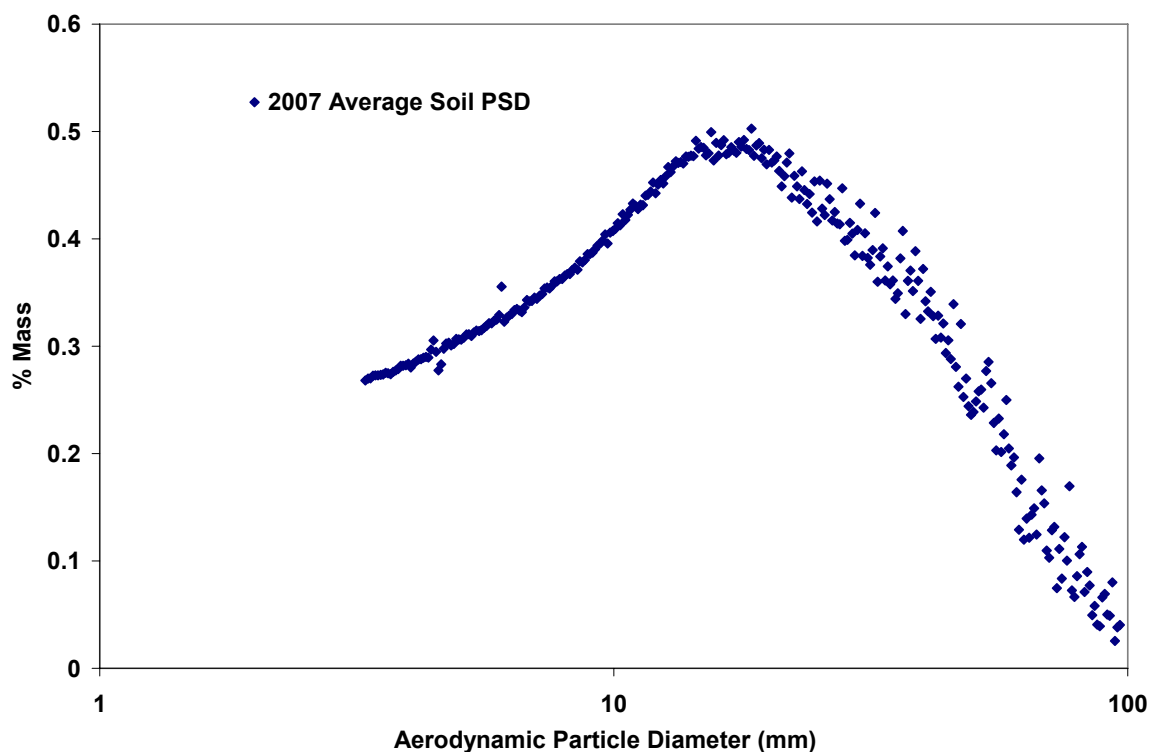


Figure 35. Average PSD for the soil material < 75 μm collected from farm 3 during 2007.

Table 43. Soil material < 75 μm PSD result statistics from samples collected on farm 3 during 2007.

	Soil Material < 75 μm PSD Statistics		
	Mean	Max	Min
<b>MMD</b>	16.3	27.2	9.5
<b>GSD</b>	2.4	2.7	2.0
<b>Lognormal Distribution</b>			
% PM <sub>10</sub>	31.1	52.6	14.6
% PM <sub>2.5</sub>	2.0	3.9	0.5
<b>Coulter Counter PSD</b>			
% PM <sub>10</sub>	32.2	51.8	19.5
% PM <sub>2.5</sub>	0.3	0.4	0.2

The particle size distribution analysis results from the cores cut from the source sampler filters are shown in Figure 36 and Table 44. The average PSD of the source sampler filters is very closely approximated by the lognormal distribution with MMD = 5.84  $\mu\text{m}$  and GSD = 1.53. The PSD of the source sampler filters is dominated by smaller particles as a consequence of the barrel cyclone in the sampling system. The cyclone is used primarily to remove large material from the air stream so that the source sampler filters are not occluded with lint fiber or large organic material. However, Tullis et al. (1997) found that the cutpoint of the barrel type cyclone is approximately 3.5  $\mu\text{m}$ . Therefore, the barrel cyclone also removes a significant portion of the fine dust sampled by the source sampler. This is evident in the average source sampler PSD shown in Figure 36.

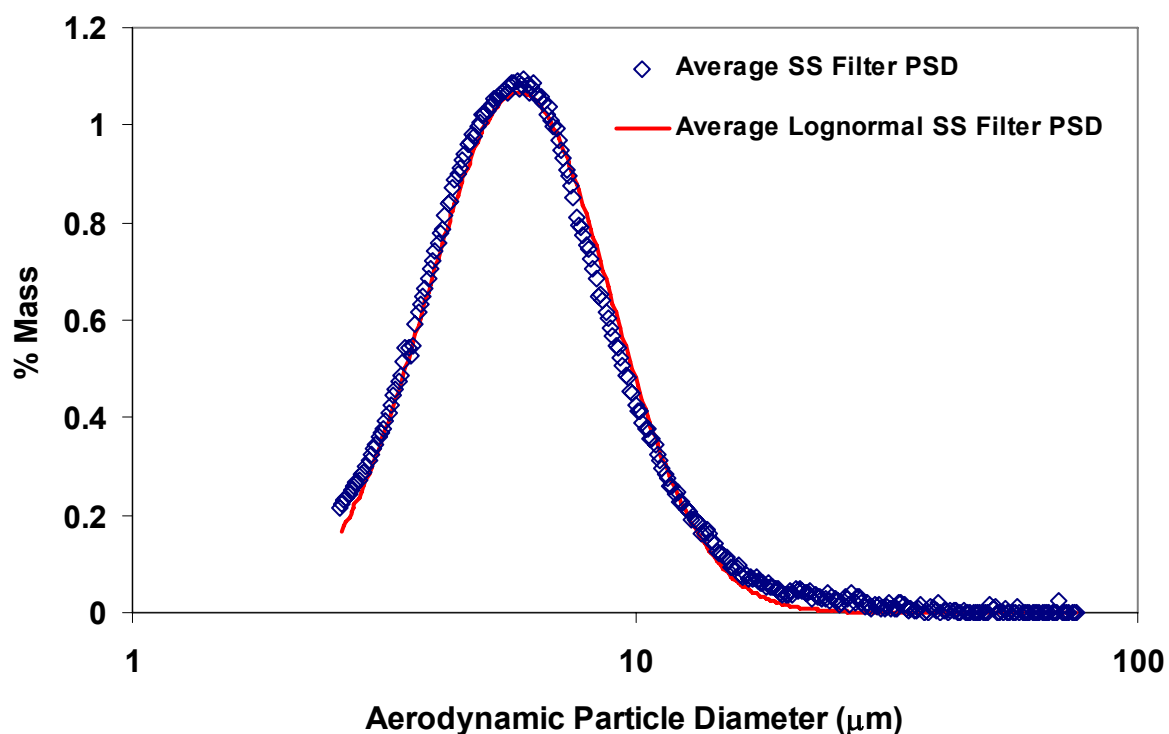


Figure 36. Average PSD of the core samples cut from the source sampler filters obtained during the tests conducted at farm 3 during 2007.



Table 44. PSD analysis result statistics for the source sampler filters collected during the tests conducted on farm 3 during 2007.

	<b>Source Sampler Filter PSD Statistics</b>		
	<b>Mean</b>	<b>Max</b>	<b>Min</b>
<b>MMD</b>	5.8	6.7	5.4
<b>GSD</b>	1.5	1.6	1.5
<b>Lognormal Distribution</b>			
<b>% PM<sub>10</sub></b>	89.8	94.6	79.2
<b>% PM<sub>2.5</sub></b>	2.3	4.4	1.3
<b>Coulter Counter PSD</b>			
<b>% PM<sub>10</sub></b>	87.6	92.9	77.0
<b>% PM<sub>2.5</sub></b>	0.2	0.3	0.1

The results of the PSD analysis on the PM < 100 µm air washed from the material captured in the source sampler cyclone bucket are shown in Figure 37 and Table 45. The lognormal approximation of the measured PSD is a fair approximation although it does not seem to match as well as the source sampler filter data. One possible reason for this is the increased presence of small lint fiber and pulverized leaf material.

Table 45. PSD results for the PM < 100 µm air washed from the material captured in the source sampler cyclone bucket from the tests conducted on farm 3 during 2007.

	<b>Source Sampler Cyclone Bucket PM &lt; 100 µm PSD Statistics</b>		
	<b>Mean</b>	<b>Max</b>	<b>Min</b>
<b>MMD</b>	16.6	18.8	14.7
<b>GSD</b>	2.0	2.2	1.9
<b>Lognormal Distribution</b>			
<b>% PM<sub>10</sub></b>	24.1	29.3	19.4
<b>% PM<sub>2.5</sub></b>	0.4	0.7	0.2
<b>Coulter Counter PSD</b>			
<b>% PM<sub>10</sub></b>	25.3	29.8	21.4
<b>% PM<sub>2.5</sub></b>	0.0	0.0	0.0

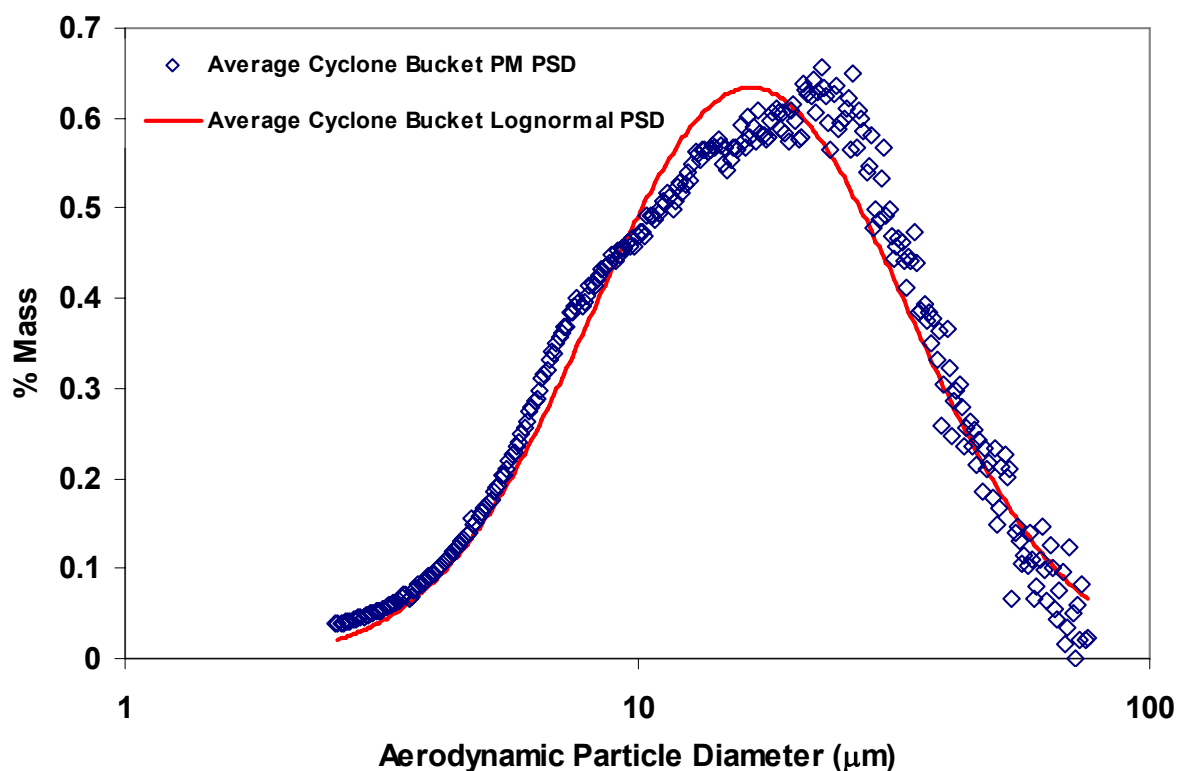


Figure 37. Average PSD of the PM < 100  $\mu\text{m}$  air washed from the source sampler cyclone bucket from the tests conducted on farm 3 during 2007.

Mass weighted average composite PSDs for the PM collected by the source sampling system in 2007 were constructed using the PSDs from the source sampler filters and the PM < 100  $\mu\text{m}$  air washed from the material collected in the source sampler cyclone bucket. The results of the composite PSD analyses are shown in Figure 38 and Table 46. The mass of PM < 100  $\mu\text{m}$  collected in the cyclone bucket was by far greater than the total net mass collected on the source sampler filters during each test. Thus, the composite PSDs trended very close to the PSD of the PM < 100  $\mu\text{m}$  from the material collected in the cyclone bucket.

A complete listing of the summary statistics for the PSD analyses done on the PM captured by the TSP samplers and by the source sampler are included in Appendix G.

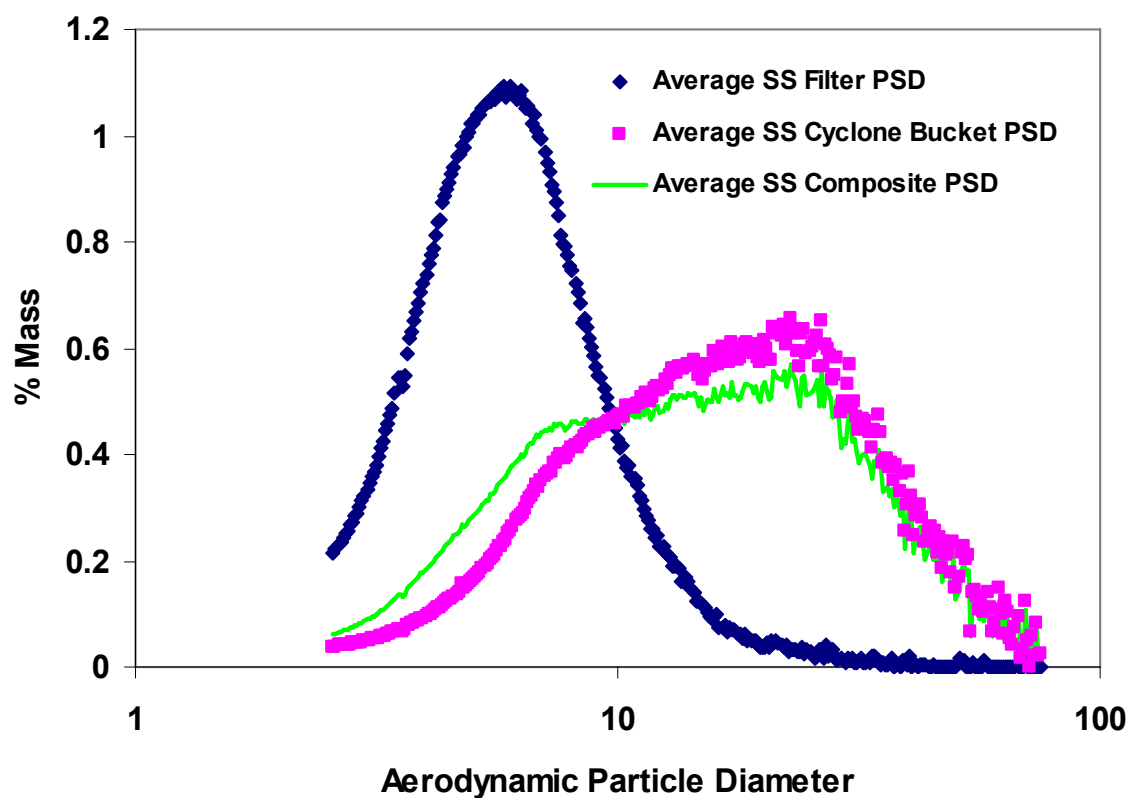


Figure 38. Average PSDs for the source sampler filters, PM < 100 μm captured in the source sampler cyclone bucket, and the mass weighted average composite PSD for the tests conducted on farm 3 during 2007.

Table 46. Result statistics for the mass weighted average composite PSDs developed from the PSDs of the source sampler filters and PM < 100 µm captured in the source sampler cyclone bucket during 2007.

	<b>Source Sampler Composite PSD Statistics</b>		
	<b>Mean</b>	<b>Max</b>	<b>Min</b>
<b>MMD</b>	14.3	16.6	13.4
<b>GSD</b>	2.2	2.4	2.1
<b>Lognormal Distribution</b>			
<b>% PM<sub>10</sub></b>	32.7	35.5	27.3
<b>% PM<sub>2.5</sub></b>	1.40	2.44	0.84
<b>Coulter Counter PSD</b>			
<b>% PM<sub>10</sub></b>	34.0	36.6	29.5
<b>% PM<sub>2.5</sub></b>	0.06	0.07	0.05

## CHAPTER VI

### SUMMARY AND CONCLUSIONS

Cotton producers in some states across the US cotton belt are facing increased regulatory pressure from state air pollution regulatory agencies through the air quality permitting process. Historically, producers of agricultural crops have been exempt from air pollution permitting requirements. Today this is not the case. Growers in California and Arizona are required to obtain air quality permits from state regulators for each crop they plant, including cotton. These permits are granted to the producer once they have submitted management practice plans which detail the steps that the producer will use to help reduce fugitive emissions from their operation.

Poor regional air quality in these areas forced regulators to focus in on sources, identified through annual emissions inventories, which significantly contribute to the ambient concentration of regulated sizes of PM. Through this process, cotton production was identified as a significant source of PM<sub>10</sub> in the San Joaquin Valley of California. A likely cause for the identification of cotton production as a significant source of PM<sub>10</sub> is the inaccurate emission factor used to calculate the annual PM<sub>10</sub> emissions inventory for the region.

Emission factors are estimates of the amount of a specific pollutant emitted by an operation on a unit of production basis (e.g. kg PM<sub>10</sub>/ha or kg PM<sub>10</sub>/bale). Emission factors are used by air pollution regulators to calculate emissions inventories and as the basis for emission rates used in dispersion modeling to predict downwind concentrations from a source. Accurate emission factors are essential to the regulatory process for the appropriate regulation of industrial and agricultural sources and for the protection of human health and wellbeing.

Little accurate emission factor data is available for PM emissions generated by agricultural field operations including cotton harvesting. The objective of this work was to develop an accurate, science based, PM emission factor for cotton harvesting in terms of TSP, PM<sub>10</sub>, and PM<sub>2.5</sub>.

