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SOURCE ASSESSMENT: MECHANICAL HARVESTING OF COTTON
State of the Art

Industrial Environmental Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, North Carolina 27711

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SOURCE ASSESSMENT:
MECHANICAL HARVESTING OF COTTON
State of the Art

by

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PREFACE

The Industrial Environmental Research Laboratory (IERL) of EPA has the responsibility for insuring that pollution control technology is available for stationary sources to meet the requirements of the Clean Air Act, the Federal Water Pollution Control Act and solid waste legislation. If control technology is unavailable, inadequate, uneconomical or socially unacceptable, then financial support is provided for the development of the needed control techniques for industrial and extractive process industries. The Chemical Processes Branch of the Industrial Processes Division of IERL has the responsibility for investing tax dollars in programs to develop control technology for a large number (>500) of operations in the chemical industries.

Monsanto Research Corporation (MRC) has contracted with EPA to investigate the environmental impact of various industries which represent sources of pollution in accordance with EPA's responsibility as outlined above. Dr. Robert C. Binning serves as MRC Program Manager in this overall program entitled, "Source Assessment," which includes the investigation of sources in each of four categories: combustion, organic materials, inorganic materials, and open sources. Dr. Dale A. Denny of the Industrial Processes Division at Research Triangle Park serves as EPA Project Officer. Reports prepared in the Source Assessment Program are of two types: Source Assessment Documents, and State of the Art Reports.

Source Assessment Documents contain data on emissions from specific industries. Such data are gathered from the literature, government agencies and cooperating companies. Sampling and analysis are also performed by the contractor when the available information does not adequately characterize the source emissions. These documents contain all of the information necessary for IERL to decide whether a need exists to develop additional control technology for specific industries.

State of the Art Reports include data on emissions from specific industries which are also gathered from the literature, government agencies and cooperating companies. However, no extensive sampling is conducted by the contractor for such industries. Sources in this category are considered by EPA to be of insufficient priority to warrant complete assessment for control technology decision making. Therefore, results from such studies are published as State of the Art Reports for potential utility by the government, industry, and others having specific needs and interests.

This study was undertaken to provide information on air emissions from the mechanical harvesting of cotton. In this project, Mr. D. K. Oestreich served as EPA Project Leader.

CONTENTS

CONTENTS (Continued)

FIGURES

TABLES

TABLES (Continued)

SYMBOLS

Symbol	Definition
A_B	Harvested area required to fill one harvester basket with seed cotton
A_T	Harvested area required to fill one cotton trailer with seed cotton
$\dot{A}$	Harvest rate, area harvested per unit time
$(CL)_{2,B}$	Confidence limit for two-row strippers with baskets
$(CL)_{2,T}$	Confidence limit for two-row strippers pulling trailers
$(CL)_4$	Confidence limit for four-row strippers
$(CL)_{95\%}$	95% confidence limit
$(CL)_S$	Confidence limit for stripping
C_T	Cotton trailer capacity, weight of lint cotton
D	Representative distance from source to receptor, or representative field transport distance
$D_L(x)$	Dose of pollutant from basket dumping at distance x from trailer
$D_T(x)$	Total dosage in plume at distance x from source
E_H	Harvester emission factor
E_L	Trailer loading emission factor
E_T	Field transport emission factor
E_{TD}	Field transport emission factor based on distance
E_{TOT}	Total emission factor
$f_{2,B}$	Fraction of strippers that are two-row models with baskets
$f_{2,T}$	Fraction of strippers that are two-row models pulling trailers
f_4	Fraction of strippers that are four-row models
f_p	Fraction of time that receptor is exposed to harvester plume in one harvester pass
f_T	Fraction of time that receptor is exposed to transport plume in one transport pass
F	Hazard factor
F_{SiO_2}	Free silica hazard factor
ID	Inert dust
L	Length of representative field

Symbol	Definition
LD_{50}	Chemical dose lethal to 50% of a population of test animals
M	Diffusion model designated as 1, 2, or 3 for point, line, or dose model, respectively
mph	Miles per hour
n	Number of samples
n_1	Number of harvesting and basket dumping cycles completed in 1 day
n_B	Number of harvester baskets required to fill one cotton trailer
n_p	Number of harvester passes required to fill one harvester basket
n_T	Number of cotton trailers filled in 1 day
N	Number in total population
ppm	Parts per million
Q	Mass emission rate, mass per unit time
$\overline{Q}$	Average emission rate
Q_i	Emission rate from the i^{th} sample
Q_H	Harvester emission rate
Q_L	Emission mass from dumping one harvester basket
Q_{TR}	Field transport emission rate
r	Number of rows
RCD	Raw cotton dust
S	Source severity of pollutant
S'	Atmospheric stability class designated as A, B, C, D, E, or F
SiO_2	Silicon dioxide; free silica
S_H	Severity for harvester
S_L	Severity for trailer loading
S_{RCD}	Raw cotton dust severity
S_{Total}	Total source severity
S_{TR}	Severity for field transport
TLV	Threshold limit value
TSP	Total suspended particulate

SYMBOLS (Continued)

Symbol	Definition
$t_{95\%}$	± Values of "Student t" distribution between which 95% of the area lies
t_1	Time required to fill and dump one harvester basket
t_e	Time of receptor exposure to pollutant puff
t_B	Time consumed in dumping one harvester basket
t_F	Time base of hazard factor
t_L	Time required to harvest one length of representative field
t_0	Daily operating time
$(t_0)_B$	Total basket dumping time in 1 day
$(t_0)_H$	Total harvester operating time in 1 day
$(t_0)_T$	Total time devoted to field transport in 1 day
t_p	Time for one harvester pass
t_s	Sampling time
t_t	Time for harvester to turn after each pass
$\bar{u}$	Mean wind speed
v_H	Mean harvester speed
v_T	Mean cotton trailer field transport speed
w_p	Width of plume
w_r	Row spacing
w_s	Swath width
x	Distance downwind from source in the direction of the mean wind
y	Crosswind distance
Y	Lint cotton yield, mass per unit harvested area
Δ	Difference between converted concentration and background concentration
$\hat{\sigma}$	Estimated population standard deviation
σ_y	Standard deviation in the crosswind direction of the plume concentration distribution
σ_z	Standard deviation in the vertical direction of the plume concentration distribution
χ	Pollutant concentration, mass per unit volume

SYMBOLS (Continued)

Symbol	Definition
$\chi(x)$	Pollutant concentration in plume at distance x from source
$\chi(x,y)$	Pollutant concentration located at point (x,y) in plume
$\chi_A(x)$	Crosswind integrated plume concentration at distance x from source
$(\chi_B)_{max}$	Average maximum receptor concentration during basket dumping
$\chi_e(D)$	Concentration during exposure to pollutant puff at distance D from source
$\chi_e(x)$	Average concentration at receptor during exposure to pollutant puff
$(\chi_e)_{max}$	Maximum receptor concentration during exposure to instantaneous puff
$\chi_p(D)$	Concentration in plume at distance D from source
$\chi_p(x)$	Average ground level concentration in plume at distance x from source
$(\chi_p)_{max}$	Maximum ground level concentration in the plume at at edge of representative field
$\bar{\chi}_{max}$	Time-averaged maximum pollutant concentration at edge of representative source
$(\bar{\chi}_{max})_B$	Time-averaged maximum receptor concentration from basket dumping
$(\bar{\chi}_{max})_H$	Time-averaged maximum receptor concentration from harvester emissions
$(\bar{\chi}_{max})_0$	Maximum average receptor concentration during source operation
$(\bar{\chi}_{max})_{TR}$	Time-averaged maximum receptor concentration from field transport

SECTION I

INTRODUCTION

Cotton harvesting includes the removal and collection of seed cotton (fibers with seeds) from mature plants and the transport of this cotton from the fields. Machines now account for more than 99% (by weight) of all cotton harvested, and machine and field transport activities cause air pollution in the form of respirable dust.

The objective of this work was to assess the environmental impact of mechanical cotton harvesting activities and to produce a State of the Art Report summarizing available data on air emissions from this source. This document was prepared by acquiring and analyzing information on: (1) the cotton harvesting process and equipment; (2) source locations and distribution; (3) mass emissions, state and nationwide; (4) effects on air quality; (5) air pollution control technology; and (6) projected growth and anticipated technological developments of the industry.

Emission information was developed from a limited sampling program involving cotton harvesting operations at three farms characteristic of the industry. Resulting emission rates and factors were used to estimate air quality impact and state and nationwide emissions.

SECTION II

SUMMARY

The 1971-73 average annual production of lint cotton[a] was 2.70 x 10^6 metric tons[b] (2.97 x 10^6 tons) harvested from 49,200 km^2 (12.1 x 10^6 acres) in 19 states, predominantly south of the 36th parallel. The four leading states were: Texas, which harvested 31% of the national production from 41% of the cotton area harvested; Mississippi, which harvested 15% of the cotton from 12% of the area harvested; California, which harvested 12% from 7% of the area; and Arkansas, which produced 10% from 10% of the area.

More than 99% of both national production and cotton area were harvested mechanically. The two principal harvest methods were machine picking, with 70% of the harvest from 61% of the area, and machine stripping, with 29% of the harvest from 39% of the area. Picking is practiced throughout the cotton regions of the U.S., while stripping is practiced chiefly in the dry plains of Texas and Oklahoma. Mechanical gleaning, a cleanup operation after picking, was not

[a] Lint cotton is cotton that has been cleaned and had the seeds removed; it is the product of cotton gins. Production figures are usually presented by weight of lint cotton rather than seed cotton, which is raw cotton before ginning.

[b] 1 metric ton = 10^6 grams = 2,205 pounds = 1.1 short tons (short tons are designated "tons" in this document); other conversion factors and metric system prefixes are presented in Section X.

considered in this study, since it accounts for less than 1% of the national production and is similar to stripping.

Three unit operations are involved in mechanical harvesting of cotton: harvesting, trailer loading (basket dumping), and transport of trailers in the field. Respirable particulate (<7 μm in diameter) emission factors for these operations in representative picking and stripping are presented in Table 1. All of the emissions from harvesting and trailer loading in this table are raw cotton dust, which is associated with byssinosis. Raw cotton dust is predominantly plant fragments but it also contains some free silica due to soil dust. Emissions from field transport are all soil dust. Free silica accounts for 7.9% by weight of the total emissions from picking operations; the figure for stripping operations is 2.3%. Maximum pesticides content in emissions from cotton harvesting operations, mainly consisting of organochlorines such as Endrin, is estimated as 220 ppm, maximum defoliant content is 17 ppm of DEF (tributylphosphorotrithioate) for picking, and maximum desiccant content is 2,200 ppm of arsenic for stripping.

Table 1. RESPIRABLE PARTICULATE EMISSION FACTORS FOR REPRESENTATIVE COTTON HARVESTING OPERATIONS
kg emitted/km^2 harvested (lb emitted/1,000 acres harvested)

Type of harvester	Unit operation			
	Harvesting[a]	Trailer loading[b]	Transport[a]	Total
Mechanical picker	0.455 ± 0.738 (4.06 ± 6.58)	0.0699 (0.624)	0.427 ± 0.119 (3.81 ± 1.06)	0.952 (8.49)
Mechanical stripper	2.30 ± 0.82 (20.5) ± 7.32)	0.0918 (0.819)	0.279 ± 0.078 (2.49 ± 0.70)	2.67 (23.8)

[a]Confidence limits at the 95% confidence level.

[b]Insufficient data to assign confidence limits.

Cotton harvesting operations accounted for 0.002% of the national respirable particulate emissions in 1972. The highest state contributions were 0.046% in Texas and 0.025% in Oklahoma. Both are predominantly stripping states, with 95% of total cotton harvesting emissions caused by stripping.

The air quality impact of cotton harvesting emissions was determined by the maximum severity from representative picking and stripping sources. Source severity is defined as the ratio of the time-averaged maximum ground-level pollutant concentration to the pollutant hazard factor. The hazard factor for total suspended particulate is the 24-hour primary national ambient air quality standard; for other cotton harvesting pollutants it is the threshold limit value (TLV®) divided by a safety factor of 100.

The representative cotton farm is defined as harvesting 0.786 km^2 (194 acres) from one square field, with the downwind side subject to public exposure. Solid planting (no rows skipped) with a row spacing of 1.02 m (40 in.) is the representative row pattern, and cotton is harvested with one mechanical harvester 8 hr/day during the harvest season, which lasts an average of 10 weeks in any specific area. The operating parameters for picking and stripping are different, so the two harvest methods were treated separately.

The representative yield from mechanical picking is 63.0 metric tons of lint cotton per km^2 harvested (562 lb/acre) with chemical defoliation practiced. The representative picker harvests two cotton rows simultaneously at 1.34 m/s (3.0 mph) and has a harvester-mounted basket for collecting the picked cotton.

Representative stripper yield is 41.2 metric tons of lint cotton per km^2 harvested (368 lb/acre) with chemical desiccation practiced. The representative stripper harvests two rows of cotton simultaneously at 2.23 m/s (5.0 mph) and has a harvester-mounted cotton collection basket. Six stripper or picker baskets are required to fill a cotton trailer with 654 kg (1,440 lb or 3 bales[a]) of lint cotton. For both picking and stripping, filled cotton trailers are transported from the field at a speed of 4.47 m/s (10.0 mph).

The highest source severity is for raw cotton dust, at 0.00703 for picking operations and 0.0350 for stripping operations. Severities for other pollutants are less than 0.001.

No emission control technology is applied to cotton harvesting operations, and no voluntary future application is expected.

Average annual cotton production in the U.S. is not expected to increase more than a few percent by 1978. Average annual harvested area is expected to remain constant. Future cotton production will be influenced by the price of petroleum, used to make synthetic fibers. The trend is to fewer but larger cotton farms, resulting in increased use of multiple harvesters with higher harvest rates.

[a]1 bale = 480 lb (net weight) of lint cotton.

SECTION III

SOURCE DESCRIPTION

A. SOURCE DEFINITION

Cotton, the principal fiber crop of the U.S., is best known for the thread and cloth made from its fibers. By-products from cotton, however, are a large portion of its crop value. The seeds are pressed for their oil which is used in vegetable oils, margarine, lubricants, soaps, and paints. The remaining cottonseed cake is ground for high protein cattle feed or fertilizer. Cottonseed hulls are used for low grade cattle roughage, paper, fiberboard and fertilizer.[1] Cotton linters, the short fibers left on the seeds after ginning, are used for cellulose in making rayon.[2]

More than 99% of all cotton grown in the U.S. is of the American upland varieties.[3] Most of the remainder is American-Pima (formerly called American-Egyptian) cotton.[1]

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[1]Kipps, M. S. Production of Field Crops, 6th Edition. New York, McGraw-Hill Book Company, 1970. p. 447-483.

[2]Linton, G. E. Natural and Manmade Textile Fibers. New York, Duell, Sloan and Pearce, 1966. p. 208-219.

[3]Agricultural Statistics, 1973. Washington, U.S. Department of Agriculture, Yearbook Statistical Committee (U.S. Government Printing Office Stock Number 0100-02841). 1973. p. 58-75.

Upland cotton has a staple (fiber) length of 19 mm to 38 mm, and typical lint (ginned) cotton yield is about 53 metric tons of lint cotton/km^2 harvested although irrigated areas of Arizona and California may yield more than twice that amount.[3,4] American-Pima cotton is grown in irrigated areas of the Southwest, has very strong fibers from 38 mm to 44 mm long,[1] and yields about 52 metric tons of lint cotton/km^2 harvested.[3]

Use of machines to harvest cotton has increased rapidly in the last two decades, stimulated by increasingly scarce and expensive agricultural labor. An average worker can hand pick roughly 70 kg to 90 kg of seed cotton a day if the yield is good.[1] Since about 75% of seed cotton weight is the seed, it requires 2,300 to 3,100 man-days to hand pick 1 km^2 of cotton with an average lint yield of 53 metric tons/km^2. By contrast, a single harvesting machine can harvest the same area in 4 to 20 days. Production of mechanical harvesters was limited before 1950; by 1953, 22% of all cotton in the U.S. was machine harvested; in 1963, the figure rose to 72%.[5] Hand labor is now used mainly at the start of the harvest season or on farms with a few thousand square meters or less of cotton.[6]

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[4]Crop Production, 1974 Annual Summary. U.S. Department of Agriculture, Statistical Reporting Service, Crop Reporting Board. Washington. Publication No. CrPr 2-1(75). January 16, 1975. 64 p.

[5]Colwick, R. F., et al. Mechanized Harvesting of Cotton. U.S. Department of Agriculture, Agricultural Research Service. Beltsville. Southern Cooperative Series, Bulletin No. 100. March 1965. 70 p.

[6]Voelkel, K. E. Texas Cotton Review, 1973-74. The University of Texas at Austin, Natural Fibers Economic Research. Austin. Research Report No. 104. July 1974. 143 p.

In 1969, 137,000 U.S. farms harvested 2.18 x 10^6 metric tons of lint cotton from 44,800 km^2. Although cotton-type farms (farms with cotton sales of at least $10,000 or 50% of the total value of all farm products sold) accounted for 29% of all farms growing cotton, they harvested 52% (by weight) of all cotton on 48% of all land devoted to cotton.[7] Mechanical harvesters accounted for 99% of all cotton harvested from cotton-type farms in 1971: mechanical pickers harvested 79%; mechanical strippers, 19%; and mechanical gleaners or ground harvesters, 1%.[8]

Emissions in the form of respirable dust are generated by mechanical cotton harvesting. As discussed in this document, cotton harvesting refers to the removal of cotton from plants, the collection of this cotton, and its transport from the fields. Differences in the characteristics of machine picking, machine stripping, and machine gleaning make it necessary to consider each method as a source subtype in assessing emissions from mechanical harvesting of cotton.

B. PROCESS DESCRIPTION

1. Mechanical Cotton Pickers

Mechanical cotton pickers, as their name implies, selectively pick locks of seed cotton from open cotton bolls, and leave

[7]Census of Agriculture, 1969. Volume II, General Report. Chapter 8, Type of Farm. Washington, U.S. Bureau of the Census, 1973. 287 p.

[8]Census of Agriculture, 1969. Volume V, Special Reports. Part 3, Cotton. Washington, U.S. Bureau of the Census, 1973. 184 p.

the empty burs and unopened bolls on the plant. Typical modern pickers are self-propelled and require only one operator to harvest two rows of cotton simultaneously at a speed of 1.1 m/s to 1.6 m/s. A mechanical cotton picker is shown in Figure 1.

The key section of a picker is presented in Figure 2.[9] Gear-driven rotating spindles are mounted in vertical rows on cam-oriented picking bars which make the spindles enter and leave the plants at right angles to the rows. The spindles are tapered and barbed, straight and toothed, or fluted so that the seed cotton locks wrap around them as they pass through the plants. The doffers pull the cotton off the spindles by evenly spaced discs with uneven surfaces mounted on rotating vertical cylinders. Blower-forced air moves the cotton from the doffers into the pneumatic conveyor ducts which carry it into the picker-mounted basket. The doffed spindles are cleaned of sticky residues by passing over water-moistened pads before entering the cotton row again.[9]

When the picker basket is filled with seed cotton, the machine is driven to a cotton trailer at the edge of the field. A cotton trailer is simply a flatbed wagon with the sides and ends enclosed by slats or wire screen. The basket is raised and tilted hydraulically, the top swings open, and the cotton falls into the trailer. To make maximum use of the trailer volume, the cotton is spread out and sometimes compacted by tramping. When the trailer is full it is pulled from the field, usually by pickup truck, and taken to a cotton gin.

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[9]Kelly, C. F. Mechanical Harvesting. Scientific American. 217(2):50-59, August 1967.

Figure 1. Mechanical cotton picker

Courtesy of International Harvester Company.

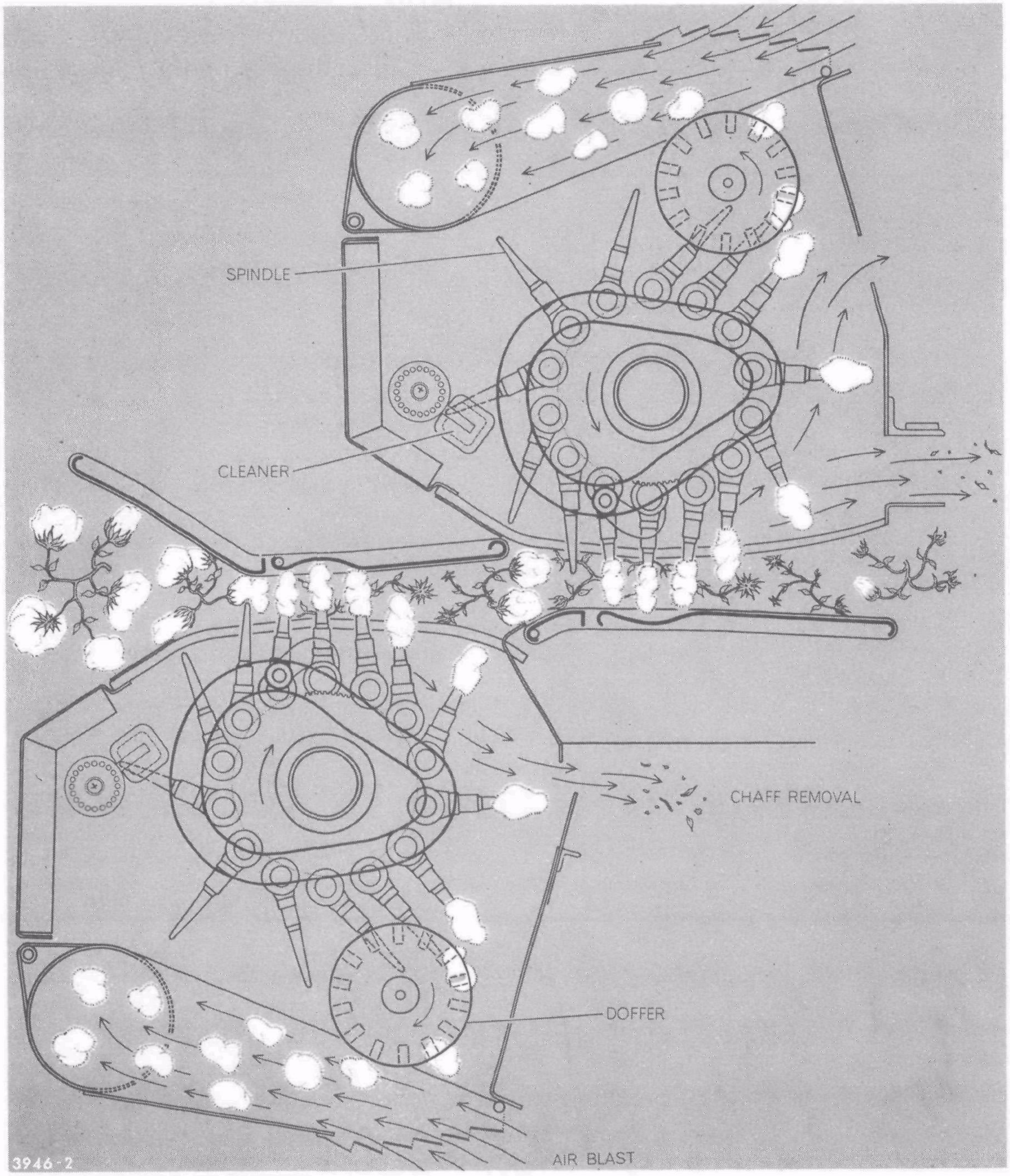

Figure 2. Key section of mechanical cotton picker

To maximize harvesting efficiency and minimize cotton trash, leaf stain, and moisture content, picker-type cotton is usually defoliated before machine harvesting. Chemical defoliants are applied by airplane or ground rig when 60% or more of the bolls are open.[5,10] The defoliants cause an abscission layer to develop on the leaf stem where it is attached to the branch, and the leaves subsequently become detached and fall.[11] With the proper defoliant application and favorable weather conditions, the cotton is ready for machine picking about 2 weeks later. This time span allows the leaves to fall and defoliant residues to be reduced to allowable limits set by the Department of Agriculture,[10] and normally precludes leaf regrowth problems. A second application is sometimes used if heavy rain follows the first application, if the cotton is especially tall or has lush foliage, or if excessive leaf regrowth occurs.

In a good season cotton is often machine picked a second time, about 2 weeks after the first, which can add 50% to the yield.[12] In this case the defoliant dose must be low enough to prevent killing the plants or damaging the green and unopened bolls. The process of defoliant application and emissions thereof are discussed in another document.[13]

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[10]Elliott, F. C. Cotton Defoliation Guide for Texas. Texas A&M University, Texas Agricultural Extension Service. College Station. Bulletin No. L-145. 1969.

[11]Addicott, F. T., and R. S. Lynch. Defoliation and Desiccation: Harvest-Aid Practices. In: Advances in Agronomy, Volume IX. New York, Academic Press Inc., 1957. p. 69-93.

[12]Personal communication. Dr. R. B. Metzer, Texas Agricultural Extension Service, Texas A&M University, College Station. October 24, 1975.

[13]Peters, J. A., and T. R. Blackwood. Source Assessment: Defoliation of Cotton, State of the Art. Monsanto Research Corporation, EPA Contract 68-02-1874. Dayton. Preliminary document submitted to the EPA, February 1976. 124 p.

2. Mechanical Cotton Strippers

Mechanical cotton strippers remove opened and unopened bolls along with the burs, leaves, and stems from cotton plants and leave only bare branches. Stripping is necessarily a once over operation although strippers can be used as the final harvest operation after machine picking. The principal advantage of mechanical stripping is economy since the typical cost to own and operate mechanical strippers is half that for cotton pickers.[5] Strippers also harvest faster with lower field losses. They are tractor-mounted, tractor-pulled, or self-propelled; require one operator; strip plants with pairs of rotating rolls, rolls with stationary picking bars, or stationary fingers and slits; and harvest from one to four rows of cotton at speeds of 1.8 m/s to 2.7 m/s. Some common types of strippers are shown in Figures 3, 4, and 5.

When stripping rolls are used, their axes are parallel to the rows and tilted at approximately 0.52 rad (30°) to the horizontal with the front end lower. The rolls are smooth or machine-roughened, or equipped with fingers or longitudinal strips, and are made of steel, rubber, or bristle-brush material. The gap between pairs of rolls allows cotton plants, but not bolls, to pass through. Bolls are torn from the plants by the rollers. The arrangement for a single stripper roll is similar, except that the gap is between the roll and a stationary stripping bar.[5] When stationary fingers are used they are mounted in the direction of the rows on stripping heads. The assembly looks much like a comb. As the machine moves forward, the cotton plants follow the slits between fingers which are spaced so that they strip the plant branches.

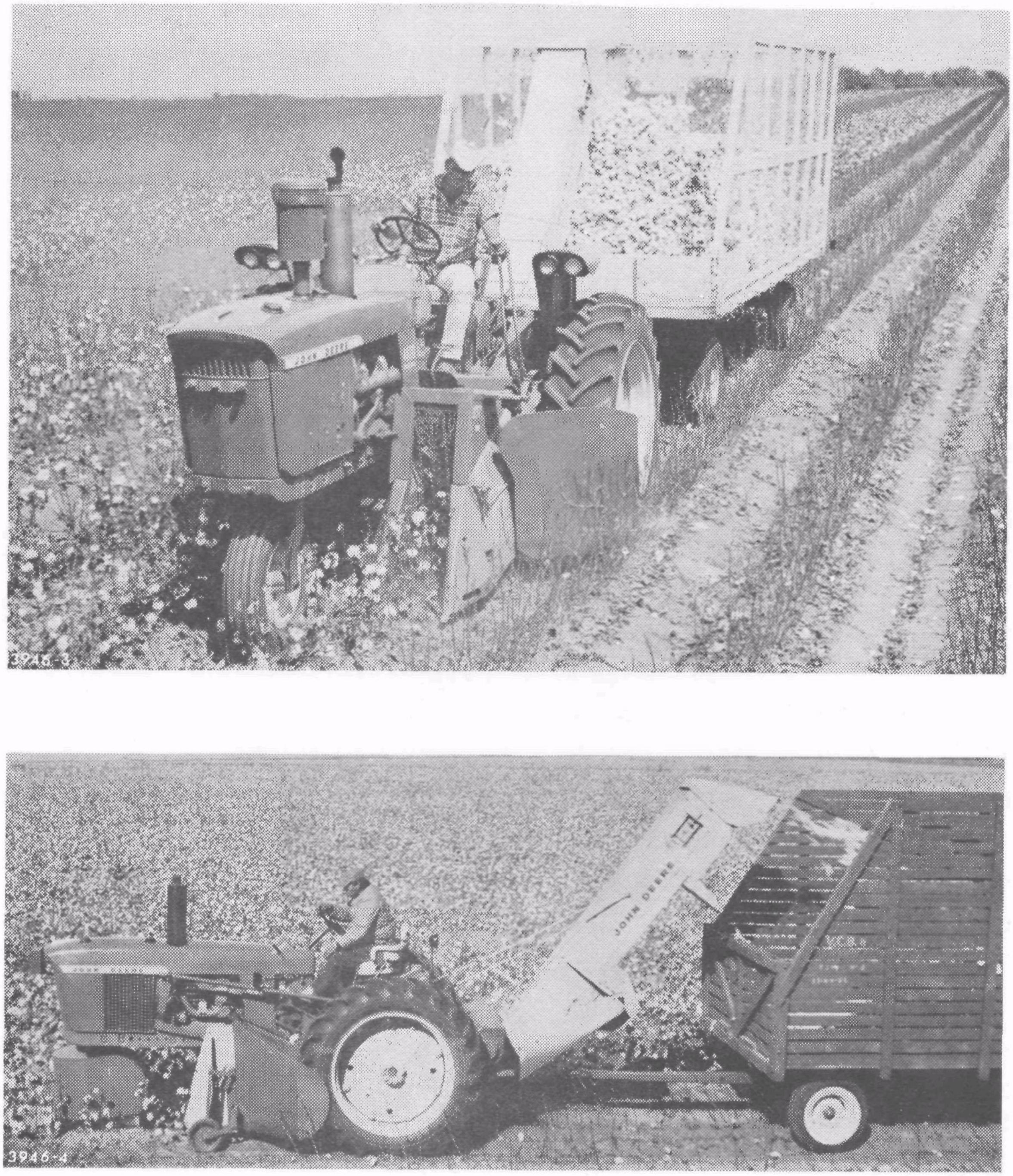


Figure 3. Two-row brush-type (rollers with brushes) cotton strippers[5]