PM emissions from cotton harvesting operations in Texas during 2006 and 2007 were measured using both indirect and direct techniques. The first protocol (indirect technique) used TSP concentration measurements collected downwind of the source, meteorological data collected onsite, and a dispersion model to back calculate emission flux estimates from harvesting operations. The resulting TSP emission flux values were converted to emission factors in terms of kg/ha and kg/bale harvested. Mass fraction measurements for PM<sub>10</sub> and PM<sub>2.5</sub> from PSD analyses on the TSP filters were used to calculate PM<sub>10</sub> and PM<sub>2.5</sub> emission factors from the TSP emission factors.

The second protocol (direct technique) measured emission concentrations onboard a six-row cotton picker as it harvested cotton. Air flow measurements were used with emission concentrations to determine TSP emission rates from the harvester on a mass per unit time basis. Production data on crop yield and area harvested were used to convert emission rates to emission factors in terms of kg/ha and kg/bale harvested. The results of PSD analyses on the PM collected by the source sampling system were used to calculate PM<sub>10</sub> and PM<sub>2.5</sub> emission factors from TSP emission factors.

The emission factor data from both protocols was correlated with measurements of soil moisture content, soil mass % < 75 and 106  $\mu\text{m}$ , seed cotton moisture content, crop yield, and test plot area. These correlations helped to give insight to the factors leading to increased PM emissions.

The major findings of this work are:

- Statistically significant differences between the two-row and six-row treatment emission factors developed in ISCST3 were not observed for the combined data set. However, the emission factors developed for the two-row and six-row treatments in AERMOD were significantly different. However, both models indicated a substantial difference between the two-row and six-row emission factors. Additionally, both models showed the two-row treatment emission factors to be higher than those of the six-row treatment. The difference in the mean PM<sub>10</sub>

emission factors for the two-row and six-row treatments developed in ISCST3 and AERMOD were 1.08 and 3.61 kg/ha, respectively.

- Source measurement of emissions onboard the six-row cotton picker were successfully conducted during 2006 and 2007. The emission factors developed with the source sampling protocol are the most accurate emission factors ever developed for cotton harvesting. Furthermore, the emission factors developed through the source measurement protocol are recommended for regulatory use due to the low uncertainty and high precision of the measurements. The TSP, PM<sub>10</sub>, and PM<sub>2.5</sub> emission factors from the source measurements conducted during 2007 were  $1.64 \pm 0.37$ ,  $0.55 \pm 0.12$ , and  $1.58\text{E-}03 \pm 4.5\text{E-}04$  kg/ha, respectively ( $1.46 \pm 0.33$ ,  $0.49 \pm 0.11$ , and  $1.41\text{E-}03 \pm 4.01\text{E-}04$  lb/ac, respectively). These emission factors are inclusive of the emission factors for the PM generated by the interaction of the harvester wheels and the soil surface as the machine moves through the field. The PM generated by the wheels of the harvester account for approximately 15% of the total emission factor.
- Additional analysis of the emission rates calculated from the source emission concentration measurements indicates that PM emissions from cotton harvesting operations are more closely correlated with crop yield than with land area harvested. Thus, the most appropriate basis on which to report emission factors from cotton harvesting is in terms of mass per lint bale harvested (e.g. kg/bale). In terms of kg/bale, the TSP, PM<sub>10</sub>, and PM<sub>2.5</sub> emission factors from the source measurements of PM emissions from the six row machine were  $0.22 \pm 0.019$ ,  $0.07 \pm 0.007$ , and  $2.15\text{E-}4 \pm 1.49\text{E-}5$  kg/bale, respectively ( $0.48 \pm 0.04$ ,  $0.15 \pm 0.015$ , and  $4.74\text{E-}4 \pm 3.3\text{E-}5$  lb/bale, respectively). These emission factors are inclusive of the PM emissions generated by the harvester wheel/soil surface interaction and represent the average mass per bale emission factors measured over a crop yield range from 5.9 to 9.3 bales/ha (2.4 to 3.8 bales/ac).
- Particle size distribution analysis of the TSP sampler filters indicates that the PSD of the dust measured downwind of the harvesting operation can be approximated by a

lognormal density function characterized by MMD and GSD values of 14  $\mu\text{m}$  and 2.2 respectively. The mass percent  $\text{PM}_{10}$  and  $\text{PM}_{2.5}$  from PSD analysis of the TSP filters were on the order of 35 and 0.1%, respectively. These results are further corroborated by the PSD analysis on the PM captured on the source sampler filters and  $\text{PM} < 100 \mu\text{m}$  captured in the source sampler cyclone bucket.

## **FUTURE WORK**

The emission factors resulting from this work were developed with state-of-the-art methods in order to produce accurate, science based PM emissions data from cotton harvesting. However, additional work is needed to better quantify the uncertainty in the emission factors developed through the dispersion modeling process. As AERMOD is incorporated into the regulatory program of each state, it is imperative that appropriate emission factors are used to predict downwind source impacts. It is likely the case that most states will use emission factors in AERMOD which were previously used in ISCST3. This scenario will be problematic from a regulatory standpoint.

The following have been identified for future work in this area:

1. Quantification of the variability in emission factors developed in ISCST3 and AERMOD due to variability in wind speed and direction. While traditional first order sensitivity analysis on ISCST3 and AERMOD may be problematic, a Monte Carlo simulation model may be used to generate meteorological data files containing several thousand lines of data from wind speed and wind direction distributions. These files could then be used to develop emission factors for several different receptor locations within ISCST3 or AERMOD. Additional variations on this might include different source to receptor configurations.
2. Compare the emission factor results from AERMOD using meteorological data prepared through the AERMET preprocessor and meteorological data prepared using the procedures described in this work.
3. Begin the process of obtaining adoption of the emission factors developed in this work at the state and national regulatory levels.



## REFERENCES

- Beckman Coulter. 2002. Beckman Coulter Multisizer 3 – Operator’s Manual. PN 8321681 rev. B. Fullerton, CA.: Beckman Coulter, Inc.
- Beychok, M.R. 1994. *Fundamentals of Stack Gas Dispersion*. 3rd ed. Newport Beach, CA: Milton R. Beychok.
- Buser, M. D., C.B. Parnell, R. E. Lacey, B.W. Shaw, and B.W. Auvermann. 2001. Inherent biases of PM<sub>10</sub> and PM<sub>2.5</sub> samplers based on the interaction of particle size and sampler performance characteristics. ASAE Paper No. 011167. St. Joseph, MI.: ASAE.
- Buser, M.D. 2004. Errors associated with particulate matter measurements on rural sources: Appropriate basis for regulating cotton gins. Unpublished Ph.D. diss. College Station, TX.: Texas A&M University, Department of Biological and Agricultural Engineering.
- California Air Resources Board (CARB). 2003. Senate Bill 700 - Florez. Sacramento, CA: California Air Resources Board. Available at, <http://www.arb.ca.gov/ag/sb700/sb700.pdf>. Accessed 12/15/2006.
- Capareda, S.C., C.B. Parnell, B.W. Shaw, and J.D. Wanjura. 2005. Particle size distribution analysis of cotton gin dust and its impact on PM<sub>10</sub> concentration measurements. *In Proc. of the 2005 Beltwide Cotton Conferences*, CD-Rom. New Orleans, LA.: National Cotton Council.
- Code of Federal Regulations (CFR). 1996. Requirements for preparation, adoption, and submittal of implementation plans, Subpart I: Review of new sources and modifications. 40CFR, Part 51.160: Office of the Federal Register, National Archives, and Records Administration. Washington DC: U.S. Government Printing Office.
- Code of Federal Regulations (CFR). 1999. Method 5: Determination of particulate matter emissions from stationary sources. 40CFR, Part 60: Appendix A-3. Office of the Federal Register, National Archives, and Records Administration. Washington D.C.: U.S. Government Printing Office.

- Code of Federal Regulations (CFR). 2007. Determination of particulate matter emissions from stationary sources. 40CFR, Part 60: Appendix A. Office of the Federal Register, National Archives, and Records Administration. Washington D.C.: U.S. Government Printing Office.
- Environmental Protection Agency (EPA). 1995a. Compilation of air pollutant emission factors (AP-42). Research Triangle Park, NC: EPA.
- Environmental Protection Agency (EPA). 1995b. User's guide for the industrial source complex dispersion models – Volume II: description of model algorithms. EPA-454/B-95-003b. Office of Air Quality Planning and Standards - Emissions Monitoring and Analysis Division. Research Triangle Park, NC. USEPA.
- Environmental Protection Agency (EPA). 2000. Meteorological monitoring guidelines for regulatory modeling applications. EPA-454/R-99-005. Research Triangle Park, NC.: US Environmental Protection Agency, Office of Air Quality Planning and Standards Emission Factors and Inventory Group.
- Environmental Protection Agency (EPA). 2004. AERMOD: Description of model formulation. EPA-454/R-03-004. Office of Air Quality Planning and Standards - Emissions Monitoring and Analysis Division. Research Triangle Park, NC. USEPA.
- Environmental Protection Agency (EPA). 2006. Fact sheet: Final revisions to the national ambient air quality standards for particle pollution (Particulate Matter). Research Triangle Park, NC.: US Environmental Protection Agency. Available at, <http://epa.gov/pm/actions.html>. Accessed 12/15/2006.
- Etling, D. 1996. Temporal and spatial variations in the ABL. In *Modeling of Atmospheric Flow Fields*, 21 – 41. River Edge, NJ: World Scientific Publishing Company.
- Faulkner, W.B. and B.W. Shaw. 2006. Efficiency and pressure drop of cyclones across a range of inlet velocities. *Applied Engineering in Agriculture* 22(1): 155-161.
- Federal Register. 2005. Revision to the guideline on air quality models: Adoption of a preferred general purpose (Flat and Complex Terrain) dispersion model and other revisions; Final rule. *Federal Register* 70:68218-3.

- Federal Register. 2006. National ambient air quality standards for particulate matter; Final rule. 40 CFR Part 50. *Federal Register* 71 (200): 61144. Office of the Federal Register, National Archives, and Records Administration. Washington DC: U.S. Government Printing Office.
- Flocchini, R.G., et al. 2001. Sources and sinks of PM<sub>10</sub> in the San Joaquin valley, final report. United States Department of Agriculture – Special Research Grants Program. Contract Nos. 94-33825-0383 and 98-38825-6063. Davis, CA: University of California at Davis.
- Garratt, J.R. 1992. *The Atmospheric Boundary Layer*. New York, N.Y. Cambridge University Press.
- Goodrich, L.B. 2006. A PM<sub>10</sub> emission factor for free stall dairies. MS thesis. College Station, TX.: Department of Biological and Agricultural Engineering, Texas A&M University.
- Hinds, W. C. 1999. *Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles*. 2nd ed. New York, N.Y.: John Wiley & Sons, Inc.
- Hiscox, A.L., D.R. Miller, C.J. Nappo, and J. Ross. 2006. Dispersion of fine spray from aerial applications in stable atmospheric conditions. *Trans. ASAE* 49(5): 1513-1520.
- Johnson, R.A. and D.W. Wichern. 2002. *Applied Multivariate Statistical Analysis*. 5th ed. Upper Saddle River, N.J.: Prentice-Hall, Inc.
- Kaimal, J.C., Finnigan, J.J. 1994. *Atmospheric Boundary Layer Flows: Their Structure Measurement*. New York, N.Y.: Oxford University Press.
- Kline, S.J., and F.A. McClintock. 1953. Describing uncertainties in single sample experiments. *Mechanical Engineering* 75:3-8.
- Manwell, J.F., J.G. McGowan, and A.L. Rogers. 2002. *Wind Energy Explained – Theory, Design, and Application*, 44 - 45. West Sussex, England: John Wiley & Sons. Ltd.
- McFarland, A. R. and C. A. Ortiz. 1983. Evaluation of prototype PM-10 inlets with cyclonic fractionators. Paper No. 33.5 presented at, *The 76th Annual Meeting and Exposition of the Air Pollution Control Association*. Atlanta, GA.

- Mihalski, K.D. 1996. The design of a pre-collector for cyclone separators. MS thesis. College Station, TX.: Department of Biological and Agricultural Engineering, Texas A&M University.
- Parnell, S. 1994. Dispersion modeling for prediction of emission factors for cattle feedyards. MS thesis. College Station, TX.: Department of Agricultural Engineering, Texas A&M University.
- Reynolds, O. 1895. On the dynamical theory of incompressible viscous fluids and the determination of the criterion. Philos. *Transactions of the Royal Society of London* 186A, 123 – 164.
- San Joaquin Valley Air Pollution Control District (SJVAPCD). 2004a. Rule 4550 – Conservation Management Practices. Modesto, CA.: SJVAPCD.
- San Joaquin Valley Air Pollution Control District (SJVAPCD). 2004b. List of Conservation Management Practices. Modesto, CA.: SJVAPCD.
- Snyder, J.W., T.R. Blackwood. 1977. Source assessment: Mechanical harvesting of cotton – state of the art. EPA-600/2-77-107d. Cincinnati, OH: United States Environmental Protection Agency.
- Stull, R.B. 1988. *An Introduction to Boundary Layer Meteorology*. Boston, MA.: Kluwer Academic Publishers.
- Texas Commission on Environmental Quality (TCEQ). 2005. *AERMOD Training*. available on the web at:  
[http://www.tceq.state.tx.us/files/aermet.pdf\\_4012036.pdf](http://www.tceq.state.tx.us/files/aermet.pdf_4012036.pdf). Accessed 11/25/2007.
- Texas Commission on Environmental Quality (TCEQ). 2007. One year meteorological data file for Burleson Co. available on the web at:  
<ftp://ftp.tceq.state.tx.us/pub/OPRR/APD/AERMET/AERMETv04300/AERMETDataSetsByCounty/>. Accessed 11/25/2007.
- Trinity Consultants. 2007. *BREEZE MetView v6.0.7 – User's Manual*. Dallas, TX.: Trinity Consultants.

- Tullis, A.W., B.W. Shaw, C.B. Parnell, P.P. Buharivala, M.A. Demny, and S.S. Flannigan. 1997. Design and analysis of the barrel cyclone. In *Proc. Beltwide Cotton Conference*, 2:1520-1525. Memphis, TN.: National Cotton Council.
- USDA. 1972. Standard Procedures for Foreign Matter and Moisture Analytical Tests Used in Cotton Ginning Research. *Agriculture Handbook* No. 422. US Government Printing Office: 1972 O-443-789.
- USDA. 2007. Cotton Production in the US: 1977 – 2007. National Agricultural Statistics Database. Washington, DC.: USDA National Agricultural Statistics Service. Available at, <http://www.nass.usda.gov/QuickStats/>. Accessed 25 November, 2007.
- Van Boxel, J.H., G. Sterk, and S.M. Arens. 2004. Sonic anemometers in aeolian sediment transport research. *Geomorphology* 59: 131 – 147.
- Wanjura, J.D., C.B. Parnell, Jr., B.W. Shaw and R.E. Lacey. 2004. A protocol for determining a fugitive dust emission factor from a ground level area source. ASAE Paper No. 044018. St. Joseph, MI: ASAE.
- Wanjura, J.D., M.D. Buser, D.P. Whitelock, S.C. Capareda, C.B. Parnell, Jr., B.W. Shaw, and R.E. Lacey. 2005a. A method of estimating FRM PM<sub>10</sub> sampler performance characteristics using particle size analysis and collocated TSP and PM<sub>10</sub> samplers. ASAE Paper No. 054015. St. Joseph, MI: ASAE.
- Wanjura, J.D., C.B. Parnell, Jr., B.W. Shaw, and R.E. Lacey. 2005b. Design and evaluation of a low volume total suspended particulate sampler. *Trans. ASAE* 48(4): 1547-1552.
- Wanjura, J.D., M.D. Buser, C.B. Parnell, B.W. Shaw, and R.E. Lacey. 2005c. A simulated approach to estimating PM<sub>10</sub> and PM<sub>2.5</sub> concentrations downwind from cotton gins. *Trans. ASAE* 48(5): 1919-1925.
- Wanjura, J.D. 2005. Engineering approaches to address errors in measured and predicted particulate matter concentrations. MS thesis. College Station, TX.: Department of Biological and Agricultural Engineering, Texas A&M University.
- Wanjura, J.D., C.B. Parnell, Jr., B.W. Shaw, and S.C. Capareda. 2006. Particle size distribution of PM emitted from cotton harvesting. ASABE Paper No. 064168. St. Joseph, MI.: ASABE.

Wanjura, J.D., B.W. Shaw, C.B. Parnell Jr., S.C. Capareda, and W.B. Faulkner. 2007. A preliminary particulate matter emission factor from cotton harvesting. In *Proc. 2007 Beltwide Cotton Conferences*, CD-Rom. Memphis, TN.: National Cotton Council.

## **APPENDIX A**

### **SOIL SIEVING PROCEDURE**

The following procedure was used to sieve the soil samples collected from farms 1, 2, and 3 during 2006 and 2007. The soil mass percent  $< 75$  and  $106 \mu\text{m}$  were determined through this procedure.

### **Cleaning the Sieves:**

*How do you know if the sieve is clean?*

You can determine if they are clean by weighing them and comparing their current weight to the clean weight written on the side of the sieve. Be sure that the current weight is within 0.01 g of the clean weight.

*Cleaning the sieves:*

The large opening sieves can be cleaned with a nylon bristle brush (paint brush) and the small mesh sieves (opening size  $< \#80$ ) should be brushed off first before being placed in the ultrasonic cleaner for 5 minutes. (The ultrasonic bath should be filled with water so that the top of the water is about  $\frac{1}{2}$ " above the top rim of the sieve.) After the sieves come out of the ultrasonic bath, they must be dried thoroughly. Complete drying of the small mesh sieves can be accomplished by placing them in a drying oven at  $100^{\circ}\text{C}$  for 1 hour. After drying the sieves make sure that the current weight matches the clean weight within 0.01g.

### **Sieve Analysis Procedure**

Step 1:

Locate the following sieves and place in the indicated order with the largest opening size on top:

Stack 1: 0.875", 0.625", 0.375", 0.3125", #10, Pan #1

Stack 2: #14, #25, #80, #140, #200, Pan #2

Place a lid on top of each stack before loading the two stacks into the shaker. Make sure that the lids, pans, and sieves are clean before use.



**Step 2:**

Next weigh out approximately 500 – 700 g of material in a scale pan. Record the total (gross) weight of the scale pan plus the material on the work sheet.