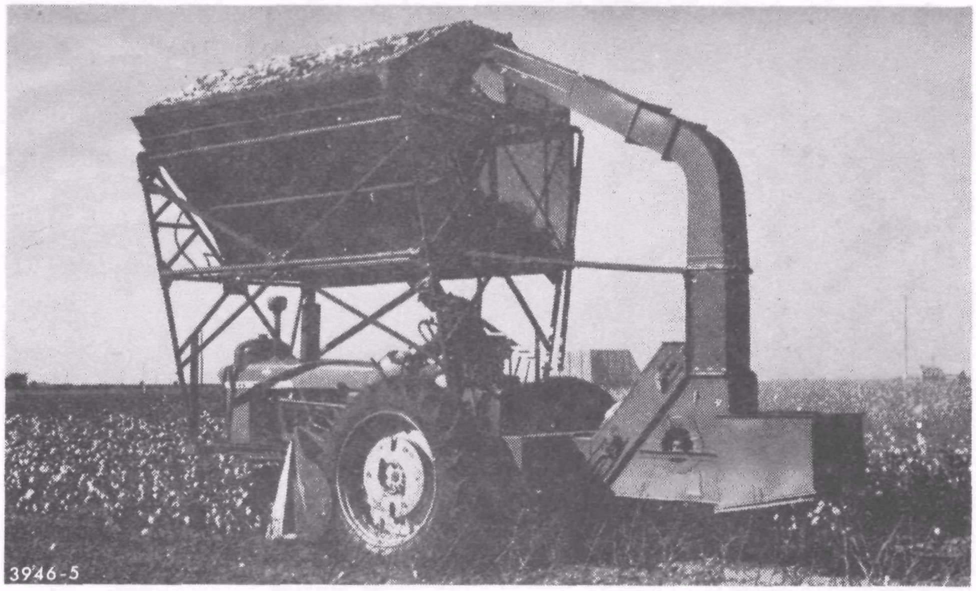
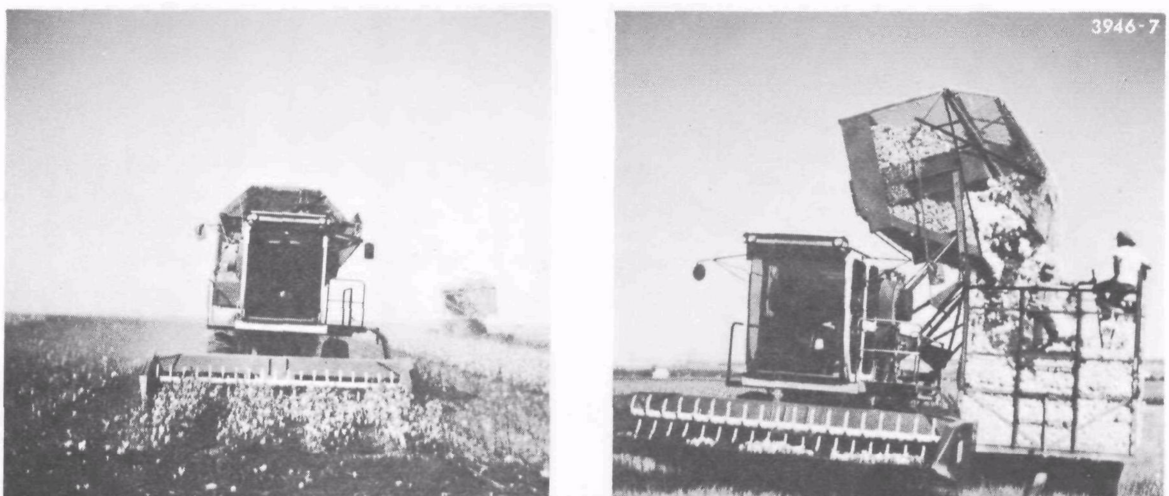


Figure 4. Two-row cotton stripper with green boll separator elevator and tractor-mounted basket[5]



(a) (b)

Figure 5. Four-row self-propelled cotton stripper with stationary fingers and slits on stripping head: (a) harvesting; (b) loading cotton trailer

After the cotton is stripped, it enters a conveying system which carries it from the stripping unit to an elevator. Most conveyors utilize either augers or series of rotating spiked-tooth cylinders and also accomplish some cleaning by moving the cotton over perforated, slotted, or wire mesh screens. Dry plant material (burs, stems, and leaves) is crushed and falls through the openings to the ground. Blown air is sometimes used to assist cleaning.[5] Many strippers are also equipped to remove the burs from the seed cotton.

The elevator is a belt or chain with cross-flights, a duct carrying blower-forced air, or both. Most pneumatic elevators are also designed as green boll separators. Air carries the fluffy seed cotton up the elevator and through a spout into a pulled cotton trailer or harvester-mounted basket. The heavier unopened green bolls fall or roll by gravity into a collection bin. They are dumped on piles at the edges of the field, since many will later open and can be salvaged.[5]

Since mechanical strippers are designed to leave only bare plant branches, efforts are made to minimize trash and moisture content and maximize cotton grade and harvesting efficiency by reducing plant foliage. The easiest and cheapest method is to delay harvesting until after the first frost or freeze in the fall; frost causes leaves to defoliate, and a freeze desiccates (kills and dries) them. However, this method can be practiced only in areas where the freeze occurs soon after cotton maturity, since wind, rain, long standing time, or a combination of these will result in excessive crop loss and grade reduction. Another method is chemical defoliation, as discussed for picker-type cotton.

The most widely practiced method of harvest-aid treatment prior to stripper harvesting is chemical desiccation.

Chemicals which stop plant growth and kill and dry the foliage are applied when 75% to 90% of the bolls are open. Desiccant application and associated emissions are discussed in another document.[13] Some leaves drop but most stay on the plants and dry out, an effect similar to that of natural freezing.[5,10,11] The cotton is often dry enough to harvest in about a week, but 2 weeks are often needed for desiccant residues to drop to allowable levels.[10,13] Some of the dry, brittle leaves are shaken from the plants during stripping and some leaves and burs are removed from the cotton by the strippers. Much trash remains with the seed cotton, but gins in stripping areas are equipped to adequately remove dry leaves, burs, and stems.

3. Mechanical Cotton Gleaners

Gleaners are used to salvage cotton left in the fields after conventional harvesting, usually machine picking. They are used primarily in arid cotton-growing areas where dry ground and air prevent serious lint damage by rotting. Some gleaners are independent machines, but there are also gleaning attachments for pickers. The most common gleaner designs use notched belts to collect the cotton and include equipment for partial cleaning. Gleaners harvest about 13,000 m^2/hr at ground speeds of 1.3 m/s to 2.2 m/s. Approximately 0.15 km^2 will yield 1 ~~kg~~ metric ton of lint cotton at gleaning efficiencies near 50%.[5]

Mechanical cotton gleaners were not specifically studied for this report, due to their minor role in cotton production. Less than 1% of the U.S. cotton crop is harvested with gleaning machines.[8] Since their principles of operation are similar, gleaners and strippers are assumed to have the same emission factors in calculating total emissions from cotton harvesting.

C. FACTORS AFFECTING EMISSIONS

1. Harvesting Machines

The major factors affecting emissions from mechanical cotton harvesters are: (1) type of harvester (picker or stripper) and design; (2) type (variety) of cotton; (3) preharvest treatment and condition of crop; (4) harvest rate; and (5) extent of machine cleaning (trash removal). Each of these interrelated characteristics varies widely; however, by categorizing the process by harvester type, the ranges of variables are reduced.

A quantitative study of the factors affecting emissions was not attempted. No data have been published and a massive sampling project would be required to establish the quantitative functional dependence of emissions on the affecting variables. The following qualitative discussion offers some insight into how the factors influence composition and rate of emissions.

Emissions from strippers and gleaners are higher than those from pickers because more cotton trash is handled. Machine-picked cotton averages about 0.2 kg of trash (hulls, sticks, stems, leaves, and dirt) excluding seed weight, per kg of lint cotton. By contrast, machine-stripped cotton averages 1.1 kg/kg, and machine-scrapped (gleaned) cotton averages 1.8 kg/kg.[14] Some trash is crushed into fine particles and emitted by harvester conveying and cleaning systems.

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[14]Control and Disposal of Cotton-Ginning Wastes. U.S. Public Health Service, National Air Pollution Control Administration. Raleigh. Publication No. 999-AP-31. 1967. 103 p.

Stripper cotton varieties generally produce smaller, hardier plants than picker cotton. Stripper plants, usually less than 0.9 m high, were developed for varying degrees of storm resistance, depending on the areas for which they were intended, so that cotton is not lost before harvest. Picker cotton varieties are generally more than 0.9 m high; they have lusher foliage and wide-opening bolls to facilitate picking, and give higher yields than stripper cotton. Varieties and harvesting methods are usually matched. However, strippers are sometimes used to harvest common picker varieties, especially for final harvest, resulting in higher emissions, particularly if the preharvest treatment is desiccation rather than defoliation.

The condition of the crop depends on several factors, including cultural practices, fertilization, precipitation and/ or irrigation, weather during growing season, pest damage and control, preharvest treatment, and harvest timing. All affect the yield and trash content, and hence the quantity of emissions, of machine-harvested cotton. Pest control and preharvest treatment also affect the composition of emissions. Thousands of pesticides are registered with EPA for use on cotton to control hundreds of different insects, worms, fungi, weeds, and other pests.[15] Pesticide application ranges from none to once every 3 or 4 days with amounts per application varying by as much as an order of magnitude. Residues on the plants during harvest depend on the chemical, time and rate of application, and weather (particularly precipitation) prior to harvest. Chemical defoliants, desiccants, and regrowth inhibitors used in varying amounts also leave residues on the cotton.

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[15] Personal communication. Elgin G. Fry, Office of Pesticides Programs, U.S. Environmental Protection Agency, Washington. October 29, 1975.

In general, increased harvest rate increases emission rate due to the rate of material handling. For instance, a two-row stripper harvesting at the same speed as a one-row stripper of the same design causes a higher emission rate. Design differences can override harvest rates in affecting emissions. Harvester speeds are usually too slow for entrainment of soil dust unless the soil is especially dry or windspeed is high.

Seed cotton trash removal is the prime cause of dust emissions from cotton harvesters. The purpose of harvester cleaning systems is to leave trash in the fields so cleaner cotton can be taken to the gin, resulting in higher income to the farmer through lower ginning fees and higher cotton grade. Fine particles in the trash become airborne when exhausted from the harvesters, the major source being pneumatic elevators. One of the reasons for using blower-forced air to carry cotton to wire-screened or slatted cages or trailers is to gain trash separation.[16] Fine trash remains airborne while the seed cotton is caught by the screen. Higher wind speed enhances dust entrainment, especially when the harvester is traveling into the wind.

2. Trailer Loading

When harvester-mounted baskets are used, the cotton is dumped into transport vehicles, usually trailers (wagons), for hauling to gins. The basket is hydraulically raised and tilted, allowing the cotton to fall by gravity into the trailer. Air movement from wind and the falling cotton causes a puff of dust composed of soil and trash. Wind speed, amount and type of trash in the cotton, height of fall, and type of trailer affect the amount of dust generated.

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[16]Elliott, F. C. Keep Cotton...Dry-Loose-Clean. Texas A&M University, Texas Agricultural Extension Service. College Station. Publication No. MP-297. 8 p.

3. Field Transport

Emissions from field transport of cotton depend on vehicle types and speed, type of surface traveled, and surface moisture. Field "road" surfaces range from grass, to dirt tracks in grass from repeated travel, to bare soil. For given transport conditions, cotton yield and trash content determine the number of trailers pulled to and from the field and hence the total emissions generated in transporting the harvested cotton.

D. GEOGRAPHICAL DISTRIBUTION

Virtually all cotton in the United States is grown south of the 36th parallel[17] where 19 states produce cotton. The distribution of cotton harvesting areas is shown in Figure 6.[18]

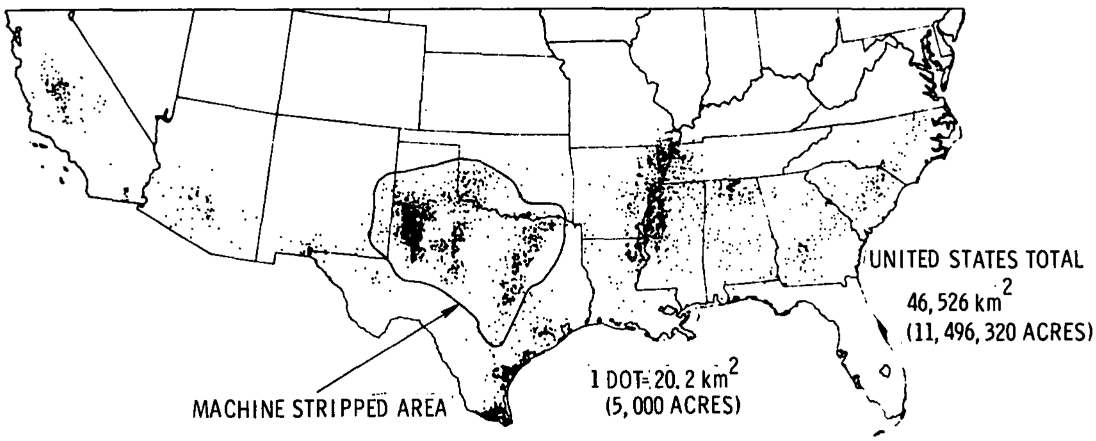

Figure 6. Cotton harvested, 1969[18]

[17]Burkhead, C. E., R. C. Max, R. B. Karnes, and E. Reid. Field and Seed Crops - Usual Planting and Harvesting Dates by States in Principal Producing Areas. U.S. Department of Agriculture, Statistical Reporting Service. Washington. Agriculture Handbook No. 283. 1972. p. 10-12.

[18]Census of Agriculture, 1969. Volume V, Special Reports. Part 15, Graphic Summary. Washington, U.S. Bureau of the Census, 1973. p. 125.

The principal cotton-producing areas are apparent from this map: the plains of western Texas, the Blacklands of eastern Texas, the Mississippi Valley, and the San Joaquin Valley of California. The region encompassing the plains of eastern New Mexico, western Texas, and southwestern Oklahoma and the Texas Blacklands is primarily stripper harvested while cotton in the rest of the country is machine picked. Mechanical gleaning is practiced mainly in Arizona, but represents only 10% by weight of the state harvest and 1% of the national harvest.

Table 2 presents average cotton production figures for the 1971-1973 harvest seasons by state. Averages for the 1971-1973 seasons, rather than the 1972 season alone, are shown so that localized effects (mostly due to weather) during a particular season are deemphasized. Texas is the leading cotton state, accounting for 31% of U.S. total weight and 41% of U.S. total harvested area. The top 12 states harvest 97% of the national total of 2.70×10^6 metric tons of lint cotton from 97% of the total 49,173 km^2 harvested.

Table 3 shows the breakdown of cotton harvesting methods by state and the contribution of each state to the total production by each harvest method based on cotton-type farms in 1971. Machine picking is the predominant harvest method in the U.S., accounting for 70% of the national production and greater than 97% of the production in 9 of the 12 leading cotton states. Cotton stripping accounts for 29% of the national harvest, and predominates only in Texas and Oklahoma. Mechanical gleaning is important only in Arizona, and accounts for less than 1% of the national harvest.

Table 2. 1971-73 AVERAGE COTTON PRODUCTION BY STATE[3,4]

Production rank	State	Lint cotton production[a] 10^3 metric tons	Percent of U.S. production	Area harvested, km^2	Percent of U.S. area harvested	Yield, metric tons/km^2
1	Texas	842	31.2	20,250	41.2	41.6
2	Mississippi	401	14.9	5,767	11.7	69.5
3	California	336	12.5	3,438	7.0	97.7
4	Arkansas	270	10.0	4,759	9.7	56.7
5	Louisiana	133	4.9	2,276	4.6	58.4
6	Arizona	132	4.9	1,223	2.5	107.9
7	Alabama	120	4.4	2,223	4.5	54.0
8	Tennessee	110	4.1	1,823	3.7	60.3
9	Georgia	81	3.0	1,608	3.3	50.4
10	Missouri	74	2.7	1,203	2.5	61.5
11	Oklahoma	68	2.5	1,932	3.9	35.2
12	South Carolina	63	2.3	1,288	2.6	48.9
	All other[b]	69	2.6	1,383	2.8	49.9
U.S. TOTAL		2,699	100	49,173	100	54.9

[a]Cotton after cleaning and seed removal by ginning.

[b]All other cotton producing states including North Carolina, New Mexico, Florida, Kentucky, Virginia, Nevada, and Illinois.

Table 3. COTTON PRODUCTION BY HARVEST METHOD FOR COTTON-TYPE FARMS[a] IN 1971[8]

Production rank	State	Percent of state production				Percent of U.S. total production			
		Machine picked	Machine stripped	Machine gleaned	Hand labor	Machine picked	Machine stripped	Machine gleaned	Hand labor
1	Texas[b]	15	85			5	27		
2	Mississippi	99			1	15			
3	California	100				12			
4	Arkansas	99				10			
5	Louisiana	99			1	5			
6	Arizona	89	1	10		4		1	
7	Alabama	99			1	4			
8	Tenessee	97	1		2	4			
9	Georgia	98			1	3			
10	Missouri	99			1	3			
11	Oklahoma	16	84				2		
12	South Carolina	97			2	3			
	All other[c]	92	5	2	1	2			
U.S. TOTAL		-[d]	-[d]	-[d]	-[d]	70	29	1	

[a]As defined by the Specialized Survey of Cotton Operations, 1971, cotton-type farms are those which had: (a) $10,000 or more in cotton sales; or (b) 50% or more of total farm sales from cotton, excluding farms with total sales under $2,500.[8]

[b]Based on Texas Agricultural Extension Service data.[6]

[c]All other cotton producing states including North Carolina, New Mexico, Florida, Kentucky, Virginia, Nevada, and Illinois.

[d]Not applicable.

Note: Blanks indicate <0.5%.

No data were found which show explicitly the breakdown on area harvested by each method. However, reasonable estimates can be inferred from the production data of Table 3. Machine-picked and hand-harvested areas should have approximately the same harvest yields (mass per unit area harvested). Machine gleaning is a cleanup operation performed after machine picking; hence gleaned area is included in machine-picked area and does not cause a split in total harvested area. Therefore, only machine stripping will cause noticeable differences between proportions of total production and total harvested area. Examination of cotton production data for Texas[6,19] and Oklahoma[8] shows differences of less than 1 metric ton/km^2 between machine-stripped and overall yield for each state (see Appendix A). Therefore, it is reasonable to assume that yields for all harvest methods, except gleaning, within a state are equal, and that the proportion of area harvested by each method is the same as the proportion of production. For gleaning, a reasonable estimate is obtained by applying the fraction of picker farms which also glean to the total machine-picked area in each state.

Table 4 shows the resulting estimated average 1971-73 cotton area harvested by each method for the 12 leading cotton states and the total U.S. Of the total U.S. area harvested, 61% is machine picked, 39% is machine stripped, and less than 1% is harvested by hand labor; 4% of the machine-picked area is also machine gleaned.

[19]Caudill, C. E., P. M. Williamson, M. D. Humphrey, Jr., L. P. Garrett, and L. Canion. 1973 Texas Cotton Statistics. Texas Crop and Livestock Reporting Service, Texas Department of Agriculture. Austin. Bulletin 113. June 1974. 21 p.

Table 4. 1971-73 AVERAGE COTTON AREA HARVESTED BY HARVEST METHOD (km^2)

Production rank	State	Machine picked	Machine stripped	Hand labor	Machine gleaned[a]
1	Texas	3,000	17,200		200
2	Mississippi	5,700		100	
3	California	3,400			100
4	Arkansas	4,700			
5	Louisiana	2,300			
6	Arizona	1,200			700
7	Alabama	2,200			
8	Tennessee	1,800			
9	Georgia	1,600			
10	Missouri	1,200			
11	Oklahoma	300	1,600		
12	South Carolina	1,200			
	All other[b]	1,300	100		100
U.S. TOTAL[c]		30,000	19,000	200	1,200

[a]Based on proportion of machine-picked farms which also glean cotton.[8]

[b]All other cotton producing states including North Carolina, New Mexico, Florida, Kentucky, Virginia, Nevada, and Illinois.

[c]Data may not add to totals shown because of independent rounding.

Note: Blanks indicate <50 km^2.

Table 5 shows the average population density for the 12 leading cotton states, based on the 1970 Census.[20] To find the overall average population density for cotton harvesting the state densities were weighted according to the fraction of total harvested cotton area within the respective states. The resulting weighted average of 22 persons/km^2 is the representative population density for cotton harvesting states in the U.S.

Table 5. STATE AND WEIGHTED AVERAGE POPULATION DENSITIES FOR 12 LEADING COTTON-PRODUCING STATES

State	1970 population density,[20] persons/km^2	Percent of total U.S. cotton area harvested[a]	Weighted population density,[b] persons/km^2
Texas	16.5	41.2	6.99
Mississippi	18.1	11.7	2.18
California	49.3	7.0	3.55
Arkansas	14.3	9.7	1.43
Louisiana	31.3	4.6	1.48
Arizona	6.0	2.5	0.15
Alabama	26.2	4.5	1.21
Tennessee	36.6	3.7	1.39
Georgia	30.5	3.3	1.04
Missouri	26.2	2.5	0.67
Oklahoma	14.4	3.9	0.58
South Carolina	33.1	2.6	0.89
TOTAL		97.2	21.6

[a]1971-73 average.

[b]For example, Texas weighted density = $\frac{41.2}{97.2}$ x 16.5 = 6.99.

[20]1970 Census & Areas of Counties and States. In: 1975 World Almanac & Book of Facts. New York, Newspaper Enterprise Association, Inc., November 1974. p. 183-201.

SECTION IV

EMISSIONS

A. COMPOSITION AND HAZARD POTENTIAL

1. Major Emissions

Emissions from mechanical cotton harvesting operations are in the form of solid particulates (dust) composed of cotton plant fragments and soil dust. Respirable particulate (<7-μm mean aerodynamic diameter) emissions are of particular interest, because it is this fraction of total particulates that has the largest potential effect on human health. The respirable particulates are composed mainly of raw cotton dust and soil dust, which contains free silica.

Particulate matter is an EPA criteria pollutant, so national air quality standards have been established for it. The 24-hour primary standard for total suspended particulates (TSP) is 260 $\mu g/m^3$.[21] In addition, the American Conference of Governmental Industrial Hygienists (ACGIH) has established a TLV of 10 mg/m^3 for inert (less than 1% by weight free

[21] Code of Federal Regulations, Title 42 - Public Health, Chapter IV - Environmental Protection Agency, Part 410 - National Primary and Secondary Ambient Air Quality Standards, April 28, 1971. 16 p.

silica) dusts.[22] TLV's refer to "time-weighted concentrations for a 7- or 8-hour workday and 40-hour workweek" recommended by ACGIH to protect worker health.

All of the particulate matter emitted by harvesting machines and trailer loading operations is considered to be raw cotton dust (RCD). Prolonged exposure to RCD has been identified as causing a chronic bronchial disease called byssinosis, often referred to as "Monday sickness." The disease has been recognized in cotton textile mill workers since the early nineteenth century.[23] Symptoms are Monday morning chest tightness and shortness of breath, which are more obvious when exposure to cotton dust is resumed after a short period (a weekend, for example) of nonexposure. Cotton plant debris from bracts, stems, and leaves is believed to be the harmful component. The specific harmful agent has not been identified, but studies indicate that it is water soluble and has the properties of a polyphenol.[24,25] The TLV for raw cotton dust is 200 $\mu g/m^3$, as measured with a vertical elutriator that has a 15-μm theoretical particle size cutoff.[22,26]

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[22]TLV's® Threshold Limit Values for Chemical Substances and Physical Agents in the Workroom Environment with Intended Changes for 1975. American Conference of Governmental Industrial Hygienists. Cincinnati. 1975. 97 p.

[23]Kilburn, K. H., G. G. Kilburn, and J. A. Merchant. Byssinosis: Matter from Lint to Lungs. American Journal of Nursing. 73:1952-1956, November 1973.

[24]Merchant, J. A., J. C. Lumsden, K. H. Kilburn, V. H. Germino, J. D. Hamilton, W. S. Lynn, H. Byrd, and D. Baucom. Preprocessing Cotton to Prevent Byssinosis. British Journal of Industrial Medicine. 30:237-242, 1973.

[25]Hamilton, J. D., G. M. Halprin, K. H. Kilburn, J. A. Merchant, and J. R. Ujda. Differential Aerosol Challenge Studies in Byssinosis. Archives of Environmental Health. 26:120-124, March 1973.

Emissions from mechanical cotton harvesting also contain free silica (SiO_2) from soil dust. Silicosis can result from prolonged exposure to free silica particles. The TLV for respirable particles (<10 μm in diameter) with free silica content greater than 1% is given in mg/m^3 by:[22]

$$TLV = \frac{10}{(\%\ SiO_2) + 2} \qquad (1)$$

where the "% SiO_2" is the percentage of respirable free silica, measured as quartz, in the dust. This relationship was used for the ≤7-μm fraction of particles sampled in this study. Analysis of particulate samples showed free silica content of 7.9% for mechanical cotton picking and an average of 2.3% for mechanical cotton stripping (Appendix B).

2. Minor Emissions

Small quantities of chemical pesticide, defoliant, and desiccant residues are present in the particulates emitted by cotton harvesting. Thousands of pesticides are registered with EPA for use on cotton.[15] Table 6 lists agricultural chemicals commonly used on cotton.[27] Where TLV's have not been established, they were estimated from the LD_{50} level which is the

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[26]Neefus, J. D. Cotton Dust Sampling: I Short Termed Sampling. American Industrial Hygiene Association Journal. 36:470-476, June 1975.

[27]Rawlings, G. D., and R. B. Reznik. Source Assessment: Cotton Gins. Monsanto Research Corporation, EPA Contract 68-02-1874. Dayton. Preliminary document submitted to the EPA, December 1975. 97 p.

Table 6. TLV'S OF PESTICIDES APPLIED TO COTTON CROPS[27]

Type of pesticide	TLV,[a] mg/m^3	Acute oral LD_{50}, mg/kg
Inorganic fungicides		
Copper sulfate	1.0	300
Organic fungicides		
Dithiocarbamates		
Zineb	(5.0)	>5,200
Phthalimides		
Captan	(5.0)	9,000
Dinocap, dodine, quinones	0.4	
Phenols	19.0	
Organic herbicides		
Arsenicals	0.5	
Phenoxys		
2,4-D	10.0	300 to 1,000
Phenyl ureas		
Diuron	(5.0)	3,400
Linuron	(5.0)	1,500 to 4,000
Fluometuron	(5.0)	8,900
Amides		
Alanap	(5.0)	8,200
Alachlor	(5.0)	1,200
Carbamates, see insecticides		
Dinitro group	(0.1)	10 to 60
Triazines	(5.0)	3,000 to 5,000
Other organics		
Trifluralin	(10.0)	>10,000
Nitralin	(5.0)	2,000
Dalapon	(1.0)	970
Norea	(5.0)	2,000
Synthetic organic insecticides		
Organochlorines		
Strobane	0.5	220
DDT	1.0	113 to 118
Endrin	0.10	5 to 17.8
Dieldrin	0.25	46
Toxaphene	0.5	80 to 90
Organophosphorus		
Disulfoton	(0.1)	12.5
Bidrin	(0.1)	15 to 22
Methyl parathion	0.2	14 to 24
Parathion	0.1	3.6 to 13
Trichlorfon	(1.0)	560 to 630
Azinphosmethyl	0.2	11 to 13
Phorate	(0.1)	1.1 to 2.3
Ethion	(0.1)	27 to 65
Carbamates		
Carbaryl	5.0	500 to 850
Methomyl	(0.1)	17
Miticides		
Dicofol	(1.0)	809
Chlorobenzilate	1.0	960
Omite	(5.0)	2,200
Fumigants		
Dibromochloropropane	(0.1)	173
Telone	(0.1)	250 to 500
Defoliants and desiccants		
Arsenic acid	0.25	48 to 100
DEF	(1.0)	350
Folex	(5.0)	1,272
Sodium chlorate	(5.0)	1,200

[a]Values in parentheses are assumed TLV's based on their LD_{50}'s according to the following schedule:

TLV = 0.1 if LD_{50} <300 mg/kg
TLV = 1.0 if 300 <LD_{50} <1,000 mg/kg
TLV = 5.0 if 1,000 <LD_{50} <10,000 mg/kg
TLV = 10.0 if LD_{50} >10,000 mg/kg

dose, in mg of compound/kg of body weight, that is lethal to 50% of a population of test animals, usually male rats.

The pesticides most commonly sprayed on cotton crops in 1971 were DDT (which has since been banned from use by EPA), Toxaphene, and methyl parathion. Sodium chlorate, tributylphosphorotrithioite (Folex) and tributylphosphorotrithioate (DEF) accounted for more than 90% of all defoliants used on cotton in 1971. The predominant desiccants applied to cotton in 1971 were arsenic acid and paraquat, used in Texas and Oklahoma.[28]

No data on the agricultural chemical content of cotton harvesting dust were found in the literature. Maxima and minima of concentrations found in cotton gin trash and emissions are summarized in Table 7.[14,29-32] Field samples of

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[28]Andrilenas, P. A. Farmers' Use of Pesticides in 1971... Quantities. U.S. Department of Agriculture, Economic Research Service. Washington. Publication No. ERS-536. February 1974. 35 p.

[29]Fearheller, W. R., and D. L. Harris. Particulate Emission Measurements from Cotton Gins, Delta and Pine Land Co., Scott, Mississippi. Monsanto Research Corporation. Dayton. Report No. MRC-DA-358. Environmental Protection Agency, EMB Project Report No. 72-MM-16. November 1974. 239 p.

[30]Fearheller, W. R., and D. L. Harris. Particulate Emission Measurements from Cotton Gins, Bleckley Farm Service Co., Cochran, Georgia. Monsanto Research Corporation. Dayton. Report No. MRC-DA-357. Environmental Protection Agency, EMB Project Report No. 72-MM-23. November 1974. 265 p.

[31]Emissions from Cotton Gin at Valley Gin Company, Peoria, Arizona. PEDCo-Environmental Specialists, Inc. Cincinnati. Environmental Protection Agency, EMB Project Report No. 72-MM-20. 1973. 37 p. plus Appendix.

[32]Durrenberger, C. Cotton Gin Report. Texas Air Control Board. Austin. May 31, 1974. 50 p.