**Step 3:**

Pour the material from the scale pan into the top sieve of stack 1. Replace the lid on the top sieve and install the large (black) sieve stack cover with the cork pointing up. Lower the white hammer arm down onto the cork and set the timer on the shaker to 20 minutes.

**Step 4:**

Start the machine by pressing the start/resume button on the shaker and let the shaker run for the set time.

**Step 5:**

Once the machine has finished shaking, remove the first stack of sieves and carry them to the scale. Carefully weigh each sieve and the pan in the stack to the nearest 0.01g and record these weights on the work sheet under the gross weight column. Be very careful not to loose any material out of the sieves or pan during the weighing process.

**Step 6:**

After the sieves have been weighed, collect material samples from each sieve and pan according to the details of the experiment design.

**Step 7:**

Pour the material from the pan in stack one into the top sieve in stack two and replace the brass lid on top of stack 2.

**Step 8:**

Once the samples have been taken and the material in the pan transferred to the second stack, empty and clean each sieve and pan with the nylon bristle brush. After cleaning, weigh each sieve and pan and record the weight on the work sheet under the tare column. Make sure that the tare weight is within 0.01g of the clean weight on the side of the sieve.

**Step 9:**

Reload the first stack of sieves into the machine. Weigh out a new sample of material to be placed in the top sieve of stack 1 as was done in step 2 – 3. Be sure to record this new gross weight of initial material mass on a new work sheet.

**Step 10:**

Repeat steps 3 – 6 for both stacks of sieves. At this point, be sure to record the gross and tare weights of the second stack sieves on the first work sheet and the gross and tare weights of the first stack sieves on the second work sheet. This is a semi-continuous batch process where the machine always has two samples running at one time.

**Step 11:**

When cleaning the second stack of sieves, brush them off first and check the clean weights before cleaning them in the ultrasonic bath. Several samples may be able to be run before cleaning the small mesh screens in the ultrasonic bath. Don't run more than 3 samples before cleaning the small mesh screens in the ultrasonic bath.

Once all of the samples have been processed for one day, clean the sieves according to the previous instructions.

## **APPENDIX B**

### **METEOROLOGICAL DATA DEVELOPED FOR USE IN AERMOD FROM 3D SONIC ANEMOMETER MEASUREMENTS**

Table B-1. Meteorological parameters measured and observed onsite during the tests conducted on farm 3 during 2007.

Test	HR	Wind Speed	Wind Direction	Wind Reference Height	Temp	Temperature Reference Height	Precipitation Code	Precipitation Rate	Relative Humidity	Station Pressure	Cloud Cover
		m/s	degrees	m	K	m		mm/hr	%	mb	tenths
1	14	2.21	31	3.0	303.8	2.0	0	0.00	59	1010	0
1	15	2.31	35	3.0	304.0	2.0	0	0.00	59	1010	0
2	11	1.87	57	3.0	299.9	2.0	0	0.00	51	990	0
3	15	2.25	25	3.0	303.0	2.0	0	0.00	34	1008	1
4	16	1.82	27	3.0	303.3	2.0	0	0.00	32	1007	2
5	18	1.00	34	3.0	301.8	2.0	0	0.00	46	1006	1
6	15	1.70	132	3.0	303.3	2.0	0	0.00	32	1007	0
6	16	2.16	157	3.0	303.4	2.0	0	0.00	32	1007	0
7	18	1.44	128	3.0	297.9	2.0	0	0.00	48	1005	0
7	19	1.05	124	3.0	296.3	2.0	0	0.00	48	1005	0
8	11	5.47	183	3.0	299.6	2.0	0	0.00	46	1006	0
8	12	5.24	178	3.0	300.2	2.0	0	0.00	46	1006	0
9	13	4.91	171	3.0	302.3	2.0	0	0.00	31	1004	1
9	14	4.91	178	3.0	302.9	2.0	0	0.00	31	1004	1
10	15	5.34	165	3.0	303.5	2.0	0	0.00	30	1003	2

Table B-1 Continued.

Test	HR	Wind Speed	Wind Direction	Wind Reference Height	Temp	Temperature Reference Height	Precipitation Code	Precipitation Rate	Relative Humidity	Station Pressure	Cloud Cover
		m/s	degrees	m	K	m		mm/hr	%	mb	tenths
11	17	5.53	157	3.0	302.2	2.0	0	0.00	37	1002	2
12	19	3.64	153	3.0	297.5	2.0	0	0.00	53	1003	3
13	13	7.20	162	3.0	302.9	2.0	0	0.00	53	1002	6
13	14	7.12	157	3.0	302.9	2.0	0	0.00	53	1002	6
14	15	7.62	147	3.0	303.1	2.0	0	0.00	56	1001	7
15	16	7.48	143	3.0	300.8	2.0	0	0.00	64	1001	8
16	16	1.84	25	3.0	296.1	2.0	0	0.00	39	1014	0
16	17	0.20	20	3.0	295.8	2.0	0	0.00	39	1014	0
17	11	1.70	219	3.0	294.3	2.0	0	0.00	50	1018	0
17	12	1.21	32	3.0	295.0	2.0	0	0.00	50	1018	0
18	14	1.38	71	3.0	297.9	2.0	0	0.00	40	1014	0
18	15	1.67	76	3.0	297.7	2.0	0	0.00	40	1014	0
18	16	1.70	91	3.0	297.9	2.0	0	0.00	40	1014	0
18	17	1.86	136	3.0	298.0	2.0	0	0.00	40	1014	0
19	12	2.15	180	3.0	297.7	2.0	0	0.00	55	1012	0
19	13	2.11	196	3.0	298.3	2.0	0	0.00	55	1012	0
19	14	2.39	199	3.0	298.7	2.0	0	0.00	55	1012	0

Table B-1 Continued.

Test	HR	Wind Speed	Wind Direction	Wind Reference Height	Temperature	Temperature Reference Height	Precipitation Code	Precipitation Rate	Relative Humidity	Station Pressure	Cloud Cover
		m/s	degrees	m	K	m		mm/hr	%	mb	tenths
20	15	2.83	159	3.0	300.5	2.0	0	0.00	41	1010	0
20	16	3.27	167	3.0	300.5	2.0	0	0.00	41	1010	0
21	17	2.40	140	3.0	299.0	2.0	0	0.00	47	1010	0

Table B-2. Meteorological parameters used in AERMOD calculated from 3D sonic anemometer wind vector measurements (sensible heat flux, friction velocity, convective velocity scale, and Monin-Obukhov Length) and assumed from Texas Commission on Environmental Quality guidance.

Test	HR	Calculated Values				Assumed from TCEQ Guidance					
		Sensible Heat Flux	Friction Velocity	Convective Velocity Scale	Monin-Obukhov Length	Vertical Potential Temperature Gradient	Convective Mixing Height	Mechanical Mixing Height	Surface Roughness	Bowen Ratio	Albedo
		W/m2	m/s	m/s	m	K/m	m	m	m		
1	14	82.0	0.363	1.334	-52.3	0.005	1035	809	0.500	0.60	0.15
1	15	45.3	0.358	1.136	-91.0	0.005	1159	885	0.500	0.60	0.16
2	11	128.8	0.253	1.468	-11.0	0.005	861	1613	0.500	0.60	0.16
3	15	107.0	0.309	1.668	-24.5	0.005	1549	1209	0.500	0.60	0.16
4	16	57.9	0.265	1.393	-28.6	0.005	1667	1777	0.500	0.60	0.18
5	18	7.3	0.108	0.682	-15.4	0.005	1550	1550	0.500	0.60	0.46
6	15	101.3	0.171	1.650	-4.3	0.008	1562	1058	0.500	0.60	0.16
6	16	70.7	0.129	1.469	-2.7	0.008	1600	1016	0.500	0.60	0.18
7	18	7.1	0.056	0.545	-2.2	0.005	816	816	0.500	0.60	0.47
7	19	3.8	0.082	0.505	-12.8	0.005	1212	1212	0.500	0.60	1.00
8	11	154.8	0.454	1.294	-53.9	0.005	499	1212	0.500	0.60	0.16
8	12	178.8	0.415	1.525	-35.7	0.005	709	1044	0.500	0.60	0.15
9	13	194.0	0.394	1.699	-28.0	0.005	900	1214	0.500	0.60	0.15
9	14	185.1	0.396	1.775	-29.9	0.005	1078	1390	0.500	0.60	0.16

Table B-2 Continued.

Test	HR	Calculated Values				Assumed from TCEQ Guidance					
		Sensible Heat Flux	Friction Velocity	Convective Velocity Scale	Monin-Obukhov Length	Vertical Potential Temperature Gradient	Convective Mixing Height	Mechanical Mixing Height	Surface Roughness	Bowen Ratio	Albedo
		W/m2	m/s	m/s	m	K/m	m	m	m		
10	15	165.0	0.440	1.767	-45.9	0.005	1189	1383	0.500	0.60	0.16
11	17	12.2	0.438	0.764	-612.0	0.005	1297	1323	0.500	0.60	0.25
12	19	-29.2	0.280	-0.740	67.1	0.005	495	495	0.500	0.60	1.00
13	13	141.5	0.533	1.586	-94.9	0.005	1001	357	0.500	0.60	0.15
13	14	135.1	0.552	1.626	-110.8	0.005	1131	1050	0.500	0.60	0.15
14	15	86.5	0.592	1.445	-212.9	0.006	1238	525	0.500	0.60	0.16
15	16	44.4	0.603	1.179	-438.7	0.006	1310	855	0.500	0.60	0.18
16*	16	53.1	1.101	1.203	-2233.9	0.005	1165	2648	0.500	0.60	0.20
16*	17	20.0	1.031	0.875	-4856.6	0.005	1187	2422	0.500	0.60	0.29
17	11	133.5	0.092	0.986	-0.5	0.005	258	836	0.500	0.60	0.16
17	12	122.2	0.159	1.001	-3.0	0.005	296	1550	0.500	0.60	0.16

\*3D sonic anemometer data was not available for test 16 and all values were assumed from TCEQ guidance.



Table B-2 Continued.

Test	HR	Calculated Values				Assumed from TCEQ Guidance					
		Sensible Heat Flux	Friction Velocity	Convective Velocity Scale	Monin-Obukhov Length	Vertical Potential Temperature Gradient	Convective Mixing Height	Mechanical Mixing Height	Surface Roughness	Bowen Ratio	Albedo
		W/m <sup>2</sup>	m/s	m/s	m	K/m	m	m	m		
18	14	194.0	0.488	1.263	-53.7	0.005	372	808	0.500	0.60	0.16
18	15	95.6	0.182	1.022	-5.7	0.005	401	1545	0.500	0.60	0.17
18	16	47.2	0.151	0.819	-6.5	0.005	420	1316	0.500	0.60	0.20
18	17	11.6	0.173	0.469	-40.0	0.005	320	684	0.500	0.60	0.29
19	12	145.0	0.149	1.091	-2.0	0.006	320	809	0.500	0.60	0.16
19	13	166.1	0.066	1.218	-0.2	0.006	390	1139	0.500	0.60	0.16
19	14	155.6	0.072	1.253	-0.2	0.006	455	822	0.500	0.60	0.16
20	15	106.8	0.200	1.148	-6.7	0.006	507	1132	0.500	0.60	0.17
20	16	54.7	0.227	0.966	-19.1	0.005	591	1152	0.500	0.60	0.20
21	17	3.7	0.186	0.396	-153.6	0.005	595	1295	0.500	0.60	0.30

## **APPENDIX C**

### **TSP AND PM<sub>10</sub> CONCENTRATION MEASUREMENTS TAKEN DURING THE SAMPLING EVENTS DURING 2006 AND 2007**

Table C-1. TSP and PM<sub>10</sub> concentration measurements from farm 1 during 2006.

Test	Sampler Location/Type	Fan	Date	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	HOBO Conc. (mg/m <sup>3</sup> )	Log Sheet Conc. (mg/m <sup>3</sup> )	Final Conc. (mg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
1	E1TSP	18	8/16/2006	3.23	3.83	0.00029	90	76	76	0.79
1	E2TSP	21	8/16/2006	3.32	3.88	0.00034	101	87	87	
1	NTSP	19	8/16/2006	3.19	4.11	0.00045	140	109	109	0.20
1	W1TSP	2	8/16/2006	3.91	4.09	0.00028	71	68	71	0.73
1	W2TSP	3	8/16/2006	5.05	3.92	0.00029	57	74	74	0.76
1	E1PM10	10	8/16/2006	4.26	4.36	0.00025	59	58	59	
1	E2PM10		8/16/2006							
1	NPM10	20	8/16/2006	3.90	4.21	0.00009	22	21	22	
1	W1PM10	5	8/16/2006	3.62	4.08	0.00019	52	46	52	
1	W2PM10	4	8/16/2006	3.82	3.95	0.00021	56	54	56	
1	SPM10	1	8/16/2006	3.84	3.83	0.00020	52	52	52	
1	STSP	6	8/16/2006	3.67	3.82	0.00024	65	63	65	
2	E1TSP	2	8/16/2006	1.02	1.03	0.00012	121	120	121	
2	E2TSP	3	8/16/2006	1.19	1.01	0.00020	172	201	172	
2	NTSP	19	8/16/2006	1.48	1.42	0.00032	214	223	214	0.20
2	W1TSP	18	8/16/2006	1.29	1.32	0.00046	354	347	354	0.20
2	W2TSP	21	8/16/2006	1.38	1.39	0.00032	234	232	234	
2	E1PM10	5	8/16/2006	0.98	1.03	0.00001	13	12	13	
2	E2PM10	4	8/16/2006	1.02	1.03	0.00003	33	32	33	
2	NPM10	20	8/16/2006	1.58	1.48	0.00007	42	45	42	
2	W1PM10	10	8/16/2006	1.40	1.47	0.00010	71	68	71	
2	W2PM10	22	8/16/2006	8.39	1.38	-0.00633				
2	SPM10	1	8/16/2006	1.40	1.41	0.00014	100	100	100	
2	STSP	6	8/16/2006	1.43	1.41	0.00021	147	149	147	

Table C-1 Continued.

Test	Sampler Location/ Type	Fan	Date	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	HOBO Conc. (mg/m <sup>3</sup> )	Log Sheet Conc. (mg/m <sup>3</sup> )	Final Conc. (mg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
3	E1TSP	18	8/17/2006	2.30	2.40	0.00027	118	113	118	0.10
3	E2TSP	21	8/17/2006	2.62	2.73	0.00023	86	83	86	
3	NTSP	19	8/17/2006	1.68	2.65	0.00021	123	78	78	0.54
3	W1TSP	3	8/17/2006	3.42	2.72	0.00019	57	71	71	0.25
3	W2TSP	2	8/17/2006	2.39	2.59	0.00011	45	41	45	0.70
3	E1PM10	10	8/17/2006	2.61	2.73	0.00003	12	11	12	
3	E2PM10	22	8/17/2006	2.42	2.54	0.00000				
3	NPM10	20	8/17/2006	2.25	2.76	0.00012	52	42	42	
3	W1PM10	4	8/17/2006	2.62	2.71	0.00005	18	17	18	
3	W2PM10	5	8/17/2006	2.35	2.69	0.00007	31	27	31	
3	SPM10	1	8/17/2006	2.47	2.65	0.00022	88	82	88	
3	STSP	6	8/17/2006	2.52	2.71	0.00022	86	80	86	
4	E1TSP	3	8/17/2006	1.50	1.20	0.00014	96	120	120	
4	E2TSP	2	8/17/2006	1.19	1.24	0.00022	182	175	182	
4	NTSP	19	8/17/2006	1.19	1.14	0.00105	882	921	882	
4	W1TSP	18	8/17/2006	1.08	1.10	-0.00480				
4	W2TSP	21	8/17/2006	0.03	1.27	0.00018	5271	139	139	0.64
4	E1PM10	4	8/17/2006	1.15	1.23	-0.00012				
4	E2PM10	5	8/17/2006	1.12	1.35	0.00006	51	42	42	
4	NPM10	20	8/17/2006	1.23	1.10	0.00022	179	200	179	
4	W1PM10	10	8/17/2006	1.19	1.24	-0.00093				
4	W2PM10	22	8/17/2006	1.17	1.19	0.00010	89	87	89	
4	SPM10	1	8/17/2006	1.25	1.25	0.00002	16	16	16	
4	STSP	6	8/17/2006	1.29	1.29	0.00008	62	62	62	0.26

Table C-1 Continued.

Test	Sampler Location/ Type	Fan	Date	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	HOBO Conc. (mg/m <sup>3</sup> )	Log Sheet Conc. (mg/m <sup>3</sup> )	Final Conc. (mg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
5	E1TSP	18	8/18/2006	3.43	3.98	3600	0.00023	67	58	58
5	E2TSP	21	8/18/2006	0.00	4.11	3599	0.00015		37	37
5	W1TSP	2	8/18/2006	3.67	3.96	3602	0.00028	77	71	77
5	W2TSP	3	8/18/2006	5.17	4.04	3603	0.00045	87	111	111
5	STSP	6	8/18/2006	3.93	4.20	3604	0.00121	307	287	307
5	E1PM10	10	8/18/2006	3.85	4.11	3606	0.00003	8	7	8
5	E2PM10	22	8/18/2006	3.65	3.89	3605	0.00003	7	7	7
5	W1PM10	5	8/18/2006	3.17	3.99	3608	0.00009	27	22	22
5	W2PM10	4	8/18/2006	3.75	3.92	3609	0.00013	34	32	34
5	SPM10	1	8/18/2006	4.08	4.08	3610	0.00048	117	117	117
5	NPM10	20	8/18/2006	3.03		3607	0.00000	0		
5	NTSP	19	8/18/2006	2.26		3601	0.00016	69		69
6	E1TSP	3	8/18/2006	1.53	1.01	3614	0.00031	200	303	303
6	E2TSP	2	8/18/2006	1.08	0.95	3613	0.00013	120	137	120
6	NTSP	19	8/18/2006	0.73	1.03	3615	0.00018	242	172	172
6	W1TSP	21	8/18/2006	0.00	1.11	3616	0.00026		235	235
6	W2TSP	18	8/18/2006	1.01	1.02	3617	0.00033	330	326	330
6	E1PM10	4	8/18/2006	1.06	0.98	3612	0.00005	47	51	47
6	E2PM10	5	8/18/2006	0.99	0.94	3611	0.00004	44	46	44
6	NPM10	20	8/18/2006	1.12	1.10	3625	-0.00003			
6	W1PM10	22	8/18/2006	1.08	1.05	3626	0.00009	86	89	86
6	W2PM10	10	8/18/2006	1.17	1.11	3627	0.00017	145	153	145
6	SPM10	1	8/18/2006	1.20	1.19	3628	0.00008	67	67	67
6	STSP	6	8/18/2006	0.00	1.20	3618	0.00000		0	

Table C-1 Continued.