Table 7. AGRICULTURAL CHEMICAL CONCENTRATIONS IN COTTON GIN EMISSIONS AND TRASH

Emission/trash	Concentration, ppm by weight	
	Maximum - where measured	Minimum[a] - where measured
Organochlorine pesticides		
p,p'-DDT	53.0 - inclined cleaner trash[29]	<0.01 - inline filter inlet[31]
o,p-DDT	5.94 - inclined cleaner trash[29]	1.0 - green leaf and stick extractor[29]
p,p'-TDE[b]	2.60 - inclined cleaner trash[29]	<0.01 - inline filter inlet[31]
p,p'-DDE[b]	3.91 - inclined cleaner trash[29]	0.02 - inline filter inlet[31]
Toxaphene	136 - inclined cleaner trash[29]	0.32 - inline filter inlet[31]
Endrin	0.05 - inline filter inlet[31]	<0.01 - total gin trash[30]
Dieldrin	0.05 - inline filter inlet[31]	0.01 - inline filter inlet[31]
TOTAL	202	
Organophosphorus pesticides		
Parathion	14.8 - total gin trash[31]	0.14 - inline filter inlet[31]
Methyl parathion	5.1 - total gin trash[31]	0.01 - inline filter inlet[31]
Merphos	0.6 - total gin trash[31]	--[c]
Diazinon	0.04 - inline filter inlet[31]	<0.02 - inline filter inlet[31]
TOTAL	20.5	
Defoliants		
DEF	17.1 - total gin trash[31]	0.06 - inline filter inlet[31]
Desiccants		
Arsenic acid (as arsenic)	2,200 - air downwind from gin[32]	5.67 - gin emission sample[31]

[a] Minimum of detectable concentrations.

[b] Degradation product of DDT.

[c] Only one sample taken.

cotton harvesting emissions contained 2.94 ppm parathion, 1.47 ppm methyl parathion, and 4.90 ppm DEF in picker harvesting emissions and <0.07 ppm arsenic in stripper harvesting emissions (see Appendix B). These concentrations are within the ranges of those at cotton gins, so it is reasonable to assume that Table 7 represents ranges that could be expected in harvesting emissions.

B. EMISSION FACTORS AND EMISSION BURDENS

Table 8 lists respirable particulate (<7-μm diameter) emission factors for the principal types of cotton harvesting operations in the U.S. The factors are based on average machine speed, basket capacity, trailer capacity, lint cotton yield, transport speed, and mass emission rates for the respective harvester types. The confidence limits are based on those for emission rates at the 95% confidence level. Details of the calculations are shown in Appendix C. The weighted average stripper factors are based on estimates that 2% of all strippers are four-row models with baskets, and 40% and 60% of the remainder are two-row models pulling trailers and two-row models with mounted baskets, respectively.[33] Raw cotton dust emission factors are the sum of those from harvesting and trailer loading, since field transport emissions are soil dust only.

The free silica emission factors presented in Table 9 are calculated from the total emission factors in Table 8 and the free silica content as measured in emission samples from picker and stripper harvesting.

[33] Personal communication. Dr. R. B. Metzer, Texas Agricultural Extension Service, Texas A&M University, College Station. January 13, 1976.

Table 8. RESPIRABLE PARTICULATE EMISSION FACTORS FOR COTTON HARVESTING OPERATIONS
(kg emitted/km^2 harvested)

Type of harvester	Unit operation: Harvesting	Unit operation: Trailer loading[a]	Unit operation: Transport	Total
Picker				
Two-row, with basket	0.455 ± 0.738	0.0699	0.427 ± 0.119	0.952
Stripper				
Two-row, pulled trailer	7.37 ± 16.7	-[b]	0.279 ± 0.078	7.65
Two-row, with basket	2.30 ± 0.82	0.0918	0.279 ± 0.078	2.67
Four-row, with basket	2.31 ± 0.82	0.0918	0.279 ± 0.078	2.68
Weighted average[c]	4.28 ± 6.53	0.0560	0.279 ± 0.078	4.61

[a]No confidence limits, since factors based on only one sample.

[b]Not applicable.

[c]Based on proportions of stripper types.

Table 9. FREE SILICA EMISSION FACTORS FOR COTTON HARVESTING
(kg emitted/km^2 harvested)

Type of harvester	Emission factor
Picker	
Two-row, with basket	0.0752
Stripper	
Two-row, pulled trailer	0.176
Two-row, with basket	0.061
Four-row, with basket	0.062
Weighted average[a]	0.106

[a]Based on proportions of stripper types.

Table 10 presents estimated maximum emission factors for pesticides, defoliants, and desiccants based on Tables 7 and 8. Totals for organochlorine and organophosphate pesticides are given since application of specific chemicals varies widely.

Annual respirable particulate emissions from cotton harvesting and their contribution to total emissions[34] are listed by state in Table 11. The emissions were calculated from the emission factors in Table 8 and the 1971-73 average area harvested in Table 4. It was assumed that picker area was picked twice, excluding gleaned area, since it is common practice to harvest picker cotton twice in one season.[12] Stripping emissions were calculated from the weighted average total emission factor for stripper operations, which was also assumed applicable to gleaning. Using Texas as an example, emissions from picking are:

$$\left[0.455 \frac{kg}{km^2}\right]\left[(2 \times 3{,}000 - 200)\,km^2\right] + \left[(0.0699 + 0.427)\frac{kg}{km^2}\right]\left[3{,}000\ km^2\right]$$

$$= 4{,}100\ kg = 4.1\ \text{metric tons}$$

In the equation above it is not necessary to apply the factors for trailer loading and field transport to twice the harvested area, since those factors are based on total annual yield (Appendix C). Annual emissions from Texas stripping and gleaning operations are:

$$\left[4.61 \frac{kg}{km^2}\right]\left[(17{,}200 + 200)\,km^2\right] = 80{,}200\ kg = 80.2\ \text{metric tons}$$

[34]1972 National Emissions Report. U.S. Environmental Protection Agency. Research Triangle Park. Publication No. EPA-450/2-74-012. June 1974. 422 p.

Table 10. ESTIMATED MAXIMUM PESTICIDE, DEFOLIANT, AND DESICCANT EMISSION FACTORS FOR COTTON HARVESTING
(mg emitted/km^2 harvested)

Type of harvester	Pesticides		Harvest-aid chemicals	
	Organo-chlorines	Organo-phosphates	Defoliants[a]	Desiccants[b]
Picker				
Two-row, with basket	192	19.5	16.3	
Stripper				
Two-row, pulled trailer	1,545	157		16,800
Two-row, with basket	539	54.7		5,870
Four-row, with basket	541	54.9		5,900
Weighted average[c]	931	94.5		10,100

[a] Assuming DEF.

[b] Assuming arsenic.

[c] Based on proportions of stripper types.

Note: Blanks indicate not applicable.

Table 11. ANNUAL RESPIRABLE PARTICULATE EMISSIONS AND EMISSION BURDENS FROM COTTON HARVESTING

State	Respirable particulates from cotton harvesting, metric tons/yr		State total particulate emissions,[34] metric tons/yr	Emission burden from cotton harvesting, %[c]
	Picking[a]	Stripping and gleaning[b]		
Texas	4.1	80.2	549,399	0.046
Mississippi	8.0		168,355	0.014
California	4.7	0.5	1,006,452	0.002
Arkansas	6.6		137,817	0.014
Louisiana	3.2		380,551	0.003
Arizona	1.4	3.2	72,685	0.019
Alabama	3.1		1,178,643	0.001
Tennessee	2.5		409,704	0.002
Georgia	2.3		404,574	0.002
Missouri	1.7		202,435	0.003
Oklahoma	0.4	7.4	93,595	0.025
South Carolina	1.7		198,767	0.003
All other[d]	1.8	0.9	1,928,310	
U.S. TOTAL (all states)	41.5	92.2	17,872,000	0.002

[a] Assuming picker area picked twice, excluding gleaned area (see text).

[b] Using weighted average factor for stripping and assuming it applies to gleaning.

[c] Assuming one-third of total particulates is respirable.

[d] All other cotton producing states including North Carolina, New Mexico, Florida, Kentucky, Virginia, Nevada, and Illinois.

Note: Blanks indicate <0.2 metric ton/yr.

The emission burden is the fraction of total particulate emissions contributed by cotton harvesting operations. Since only respirable particulate emissions were sampled (Appendix B), the emission burden was calculated by assuming that one-third of a state's total particulate emissions are respirable (<7 μm in diameter). Emission burdens are shown in Table 11.

C. DEFINITION OF REPRESENTATIVE SOURCE

According to the 1969 Census of Agriculture, "cotton-type" farms accounted for 29% of all U.S. farms growing cotton, but harvested 52% of all lint cotton from 48% of all land devoted to cotton. A "cotton-type" farm is defined as one with annual cotton sales of at least $10,000 or 50% of the total value of all farm products sold.[7] In this document, the representative cotton harvesting source is defined as a cotton-type farm harvesting the average area of cotton which, in 1971, was 0.786 km^2.[8] By defining the representative source as a cotton-type farm, farms with a few thousand square meters or less in cotton are eliminated from consideration. These small farms are likely to harvest cotton by hand and are not characteristic of mechanical harvesting operations. Solid planting (no rows skipped) was the predominant (74% of all area) planting pattern on cotton-type farms in 1971.[8] Representative row spacing is 1.02 m (40 in.).

To maintain good cotton quality, the seed cotton must not contain too much moisture. Seed cotton moisture is controlled by the relative humidity in the field, which is highest before dew evaporates in early morning and when dew begins to form in late afternoon. For this reason, cotton is usually harvested from midmorning until late afternoon, or approximately from 9 a.m. or 10 a.m. until 6 p.m. or

7 p.m. on warm sunny days.[14,16] Acceptable hours are shorter on cool or cloudy days. On this basis, 8 hr was chosen as the length of a representative cotton harvesting day.

Mechanical cotton pickers and cotton strippers have distinctly different operating characteristics. Thus, it is necessary to treat picker and stripper operations separately. Representative picker yield is 63.0 metric tons of lint cotton/km^2 harvested (from Tables 2, 3 and 4). The representative picker is self-propelled, harvests two cotton rows simultaneously at a speed of 1.34 m/s, and has a harvester-mounted basket for collecting the picked cotton.[12] Six harvester baskets of cotton are required to fill a representative cotton trailer, which has a capacity of 654 kg of lint (ginned) cotton.[35] The previously presented emission factors for picking operations apply to the representative picker source. Cotton-type farms that machine picked cotton in 1971 averaged one picker per farm.[8]

An estimated 98% of all cotton strippers are two-row models, ∿60% of which have mounted baskets and 40% pull trailers to collect the harvested cotton.[33] Hence, the representative stripper is defined as a two-row model with a mounted basket. Average speed while harvesting is 2.23 m/s.[12] Representative stripper yield is 41.2 metric tons of lint cotton/km^2 harvested (from Tables 2, 3 and 4). Six harvester baskets are required to fill the representative cotton trailer with 654 kg of lint cotton. Cotton-type farms that stripped cotton in 1971 averaged one stripper per farm.[8]

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[35]Personal communication. Dr. R. B. Metzer, Texas Agriculture Extension Service, Texas A&M University, College Station. December 16, 1975.

For both pickers and strippers, 0.3 min is required for turning at the ends of rows, 2 min are required for the basket dumping operation, and filled cotton trailers are transported in the field at a speed of 4.47 m/s.[a]

D. SOURCE SEVERITIES

Source severity is intended to be a relative measure of the air quality impact of an air pollution source when compared to other sources. Of particular interest is the maximum severity from the representative source, defined as:

$$S \equiv \frac{\bar{\chi}_{max}}{F} \quad (2)$$

where S = maximum severity from the representative source

$\bar{\chi}_{max}$ = maximum time-averaged pollutant concentration to which the general public is exposed due to emissions from the representative source

F = pollutant "hazard" factor

The concentration must be averaged over the same time base as the hazard factor. The same units should be used for the concentration and the hazard factor; the resulting source severity value is dimensionless. For total suspended particulates (TSP) the hazard factor is defined as the national 24-hr primary ambient air quality standard of 260 $\mu g/m^3$; hence the 24-hr average concentration must be used to calculate TSP severity. For other pollutants from cotton harvesting, the hazard factor is an adjusted TLV. The representative cotton harvesting day is 8 hr long, which is the time base for TLV's, so no time adjustment is necessary. However, TLV's are

[a] From observation of representative operations.

designed for industrial workers, so the hazard factor is defined as TLV/100 to account for exposure to the general public. Eight-hour average concentrations are used to calculate severities from these TLV-based hazard factors.

To calculate maximum concentrations, the representative harvest area (0.786 km^2/farm) was combined into one square field, as shown in Figure 7. The representative distance from emission sources to the receptor is one-half of a side of the field. The receptor is located so as to be exposed to the maximum pollutant concentration due to all operations. Maximum concentrations were calculated from average respirable particulate emission rates (developed in Appendix D) and operating parameters for the representative sources by applying appropriate Gaussian diffusion models.[36] The national annual average wind speed of 4.5 m/s and Class C atmospheric stability were used. A dose model was applied to trailer loading, and a modified point source cross-wind integrated concentration model was applied to harvesters and field transport. The concentrations were then averaged over the representative operating time of 8 hr; 24-hr average concentrations are found by dividing the 8-hr concentrations by three. The detailed calculations are contained in Appendix D.

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[36]Turner, D. B. Workbook of Atmospheric Dispersion Estimates, Revised 1970. U.S. Environmental Protection Agency, Office of Air Programs. Publication No. AP-26. July 1971. 84 p.

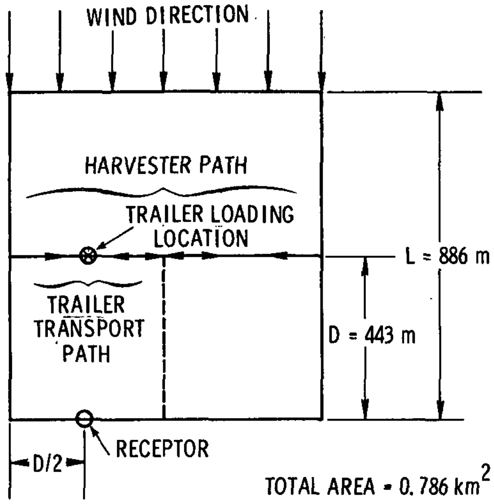

Figure 7. Representative field for calculating cotton harvesting severities

Calculated time-averaged maximum respirable particulate concentrations for the representative sources are listed with the resulting source severities for total suspended particulates (TSP), "inert" dust, and raw-cotton dust in Table 12. The 24-hr average concentration was used for TSP severities; the 8-hr average was used for other pollutants. The highest severities are from raw-cotton dust (which represents all emissions from harvesting and trailer loading): 0.00703 for mechanical picking operations (47% from harvesting and 53% from trailer loading), and 0.0350 from mechanical stripping operations (77% from harvesting and 23% from trailer loading). Source severities for other types of strippers are calculated in Appendix D.

Source severities for free silica and agricultural chemical residues in the respirable particulate emissions are listed in Table 13. Free silica severities are less than 0.01 and the sums of all maximum agricultural chemical severities are less than 10^{-4} for representative picking and stripping operations.

Table 12. MAXIMUM SEVERITIES FOR TOTAL SUSPENDED PARTICULATES, "INERT" DUST, AND RAW COTTON DUST FROM REPRESENTATIVE COTTON HARVESTING OPERATIONS

Harvesting operation	Unit operation: Harvesting	Unit operation: Trailer loading	Unit operation: Transport	Total
Mechanical picking				
Time-averaged maximum concentration ($\bar{\chi}_{max}$), μg/m³				
24-hr avg	0.00222	0.00247	0.00416	0.00885
8-hr avg	0.00665	0.00742	0.0125	0.0266
Severity, S				
Total suspended particulate[a]	0.00000854	0.0000095	0.000016	0.000034
"Inert" respirable dust[b]	0.0000665	0.0000742	0.000125	0.000266
Raw cotton dust[c]	0.00332	0.00371		0.00703
Mechanical stripping				
Time-averaged maximum concentration ($\bar{\chi}_{max}$), μg/m³				
24-hr avg	0.0181	0.00525	0.00440	0.0278
8-hr avg	0.0542	0.0158	0.0132	0.0832
Severity, S				
Total suspended particulate[a]	0.0000696	0.0000202	0.00440	0.000107
"Inert" respirable dust[b]	0.000542	0.000158	0.0132	0.000832
Raw cotton dust[c]	0.0271	0.00790		0.0350

[a]Hazard factor, F = 260 μg/m³, 24-hr average.

[b]Hazard factor, F = 100 μg/m³, 8-hr average; applies to dust with <1% free silica.

[c]Hazard factor, F = 2 μg/m³, 8-hr average.

Note: Blanks indicate no cotton dust emissions from transport.

Table 13. MAXIMUM SEVERITIES FOR FREE SILICA AND AGRICULTURAL CHEMICAL RESIDUES FROM REPRESENTATIVE COTTON HARVESTING OPERATIONS

Pollutant	Fraction of total respirable particulates[a]	Source severity
Free silica[b]		
Picking	7.9%	0.00263
Stripping	2.3%	0.00357
Agricultural chemicals		
Pesticides		
Organochlorines[c]	202 ppm	
Picking		0.00000537
Stripping		0.0000168
Organophosphates[d]	20.5 ppm	
Picking		0.000000545
Stripping		0.0000017
Total pesticides[e]	222 ppm	
Picking		0.00000592
Stripping		0.0000185
Defoliants (picking only)		
DEF[f]	17.1 ppm	0.000000046
Desiccants (stripping only)		
Arsenic acid (as arsenic)[g]	2,200 ppm	0.00000732
Total agricultural chemicals	2,440 ppm	
Picking		0.00000597
Stripping		0.0000258

[a]For agricultural chemicals, the maximum of all measurements is listed (see Table 7).

[b]TLV given by Equation 1.

[c]Minimum TLV for this group is 0.1 mg/m^3 for endrin (Table 6).

[d]Minimum TLV for this group is 0.1 mg/m^3 for parathion (Table 6).

[e]Minimum TLV for this group is 0.1 mg/m^3.

[f]TLV = 1.0 mg/m^3.

[g]TLV = 0.25 mg/m^3.

The field size given as representative is approximately the largest area that can be harvested in a day. Since the source severities are all very small (<0.01) and cotton fields are rarely larger than the representative size, severity distributions are not presented in this report.

Affected population from a representative source is defined as the number of persons exposed to a severity ≥1.0. Since maximum severities for all pollutants are less than 0.1, the affected population from representative cotton harvesting operations is zero.

SECTION V

CONTROL TECHNOLOGY

A. STATE OF THE ART

None of the current cotton harvesting equipment or practices provide for control of emissions. In fact, equipment designs and operating practices tend to maximize emissions. Harvester conveying and cleaning systems are designed to remove cotton trash and leave it in the field. Harvester collection baskets and cotton trailers are purposely designed to let blower air and/or wind carry trash and dust away from the cotton.[5,16] Trash removal in the field increases cotton grade and reduces ginning costs.

Preharvest treatment (defoliation and desiccation) and harvest timing practices are used to minimize moisture and trash in the harvested cotton and maximize harvest efficiency. These practices, especially desiccation which leaves plant parts dry and brittle, increase cotton grade and yield, but also tend to maximize emissions.

Soil dust emissions from field transport can easily be reduced by reducing vehicle speed. However, vehicle speed is usually governed by the condition of the field or road, since emissions are usually of minor concern (if any) to the drivers.

B. FUTURE CONSIDERATIONS

Control of emissions from mechanical cotton harvesters would involve enclosing cotton cleaning, conveying, and collection systems and venting them through a particulate collection device. This would require a fan or blower to move the particulate-laden air. Practical collection devices would be cyclones, skimmers, and filters or baghouses. Filters and baghouses are the least likely to be employed because the volume of trash collected would require very frequent cleaning or huge sizes. Cyclones and skimmers remove large particles (>10 μm) most efficiently and are not effective in removing respirable particles. Their efficiencies can be improved by the addition of a wetting system, but this would require hauling water on the harvesters. Any emissions control would be most easily applied to harvesters with mounted baskets.

Use of defoliants and desiccants is not likely to be reduced unless the cotton harvester manufacturing industry has unexpected success in designing machines that can efficiently harvest cotton from plants with full green foliage. Harvest timing practices are also unlikely to change, since minimizing moisture is one of the key requirements in maximizing cotton grade.

In addition to reducing vehicle speed, emissions from field transport of cotton can be reduced by watering or chemical treatment with dust suppressants or oil. Such chemical treatment is practical only if transport is on a field road, and even then is undesirable due to soil residues and leaching during rain.

Unless government agencies impose emission regulations on cotton harvesting operations, it is unlikely that emission control technology will be applied, mainly because of the high cost to farmers. Due to competition from foreign suppliers and lower priced synthetic fibers, a primary aim of U.S. cotton farmers is to reduce costs. This is the chief reason that cotton harvesting in the U.S. has become almost completely mechanized.

SECTION VI

GROWTH AND NATURE OF THE INDUSTRY

A. PRESENT TECHNOLOGY

The equipment and practices currently employed in mechanical cotton harvesting are described in Section III. More than 99% each of national cotton production and harvested area are presently harvested mechanically. Stripping is a dry-weather practice, and has evolved as the predominant harvest method in the moderately dry and arid areas of the Southwest. Though more expensive and less efficient, mechanical picking remains the chief harvest method in the Midsouth and Southeast. Stripping has been mostly experimental in these areas. Problems caused by shallow-rooted and tender plants, by loose sandy soil, and by excessive cotton losses due to rainy and windy weather while waiting for all bolls to open indicate that strippers are not well suited to humid climates and silty lowland soil.[5]

B. EMERGING TECHNOLOGY

Use of cotton strippers may rise as plant varieties are developed that can adapt to humid areas and still retain the characteristics necessary for good stripper harvesting.

Finger-type strippers are replacing roller-type strippers in some areas where plant uprooting is not a problem. The finger-type strippers are mechanically simpler, require less maintenance, and are less expensive to own and operate. They also have less potential fine particulate emissions, since there are no rollers to crush the dry leaves, stems, and burs.

Due to a decreasing number of gins and shorter ginning seasons, transport to the gin is a rising cost to the cotton farmer. Backup of loaded trailers at the gin forces farmers to have more and larger trailers available which has resulted in increased use of harvester-mounted baskets and larger trailers (with up to doubled capacity), and decreased use of harvester-pulled trailers. "Module" transport is also increasing, wherein the cotton-filled baskets are removed from the harvester and hauled to the gin on a truck, eliminating the need for trailers.

The trend toward fewer but larger cotton farms is increasing the number and size of harvesters. On larger farms it is becoming common practice to use two or more harvesters in a field simultaneously. Machines capable of harvesting up to four rows of cotton at a time are appearing.

Ginners are encouraging farmers to bring cleaner cotton to the gins. Less trash in the cotton means higher grade and price to the farmer and lower cleaning cost to the ginner. Harvester-mounted trash removal equipment adds to the harvester purchase price and increases maintenance and power requirements. The extra cost is high considering that the harvesters are used only 1 or 2 months a year. A possible alternative is a separate trash removal machine for use in the field. This would centralize trash removal and resulting emissions, making it more practical to apply emission control equipment. Field extraction of trash is not now widely practiced.[27]

C. INDUSTRY PRODUCTION TRENDS

Cotton production, harvested area, and yield trends from 1957 to 1974 are shown in Figure 8.[4,37] After a poor 1967 harvest year, production and harvested area rose and then decreased slightly from 1972 to 1974. U.S. cotton consumption *per capita* has been decreasing steadily since 1965, and cotton exports increased 100% from 1968 to 1972.[37] Increasing competition from foreign cotton producers and synthetic fibers have suppressed the growth of domestic cotton production. Unless petroleum prices rise drastically, causing a concomitant rise in synthetic fiber prices, U.S. cotton production is not expected to increase much, if any, above average 1971-73 levels by 1980. Any production increase will probably be due to increased yield rather than an increase in harvested area. Production, yield, and harvested area in any one season are completely dependent on weather conditions.

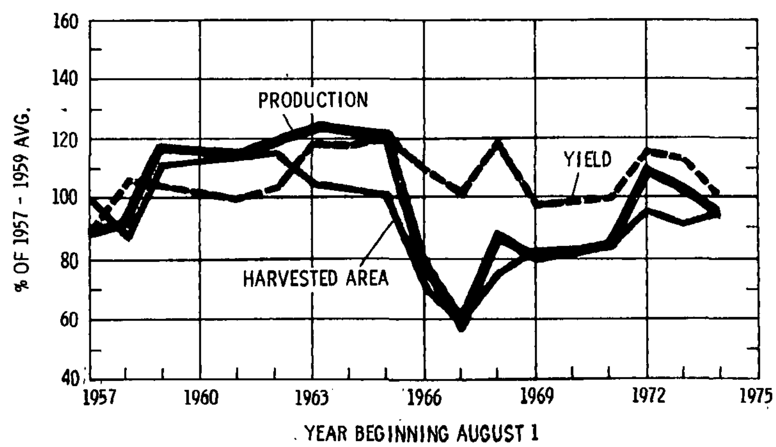

Figure 8. U.S. cotton area, yield, and production; 1957-74[4,37]

[37] 1973 Handbook of Agricultural Charts. Agricultural Handbook No. 455. Washington, U.S. Department of Agriculture, October 1973. 152 p.

SECTION VII

UNUSUAL RESULTS

A. SEASONAL NATURE OF THE INDUSTRY

As an agricultural operation, cotton harvesting is seasonal in nature. The U.S. cotton harvest season runs from August through January, but harvesting in any one area is concentrated in a much shorter period. The average cotton gin operates only 10 weeks per year;[27] the area around the average gin is harvested over the same period. Figure 9 and Table 14 show the usual cotton harvesting dates in the U.S.

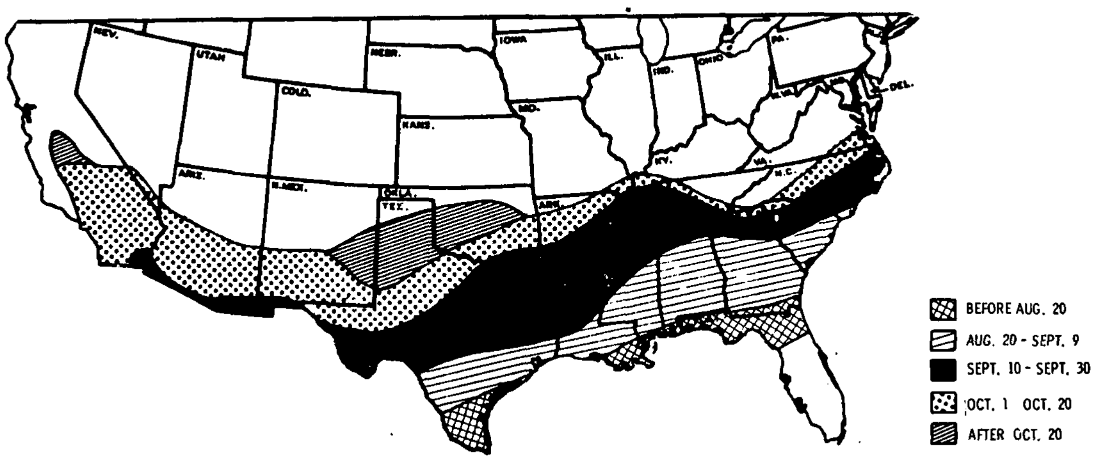

Figure 9. Usual start of cotton harvest season[17]

Table 14. USUAL COTTON HARVESTING DATES, BY STATE[17]

State	Usual harvesting dates		
	Begin	Most active	End
Illinois	Sep 15	Sep 30 - Oct 25	Nov 5
Missouri	Sep 15	Oct 1 - Nov 1	Dec 15
Virginia	Sep 15	Sep 25 - Nov 1	Dec 1
North Carolina	Sep 15	Oct 1 - Nov 15	Dec 10
South Carolina	Sep 1	Sep 20 - Nov 1	Dec 1
Georgia	Sep 1	Sep 15 - Oct 15	Nov 15
Florida	Aug 15	Sep 15 - Oct 15	Oct 30
Kentucky	Sep 15	Oct 1 - Oct 25	Dec 1
Tennessee	Sep 15	Sep 25 - Nov 15	Dec 5
Alabama	Sep 5	Sep 20 - Dec 1	Dec 20
Mississippi	Sep 20	Oct 5 - Nov 5	Dec 10
Arkansas	Sep 15	Oct 1 - Nov 10	Dec 15
Louisiana	Aug 25	Sep 15 - Nov 15	Dec 1
Oklahoma	Oct 15	Nov 10 - Dec 5	Dec 15
Texas	Aug 1	Nov 1 - Dec 1	Dec 20
New Mexico	Sep 10	Oct 15 - Nov 15	Dec 15
Arizona	Sep 1	Oct 15 - Dec 10	Jan 15
Nevada	Oct 15	Oct 25 - Dec 15	Jan 1
California	Oct 1	Oct 15 - Dec 1	Jan 15

In assessing emissions from cotton harvesting, it is important to consider the length of the season. The emission burdens presented in Section IV, for example, would be more illustrative if they could be based on a time span shorter than a year. The length of the season is also important in evaluating the impact on air quality.

B. COTTON STRIPPER EMISSION RATES

Results from field sampling (Appendix B) showed that the mean mass emission rate from the sampled four-row stripper was only 63% of the rate from the sampled two-row stripper (Appendix C). This result is surprising, considering that the four-row harvest rate is approximately twice the two-row harvest rate. Based on field observation, the major particulate emission point is located where the cotton discharges from the harvester conveying system, which is usually pneumatic. The sampled four-row stripper had a mounted basket, while the two-row model pulled a trailer to collect the seed cotton. It was concluded that harvesters with mounted baskets have lower mass emission rates due to the shorter distance and time in which the cotton and trash are airborne before reaching the collection basket.

It is possible that the anomaly in emission rates was also partly caused by the difference in stripper types. The two-row model used rotating rolls to remove the cotton from the plants, while the four-row model used stationary fingers and slits. The roll-type model has a higher potential for emitting fine particles since the rollers crush the dried leaves,stems, and burs.

C. RELATION OF FIELD SIZE TO SEVERITY

It is a common inclination to expect larger sources to cause higher pollutant concentrations (and hence severity) than smaller ones. Such is not the case with cotton harvesting. The reason is that increasing field size increases the distance to the nearest receptor and increases the area over which pollutants are emitted. With constant operating parameters and emission rate, pollutant concentration (and severity) is inversely proportional to $D^{1.814}$, where D is half of the width of the field and represents the average distance to the nearest receptor (Appendix D).

The above discussion indicates that the trend toward fewer and larger cotton farms may decrease the maximum severity for representative harvesting operations. The use of multiple and larger harvesting machines will negate the farm size effect to some degree.