Test	Sampler Location/ Type	Fan	Date	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	HOBO Conc. (mg/m <sup>3</sup> )	Log Sheet Conc. (mg/m <sup>3</sup> )	Final Conc. (mg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
7	E1TSP	21	8/18/2006	0.00	1.92	0.00029		153	153	
7	E2TSP	18	8/18/2006	1.65	1.69	0.00023	137	134	137	
7	NTSP	19	8/18/2006	1.84	1.75	0.00031	171	179	171	
7	W1TSP	3	8/18/2006	2.38	1.84	0.00003	13	16	16	0.96
7	W2TSP	2	8/18/2006	1.79	1.80	0.00025	138	137	138	0.38
7	E1PM10	22	8/18/2006	1.75	1.85	-0.00002				
7	E2PM10	10	8/18/2006	1.76	1.85	0.00010	57	54	57	
7	NPM10	20	8/18/2006	1.97	1.86	0.00002	12	13	12	
7	W1PM10	4	8/18/2006	1.70	1.76	0.00003	16	15	16	
7	W2PM10	5	8/18/2006	1.67	1.79	0.00009	52	48	52	
7	SPM10	1	8/18/2006	1.82	1.83	-0.00002				
7	STSP	6	8/18/2006	1.92	1.89	0.00004	21	21	21	
8	E1TSP	3	8/19/2006	2.41	1.98	0.00024	100	121	121	
8	E2TSP	2	8/19/2006	1.73	1.88	0.00012	71	66	71	
8	NTSP	19	8/19/2006	1.93	1.95	-0.00003				
8	W1TSP	18	8/19/2006	1.76	1.80	0.00002	9	9	9	0.73
8	W2TSP	21	8/19/2006	0.00	2.03	0.00009		43	43	0.73
8	E1PM10	4	8/19/2006	1.83	1.87	-0.00008				
8	E2PM10	5	8/19/2006	1.23	1.90	-0.00005				
8	NPM10	20	8/19/2006	2.14	1.95	0.00000				
8	W1PM10	10	8/19/2006	1.94	1.99	0.00001	7	7	7	
8	W2PM10	22	8/19/2006	1.93	1.98	0.00006	31	30	31	
8	SPM10	1	8/19/2006	2.17	2.20	0.00009	40	39	40	
8	STSP	6	8/19/2006	1.96	2.23	-0.00005				

Table C-1 Continued.

Test	Sampler Location/ Type	Fan	Date	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	HOBO Conc. (mg/m <sup>3</sup> )	Log Sheet Conc. (mg/m <sup>3</sup> )	Final Conc. (mg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
9	E1TSP	18	8/19/2006	3.20	3.25	0.00021	67	66	67	
9	E2TSP	21	8/19/2006	0.00	3.46	0.00002		7	7	
9	NTSP	20	8/19/2006	3.16	3.56	0.00003	8	7	8	
9	W1TSP	3	8/19/2006	4.30	3.63	0.00026	61	73	73	0.25
9	W2TSP	2	8/19/2006	3.23	3.46	0.00035	107	100	107	0.15
9	E1PM10	10	8/19/2006	3.27	3.61	0.00003	10	9	10	
9	E2PM10	22	8/19/2006	3.16	3.27	-0.00004				
9	NPM10	19	8/19/2006	0.00						
9	W1PM10	4	8/19/2006	3.32	3.54	0.00006	18	17	18	
9	W2PM10	5	8/19/2006	2.66	3.55	0.00006	21	16	16	
9	SPM10	1	8/19/2006	3.53	3.53	0.00003	9	9	9	
9	STSP	6	8/19/2006	3.45	3.65	0.00013	39	36	39	0.24
10	E1TSP	3	8/19/2006	3.37	2.64	0.00020	60	77	77	
10	E2TSP	2	8/19/2006	2.87	2.46	0.00026	92	107	92	
10	NTSP	20	8/19/2006	3.26	2.75	0.00037	112	133	133	
10	W1TSP	21	8/19/2006	0.28	2.92	0.00031	1092	105	105	0.29
10	W2TSP	18	8/19/2006	3.08	2.73	0.00024	77	87	77	0.41
10	E1PM10	4	8/19/2006	3.07	2.54	0.00007	24	29	29	
10	E2PM10	5	8/19/2006	2.71	2.53	0.00007	27	29	27	
10	NPM10	19	8/19/2006	0.27	2.50	0.00011	421	45	45	
10	W1PM10	22	8/19/2006	3.12	2.70	0.00009	30	35	30	
10	W2PM10	10	8/19/2006	3.00	2.77	0.00009	31	34	31	
10	SPM10	1	8/19/2006	3.28	2.58	0.00014	43	54	54	
10	STSP	6	8/19/2006	3.50	2.91	0.00007	21	25	25	2.15

Table C-2. TSP and PM<sub>10</sub> concentration measurements taken at farm 2 during 2006.

Test	Sampler Location/ Type	Fan	Date	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	HOBO Conc. (mg/m <sup>3</sup> )	LS Conc. (mg/m <sup>3</sup> )	Final Conc. (mg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
1	D1TSP	2	9/1/2006	0.00	1.54	0.00009	0	58	58	0.36
1	D2TSP	22	9/1/2006	1.15	1.41	0.00007	58	47	47	0.38
1	D3TSP	1	9/1/2006	1.41	1.41	0.00006	45	45	45	0.98
1	D4TSP	5	9/1/2006	0.00	1.50	0.00007	0	49	49	1.04
1	D5TSP	21	9/1/2006	1.43	1.48	0.00019	133	129	133	0.32
1	D1PM10	4	9/1/2006	1.44	1.54	0.00003	21	20	21	
1	D2PM10	17	9/1/2006	1.50	1.46	0.00003	18	18	18	
1	D3PM10	20	9/1/2006	1.44	1.61	0.00006	44	39	44	
1	D4PM10	3	9/1/2006	0.03	1.52	0.00008	2730	51	51	
1	D5PM10	18	9/1/2006	1.49	1.48	0.00006	42	43	42	
1	U1TSP	19	9/1/2006	0.73	0.00	0.00003	46	0	46	
1	U1PM10	6	9/1/2006	0.00	1.75	0.00008	0	46	46	
2	D1TSP	2	9/1/2006	0.00	0.00	0.00001	0	0		
2	D2TSP	1	9/1/2006	2.35	2.36	0.00016	70	69	70	0.98
2	D3TSP	21	9/1/2006	2.39	2.44	0.00011	45	44	45	0.80
2	D4TSP	22	9/1/2006	0.30	2.36	0.00001	23	3		
2	D5TSP	5	9/1/2006	0.00	0.00	0.00005	0	0		
2	D1PM10	4	9/1/2006	0.71	0.00	0.00000	5	0		
2	D2PM10	20	9/1/2006	2.60	2.69	0.00018	68	66	68	
2	D3PM10	18	9/1/2006	2.42	2.49	0.00009	36	35	36	
2	D4PM10	17	9/1/2006	0.24	0.00	0.00003	123	0	123	
2	D5PM10	3	9/1/2006	0.33	0.00	0.00000	10	0	10	
2	U1TSP	19	9/1/2006	0.83	0.00	0.00000	0	0		
2	U1PM10	6	9/1/2006	0.00	0.00	0.00006	0	0		



Table C-2 Continued.

Test	Sampler Location/ Type	Fan	Date	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	HOBO Conc. (mg/m <sup>3</sup> )	LS Conc. (mg/m <sup>3</sup> )	Final Conc. (mg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
3	D1TSP	1	9/2/2006	1.04	1.07	0.00004	35	34	35	
3	D2TSP	21	9/2/2006	1.08	1.09	0.00002	19	18	19	
3	D3TSP	2	9/2/2006	0.00	1.00	0.00004	0	37	37	
3	D4TSP	22	9/2/2006	1.04	1.07	0.00005	51	50	51	
3	D5TSP	5	9/2/2006	0.00	1.03	0.00004	0	39	39	
3	D1PM10	20	9/2/2006	0.80	1.17	0.00004	50	34	34	
3	D2PM10	18	9/2/2006	1.09	1.10	0.00005	46	45	46	
3	D3PM10	4	9/2/2006	1.02	1.05	0.00000	0	0		
3	D4PM10	17	9/2/2006	0.98	1.02	-0.00011				
3	D5PM10	3	9/2/2006	1.22	1.02	0.00000	3	3		
3	U1TSP	19	9/2/2006	0.73	1.08	0.00006	78	52	52	0.053
3	U1PM10	6	9/2/2006	0.00	1.20	0.00000	0	3	3	
4	D1TSP	1	9/2/2006	3.70	3.76	0.00018	49	48	49	
4	D2TSP	21	9/2/2006	3.77	3.93	0.00000	1	1		
4	D3TSP	2	9/2/2006	0.00	3.57	0.00019	0	54	54	0.91
4	D4TSP	22	9/2/2006	3.62	3.76	0.00024	66	64	66	0.72
4	D5TSP	5	9/2/2006	0.00	3.73	0.00024	0	63	63	0.11
4	D1PM10	20	9/2/2006	2.56	0.00	0.00007	26	0	26	
4	D2PM10	18	9/2/2006	3.84	3.92	0.00015	40	39	40	
4	D3PM10	4	9/2/2006	3.60	3.77	0.00018	49	47	49	
4	D4PM10	17	9/2/2006	3.37	3.56	0.00016	47	45	47	
4	D5PM10	3	9/2/2006	4.66	3.71	0.00003	6	7	7	
4	U1TSP	10	9/2/2006	4.08	4.17	0.00018	44	43	44	
4	U1PM10	6	9/2/2006	0.00	4.32	0.00005	0	12	12	

Table C-2 Continued.

Test	Sampler Location/ Type	Fan	Date	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	HOBO Conc. (mg/m <sup>3</sup> )	LS Conc. (mg/m <sup>3</sup> )	Final Conc. (mg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
5	D1TSP	1	9/2/2006	2.57	2.60	0.00044	170	168	170	
5	D2TSP	21	9/2/2006	2.75	2.69	0.00053	193	197	193	0.47
5	D3TSP	2	9/2/2006	0.00	2.55	0.00052	0	205	205	0.57
5	D4TSP	22	9/2/2006	2.80	2.60	0.00057	202	218	202	0.62
5	D5TSP	5	9/2/2006	0.00	2.80	0.00049	0	176	176	0.65
5	D1PM10	20	9/2/2006	2.81	2.80	0.00034	121	121	121	
5	D2PM10	18	9/2/2006	2.78	2.78	0.00025	91	91	91	
5	D3PM10	4	9/2/2006	2.63	2.69	0.00031	116	114	116	
5	D4PM10	17	9/2/2006	2.57	2.56	0.00032	125	125	125	
5	D5PM10	3	9/2/2006	3.43	2.84	0.00033	95	115	115	
5	U1TSP	10	9/2/2006	1.39	2.80	0.00026	190	94	94	
5	U1PM10	6	9/2/2006	0.00	0.00	0.00020	0	0		
6	D1TSP	1	9/3/2006	3.81	3.82	0.00018	46	46	46	
6	D2TSP	21	9/3/2006	3.86	4.05	0.00018	47	44	47	0.86
6	D3TSP	2	9/3/2006	0.00	3.72	0.00016	0	42	42	0.90
6	D4TSP	22	9/3/2006	3.84	4.00	0.00023	59	57	59	
6	D5TSP	5	9/3/2006	0.00	4.00	0.00018	0	44	44	0.62
6	D1PM10	20	9/3/2006	2.23	0.00	0.00002	9	0	9	
6	D2PM10	18	9/3/2006	3.80	3.96	0.00015	40	39	40	
6	D3PM10	4	9/3/2006	3.70	3.92	0.00014	38	36	38	
6	D4PM10	17	9/3/2006	3.55	3.80	0.00000	0	0		
6	D5PM10	3	9/3/2006	4.85	3.98	0.00011	23	28	28	
6	U1TSP	10	9/3/2006	4.01	4.15	0.00022	54	52	54	
6	U1PM10	6	9/3/2006	0.00	4.25	0.00000	0	1		

Table C-2 Continued.

Test	Sampler Location/ Type	Fan	Date	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	HOBO Conc. (mg/m <sup>3</sup> )	LS Conc. (mg/m <sup>3</sup> )	Final Conc. (mg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
7	D1TSP	22	9/3/2006	2.28	2.28	0.00024	105	105	105	0.18
7	D2TSP	5	9/3/2006	0.00	2.32	0.00016	0	67	67	0.43
7	D3TSP	10	9/3/2006	2.05	2.11	0.00013	65	63	65	0.86
7	D4TSP	2	9/3/2006	0.00	1.84	0.00035	0	190	190	0.32
7	D5TSP	21	9/3/2006	1.79	1.87	0.00027	151	144	151	0.20
7	D1PM10	17	9/3/2006	2.13	2.16	0.00004	19	19	19	
7	D2PM10	3	9/3/2006	2.80	2.32	0.00007	24	29	29	
7	D3PM10	6	9/3/2006	0.00	2.20	0.00012	0	56	56	
7	D4PM10	4	9/3/2006	1.77	1.95	0.00011	60	55	60	
7	D5PM10	18	9/3/2006	1.83	1.85	0.00006	31	31	31	
7	U1TSP	1	9/3/2006	0.00	2.28	0.00006	0	26	26	
7	U1PM10	20	9/3/2006	0.00	2.43	0.00005	0	19	19	
8	D1TSP	5	9/3/2006	0.00	2.58	0.00040	0	154	154	
8	D2TSP	22	9/3/2006	2.65	2.51	0.00019	73	77	73	
8	D3TSP	20	9/3/2006	2.70	2.56	0.00035	129	136	129	0.38
8	D4TSP	2	9/3/2006	0.00	2.55	0.00033	0	129	129	0.35
8	D5TSP	21	9/3/2006	2.75	2.78	0.00009	34	34	34	
8	D1PM10	3	9/3/2006	2.82	2.52	0.00012	44	49	44	
8	D2PM10	17	9/3/2006	2.52	2.55	0.00012	46	46	46	
8	D3PM10	1	9/3/2006	2.57	2.51	0.00013	49	50	49	
8	D4PM10	4	9/3/2006	2.57	2.67	0.00012	45	44	45	
8	D5PM10	18	9/3/2006	2.70	2.78	0.00000				
8	U1TSP	10	9/3/2006	2.33	2.32	0.00034	146	146	146	
8	U1PM10	6	9/3/2006	0.00	2.46	0.00010	0	42	42	

Table C-3. TSP and PM<sub>10</sub> concentrations measured at farm 3 during 2006.

Test	Sampler Location/ Type	Fan	Date	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	HOBO Conc. (mg/m <sup>3</sup> )	LS Conc. (mg/m <sup>3</sup> )	Final Conc. (mg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
1	DSTSP	19	9/14/2006	2.332		0.00040	170	0	170	
1	L1TSP	1	9/14/2006	3.288	3.231	0.00092	279	284	279	0.27
1	L2TSP	2	9/14/2006	0.000	3.121	0.00093	0	297	297	0.25
1	R1TSP	3	9/14/2006	0.000	3.450	0.00070	0	202	202	
1	R2TSP	17	9/14/2006	2.987	3.342	0.00079	263	235	263	
1	DSPM10	20	9/14/2006	1.672		0.00017	102	0	102	
1	L1PM10	4	9/14/2006	3.228	3.351	0.00024	74	72	74	
1	L2PM10	6	9/14/2006	3.648	3.622	0.00027	75	75	75	
1	R1PM10	5	9/14/2006	0.000	3.444	0.00022	0	65	65	
1	R2PM10	10	9/14/2006	3.861	3.546	0.00023	60	66	60	
1	UWTSP	22	9/14/2006	1.828	3.231	0.00011	58	33	33	
1	UWPM10	21	9/14/2006	1.678		0.00006	36	0	36	
2	DSTSP	19	9/14/2006	1.965	1.893	0.00032	163	169	163	0.49
2	L1TSP	3	9/14/2006	0.000	2.071	0.00030	0	147	147	
2	L2TSP	17	9/14/2006	1.743	1.911	0.00032	184	167	184	0.38
2	R1TSP	1	9/14/2006	1.974	1.958	0.00019	95	95	95	
2	R2TSP	6	9/14/2006	2.238	2.178	0.00052	232	239	232	
2	DSPM10	20	9/14/2006	2.052	2.012	0.00016	80	81	80	
2	L1PM10	5	9/14/2006	0.000	1.994	0.00027	0	135	135	
2	L2PM10	10	9/14/2006	2.182	2.091	0.00015	70	73	70	
2	R1PM10	4	9/14/2006	1.937	2.019	0.00015	79	76	79	
2	R2PM10	2	9/14/2006	0.000	1.912	0.00015	0	78	78	
2	UWTSP	22	9/14/2006	2.004	1.958	0.00004	20	20	20	
2	UWPM10	21	9/14/2006	1.875	1.882	0.00014	75	74	75	

Table C-3 Continued.