SECTION VIII

APPENDIXES

A Comparison of Stripped and Overall Cotton Yield

B Sampling and Analysis Procedures and Results

C Emission Rate and Emission Factor Calculations

D Source Severity Calculations

APPENDIX A

COMPARISON OF STRIPPED AND OVERALL COTTON YIELD

Information on harvested cotton yield is necessary to determine the area harvested by each harvest method when only production weight data are available. As discussed in Section III, only stripper-harvested yield should cause a noticeable difference between proportions of weight and area harvested among machine picking, stripping, and gleaning. To determine stripper yield, production data from Texas and Oklahoma were examined; these two states together harvest 99.6% of the total weight of stripped cotton.

Texas estimates were based on data from seven crop reporting districts which accounted for 95.7% of the total stripping machines in the state but only 1.8% of the total picking machines.[6] Data from the 1971-73 seasons were averaged to negate effects of particularly good or poor harvests. The data and results are shown in Table A-1. The average yield for the seven districts was 41.2 metric tons/km^2 harvested compared with the average overall state yield of 41.6 metric tons/km^2.

Oklahoma estimates were based on data from seven counties in which machine picking accounted for less than 10% of the harvested weight from cotton-type farms in 1971.[8] The data and results are shown in Table A-2. The yield for primary stripper counties was 27.2 metric tons/km^2 harvested compared with a state yield of 27.9 metric tons/km^2 for all cotton-type farms.

Since the difference between estimated stripper yield and overall state yield is less than 1 metric ton/km^2 for both states, it is reasonable to assume that yields within a state are the same for machine picking, machine stripping, and hand labor harvesting.

Table A-1. LINT COTTON YIELD FOR PRIMARY STRIPPING DISTRICTS IN TEXAS, 1971-73

District	Area harvested, km^2			Lint cotton production, 10^3 metric tons		
	1971[6]	1972[6]	1973[19]	1971[6]	1972[6]	1973[19]
1-N	1,651	1,619	1,708	47.5	89.1	94.6
1-S	7,374	7,596	9,166	225.8	382.7	513.0
2-N	1,716	1,817	2,104	44.7	83.9	105.0
2-S	2,064	2,214	2,226	43.8	90.4	100.2
3	105	138	138	1.3	3.3	4.4
4	3,096	3,136	2,857	67.8	107.0	93.1
7	243	356	360	8.1	12.0	12.6
Total for above districts	16,249	16,876	18,559	439.0	768.4	922.9
	1971-73 Avg.: 17,228			1971-73 Avg.: 710.1		
	1971-73 Avg. yield: 41.2 metric tons/km^2					
For Texas	1971-73 Avg.: 20,250			1971-73 Avg.: 841.8		
	1971-73 Avg. yield: 41.6 metric tons/km^2					

Table A-2. LINT COTTON YIELD FOR COTTON-TYPE FARMS IN PRIMARY STRIPPING COUNTIES IN OKLAHOMA, 1971[8]

County	Area harvested, km^2	Lint cotton production, metric tons
Caddo	12.4	318
Custer	16.3	528
Grady	10.7	307
Greer	13.4	379
Kiowa	32.9	950
Tillman	55.9	1,241
Washita	84.0	2,411
Total for above counties	225.6	6,134
	1971 yield: 27.2 metric tons/km^2	
Total for Oklahoma	438.6	12,232
	1971 yield: 27.9 metric tons/km^2	

APPENDIX B

SAMPLING AND ANALYSIS PROCEDURES AND RESULTS

1. RESPIRABLE PARTICULATES

A GCA Model RDM 101-4 portable respirable dust monitor[a] was used to sample emissions from cotton harvesting operations. With this monitor, digital readout of mass concentration is obtained from electronic measurement of beta ray absorption of the collected sample. A small cyclone removes particles of ≥7-μm mean aerodynamic diameter ahead of the collection chamber, so that only respirable concentrations are measured. With the cyclone removed, the instrument is capable of measuring total particulate mass concentrations. However, the high concentration of large plant fragments from cotton harvesting presented the danger of plugging the sampling orifice and, consequently, total particulate concentrations were not measured. The instrument is capable of measuring dust concentrations from 20 $\mu g/m^3$ to 10,000 $\mu g/m^3$ with sampling times of 4 min or longer. The accuracy of the instrument is defined by the manufacturer as "...within ±25% of the measurements obtained from a companion simultaneous gravimetric respirable mass sample for 95% of the samples."

Dust concentrations from harvesting were measured by following each harvesting machine through the field at a constant distance directly downwind from the machine while staying in the visible plume centerline. The respirable dust monitor was carried overhead with arms extended to minimize ground effects and body interference. Distance downwind was

[a]GCA Corporation; GCA/Technology Division; Bedford, Massachusetts.

visually estimated, using the cotton row spacing and number of rows as a reference. The procedure for trailer loading was the same, but since the trailer is stationary while being loaded, it was necessary only to stand a fixed distance directly downwind from the trailer while the plume or puff passed over. Readings taken upwind of all field activity gave background concentrations.

Wind speeds were measured with an anemometer assembled by MRC which has cup-type rotors attached to the shaft of a small electric motor. Generated current is read in micro-amperes from an ammeter and converted to wind speed with a calibration chart. Readings of ∿15 s were taken before and after each particulate sample, and the average was recorded.

Atmospheric stability class was determined from wind speed and atmospheric conditions by using the chart of Figure B-1.[38] Field data were recorded on the form shown in Figure B-2. The terms on the form are explained in Table B-1.

Table B-1. EXPLANATION OF TERMS ON FIELD DATA FORM

Term	Meaning
Read., mg/m^3	Concentration reading
Conc., $\mu g/m^3$	Converted concentration for sampling times greater than 4 min (lower right hand corner)
R/T	R = respirable reading T = total mass reading
BGD, $\mu g/m^3$	Background concentration
Δ, $\mu g/m^3$	The difference between the converted concentration and the background
Q, g or g/s	Calculated emission rate
S'	Stability for the time of day the unit operation was sampled
M	The diffusion model used, referenced as 1, 2, or 3 (point, line, or dose, respectively)

[38]Blackwood, T. R., T. F. Boyle, T. L. Peltier, E. C. Eimutis, and D. L. Zanders. Fugitive Dust from Mining Operations. Monsanto Research Corporation. Dayton. Report No. MRC-DA-442. (EPA Contract 68-02-1320, Task 6.) May 1975. p. 34.

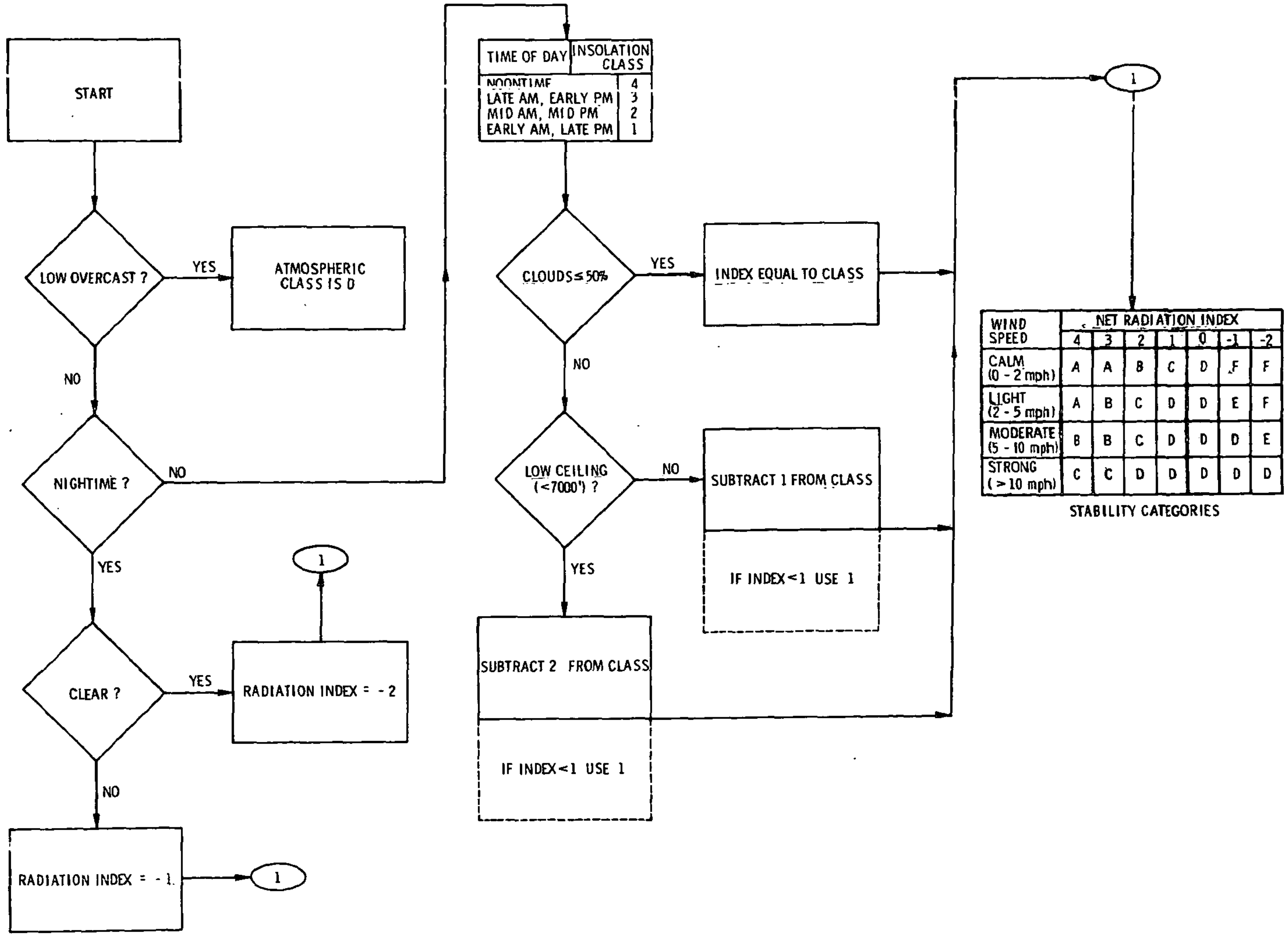

Figure B-1. Flow chart for atmospheric stability class determination[38]

MODEL: POINT = 1
LINE = 2
DOSE = 3

SOURCE TYPE ____________

DATE ________
BY ________

UNIT OPERATION	WIND SPEED, MPH	DISTANCE, FT. X	Y	Z	TIME, MIN.	READ., mg/m^3	CONC., $\mu g/m^3$	R/T	BGD, $\mu g/m^3$	Δ, $\mu g/m^3$	Q, g	S'	M	COMMENTS

TIME OF DAY ____ ____ ____ ____ ____
ATM.STABILITY ____ ____ ____ ____ ____

TOTAL SAMPLING TIME	MULTIPLY READING BY
4 MINUTES	1
8 MINUTES	0.46
16 MINUTES	0.23
20 MINUTES	0.184
30 MINUTES	0.122
37 MINUTES	0.1

Figure B-2. Field data form

Mass emission rates were calculated from the field data with appropriate Gaussian plume diffusion models. Emission rates for harvester emissions were calculated with the model for ground level concentration at the plume centerline from a stationary ground level point source:[36]

$$\chi(x) = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \qquad \text{(B-1)}$$

where

χ = ground level concentration at plume centerline, g/m^3

x = distance downwind from source, m

Q = source mass emission rate, g/s

π = 3.14

σ_y, σ_z = standard deviation of plume concentration distribution horizontal and vertical to the plume, respectively, m

$\bar{u}$ = mean wind speed, m/s

This model assumes that the plume spread has a Gaussian distribution in the horizontal and vertical planes, that there is total reflection of the plume at the earth's surface (no deposition or reaction), and that sampling time is a few minutes. The standard deviations, σ_y and σ_z, are calculated from Tables B-2 and B-3, developed from published empirical plots of σ_y and σ_z versus downwind distance from the source.[39,40] Although the harvester was a moving source, the receptor was also moving; thus the sampling procedure employed enables treatment as a stationary point source.

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[39] Eimutis, E. C., and M. G. Konicek. Derivations of Continuous Functions for the Lateral and Vertical Atmospheric Dispersion Coefficients. Atmospheric Environment. 6:859-863, November 1972.

[40] Martin, D. V., and J. A. Tikvart. A General Atmospheric Diffusion Model for Estimating the Effects on Air Quality of One or More Sources. Presented at 61st Annual Meeting of the Air Pollution Control Association, for NAPCA, St. Paul, 1968. 18 p.

Table B-2. CONTINUOUS FUNCTION FOR LATERAL ATMOSPHERIC DIFFUSION COEFFICIENT, σ_y[39]

$$\sigma_y = ax^{0.9031}$$

where x = downwind distance from source

Stability class	a
A	0.3658
B	0.2751
C	0.2089
D	0.1471
E	0.1046
F	0.0722

Table B-3. CONTINUOUS FUNCTION FOR VERTICAL ATMOSPHERIC DIFFUSION COEFFICIENT, σ_z[40]

$$\sigma_z = cx^d + f$$

Usable range	Stability class	Coefficient		
		c_1	d_1	f_1
>1,000 m	A	0.00024	2.094	-9.6
	B	0.055	1.098	2.0
	C	0.113	0.911	0.0
	D	1.26	0.516	-13
	E	6.73	0.305	-34
	F	18.05	0.18	-48.6
		c_2	d_2	f_2
100-1,000 m	A	0.0015	1.941	9.27
	B	0.028	1.149	3.3
	C	0.113	0.911	0.0
	D	0.222	0.725	-1.7
	E	0.211	0.678	-1.3
	F	0.086	0.74	-0.35
		c_3	d_3	f_3
<100 m	A	0.192	0.936	0
	B	0.156	0.922	0
	C	0.116	0.905	0
	D	0.079	0.881	0
	E	0.063	0.871	0
	F	0.053	0.814	0

Mass emission rates for cotton trailer loading (harvester basket dumping) were calculated with the Gaussian model for ground level dosage at the plume centerline from a stationary ground level point source with a finite mass release:[36]

$$D_T(x) = \frac{Q_T}{\pi \sigma_y \sigma_z \bar{u}} \qquad \text{(B-2)}$$

where $D_T(x)$ = total dosage, g-s/m^3
Q_T = total mass release, g

The total dosage can be estimated as

$$D_T(x) \cong \chi(x) \cdot t_s \qquad \text{(B-3)}$$

where $\chi(x)$ = measured concentration from sampling, g/m^3
t_s = sampling time, s

In using Equation B-2 care must be taken that σ_y and σ_z are representative of the release time and that the plume path is accurately known. Sample time was 4 min and wind speed and direction were steady during sampling, so the dose model should give reasonable results.

Mass emission rates for each sample were calculated by computer. Data were screened for validity and void samples were eliminated before calculations were performed. The input data and calculated emission rates are presented in Table B-4.