Test	Sampler Location/ Type	Fan	Date	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	HOBO Conc. (mg/m <sup>3</sup> )	LS Conc. (mg/m <sup>3</sup> )	Final Conc. (mg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
3	DSTSP	19	9/15/2006	4.392	4.278	0.00025	57	58	57	
3	L1TSP	1	9/15/2006	4.205	4.235	0.00035	84	83	84	0.48
3	L2TSP	2	9/15/2006	0.000	4.072	0.00037	0	90	90	0.38
3	R1TSP	3	9/15/2006	0.000	4.264	0.00026	0	62	62	
3	R2TSP	17	9/15/2006	3.552	4.008	0.00032	89	79	89	
3	DSPM10	20	9/15/2006	3.331	4.405	0.00011	32	24	24	
3	L1PM10	4	9/15/2006	4.091	4.302	0.00017	41	39	41	
3	L2PM10	6	9/15/2006	4.617	4.596	0.00016	34	34	34	
3	R1PM10	5	9/15/2006	0.000	4.201	0.00011	0	25	25	
3	R2PM10	10	9/15/2006	4.502	4.254	0.00007	16	17	16	
3	UWTSP	22	9/15/2006	4.393	4.235	0.00049	112	116	112	
3	UWPM10	21	9/15/2006	4.188	4.397	0.00012	29	28	29	
5	DSTSP	19	9/16/2006	1.080	1.541	0.00006	52	37	37	
5	L1TSP	2	9/16/2006	0.000	1.556	0.00012	0	75	75	
5	L2TSP	1	9/16/2006	1.491	1.556	0.00028	190	182	190	0.21
5	R1TSP	3	9/16/2006	0.000	1.833	0.00020	0	111	111	
5	R2TSP	17	9/16/2006	1.553	1.750	0.00017	112	99	112	
5	DSPM10	20	9/16/2006	1.255	1.603	0.00092	733	574	574	
5	L1PM10	6	9/16/2006	1.425	1.568	0.00003	23	21	23	
5	L2PM10	4	9/16/2006	1.448	1.502	0.00006	39	38	39	
5	R1PM10	5	9/16/2006	0.000	1.810	0.00004	0	24	24	
5	R2PM10	10	9/16/2006	1.967	1.885	0.00000	0	0		
5	UWTSP	22	9/16/2006	1.537	1.556	0.00000	2	2	2	
5	UWPM10	21	9/16/2006	1.541	1.622	0.00000	2	2	2	

Table C-3 Continued.

Test	Sampler Location/ Type	Fan	Date	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	HOBO Conc. (mg/m <sup>3</sup> )	LS Conc. (mg/m <sup>3</sup> )	Final Conc. (mg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
6	DSTSP	19	9/16/2006	0.062		0.00004	704	0	704	
6	L1TSP	3	9/16/2006	0.000	3.427	0.00031	0	91	91	0.40
6	L2TSP	17	9/16/2006	2.790	3.240	0.00033	118	102	102	0.56
6	R1TSP	2	9/16/2006	0.000		0.00015	0	0		
6	R2TSP	1	9/16/2006	3.420		0.00017	50	0	50	
6	DSPM10	20	9/16/2006	0.066		0.00000	0	0		
6	L1PM10	5	9/16/2006	0.000	3.345	0.00012	0	37	37	
6	L2PM10	10	9/16/2006	3.653	3.458	0.00021	57	61	57	
6	R1PM10	6	9/16/2006	3.347		0.00011	33	0	33	
6	R2PM10	4	9/16/2006	3.144		0.00007	22	0	22	
6	UWTSP	22	9/16/2006	0.888		0.00004	49	0	49	
6	UWPM10	21	9/16/2006	0.911		0.00002	18	0	18	

Table C-4. TSP and PM<sub>10</sub> concentrations measured at farm 3 during 2007.

Test	Sampler Type	Easting Coordinates	Northing Coordinates	Fan	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	Final Conc. (µg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
1	TSP	747135	3382037	7	n/a	1.67	0.00016	94	0.66
1	TSP	747183	3382008	3	1.58	1.75	0.00025	160	0.62
1	TSP	747227	3382156	12	n/a	1.62	0.00024	150	0.77
1	TSP	747275	3382122	4	1.79	1.98	0.00025	141	0.86
1	TSP	747987	3381465	15	n/a	1.67	0.00010	58	0.55
1	PM10	747135	3382037	21	1.74	1.76	0.00011	61	
1	PM10	747183	3382008	14	n/a	1.74	0.00017	100	
1	PM10	747227	3382156	11	1.41	1.63	0.00016	116	
1	PM10	747275	3382122	6	1.86	1.98	0.00023	122	
1	PM10	747987	3381465	17	2.22	2.35	0.00007	32	
2	TSP	747275	3381944	7	1.44	0.97	0.00009	65	
2	TSP	747317	3381914	3	n/a	1.04	0.00015	144	0.67
2	TSP	747377	3382075	12	1.10	0.90	0.00016	149	0.90
2	TSP	747421	3382041	4	1.17	1.28	0.00021	183	
2	TSP	747987	3381465	15	n/a	5.71	0.00014	25	0.73
2	PM10	747275	3381944	21	0.86	0.95	0.00009	101	
2	PM10	747317	3381914	14	n/a	1.18	0.00011	96	
2	PM10	747377	3382075	11	0.75	0.90	0.00010	133	
2	PM10	747421	3382041	6	1.21	1.28	0.00011	94	
2	PM10	747987	3381465	17	7.69	8.20	0.00014	18	

Table C-4 Continued.

Test	Sampler Type	Easting Coordinates	Northing Coordinates	Fan	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	Final Conc. (µg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
3	TSP	747469	3381743	7	0.92	0.75	0.00005	51	
3	TSP	747518	3381714	3	n/a	0.82	0.00019	229	0.41
3	TSP	747532	3381825	12	0.93	0.76	0.00016	175	
3	TSP	747574	3381790	4	0.84	0.91	0.00015	182	0.08
3	PM10	747469	3381743	21	0.67	0.73	0.00015	227	
3	PM10	747518	3381714	14	n/a	0.93	0.00009	93	
3	PM10	747532	3381825	11	0.70	0.76	0.00007	96	
3	PM10	747574	3381790	6	0.91	0.94	0.00001	15	
4	TSP	747510	3381712	3	n/a	0.75	0.00010	138	0.39
4	TSP	747554	3381677	7	1.19	1.00	0.00041	346	0.49
4	TSP	747572	3381787	4	0.75	0.81	0.00013	168	
4	TSP	747614	3381759	12	1.20	0.97	0.00022	184	0.91
4	PM10	747510	3381712	14	n/a	0.86	0.00005	54	
4	PM10	747554	3381677	21	0.93	0.92	0.00016	168	
4	PM10	747572	3381787	6	0.82	0.82	0.00006	69	
4	PM10	747614	3381759	11	0.94	1.01	0.00016	168	



Table C-4 Continued.

Test	Sampler Type	Easting Coordinates	Northing Coordinates	Fan	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	Final Conc. (µg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
5	TSP	747752	3381488	3	n/a	0.94	0.00006	64	
5	TSP	747800	3381550	4	1.08	1.12	0.00018	164	
5	TSP	747804	3381462	7	1.32	1.07	0.00012	94	0.36
5	TSP	747845	3381517	12	1.25	1.01	0.00011	91	0.99
5	PM10	747752	3381488	14	n/a	1.09	0.00007	64	
5	PM10	747800	3381550	6	1.13	1.13	0.00004	38	
5	PM10	747804	3381462	21	1.08	1.04	0.00004	34	
5	PM10	747845	3381517	11	0.96	1.00	0.00009	90	
6	TSP	747223	3382056	7	2.65	1.86	0.00027	101	0.61
6	TSP	747268	3382021	3	n/a	1.79	0.00017	95	
6	TSP	747304	3382160	12	2.15	1.83	0.00043	198	0.27
6	TSP	747350	3382129	4	2.01	2.15	0.00026	127	
6	TSP	747987	3381465	15	n/a	3.35	0.00012	35	0.36
6	PM10	747223	3382056	21	1.91	1.86	0.00012	61	
6	PM10	747268	3382021	14	n/a	2.01	0.00016	81	
6	PM10	747304	3382160	11	2.26	1.83	0.00012	53	
6	PM10	747350	3382129	6	n/a	2.16	0.00015	71	
6	PM10	747987	3381465	17	4.59	4.84	0.00006	12	

Table C-4 Continued.

Test	Sampler Type	Easting Coordinates	Northing Coordinates	Fan	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	Final Conc. (µg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
7	TSP	747265	3382016	3	n/a	1.45	0.00018	122	0.22
7	TSP	747306	3381983	7	2.42	1.68	0.00013	54	
7	TSP	747349	3382130	4	1.21	1.24	0.00027	221	0.36
7	TSP	747393	3382091	12	2.18	1.75	0.00014	64	
7	PM10	747265	3382016	14	n/a	1.60	0.00004	27	
7	PM10	747306	3381983	21	1.57	1.71	0.00010	64	
7	PM10	747349	3382130	6	n/a	1.25	0.00010	80	
7	PM10	747393	3382091	11	1.74	1.81	0.00006	34	
8	TSP	747366	3381856	3	1.71	1.34	0.00023	133	0.43
8	TSP	747396	3381827	7	2.28	1.60	0.00009	38	
8	TSP	747434	3381945	4	1.36	1.45	0.00026	191	0.35
8	TSP	747469	3381916	12	n/a	1.73	0.00009	52	
8	TSP	747987	3381465	15	n/a	7.11	0.00012	17	1.60
8	PM10	747366	3381856	14	n/a	1.52	0.00009	57	
8	PM10	747396	3381827	21	0.00	1.62	0.00003	17	
8	PM10	747434	3381945	6	1.38	1.42	0.00009	68	
8	PM10	747469	3381916	11	1.65	1.71	0.00002	12	
8	PM10	747987	3381465	17	6.42	10.19	0.00017	27	

Table C-4 Continued.

Test	Sampler Type	Easting Coordinates	Northing Coordinates	Fan	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	Final Conc. (µg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
9	TSP	747391	3381823	7	1.82	1.27	0.00019	102	0.49
9	TSP	747434	3381791	3	n/a	1.29	0.00005	41	
9	TSP	747463	3381914	12	n/a	1.32	0.00022	164	0.43
9	TSP	747505	3381779	4	1.45	1.52	0.00001	7	
9	PM10	747391	3381823	21	n/a	1.27	0.00006	50	
9	PM10	747434	3381791	14	n/a	1.49	0.00005	31	
9	PM10	747463	3381914	11	1.23	1.29	0.00009	70	
9	PM10	747505	3381779	6	1.48	1.50	0.00000	0	
10	TSP	747437	3381788	3	n/a	1.20	0.00031	259	0.10
10	TSP	747477	3381758	7	1.85	1.33	0.00006	32	
10	TSP	747502	3381878	4	1.30	1.35	0.00026	198	0.56
10	TSP	747548	3381845	12	n/a	1.32	0.00011	81	
10	PM10	747437	3381788	14	n/a	1.34	0.00003	25	
10	PM10	747477	3381758	21	n/a	1.31	0.00000	3	
10	PM10	747502	3381878	6	1.35	1.35	0.00015	111	
10	PM10	747548	3381845	11	1.22	1.25	0.00001	11	

Table C-4 Continued.

Test	Sampler Type	Easting Coordinates	Northing Coordinates	Fan	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	Final Conc. (µg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
11	TSP	747555	3881675	3	n/a	0.97	0.00030	312	0.48
11	TSP	747594	3381637	7	1.33	0.92	0.00010	73	
11	TSP	747610	3381745	4	1.13	0.94	0.00042	368	0.50
11	TSP	747646	3381707	12	n/a	1.00	0.00015	150	
11	PM10	747555	3881675	14	n/a	1.06	0.00016	151	
11	PM10	747594	3381637	21	n/a	0.93	0.00000	0	
11	PM10	747610	3381745	6	0.92	0.92	0.00017	186	
11	PM10	747646	3381707	11	0.96	0.99	0.00003	35	
12	TSP	747592	3381635	7	1.78	1.26	0.00036	205	0.51
12	TSP	747629	3381595	3	n/a	0.84	0.00004	51	
12	TSP	747646	3381703	12	n/a	1.15	0.00036	310	0.55
12	TSP	747684	3381662	4	1.19	1.04	0.00004	34	
12	PM10	747592	3381635	21	n/a	1.24	0.00013	105	
12	PM10	747629	3381595	14	n/a	0.88	0.00002	19	
12	PM10	747646	3381703	11	1.08	1.12	0.00018	171	
12	PM10	747684	3381662	6	1.00	1.02	0.00006	64	

Table C-4 Continued.

Test	Sampler Type	Easting Coordinates	Northing Coordinates	Fan	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	Final Conc. (µg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
13	TSP	747632	3381595	3	n/a	1.33	0.00023	170	0.61
13	TSP	747677	3381565	7	1.75	1.44	0.00010	55	
13	TSP	747683	3381662	4	1.36	1.42	0.00031	230	0.63
13	TSP	747724	3381622	12	1.55	1.41	0.00018	116	
13	TSP	747987	3381465	15	n/a	2.64	0.00007	27	1.03
13	PM10	747632	3381595	14	n/a	1.44	0.00015	104	
13	PM10	747677	3381565	21	n/a	1.45	0.00012	81	
13	PM10	747683	3381662	6	1.35	1.41	0.00020	146	
13	PM10	747724	3381622	11	1.33	1.39	0.00009	70	
13	PM10	747987	3381465	17	n/a	3.78	0.00010	27	
14	TSP	747677	3381568	21	0.88	0.90	0.00051	574	
14	TSP	747720	3381629	12	n/a	0.91	0.00020	221	0.68
14	TSP	747721	3381538	3	n/a	1.03	0.00011	110	
14	TSP	747768	3381593	4	0.99	1.03	0.00019	188	
14	PM10	747677	3381568	7	1.01	0.87	0.00019	185	
14	PM10	747720	3381629	11	0.85	0.90	0.00013	150	
14	PM10	747721	3381538	14	n/a	1.04	0.00008	80	
14	PM10	747768	3381593	6	1.00	1.03	0.00005	53	

Table C-4 Continued.

Test	Sampler Type	Easting Coordinates	Northing Coordinates	Fan	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	Final Conc. (µg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
15	TSP	747721	3381538	3	0.66	0.66	0.00008	116	0.85
15	TSP	747762	3381497	7	n/a	0.69	0.00004	53	
15	TSP	747766	3381599	4	0.69	0.69	0.00030	431	0.34
15	TSP	747807	3381557	12	n/a	0.71	0.00002	28	
15	PM10	747721	3381538	14	n/a	0.74	0.00007	99	
15	PM10	747762	3381497	21	0.67	0.68	0.00003	40	
15	PM10	747766	3381599	6	0.68	0.70	0.00010	146	
15	PM10	747807	3381557	11	0.67	0.75	0.00001	10	
16	TSP	747625	3381504	15	n/a	1.74	0.00007	38	0.89
16	TSP	747906	3381313	3	n/a	1.84	0.00050	272	0.34
16	TSP	747950	3381328	12	2.41	2.05	0.00003	14	
16	TSP	748014	3381246	4	1.77	1.84	0.00050	282	0.32
16	TSP	748052	3381264	7	n/a	2.07	0.00011	55	
16	PM10	747625	3381504	17	2.27	2.35	0.00008	34	
16	PM10	747906	3381313	14	n/a	2.10	0.00020	94	
16	PM10	747950	3381328	11	2.37	2.02	0.00006	27	
16	PM10	748014	3381246	6	1.77	1.83	0.00016	90	
16	PM10	748052	3381264	21	n/a	2.04	0.00004	18	

Table C-4 Continued.

Test	Sampler Type	Easting Coordinates	Northing Coordinates	Fan	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	Final Conc. (µg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
17	TSP	747625	3381504	15	n/a	4.63	0.00017	37	0.86
17	TSP	747950	3381328	12	n/a	2.05	0.00020	98	0.45
17	TSP	748050	3381310	3	1.69	1.71	0.00008	49	0.67
17	TSP	748052	3381264	7	n/a	1.99	0.00013	67	0.54
17	TSP	748133	3381259	4	1.82	1.91	0.00014	79	0.60
17	PM10	747625	3381504	17	6.33	6.67	0.00020	32	
17	PM10	747950	3381328	11	1.97	2.07	0.00009	44	
17	PM10	748050	3381310	14	n/a	1.92	0.00006	33	
17	PM10	748052	3381264	21	n/a	1.94	0.00007	36	
17	PM10	748133	3381259	6	1.76	1.83	0.00008	47	
18	TSP	748052	3381309	3	3.29	3.28	0.00021	64	0.51
18	TSP	748067	3381346	12	n/a	3.70	0.00020	55	0.15
18	TSP	748135	3381256	4	3.46	3.63	0.00026	76	0.62
18	TSP	748154	3381288	7	n/a	3.53	0.00012	34	
18	PM10	748052	3381309	14	n/a	3.65	0.00012	33	
18	PM10	748067	3381346	11	4.32	3.56	0.00004	8	
18	PM10	748135	3381256	6	3.40	3.49	0.00016	47	
18	PM10	748154	3381288	21	n/a	3.55	0.00009	25	

Table C-4 Continued.

Test	Sampler Type	Easting Coordinates	Northing Coordinates	Fan	HOBO Volume (m <sup>3</sup> )	Log Sheet Volume (m <sup>3</sup> )	Net Filter Wt. (g)	Final Conc. (µg/m <sup>3</sup> )	PM <sub>10</sub> /TSP Ratio
19	TSP	747629	3381504	15	n/a	4.67	0.00033	70	0.53
19	TSP	748069	3381341	12	n/a	2.77	0.00019	69	
19	TSP	748081	3380379	3	2.48	2.55	0.00032	130	0.38
19	TSP	748155	3381287	7	n/a	2.81	0.00014	51	
19	TSP	748165	3381323	4	2.68	2.84	0.00036	133	0.60
19	PM10	747629	3381504	17	6.22	6.55	0.00023	37	
19	PM10	748069	3381341	11	2.69	2.84	0.00016	61	
19	PM10	748081	3380379	14	n/a	2.80	0.00014	49	
19	PM10	748155	3381287	21	2.80	2.83	n/a	na	
19	PM10	748165	3381323	6	2.58	2.78	0.00021	80	
20	TSP	747843	3381428	4	1.57	1.65	0.00048	308	0.37
20	TSP	747869	3381405	12	n/a	1.50	0.00058	389	
20	TSP	747870	3381464	3	n/a	1.62	0.00051	312	0.29
20	TSP	747900	3381439	7	n/a	1.78	0.00057	318	
20	PM10	747843	3381428	6	1.57	1.63	0.00018	114	
20	PM10	747869	3381405	11	1.64	1.74	0.00019	116	
20	PM10	747870	3381464	14	n/a	1.82	0.00017	91	
20	PM10	747900	3381439	21	1.77	1.70	0.00015	87	
21	TSP	747809	3381453	7	n/a	0.73	0.00030	418	0.52
21	TSP	747842	3381486	12	n/a	0.72	0.00017	236	0.79
21	TSP	747843	3381428	4	0.79	0.84	0.00012	156	
21	TSP	747870	3381464	3	n/a	0.76	0.00006	74	
21	PM10	747809	3381453	21	0.72	n/a	0.00016	217	
21	PM10	747842	3381486	11	0.86	0.89	0.00016	187	
21	PM10	747843	3381428	6	0.81	0.83	0.00003	41	
21	PM10	747870	3381464	14	n/a	0.85	0.00005	55	



## **APPENDIX D**

### **SYSTEMATIC UNCERTAINTY ANALYSIS FOR THE SOURCE SAMPLING SYSTEM**

Table D-1. Manufacturer published uncertainty values for the components used in the source sampling system used onboard the six-row cotton picker.

Variable	Description	Instrument	Reported Uncertainty	Source
$M_{F1}$	Initial Mass of Filter Bank Filters	Metler Toledo XS205 Balance	$2 \times 10^{-4}$ g	MT Manual
$M_{F2}$	Final Mass of Filter Bank Filters	Metler Toledo XS205 Balance	$2 \times 10^{-4}$ g	MT Manual
$M_{C1}$	Initial Mass of Cyclone Bucket Filter	Metler Toledo XS205 Balance	$2 \times 10^{-4}$ g	MT Manual
$M_{C2}$	Final Mass of Cyclone Bucket Filter	Metler Toledo XS205 Balance	$2 \times 10^{-4}$ g	MT Manual
$Q_{LFE}$	Mass Flow Controller Flow Rate	Meriam Laminar Flow Element Model 50MC2-2	0.86% of reading	Meriam Manual
$D_o$	Orifice Diameter	Orifice Meter (shop made)	0.001	Mitutoyo Caliper Manual
$\Delta P_c$	Calibration pressure drop	Dwyer Series 475 Mark III Digital Manometer	0.5% Full Scale (0.1 in H <sub>2</sub> O)	Specification Sheet
$P_{atm,c}$	Calibration Ambient Pressure	Davis Perception II	1.3 mm Hg	Specification Sheet
$\phi_c$	Calibration Ambient Relative Humidity Ratio	Davis Perception II	5%	Specification Sheet
$P_{s,c}$	Calibration Saturation Pressure	Steam Table	0.0001 psia	Specification Sheet
$T_c$	Calibration Ambient Temp	Davis Perception II	1°F	Specification Sheet
$\Delta P_s$	Sample Orifice Meter Pressure Drop	Dwyer 677 Pressure Transducer (range: 0 - 2.5 in H <sub>2</sub> O, Accuracy: 0.4 %FS) + National Instruments cFP-AI-110 (0.016 %FS)	0.0104 in H <sub>2</sub> O	Specification Sheet
$P_{atm,s}$	Sampling Ambient Pressure	Setra Model 278 Barometric Pressure Transmitter (0.5 hPa) + National Instruments cFP-AI-110 (0.016 %FS)	0.009804 psia	Specification Sheet

Table D-1 Continued.

Variable	Description	Instrument	Reported Uncertainty	Source
$\phi$	Sampling Ambient Relative Humidity Ratio	Omega HX94A T/RH Probe (3.1 %) + National Instruments cFP-AI-110 (0.016 %FS)	0.00310	Specification Sheet
$P_s$	Saturation Pressure	Steam Table	0.0001 psia	Specification Sheet
T	Temperature during sampling	Omega HX94A T/RH Probe (1 degree F) + National Instruments cFP-AI-110 (0.016 %FS)	1.03392 F	Specification Sheet
t	Elapsed Time	Dell Laptop Computer - Latitude D820	0.00001 min/min	assumed
VP	Duct Velocity Pressure	Dwyer 677 Pressure Transducer (range: 0 - 1.0 in H <sub>2</sub> O, Accuracy: 0.4 %FS) + National Instruments cFP-AI-110 (0.016 %FS)	0.00416 in H <sub>2</sub> O	Specification Sheet

<b>Test # 1</b>									
Total TSP Emission Rate Uncertainty Calculations									
<b>ER Systematic Uncertainty 2.77%</b>									
Equation: $ER = Q_d \cdot EC \cdot 6$									
*Note: The 6 in the ER equation is to multiply the single duct emission rate by the number of ducts on the machine.									
Measured ER:	50.046	g/min	0.112	lb/min					
$\omega_{ER}$	1.409	g/min	0.003	lb/min					
Partials			Uncertainties					Absolute Systematic Uncertainty Contribution	% Contribution
$\partial ER / \partial (EC)$	436.036		$\omega_{EC}$	0.003 g/m <sup>3</sup>				0.477	96.0%
$\partial ER / \partial (Q_d)$	0.701		$\omega_{Q_d}$	0.400 m <sup>3</sup> /min				0.020	4.0%
Equation: $Q_d = 1 \cdot 1097 \cdot (VP / \rho_{H_2O})$									
*Note: The 1 in the equation for $Q_d$ represents the 1 ft <sup>2</sup> area of the exit duct.									
Measured $Q_d$	72.673	m <sup>3</sup> /min	VP	0.384348	in. H <sub>2</sub> O				
$\omega_{Q_d}$	0.400	m <sup>3</sup> /min	$\rho_{H_2O}$	0.070223	lb/ft <sup>3</sup>				
Partials			Uncertainties						
$\partial Q_d / \partial (VP)$	3338.689		$\omega_{VP}$	0.004 in H <sub>2</sub> O				48.226	96.8%
$\partial Q_d / \partial (\rho_{H_2O})$	-18273.582		$\omega_{\rho_{H_2O}}$	0.000 lb/ft <sup>3</sup>				1.605	3.2%
Equation: $EC = M_T / V$									
Measured EC	0.117	g/m <sup>3</sup>							
$\omega_{EC}$	0.003	g/m <sup>3</sup>							
Partials			Uncertainties						
$\partial EC / \partial (M_T)$	0.000		$\omega_{M_T}$	0.000 g				0.000	0.0%
$\partial EC / \partial (V)$	0.000		$\omega_V$	81.232 ft <sup>3</sup>				0.000	100.0%

Figure D-1. Uncertainty analysis spreadsheet calculations for the source sampling system using the data from replication 1 (test 6) from farm 3 (2007).

Equation:  $M_T = (M_{F2} - M_{F1}) + (M_{C2} - M_{C1})$

Measured  $M_T$  9.91343 g

$\omega_{MT}$  0.0004 g

Partials		Uncertainties		Bank:	JSS083	0.22840 g		
$\partial M_T/\partial(M_{F2})$	1	$\omega_{MF2}$	2.00E-04 g		JSS084	0.21122 g	0.000	25.0%
$\partial M_T/\partial(M_{F1})$	-1	$\omega_{MF1}$	2.00E-04 g		JSS085	0.57438 g	0.000	25.0%
$\partial M_T/\partial(M_{C2})$	1	$\omega_{MC2}$	2.00E-04 g		JSS086	0.39247 g	0.000	25.0%
$\partial M_T/\partial(M_{C1})$	-1	$\omega_{MC1}$	2.00E-04 g	CBPM:	JSSAW01	8.50696 g	0.000	25.0%

Equation:  $V = Q \cdot t$

Measured V 2996.39 ft<sup>3</sup>

$\omega_V$  81.232 ft<sup>3</sup>

Partials		Uncertainties				Absolute Systematic Uncertainty Contribution	% Contribution
$\partial V / \partial (Q)$	43.000	$\omega_Q$	1.889 ft <sup>3</sup> /min			1649.643	100.0%
$\partial V / \partial (t)$	69.684	$\omega_t$	0.000 min	Duration	43 min	0.000	0.0%

Equation:  $Q = 5.976 \cdot K \cdot D_o^2 \cdot (\Delta P_s / \rho_{H_2O})^{0.5}$

Measured Q 69.684 ft<sup>3</sup>/min

$\omega_Q$  1.889 ft<sup>3</sup>/min

$D_o$  2.112 in

$\Delta P_s$  1.02348 in H<sub>2</sub>O

Partials		Uncertainties		Absolute Systematic Uncertainty Contribution	% Contribution
$\partial Q / \partial (K)$	101.765	$\omega_K$	0.018	0.860	96.4%
$\partial Q / \partial (D_o)$	0.000	$\omega_{D_o}$	in K calculation		
$\partial Q / \partial (\Delta P_s)$	34.042	$\omega_{\Delta P_s}$	0.010 in H <sub>2</sub> O	0.031	3.5%
$\partial Q / \partial (\rho_{H_2O})$	-496.162	$\omega_{\rho_{H_2O}}$	0.000 lb/ft <sup>3</sup>	0.001	0.1%

Figure D-1 Continued.

Equation: $K = Q_{LFE} / (5.976 * D_o^{2.2} * (\Delta P_c)^{0.5} * (\rho_{a,c})^{-0.5})$					
Measured K	0.685	$Q_{LFE}$	97.82271 ft <sup>3</sup> /min	Absolute Systematic Uncertainty Contribution	% Contribution
$\omega_K$	0.018	$\Delta P_c$	1.99 in H <sub>2</sub> O		
Partials		Uncertainties			
$\partial K / \partial (Q_{LFE})$	0.007	$\omega_{Q_{LFE}}$	0.841 ft <sup>3</sup> /min	0.000	10.4%
$\partial K / \partial (D_o^{2.2})$	-0.648	$\omega_{D_o}$	0.001 in. H <sub>2</sub> O	0.000	0.1%
$\partial K / \partial (\Delta P_c)$	-0.172	$\omega_{\Delta P_c}$	0.100 in. H <sub>2</sub> O	0.000	89.1%
$\partial K / \partial (\rho_{a,c})$	4.942	$\omega_{\rho_{a,c}}$	0.000 lb/ft <sup>3</sup>	0.000	0.3%
Equation: $\rho_{a,c} = (P_{atm,c} - \phi_c * P_{a,c}) / (0.37 * (460 + T_c)) + \phi_c * P_{a,c} / (0.596 * (460 + T_c))$					
Measured $\rho_{a,c}$	0.069 lb/ft <sup>3</sup>	$P_{atm}$	14.5285 psia		
$\omega_{\rho_{a,c}}$	0.000 lb/ft <sup>3</sup>	$\phi_c$	0.386		
		$P_a$	1.006 psia		
		$T_c$	101 F		
Partials		Uncertainties			
$\partial \rho_{a,c} / \partial P_{atm,c}$	0.005	$\omega_{P_{atm,c}}$	0.02515 psia	0.000	38.2%
$\partial \rho_{a,c} / \partial \phi_c$	-0.002	$\omega_{\phi_c}$	0.05	0.000	22.0%
$\partial \rho_{a,c} / \partial P_{a,c}$	-0.001	$\omega_{P_{a,c}}$	0.0001 psia	0.000	0.0%
$\partial \rho_{a,c} / \partial T_c$	0.000	$\omega_{T_c}$	1 °F	0.000	39.7%
Equation: $\rho_{a,s} = (P_{atm,s} - \phi * P_a) / (0.37 * (460 + T)) + \phi * P_a / (0.596 * (460 + T))$					
Measured $\rho_{a,s}$	0.070 lb/ft <sup>3</sup>	$P_{atm,s}$	14.54473 psia		
$\omega_{\rho_{a,s}}$	0.000 lb/ft <sup>3</sup>	$\phi$	0.150582		
		$P_a$	0.89356 psia		
		$T$	97.8287 F		
Partials		Uncertainties			
$\partial \rho_{a,s} / \partial P_{atm}$	0.005	$\omega_{P_{atm}}$	0.00980 psia	0.000	11.7%
$\partial \rho_{a,s} / \partial \phi$	-0.002	$\omega_{\phi}$	0.0031	0.000	0.1%
$\partial \rho_{a,s} / \partial P_a$	0.000	$\omega_{P_a}$	0.0001 psia	0.000	0.0%
$\partial \rho_{a,s} / \partial T$	0.000	$\omega_T$	1.03392 °F	0.000	88.1%

Figure D-1 Continued.

## **APPENDIX E**

### **ASH ANALYSIS RESULTS FOR PARTICULATE MATTER LESS THAN 100 MICROMETERS CAPTURED IN THE SOURCE SAMPLER CYCLONE BUCKET**

Ash analysis of the PM<100  $\mu\text{m}$  captured in the source sampler cyclone bucket was conducted to give insight as to the primary constituents which make up the captured material. The *Standard Test Method for Ash in Biomass* (ASTM, 2001) was used to perform the analysis. Wanjura et al. (2006) indicated through the results of ash analyses that the primary constituent in the material air washed from seed cotton samples is soil. Thus, it was expected that the primary constituent in the PM <100  $\mu\text{m}$  air washed from the material captured in the cyclone bucket would also be primarily comprised of soil. However, the results of the analysis indicate that the average ash content of the samples was 25.35%. This result is likely a consequence of increased portions of volatile material such as plant material and lint fiber captured by the cyclone. The results of the ash analysis are presented in Table E-1.

Table E-1. Ash analysis results for the PM <100 $\mu\text{m}$  captured in the source sampler cyclone bucket.

<b>Test</b>	<b>Ash Content (%)</b>
1	28.2
2	26.4
3	27.2
4	25.5
5	24.6
6	23.7
7	21.5
8	21.9
9	25.8
10	28.7
<b>Mean Ash %</b>	<b>25.4</b>
<b>95% C.I.</b>	<b>1.5</b>



**References:**

- ASTM Standards. 2001. E1755-01: Standard test method for ash in biomass. West Conshohocken, PA.: ASTM International.
- Wanjura, J.D., C.B. Parnell, Jr., B.W. Shaw, and S.C. Capareda. 2006. Particle size distribution of PM emitted from cotton harvesting. ASABE Paper No. 064168. St. Joseph, Mich.: ASABE.

**APPENDIX F****TEST SUMMARY SHEETS FOR THE SOURCE SAMPLING TESTS  
CONDUCTED DURING 2007**

Table F-1. Summary sheet for source sampler replication 1 (test 6) at farm 3 during 2007.

Test	6					Cyclone Bucket		
Rep	1					Pre Wt.	754.57	g
Date	10/12/2007					Post Wt.	857.61	g
Plot	2					Net Wt.	103.04	g
Area	2.285	ha		5.647	ac			
Filters	Net Weight	% PM10	% PM2.5			Isokinetic Ratio Statistics		
JSS083	0.22840	89.22	0.27			Mean I	0.93692	
JSS084	0.21122	88.8018	0.262339			Std Dev	0.157149	
JSS085	0.57438	79.69332	0.171164			Max	1.44501	
JSS086	0.39247	88.6894	0.220845			Min	0.61433	
Total	1.40647	1.197175	0.0030			Mode	0.87085	
						Time >1.1	371	s
						Time <0.9	937	s
Air Wash Filter	Net Weight	% PM10	% PM2.5			Total Duration	2580	s
JSSAW01	8.50696	27.6311	0.0359				43	min
	TSP	PM10	PM2.5			Sampled Air Volume	84.85	m <sup>3</sup>
Total PM (g)	9.91343	3.547742	0.0061			Mean Sampler Flow Rate	69.68	ft <sup>3</sup> /min
TSP E. Conc.	116.84	mg/m <sup>3</sup>				Mean Orifice Meter ΔP	1.02	in H2O
PM10 E. Conc.	41.81	mg/m <sup>3</sup>				Duct Air Volume	3124.9	m <sup>3</sup>
PM2.5 E. Conc.	0.07	mg/m <sup>3</sup>				Mean Duct Flow Rate	2566.4	ft <sup>3</sup> /min
						Mean Duct Velocity Pressure	0.384	in H2O
TSP E. Rate	50.946	g/min	0.112	lb/min		Total Harvester Air Volume	18749.48	m <sup>3</sup>
PM10 E. Rate	18.232	g/min	0.040	lb/min		Temperature	97.8	F
PM2.5 E. Rate	0.031	g/min	0.00007	lb/min		RH	15.06	%
						Patm	14.5447	psia
						Air Density	0.0702	lb/ft <sup>3</sup>
TSP E. Factor	0.959	kg/ha	0.854	lb/ac		Average Yield	2.56	bales/ac
PM10 E. Factor	0.343	kg/ha	0.306	lb/ac		Seed Cotton Harvested		lbs
PM2.5 E. Factor	0.001	kg/ha	0.001	lb/ac		Lint Harvested		lbs
						Lint Harvested	14.46	bales
TSP E. Factor	151.534	g/bale	0.334	lb/bale				
PM10 E. Factor	54.230	g/bale	0.119	lb/bale				
PM2.5 E. Factor	0.093	g/bale	0.0002	lb/bale				
						Total TSP ER Systematic Uncertainty	2.77	%

Table F-2. Summary sheet for source sampler replication 2 (test 7) at farm 3 during 2007.

Test	7					Cyclone Bucket		
Rep	2					Pre Wt.	754.71	g
Date	10/12/2007					Post Wt.	850.59	g
Plot	3					Net Wt.	95.88	g
Area	2.064	ha	5.100	ac				
Filters	Net Weight (g)	% PM10	% PM2.5			Isokinetic Ratio Statistics		
JSS119	0.27327	91.1359	0.240331			Mean I	0.963579	
JSS120	0.34198	87.12484	0.206943			Std Dev	0.126655	
JSS121	0.30647	90.1381	0.208826			Max	1.8939	
JSS122	0.30331	88.8907	0.147423			Min	0.66698	
Total	1.22502	1.092851	0.0025			Mode	0.86453	
Air Wash Filter	Net Weight (g)	% PM10	% PM2.5			Time >1.1	307	s
JSSAW02	7.32133	27.789	0.0400			Time <0.9	688	s
						Total Duration	2543	s
							42.38333	min
	TSP	PM10	PM2.5			Sampled Air Volume	76.96	m <sup>3</sup>
Total PM (g)	8.54636	3.127376	0.0054			Mean Sampler Flow Rate	64.13	ft <sup>3</sup> /min
TSP E. Conc.	111.04	mg/m <sup>3</sup>				Mean Orifice Meter ΔP	0.88	in H2O
PM10 E. Conc.	40.63	mg/m <sup>3</sup>				Duct Air Volume	2754.1	m <sup>3</sup>
PM2.5 E. Conc.	0.07	mg/m <sup>3</sup>				Mean Duct Flow Rate	2294.8	ft <sup>3</sup> /min
						Mean Duct Velocity Pressure	0.313	in H2O
TSP E. Rate	43.293	g/min	0.095	lb/min		Total Harvester Air Volume	16524.32	m <sup>3</sup>
PM10 E. Rate	15.842	g/min	0.035	lb/min		Temperature	87.4	F
PM2.5 E. Rate	0.027	g/min	0.00006	lb/min		RH	26.23	%
						Patm	14.5434	psia
						Air Density	0.0715	lb/ft <sup>3</sup>
TSP E. Factor	0.889	kg/ha	0.792	lb/ac		Average Yield	2.41	bales/ac
PM10 E. Factor	0.325	kg/ha	0.290	lb/ac		Seed Cotton Harvested		lbs
PM2.5 E. Factor	0.001	kg/ha	0.000	lb/ac		Lint Harvested		lbs
TSP E. Factor	149.286	g/bale	0.329	lb/bale		Lint Harvested	12.29	bales
PM10 E. Factor	54.628	g/bale	0.120	lb/bale				
PM2.5 E. Factor	0.094	g/bale	0.0002	lb/bale		Total ER Systematic Uncertainty	2.81	%

Table F-3. Summary sheet for source sampler replication 3 (test 8) at farm 3 during 2007.

Test	8					Cyclone Bucket		
Rep	3					Pre Wt.	754.1	g
Date	10/13/2007					Post Wt.	804.6	g
Plot	5					Net Wt.	50.5	g
Area	1.251	ha	3.092	ac				
Filters	Net Weight (g)	% PM10	% PM2.5			Isokinetic Ratio Statistics		
JSS115	0.16510	90.59216	0.213783			Mean I	0.982389	
JSS116	0.16704	91.75049	0.242711			Std Dev	0.08747	
JSS117	0.29273	91.94145	0.233275			Max	1.26099	
JSS118	0.31108	92.94763	0.229939			Min	0.75254	
Total	0.93595	0.861112	0.0022			Mode	1.11926	
Air Wash Filter	Net Weight (g)	% PM10	% PM2.5			Time >1.1	140	s
JSSAW03	4.89988	24.7823	0.0441			Time <0.9	247	s
						Total Duration	1638	s
							27.3	min
	TSP	PM10	PM2.5			Sampled Air Volume	54.24	m <sup>3</sup>
Total PM (g)	5.83583	2.075415	0.0043			Mean Sampler Flow Rate	70.17	ft <sup>3</sup> /min
TSP E. Conc.	107.58	mg/m <sup>3</sup>				Mean Orifice Meter ΔP	1.05	in H2O
PM10 E. Conc.	38.26	mg/m <sup>3</sup>				Duct Air Volume	1887.6	m <sup>3</sup>
PM2.5 E. Conc.	0.08	mg/m <sup>3</sup>				Mean Duct Flow Rate	2441.7	ft <sup>3</sup> /min
TSP E. Rate	44.631	g/min	0.098	lb/min		Mean Duct Velocity Pressure	0.353	in H2O
PM10 E. Rate	15.872	g/min	0.035	lb/min		Total Harvester Air Volume	11325.4	m <sup>3</sup>
PM2.5 E. Rate	0.033	g/min	0.00007	lb/min		Temperature	90.6	F
						RH	20.91	%
						Patm	14.5655	psia
						Air Density	0.0712	lb/ft <sup>3</sup>
TSP E. Factor	0.974	kg/ha	0.868	lb/ac		Average Yield	2.396	bales/ac
PM10 E. Factor	0.346	kg/ha	0.309	lb/ac		Seed Cotton Harvested		lbs
PM2.5 E. Factor	0.001	kg/ha	0.001	lb/ac		Lint Harvested		lbs
TSP E. Factor	164.489	g/bale	0.362	lb/bale		Lint Harvested	7.41	bales
PM10 E. Factor	58.498	g/bale	0.129	lb/bale				
PM2.5 E. Factor	0.122	g/bale	0.0003	lb/bale				
						Total ER Systematic Uncertainty	2.77	%

Table F-4. Summary sheet for source sampler replication 4 (test 9) at farm 3 during 2007.

Test	9					Cyclone Bucket		
Rep	4					Pre Wt.	754.3	g
Date	10/13/2007					Post Wt.	823.5	g
Plot	6					Net Wt.	69.2	g
Area	1.523	ha		3.763	ac			
Filters	Net Weight (g)	% PM10	% PM2.5			Isokinetic Ratio Statistics		
JSS111	0.34544	89.63893	0.190438			Mean I	0.96648	
JSS112	0.33618	91.44995	0.219367			Std Dev	0.08659	
JSS113	0.37104	92.89806	0.25149			Max	1.81924	
JSS114	0.38655	91.5967	0.241081			Min	0.35617	
Total	1.43921	1.315841	0.0033			Mode	0.98339	
Air Wash Filter	Net Weight (g)	% PM10	% PM2.5			Time >1.1	49	s
JSSAW04	8.26629	25.5926	0.0394			Time <0.9	312	s
						Total Duration	1830	s
							30.5	min
	TSP	PM10	PM2.5			Sampled Air Volume	61.45	m <sup>3</sup>
Total PM (g)	9.70550	3.4314	0.0065			Mean Sampler Flow Rate	71.15	ft <sup>3</sup> /min
TSP E. Conc.	157.94	mg/m <sup>3</sup>				Mean Orifice Meter ΔP	1.08	in H2O
PM10 E. Conc.	55.84	mg/m <sup>3</sup>				Duct Air Volume	2169.1	m <sup>3</sup>
PM2.5 E. Conc.	0.11	mg/m <sup>3</sup>				Mean Duct Flow Rate	2511.5	ft <sup>3</sup> /min
TSP E. Rate	67.395	g/min	0.148	lb/min		Mean Duct Velocity Pressure	0.371	in H2O
PM10 E. Rate	23.828	g/min	0.052	lb/min		Total Harvester Air Volume	13014.52	m <sup>3</sup>
PM2.5 E. Rate	0.045	g/min	0.00010	lb/min		Temperature	93.8	F
						RH	14.11	%
						Patm	14.5383	psia
						Air Density	0.0708	lb/ft <sup>3</sup>
TSP E. Factor	1.350	kg/ha	1.203	lb/ac		Average Yield	2.781	bales/ac
PM10 E. Factor	0.477	kg/ha	0.425	lb/ac		Seed Cotton Harvested		lbs
PM2.5 E. Factor	0.001	kg/ha	0.001	lb/ac		Lint Harvested		lbs
TSP E. Factor	196.427	g/bale	0.433	lb/bale		Lint Harvested	10.46	bales
PM10 E. Factor	69.447	g/bale	0.153	lb/bale				
PM2.5 E. Factor	0.132	g/bale	0.0003	lb/bale		Total ER Systematic Uncertainty	2.77	%

Table F-5. Summary sheet for source sampler replication 5 (test 10) at farm 3 during 2007.

Test	10					Cyclone Bucket		
Rep	5					Pre Wt.	754	g
Date	10/13/2007					Post Wt.	832.6	g
Plot	7					Net Wt.	78.6	g
Area	1.411	ha	3.487	ac				
Filters	Net Weight (g)	% PM10	% PM2.5			Isokinetic Ratio Statistics		
JSS107	0.54115	85.83164	0.17469			Mean I	0.982663	
JSS108	0.51261	86.9347	0.166096			Std Dev	0.095908	
JSS109	0.53870	86.69446	0.178881			Max	2.02348	
JSS110	0.54439	80.39973	0.125821			Min	0.36022	
Total	2.13684	1.814819	0.0034			Mode	1.04009	
Air Wash Filter	Net Weight (g)	% PM10	% PM2.5			Time >1.1	121	s
JSSAW05	11.30808	25.5105	0.0379			Time <0.9	267	s
						Total Duration	1896	s
							31.6	min
	TSP	PM10	PM2.5			Sampled Air Volume	62.81	m <sup>3</sup>
Total PM (g)	13.44492	4.699567	0.0077			Mean Sampler Flow Rate	70.19	ft <sup>3</sup> /min
TSP E. Conc.	214.07	mg/m <sup>3</sup>				Mean Orifice Meter ΔP	1.05	in H2O
PM10 E. Conc.	74.83	mg/m <sup>3</sup>				Duct Air Volume	2166.2	m <sup>3</sup>
PM2.5 E. Conc.	0.12	mg/m <sup>3</sup>				Mean Duct Flow Rate	2420.8	ft <sup>3</sup> /min
TSP E. Rate	88.045	g/min	0.194	lb/min		Mean Duct Velocity Pressure	0.344	in H2O
PM10 E. Rate	30.775	g/min	0.068	lb/min		Total Harvester Air Volume	12996.98	m <sup>3</sup>
PM2.5 E. Rate	0.051	g/min	0.00011	lb/min		Temperature	93.3	F
						RH	15.61	%
						Patm	14.5178	psia
						Air Density	0.0707	lb/ft <sup>3</sup>
TSP E. Factor	1.972	kg/ha	1.757	lb/ac		Average Yield	3.66	bales/ac
PM10 E. Factor	0.689	kg/ha	0.614	lb/ac		Seed Cotton Harvested		lbs
PM2.5 E. Factor	0.001	kg/ha	0.001	lb/ac		Lint Harvested		lbs
TSP E. Factor	217.999	g/bale	0.480	lb/bale		Lint Harvested	12.76	bales
PM10 E. Factor	76.200	g/bale	0.168	lb/bale				
PM2.5 E. Factor	0.125	g/bale	0.0003	lb/bale		Total ER Systematic Uncertainty	2.78	%

Table F-6. Summary sheet for source sampler replication 6 (test 11) at farm 3 during 2007.

Test	11					Cyclone Bucket		
Rep	6					Pre Wt.	754.1	g
Date	10/13/2007					Post Wt.	813.7	g
Plot	10					Net Wt.	59.6	g
Area	1.232	ha	3.045	ac				
Filters	Net Weight (g)	% PM10	% PM2.5			Isokinetic Ratio Statistics		
JSS103	0.47415	89.28906	0.235751			Mean I	0.904214	
JSS104	0.51428	85.94582	0.217005			Std Dev	0.116078	
JSS105	0.20530	85.83048	0.174416			Max	1.24404	
JSS106	0.20768	85.53245	0.20493			Min	0.57405	
Total	1.40141	1.219213	0.0030			Mode	0.98755	
Air Wash Filter	Net Weight (g)	% PM10	% PM2.5			Time >1.1	37	s
JSSAW06	8.75216	26.5354	0.0349			Time <0.9	700	s
						Total Duration	1640	s
							27.33333	min
	TSP	PM10	PM2.5			Sampled Air Volume	51.32	m <sup>3</sup>
Total PM (g)	10.15357	3.541633	0.0061			Mean Sampler Flow Rate	66.30	ft <sup>3</sup> /min
TSP E. Conc.	197.86	mg/m <sup>3</sup>				Mean Orifice Meter ΔP	0.94	in H2O
PM10 E. Conc.	69.02	mg/m <sup>3</sup>				Duct Air Volume	1970.3	m <sup>3</sup>
PM2.5 E. Conc.	0.12	mg/m <sup>3</sup>				Mean Duct Flow Rate	2545.7	ft <sup>3</sup> /min
TSP E. Rate	85.577	g/min	0.188	lb/min		Mean Duct Velocity Pressure	0.383	in H2O
PM10 E. Rate	29.850	g/min	0.066	lb/min		Total Harvester Air Volume	11821.8	m <sup>3</sup>
PM2.5 E. Rate	0.051	g/min	0.00011	lb/min		Temperature	89.7	F
						RH	20.03	%
						Patm	14.5098	psia
						Air Density	0.0711	lb/ft <sup>3</sup>
TSP E. Factor	1.898	kg/ha	1.692	lb/ac		Average Yield	3.75	bales/ac
PM10 E. Factor	0.662	kg/ha	0.590	lb/ac		Seed Cotton Harvested		lbs
PM2.5 E. Factor	0.001	kg/ha	0.001	lb/ac		Lint Harvested		lbs
TSP E. Factor	204.875	g/bale	0.451	lb/bale		Lint Harvested	11.42	bales
PM10 E. Factor	71.462	g/bale	0.157	lb/bale				
PM2.5 E. Factor	0.123	g/bale	0.0003	lb/bale				
						Total ER Systematic Uncertainty	2.78	%



Table F-7. Summary sheet for source sampler replication 7 (test 12) at farm 3 during 2007.

Test	12					Cyclone Bucket		
Rep	7					Pre Wt.	753.9	g
Date	10/13/2007					Post Wt.	807.1	g
Plot	11					Net Wt.	53.2	g
Area	1.150	ha	2.842	ac				
Filters	Net Weight (g)	% PM10	% PM2.5			Isokinetic Ratio Statistics		
JSS087	0.37784	87.56545	0.207788			Mean I	1.020063	
JSS088	0.37685	88.45	0.236907			Std Dev	0.09336	
JSS089	0.23713	89.39	0.236535			Max	1.27254	
JSS090	0.21466	87.29679	0.210639			Min	0.77562	
Total	1.20648	1.06354	0.0027			Mode	1.00682	
Air Wash Filter	Net Weight (g)	% PM10	% PM2.5			Time >1.1	270	s
JSSAW07	9.76915	22.3655	0.0268			Time <0.9	151	s
						Total Duration	1465	s
							24.41667	min
	TSP	PM10	PM2.5			Sampled Air Volume	50.30	m <sup>3</sup>
Total PM (g)	10.97562	3.248458	0.0053			Mean Sampler Flow Rate	72.75	ft <sup>3</sup> /min
TSP E. Conc.	218.21	mg/m <sup>3</sup>				Mean Orifice Meter ΔP	1.14	in H2O
PM10 E. Conc.	64.59	mg/m <sup>3</sup>				Duct Air Volume	1706.4	m <sup>3</sup>
PM2.5 E. Conc.	0.11	mg/m <sup>3</sup>				Mean Duct Flow Rate	2468.0	ft <sup>3</sup> /min
TSP E. Rate	91.500	g/min	0.202	lb/min		Mean Duct Velocity Pressure	0.365	in H2O
PM10 E. Rate	27.081	g/min	0.060	lb/min		Total Harvester Air Volume	10238.2	m <sup>3</sup>
PM2.5 E. Rate	0.044	g/min	0.00010	lb/min		Temperature	83.0	F
						RH	28.53	%
						Patm	14.5263	psia
						Air Density	0.0720	lb/ft <sup>3</sup>
TSP E. Factor	1.942	kg/ha	1.731	lb/ac		Average Yield	3.384	bales/ac
PM10 E. Factor	0.575	kg/ha	0.512	lb/ac		Seed Cotton Harvested		lbs
PM2.5 E. Factor	0.001	kg/ha	0.001	lb/ac		Lint Harvested		lbs
TSP E. Factor	232.286	g/bale	0.512	lb/bale		Lint Harvested	9.62	bales
PM10 E. Factor	68.750	g/bale	0.151	lb/bale				
PM2.5 E. Factor	0.112	g/bale	0.0002	lb/bale				
						Total ER Systematic Uncertainty	2.76	%

Table F-8. Summary sheet for source sampler replication 8 (test 13) at farm 3 during 2007.

Test	13					Cyclone Bucket		
Rep	8					Pre Wt.	754.3	g
Date	10/14/2007					Post Wt.	790.5	g
Plot	12					Net Wt.	36.2	g
Area	1.073	ha	2.652	ac				
Filters	Net Weight (g)	% PM10	% PM2.5			Isokinetic Ratio Statistics		
JSS091	0.31577	77.04225	0.128076			Mean I	0.923153	
JSS092	0.41133	78.11227	0.118964			Std Dev	0.095159	
JSS093	0.18200	89.32967	0.250577			Max	1.26909	
JSS094	0.20352	92.18332	0.254697			Min	0.69133	
Total	1.11262	0.91477	0.0019			Mode	1.14645	
Air Wash Filter	Net Weight (g)	% PM10	% PM2.5			Time >1.1	65	s
JSSAW08	5.35671	21.7653	0.0331			Time <0.9	472	s
						Total Duration	1308	s
							21.8	min
	TSP	PM10	PM2.5			Sampled Air Volume	41.51	m <sup>3</sup>
Total PM (g)	6.46933	2.080673	0.0036			Mean Sampler Flow Rate	67.24	ft <sup>3</sup> /min
TSP E. Conc.	155.86	mg/m <sup>3</sup>				Mean Orifice Meter ΔP	0.96	in H2O
PM10 E. Conc.	50.13	mg/m <sup>3</sup>				Duct Air Volume	1557.7	m <sup>3</sup>
PM2.5 E. Conc.	0.09	mg/m <sup>3</sup>				Mean Duct Flow Rate	2523.3	ft <sup>3</sup> /min
TSP E. Rate	66.818	g/min	0.147	lb/min		Mean Duct Velocity Pressure	0.375	in H2O
PM10 E. Rate	21.490	g/min	0.047	lb/min		Total Harvester Air Volume	9345.97	m <sup>3</sup>
PM2.5 E. Rate	0.038	g/min	0.00008	lb/min		Temperature	89.8	F
						RH	31.72	%
						Patm	14.5054	psia
						Air Density	0.0709	lb/ft <sup>3</sup>
TSP E. Factor	1.357	kg/ha	1.210	lb/ac		Average Yield	3.319	bales/ac
PM10 E. Factor	0.436	kg/ha	0.389	lb/ac		Seed Cotton Harvested		lbs
PM2.5 E. Factor	0.001	kg/ha	0.001	lb/ac		Lint Harvested		lbs
TSP E. Factor	165.471	g/bale	0.364	lb/bale		Lint Harvested	8.80	bales
PM10 E. Factor	53.219	g/bale	0.117	lb/bale				
PM2.5 E. Factor	0.093	g/bale	0.0002	lb/bale				
						Total ER Systematic Uncertainty	2.78	%

Table F-9. Summary sheet for source sampler replication 9 (test 14) at farm 3 during 2007.

Test	14					Cyclone Bucket		
Rep	9					Pre Wt.	754.4	g
Date	10/14/2007					Post Wt.	793.4	g
Plot	13					Net Wt.	39	g
Area	1.013	ha	2.502	ac				
Filters	Net Weight (g)	% PM10	% PM2.5			Isokinetic Ratio Statistics		
JSS095	0.17838	83.80626	0.237139			Mean I	0.966917	
JSS096	0.16188	88.91568	0.284062			Std Dev	0.066255	
JSS097	0.21026	88.12787	0.308868			Max	1.1361	
JSS098	0.21795	84.35546	0.215507			Min	0.77863	
Total	0.76846	0.662572	0.0020			Mode	0.97821	
Air Wash Filter	Net Weight (g)	% PM10	% PM2.5			Time >1.1	11	s
JSSAW09	6.43266	29.7669	0.0427			Time <0.9	204	s
						Total Duration	1231	s
							20.51667	min
	TSP	PM10	PM2.5			Sampled Air Volume	41.40	m <sup>3</sup>
Total PM (g)	7.20112	2.577375	0.0048			Mean Sampler Flow Rate	71.26	ft <sup>3</sup> /min
TSP E. Conc.	173.94	mg/m <sup>3</sup>				Mean Orifice Meter ΔP	1.08	in H2O
PM10 E. Conc.	62.26	mg/m <sup>3</sup>				Duct Air Volume	1475.2	m <sup>3</sup>
PM2.5 E. Conc.	0.11	mg/m <sup>3</sup>				Mean Duct Flow Rate	2539.2	ft <sup>3</sup> /min
TSP E. Rate	75.039	g/min	0.165	lb/min		Mean Duct Velocity Pressure	0.380	in H2O
PM10 E. Rate	26.857	g/min	0.059	lb/min		Total Harvester Air Volume	8851.085	m <sup>3</sup>
PM2.5 E. Rate	0.050	g/min	0.00011	lb/min		Temperature	89.5	F
						RH	33.47	%
						Patm	14.4944	psia
						Air Density	0.0709	lb/ft <sup>3</sup>
TSP E. Factor	1.521	kg/ha	1.355	lb/ac		Average Yield	2.713	bales/ac
PM10 E. Factor	0.544	kg/ha	0.485	lb/ac		Seed Cotton Harvested		lbs
PM2.5 E. Factor	0.001	kg/ha	0.001	lb/ac		Lint Harvested		lbs
TSP E. Factor	226.812	g/bale	0.500	lb/bale		Lint Harvested	6.79	bales
PM10 E. Factor	81.179	g/bale	0.179	lb/bale				
PM2.5 E. Factor	0.150	g/bale	0.0003	lb/bale				
						Total ER Systematic Uncertainty	2.76	%

Table F-10. Summary sheet for source sampler replication 10 (test 15) at farm 3 during 2007.

Test	15					Cyclone Bucket		
Rep	10					Pre Wt.	754.5	g
Date	10/14/2007					Post Wt.	788.8	g
Plot	14					Net Wt.	34.3	g
Area	1.013	ha	2.502	ac				
Filters	Net Weight (g)	% PM10	% PM2.5			Isokinetic Ratio Statistics		
JSS099	0.12973	89.35908	0.241746			Mean I	0.880302	
JSS100	0.13718	89.78184	0.237493			Std Dev	0.124809	
JSS101	0.16551	82.9302	0.223702			Max	1.17999	
JSS102	0.15757	84.40168	0.221397			Min	0.60894	
Total	0.58999	0.509341	0.0014			Mode	1.07194	
Air Wash Filter	Net Weight (g)	% PM10	% PM2.5			Time >1.1	37	s
JSSAW10	4.15692	21.4348	0.0468			Time <0.9	651	s
						Total Duration	1179	s
							19.65	min
	TSP	PM10	PM2.5			Sampled Air Volume	35.37	m <sup>3</sup>
Total PM (g)	4.74691	1.400368	0.0033			Mean Sampler Flow Rate	63.57	ft <sup>3</sup> /min
TSP E. Conc.	134.21	mg/m <sup>3</sup>				Mean Orifice Meter ΔP	0.86	in H2O
PM10 E. Conc.	39.59	mg/m <sup>3</sup>				Duct Air Volume	1407.3	m <sup>3</sup>
PM2.5 E. Conc.	0.09	mg/m <sup>3</sup>				Mean Duct Flow Rate	2529.2	ft <sup>3</sup> /min
TSP E. Rate	57.669	g/min	0.127	lb/min		Mean Duct Velocity Pressure	0.379	in H2O
PM10 E. Rate	17.013	g/min	0.037	lb/min		Total Harvester Air Volume	8443.729	m <sup>3</sup>
PM2.5 E. Rate	0.040	g/min	0.00009	lb/min		Temperature	86.2	F
						RH	37.70	%
						Patm	14.4936	psia
						Air Density	0.0713	lb/ft <sup>3</sup>
TSP E. Factor	1.119	kg/ha	0.997	lb/ac		Average Yield	3.055	bales/ac
PM10 E. Factor	0.330	kg/ha	0.294	lb/ac		Seed Cotton Harvested		lbs
PM2.5 E. Factor	0.001	kg/ha	0.001	lb/ac		Lint Harvested		lbs
TSP E. Factor	148.231	g/bale	0.327	lb/bale		Lint Harvested	7.64	bales
PM10 E. Factor	43.729	g/bale	0.096	lb/bale				
PM2.5 E. Factor	0.103	g/bale	0.0002	lb/bale				
						Total ER Systematic Uncertainty	2.79	%

## **APPENDIX G**

### **PARTICLE SIZE DISTRIBUTION RESULT STATISTICS FOR THE TSP SAMPLER FILTERS AND PM CAPTURED BY THE SOURCE SAMPLER**

Table G-1. Summary statistics for the particle size distribution analyses on the low volume TSP sampler filters from 2006 and 2007. All particle diameters are reported in terms of aerodynamic equivalent diameter.

			Lognormal Distribution		Coulter Counter Measured PSD					
Year	Farm	Filter	% PM10	% PM2.5	MMD	GSD	% PM10	% PM2.5	D15.9 (µm)	D84.1 (µm)
2006	1	3564	33.9	1.9	14.1	2.30	33.8	0.2	6.03	31.94
2006	1	3566	41.1	1.6	11.8	2.07	39.4	0.1	5.96	25.46
2006	1	3582	22.6	0.1	16.0	1.87	23.5	0.1	8.10	28.19
2006	1	3604	38.1	1.1	12.3	2.00	37.7	0.1	6.03	24.05
2006	1	3614	41.5	2.7	11.9	2.25	40.6	0.2	5.51	27.87
2006	1	3617	37.0	1.0	12.6	2.01	36.0	0.1	6.46	26.04
2006	1	3623	24.5	0.7	17.3	2.21	26.3	0.2	6.68	32.67
2006	1	3624	50.3	4.0	9.9	2.20	49.6	0.4	4.54	21.97
2006	1	3637	34.7	0.7	13.0	1.96	33.8	0.1	6.76	26.04
2006	1	3663	35.8	1.7	13.3	2.21	36.9	0.1	5.90	28.84
2006	2	3722	59.5	3.6	8.5	1.97	58.6	0.2	4.50	17.56
2006	2	3723	64.2	4.2	7.9	1.94	63.3	0.3	4.35	16.40
2006	2	3724	53.4	6.0	9.3	2.33	52.7	0.3	4.45	24.12
2006	2	3758	40.1	2.8	12.4	2.31	40.5	0.2	5.34	28.59
2006	2	3725	60.2	7.2	8.1	2.24	58.8	0.3	4.21	21.05
2006	2	3726	43.7	4.6	11.5	2.48	43.8	0.3	4.66	28.59
2006	2	3747	34.2	1.1	13.5	2.10	33.5	0.1	6.26	27.63
2006	2	3761	43.6	3.1	11.4	2.26	43.4	0.2	5.04	25.82
2006	2	3762	44.7	3.5	11.2	2.29	44.8	0.2	4.93	25.82
2006	3	3772	24.6	0.4	16.3	2.03	25.9	0.1	7.52	31.03
2006	3	3774	39.6	2.0	12.2	2.16	39.5	0.1	5.79	27.08
2006	3	3782	28.2	0.7	15.4	2.10	28.5	0.1	7.11	31.38
2006	3	3793	34.5	1.6	13.7	2.21	34.6	0.1	6.20	30.33
2006	3	3794	29.9	1.3	15.4	2.26	30.6	0.1	6.56	33.59
2006	3	3817	26.0	0.5	15.9	2.05	26.3	0.1	7.27	30.68
2006	3	3769	37.6	1.2	12.5	2.04	38.1	0.1	6.00	25.02
2006	3	3771	19.0	0.2	18.0	1.95	21.3	0.1	8.33	31.74
2006	3	3773	18.3	0.1	17.4	1.84	19.2	0.1	8.92	30.33
2006	3	3781	39.0	1.4	12.2	2.07	38.8	0.2	5.93	25.30

Table G-1 Continued.

Year	Farm	Filter	Lognormal Distribution		Coulter Counter Measured PSD					
			% PM10	% PM2.5	MMD	GSD	% PM10	% PM2.5	D15.9 (µm)	D84.1 (µm)
2007	3	4486	26.6	1.0	16.6	2.26	30.3	0.0	6.51	33.15
2007	3	4550	31.6	2.2	15.4	2.46	33.3	0.1	5.88	35.48
2007	3	4491	21.3	0.8	19.7	2.35	25.1	0.1	7.21	39.72
2007	3	4508	24.9	0.6	16.6	2.12	23.7	0.1	7.89	35.48
2007	3	4511	26.0	1.0	17.0	2.28	27.2	0.1	7.21	37.54
2007	3	4534	29.8	1.0	15.0	2.16	31.1	0.1	6.66	30.98
2007	3	4542	41.7	2.0	11.7	2.12	40.8	0.1	5.62	25.27
2007	3	4543	33.7	2.1	14.4	2.36	34.5	0.1	6.15	34.29
2007	3	4548	48.9	4.3	10.2	2.27	47.9	0.2	4.91	25.27
2007	3	4377	33.0	1.9	14.5	2.33	33.1	0.1	6.29	34.29
2007	3	4477	26.2	1.4	17.6	2.43	29.0	0.0	6.89	40.63
2007	3	4379	45.0	3.3	11.1	2.24	44.2	0.2	5.43	27.35
2007	3	4403	52.0	2.4	9.7	1.98	50.9	0.1	5.02	19.71
2007	3	4406	31.8	1.5	14.7	2.26	33.6	0.0	6.44	32.78
2007	3	4408	48.8	3.4	10.2	2.17	48.0	0.1	5.19	24.43
2007	3	4410	36.6	1.5	13.0	2.13	37.9	0.1	5.75	26.14
2007	3	4423	31.5	1.3	14.7	2.22	33.6	0.1	6.51	32.04
2007	3	4439	16.0	0.2	21.1	2.12	21.7	0.1	7.89	35.48
2007	3	4458	22.1	1.0	19.7	2.42	22.6	0.1	7.80	45.49
2007	3	4455	38.1	2.8	13.0	2.36	38.3	0.2	5.13	28.62
2007	3	4462	25.0	1.0	17.6	2.31	28.3	0.1	6.89	36.70
2007	3	4464	30.5	1.2	15.0	2.22	32.8	0.1	6.29	30.98
2007	3	4473	23.5	1.0	18.6	2.36	27.4	0.1	6.81	37.96
2007	3	4465	43.6	1.7	11.2	2.03	43.2	0.0	5.81	23.88
2007	3	4466	48.2	3.3	10.3	2.17	47.9	0.1	5.25	24.71
2007	3	4549	36.9	0.9	12.5	1.97	36.7	0.1	6.15	23.88

Table G-2. Summary statistics for the particle size distribution analyses on the source sampler filters from 2007. All particle diameters are reported in terms of aerodynamic equivalent diameter.

Filter	Lognormal Distribution				Coulter Counter Measured PSD				Net Mass (g)
	% PM10	% PM2.5	MMD	GSD	% PM10	% PM2.5	D15.9 (μm)	D84.1 (μm)	
83	90.3	2.2	5.8	1.52	89.22	0.27	3.83	8.83	0.22840
84	89.8	2.0	5.9	1.52	88.80	0.26	3.87	8.93	0.21122
85	81.2	2.9	6.4	1.64	79.69	0.17	4.14	11.20	0.57438
86	90.1	1.9	5.9	1.51	88.69	0.22	3.91	8.93	0.39247
87	89.7	2.5	5.8	1.54	87.57	0.21	3.87	9.14	0.37784
88	91.0	3.0	5.6	1.54	88.45	0.24	3.78	8.93	0.37685
89	91.9	2.5	5.6	1.51	89.39	0.24	3.83	8.73	0.23713
90	90.0	2.3	5.8	1.53	87.30	0.21	3.91	9.14	0.21466
91	79.2	2.1	6.7	1.63	77.04	0.13	4.33	11.45	0.31577
92	80.7	1.8	6.7	1.60	78.11	0.12	4.33	11.07	0.41133
93	91.9	2.5	5.6	1.51	89.33	0.25	3.78	8.63	0.18200
94	94.4	2.2	5.4	1.47	92.18	0.25	3.74	8.07	0.20352
95	88.0	4.4	5.7	1.62	83.81	0.24	3.78	9.89	0.17838
96	92.6	3.8	5.4	1.54	88.92	0.28	3.66	8.63	0.16188
97	90.4	3.3	5.6	1.55	88.13	0.31	3.70	8.93	0.21026
98	86.9	3.1	5.9	1.59	84.36	0.22	3.87	9.78	0.21795
99	91.6	2.6	5.6	1.52	89.36	0.24	3.78	8.73	0.12973
100	92.6	2.5	5.6	1.50	89.78	0.24	3.78	8.54	0.13718
101	86.3	3.9	5.9	1.63	82.93	0.22	3.87	10.23	0.16551
102	87.9	3.4	5.8	1.59	84.40	0.22	3.87	9.78	0.15757
103	91.6	2.6	5.6	1.52	89.29	0.24	3.78	8.73	0.47415
104	89.5	2.9	5.7	1.55	85.95	0.22	3.87	9.35	0.51428
105	88.2	2.1	6.0	1.54	85.83	0.17	4.00	9.45	0.20530
106	87.6	2.3	6.0	1.55	85.53	0.20	3.96	9.56	0.20768
107	88.0	1.8	6.1	1.53	85.83	0.17	4.05	9.45	0.54115
108	89.2	1.3	6.1	1.49	86.93	0.17	4.14	9.24	0.51261
109	88.6	1.6	6.1	1.51	86.69	0.18	4.09	9.35	0.53870



Table G-2 Continued.

Filter	Lognormal Distribution				Coulter Counter Measured PSD				Net Mass (g)
	% PM10	% PM2.5	MMD	GSD	% PM10	% PM2.5	D15.9 (μm)	D84.1 (μm)	
110	82.5	1.5	6.6	1.56	80.40	0.13	4.38	10.70	0.54439
111	91.5	1.6	5.8	1.49	89.64	0.19	3.96	8.73	0.34544
112	93.0	1.9	5.6	1.48	91.45	0.22	3.83	8.35	0.33618
113	94.6	2.0	5.4	1.46	92.90	0.25	3.74	7.98	0.37104
114	93.4	2.0	5.6	1.48	91.60	0.24	3.78	8.25	0.38655
115	92.3	1.9	5.7	1.49	90.59	0.21	3.87	8.54	0.16510
116	93.4	2.0	5.6	1.48	91.75	0.24	3.83	8.35	0.16704
117	93.7	1.9	5.6	1.47	91.94	0.23	3.83	8.25	0.29273
118	94.2	1.6	5.6	1.45	92.95	0.23	3.83	8.07	0.31108
119	92.3	1.9	5.7	1.49	91.14	0.24	3.83	8.44	0.27327
120	89.3	1.9	5.9	1.52	87.12	0.21	3.96	9.14	0.34198
121	91.3	1.4	5.9	1.48	90.14	0.21	3.96	8.63	0.30647
122	90.0	0.9	6.2	1.46	88.89	0.15	4.19	8.93	0.30331

Table G-3. Summary statistics for the particle size distribution analyses on the PM <100 µm captured in the source sampler cyclone bucket. All particle diameters are reported in terms of aerodynamic equivalent diameter.

Filter	Lognormal Distribution				Coulter Counter Measured PSD				Net Mass (g)
	% PM10	% PM2.5	MMD	GSD	% PM10	% PM2.5	D15.9 (µm)	D84.1 (µm)	
SSAW01	26.82	0.45	15.4	2.00	27.63	0.04	7.54	30.28	8.50696
SSAW02	26.59	0.55	15.7	2.06	27.79	0.04	7.37	31.33	7.32133
SSAW03	24.03	0.68	17.4	2.19	24.78	0.04	7.71	37.12	4.89988
SSAW04	24.60	0.52	16.6	2.10	25.59	0.04	7.63	33.53	8.26629
SSAW05	24.03	0.33	16.3	1.99	25.51	0.04	7.80	30.98	11.30808
SSAW06	25.42	0.31	15.5	1.95	26.54	0.03	7.54	28.62	8.75216
SSAW07	21.08	0.24	17.4	1.99	22.37	0.03	8.16	32.41	9.76915
SSAW08	19.36	0.16	17.8	1.95	21.77	0.03	8.35	31.68	5.35671
SSAW09	29.31	0.61	14.7	2.03	29.77	0.04	7.05	28.94	6.43266
SSAW10	19.62	0.32	18.8	2.10	21.43	0.05	8.25	36.29	4.15692

## VITA

John David Wanjura  
 201 Scoates Hall  
 MS 2117 - TAMU  
 c/o Department of Biological and Agricultural Engineering  
 Texas A&M University  
 College Station, TX 77843-2117

### ***EDUCATION***

Doctor of Philosophy in Biological and Agricultural Engineering;  
*Texas A&M University (May 2008)*  
 Master of Science in Biological and Agricultural Engineering;  
*Texas A&M University (May 2005)*  
 Bachelor of Science in Agricultural Engineering;  
*Texas A&M University (May 2005)*  
 Bachelor of Science in Agricultural Systems Management;  
*Texas A&M University (May 2002)*

### ***HONORS***

Alpha Epsilon Honor Fraternity  
 Eagle Scout  
 Phi Eta Sigma  
 Gamma Sigma Delta Honor Society

### ***PREVIOUSLY PUBLISHED MATERIAL***

- Wanjura, J.D., C.B. Parnell, Jr., B.W. Shaw, and R.E. Lacey. 2005. Design and evaluation of a low volume total suspended particulate sampler. *Trans. ASAE* 48(4): 1547-1552.
- Wanjura, J.D., M.D. Buser, C.B. Parnell, B.W. Shaw, and R.E. Lacey. 2005. A simulated approach to estimating PM<sub>10</sub> and PM<sub>2.5</sub> concentrations downwind from cotton gins. *Trans. ASAE* 48(5): 1919-1925.
- Wanjura, J.D., C.B. Parnell, B.W. Shaw, S.C. Capareda. 2006. Particle size distribution of PM emitted from cotton harvesting. ASABE Paper No. 064168. St. Joseph, MI.: ASABE.
- Wanjura, J.D., B.W. Shaw, C.B. Parnell, Jr., R.E. Lacey, and S.C. Capareda. 2007. Comparison of continuous monitor (TEOM) vs. gravimetric sampler particulate matter concentrations. Submitted for publication in *Trans. ASAE*, 2007.