2. COMPOSITION

Particulate samples for analysis of selected compounds were collected with a General Metal Works GMWL-2000 high

Table B-4. MASS EMISSION RATES FROM COTTON HARVESTING SAMPLES - COMPUTER INPUT AND RESULTS

Unit operation	$\bar{u}$, mph	x, ft	t_s, min	$\bar{\chi}$, $\mu g/m^3$	S'	M	Q
Machine picking	7	20	4.0	190	B	1	0.002171 g/s
"	5	35	4.0	30	B	1	0.00068 g/s
"	3	40	4.0	50	B	1	0.0008677 g/s
Machine stripping							
Two-row, pulling trailer	3	100	4.0	420	C	1	0.02068 g/s
"	7	60	4.0	250	C	1	0.01140 g/s
"	7	110	4.0	500	C	1	0.06825 g/s
Four-row, with basket	20	30	4.0	610	D	1	0.01032 g/s
"	20	30	4.0	1,750	D	1	0.02961 g/s
"	10	50	4.0	550	C	1	0.02578 g/s
"	10	40	4.0	480	C	1	0.01503 g/s
"	10	40	4.0	680	C	1	0.02128 g/s
"	10	40	4.0	740	C	1	0.02317 g/s
Trailer loading							
Four-row stripper	10	40	4.0	70	B	3	0.9718 g/dump

volume air sampler[a] and Nuclepore filters.[b] To aid transport and handling, the motor and filter assembly were removed from the sampler housing and mounted on a modified tripod stand. The sampler was placed in or adjacent to the cotton fields downwind of harvesting activity in a position to collect the highest possible concentration. The sampler was powered by a portable gasoline-engine electric generator placed approximately 20 m downwind from the sampler. Air flow rate was adjusted to about 0.8 m^3/min to 1.2 m^3/min, measured with a flowmeter (visi-float) calibrated with the sampler and a clean Nuclepore filter.

All samples were analyzed for total sample mass and free silica content. Analyses for pesticides and harvest-aid chemicals (defoliants and desiccants) were selected based on discussions with the respective farm operators of what chemicals had been applied to the crop. Samples from cotton picking were analyzed for parathion, methyl parathion, and DEF; samples from cotton stripping were analyzed for arsenic. Picker and stripper cotton plant samples were also analyzed for the respective chemicals for comparison with particulate samples. A top soil sample was also analyzed for free silica.

Parathion, methyl parathion, and DEF were analyzed by gas chromatography after extraction with pesticide-quality hexane. Free silica analysis was performed by low temperature ashing followed by dilution with potassium bromide and measurement by infrared spectophotometry. The arsine generator method was used for arsenic analysis. Samples were split when necessary. Results are presented in Table B-5.

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[a]General Metal Works, Inc., Cleves, Ohio.

[b]Nuclepore Corporation, Pleasanton, California.

Table B-5. COMPOSITION ANALYSIS RESULTS

Mechanical cotton picking		
Filter samples		
Total particulate concentration	161 µg/m^3	
Parathion	2.94 ppm (wt)	
Methyl parathion	1.47 ppm (wt)	
DEF	4.90 ppm (wt)	
Free silica	7.9% (wt)	
Cotton samples		
Parathion	0.219 ppm (wt)	
Methyl parathion	0.0820 ppm (wt)	
DEF	0.417 ppm (wt)	
Mechanical cotton stripping		
Filter Samples	Sample 1	Sample 2
Total particulate concentration	337 µg/m^3	202 µg/m^3
Arsenic	<0.07 ppm (wt)	<0.07 ppm (wt)
Free silica	3.4% (wt)	1.2% (wt)
Seed cotton sample		
Arsenic	22.6 ppm (wt)	
Cotton foliage sample		
Arsenic	2.31 ppm (wt)	
Texas Blackland top soil		
Arsenic	<0.3 ppm (wt)	
Free silica	13% (wt)	

The total particulate concentrations cannot be used to calculate emission rates because of inconsistent harvesting patterns and source location, and multiple source interference.

APPENDIX C

EMISSION RATE AND EMISSION FACTOR CALCULATIONS

Neither specific data nor estimated emission rates or emission factors for cotton harvesting operations were found in the literature. Therefore, values were obtained from a limited sampling program supplemented with information from the literature and contacts with cotton experts. The sources sampled were: one two-row mechanical picker with harvester-mounted basket, one tractor-mounted two-row brush-type stripper with a tractor-pulled trailer, one self-propelled four-row finger-type stripper with harvester-mounted basket, and trailer loading from the four-row stripper. Emissions from field transport were based on results from sampling of grain harvesting activities.[41] Although the number of sources sampled was small, care was taken to choose operations representative of the cotton harvesting industry so that the resulting emission estimates would be similarly representative. The rest of this appendix shows how emission rates and emission factors were derived.

1. EMISSION RATES

Emission rates were derived in the form:

$$Q = \bar{Q} \pm (CL)_{95\%} \qquad \text{(C-1)}$$

where Q = mass emission rate

$\bar{Q}$ = arithmetic mean emission rate from all samples

$(CL)_{95\%}$ = confidence limit at 95% confidence level

[41] Wachter, R. A., and T. R. Blackwood. Source Assessment: Harvesting of Grain, State of the Art, Monsanto Research Corporation, EPA Contract 68-02-1874. Dayton. Preliminary document submitted to the EPA, December 1975. 81 p.

The confidence limits are given by:

$$(CL)_{95\%} = \frac{t_{95\%}\hat{\sigma}}{\sqrt{n}} \sqrt{\frac{N - n}{N - 1}} \qquad \text{(C-2)}$$

where $t_{95\%}$ = ± values between which 95% of the area under the "Student t" distribution lies, with n - 1 degrees of freedom

$\hat{\sigma}$ = estimated population standard deviation, estimated from the samples

n = number of samples

N = number in population

The estimated population standard deviation is given by:

$$\hat{\sigma} = \sqrt{\frac{1}{n - 1} \left[\sum_{i = 1}^{n} (Q_i^2) - \frac{(\Sigma Q_i)^2}{n} \right]} \sqrt{\frac{N - 1}{N}} \qquad \text{(C-3)}$$

where Q_i = emission rate from the i^{th} sample

For cotton harvesting, the total population is large (in the thousands) and the number of samples was small (≤6). Therefore $\hat{\sigma}$ is estimated by dropping the last square root term in Equation C-3. Similarly the confidence limits are estimated by dropping the last square root term in Equation C-2. Hence, the equations used to calculate the confidence limits were:

$$(CL)_{95\%} \cong \frac{t_{95\%}\hat{\sigma}}{\sqrt{n}} \qquad \text{(C-4)}$$

where

$$\hat{\sigma} \cong \sqrt{\frac{1}{n - 1} \left[\sum_{i = 1}^{n} (Q_i)^2 - \frac{(\Sigma Q_i)^2}{n} \right]} \qquad \text{(C-5)}$$

Emission rates were calculated as described above for cotton pickers, two-row strippers pulling trailers, and four-row strippers with harvester-mounted brackets, using the data from Table B-4.

It was assumed that emissions from a given type of harvester are proportional to the rate of material handling. Two-row strippers travel at about the speed of four-row strippers.[12] Therefore, the emission rate from two-row strippers with harvester-mounted baskets was estimated as half the rate from four-row strippers.

Travel speed for field transport was estimated as 4.47 m/s (10 mph). The emission rate for field transport was calculated from the emission factor for field transport in grain harvesting at that speed.[41]

Emissions from harvester basket dumping were assumed proportional to the quantity of cotton dumped, the height of drop, and the fine trash (fine leaf and dirt trash) content of the cotton. The sample result shown in Table B-4 was obtained from the dumping of one basket on a four-row stripper into an empty trailer. This value was halved to account for an average trailer being half full. Baskets on two-row strippers are about half the size of four-row stripper baskets, and emissions for dumping the smaller baskets were assumed to be half as much. Picker baskets are about the same size as two-row stripper baskets, but picked cotton contains only half as much fine trash,[14] so emissions from picker basket dumping were assumed to be half those from a two-row stripper basket. Wind speed also affects emissions during trailer loading, but the sample in Table B-4 was taken with a wind speed of 4.47 m/s, which equals the national annual average wind speed. Confidence limits could not be assigned for trailer loading emissions since only one sample was taken.

Resulting mass emission rates are shown in Table C-1. These rates apply only while the unit operations are being performed and cannot be totaled to obtain an overall emission rate.

Table C-1. MASS EMISSION RATES FROM COTTON HARVESTING OPERATIONS, WITH 95% CONFIDENCE LIMITS

Type of harvester	Harvesting, mg/s	Basket dumping, mg	Transport, mg/s
Picker	1.24 ± 2.01	121	22.4 ± 2.2
Stripper			
Two-row, pulling trailer	33.4 ± 75.8	-[a]	22.4 ± 2.2
Two-row, with basket	10.4 ± 3.7	243	22.4 ± 2.2
Four-row, with basket	20.9 ± 7.4	486	22.4 ± 2.2

[a]Not applicable.

2. EMISSION FACTORS

Emission factors were developed in terms of mass emitted per unit area harvested. Four chief reasons explain the choice of area harvested as the emission factor base.

(1) To be useful, emission factors must be based on easily quantified variables. The most readily attainable data for cotton harvesting are weight of lint cotton harvested and area harvested.

(2) Emission factors should be based on the variables that exert the strongest influence on total emissions. Since the time and resources available precluded

quantifying the effects of several variables, it was necessary to choose a single variable for the emission factor base. Emissions from a given cotton harvesting machine with specified crop conditions are determined by the amount of trash handled. Trash is composed mainly of plant fragments and soil dust. It was concluded that the amount of trash handled is best represented by the number of cotton plants harvested, and hence area harvested under representative planting patterns, rather than the amount of cotton harvested from those plants. Therefore, it is felt that area harvested is the variable which best represents total harvester emissions within a harvest method.

(3) Total emissions from cotton trailer loading (harvester basket dumping) and field transport may be better represented by the weight of cotton produced than by the area harvested, since the total production determines the number of times these unit operations are performed. However, if emission factors are derived from emission rates for representative conditions - as they are in this document - yield, and hence production, is inherently included in the derivations. Moreover, if trailer loading and field transport emission factors are put on a common basis with harvester emission factors, the factors within a harvest method can be added to obtain an overall total emission factor.

(4) It is common practice to harvest picker cotton twice in the same season. The second harvest may be picked, stripped, or gleaned. Emissions from this harvest area overlap are easily calculated from an area-based emission factor.

Derivations of numerical emission factors are described below.

a. Harvesters

Emission factors for cotton harvesters were derived from the basic formula:

$$E_H = \frac{Q_H}{\dot{A}} \qquad \text{(C-6)}$$

where E_H = harvester emission factor, mg/m^2 or kg/km^2 harvested

Q_H = harvester emission rate, mg/s

$\dot{A}$ = harvest rate, m^2/s

Each factor in Equation C-6 actually represents the mean from a representative source, as does each quantity shown in the rest of this appendix.

The machine harvest rate is determined by

$$\dot{A} = v_H \cdot w_s \qquad \text{(C-7)}$$

where v_H = harvester speed while harvesting, m/s

w_s = width of harvester swath, m

and the width of the harvester swath is simply

$$w_s = r \cdot w_r \qquad \text{(C-8)}$$

where r = number of cotton rows in one swath, an integer

w_r = cotton row spacing, m

The representative cotton row spacing is 1.016 m (40 in.).[42] Substituting this value in Equation C-8 and combining Equations C-6, C-7, and C-8, the harvester emission factor is given by:

$$E_H = \frac{Q_H}{v_H \cdot r \cdot (1.016\ m)} \qquad (C-9)$$

b. <u>Trailer Loading</u>

Emission factors for cotton trailer loading were derived from:

$$E_L = \frac{Q_L}{A_B} \qquad (C-10)$$

where E_L = trailer loading emission factor, mg/m^2 or kg/km^2 harvested

Q_L = emission mass from one harvester basket dump, mg

A_B = area harvested in filling one harvester basket, m^2

The area harvested in filling one harvester basket is determined by

$$A_B = \frac{A_T}{n_B} \qquad (C-11)$$

where A_T = area harvested in filling one cotton trailer, m^2

n_B = number of harvester baskets to fill one trailer, an integer

and A_T is calculated as

$$A_T = \frac{C_T}{Y} \qquad (C-12)$$

[42] Personal communication. Mr. Dan Pustejovsky, Hillsboro, Texas. October 1, 1975.

where C_T = harvested cotton capacity of one trailer, kg
Y = yield of harvested cotton, kg/m^2

Combining Equations C-10 through C-12 gives:

$$E_L = \frac{Q_L \cdot Y \cdot n_B}{C_T} \tag{C-13}$$

c. <u>Field Transport of Cotton in Trailers</u>

The area-based emission factor for field transport of cotton is derived from a distance-based emission factor developed for field transport of grain.[41] The basic formula for calculating the field transport emission factor is:

$$E_T = \frac{E_{TD} \cdot D \cdot 2}{A_T} \tag{C-14}$$

where E_T = field transport emission factor based on area harvested, mg/m^2 or kg/km^2 harvested
E_{TD} = field transport emission factor based on distance traveled, mg/m
D = distance traveled in transporting one trailer of harvested cotton from the field, m
A_T = area harvested in filling one cotton trailer, m^2

In Equation C-14 the factor of two accounts for the fact that the travel distance is covered twice - once in bringing the empty trailer into the field and once in taking it out loaded. The distance traveled, D, is the mean field transport distance for a representative cotton harvesting operation, and equals one-half the side of a representative harvesting operation area: 443 m (see Section IV and Appendix D). Equation C-12 is used to find A_T .

The distance-based emission factor, E_{TD}, is 5.0 ± 1.4 mg/m (95% confidence level) at a vehicle speed of 4.47 m/s (10 mph),[41] considered the mean vehicle speed for field transport of cotton.

Substituting for E_{TD}, D, and A_T gives the equation used to calculate field transport emission factors:

$$E_T = \frac{(4{,}430 \pm 1{,}240 \text{ mg}) \cdot Y}{C_T} \qquad \text{(C-15)}$$

The emission factors and base data used in deriving them are presented in Table C-2. Average yields for picking and stripping were calculated from the U.S. total production (Tables 2 and 3) divided by the U.S. total area harvested (Table 4) for the respective harvest methods. Other data are from field observations and discussions with cotton experts. The 95% confidence limits shown for the emission factors are based on the confidence limits of emission rates (for field transport, the confidence limits of the distance-based emission factor). All quantities other than emission rates were considered absolute.

The average emission factors for stripper harvesting in Table C-2 are weighted averages based on the proportions of stripper types. It is estimated that 2% of all strippers are four-row models with mounted baskets, 59% are two-row models with mounted baskets, and 39% are two-row models pulling trailers (i.e., 60% of two-row strippers have mounted baskets and 40% pull trailers).[33] The confidence limits associated with the weighted averages were calculated as:

$$(CL)_S = \sqrt{\left[f_4 (CL)_4\right]^2 + \left[f_{2,B}(CL)_{2,B}\right]^2 + \left[f_{2,T}(CL)_{2,T}\right]^2} \qquad \text{(C-16)}$$

Table C-2. RESPIRABLE PARTICULATE EMISSION FACTORS AND SUPPORTING DATA FOR COTTON HARVESTING OPERATIONS

Parameter	Harvester type				
	Picker, two-row, with basket	Stripper			
		Two-row pulled trailer	Two-row, with basket	Four-row, with basket	Average[a]
Q_H,[b] mg/s	1.24 ± 2.01[c]	33.4 ± 75.8	10.4 ± 3.7	20.9 ± 7.4	
v_H,[d] m/s	1.34	2.23	2.23	2.23	
r	2	2	2	4	
E_H, mg/m^2 or kg/km^2 harvested	0.455 ± 0.738	7.37 ± 16.7	2.30 ± 0.82	2.31 ± 0.82	4.28 ± 6.53
Q_L,[b,e] mg	121		243	486	
Y,[f] kg/m^2 harvested	0.0630	0.0412	0.0412	0.0412	
n_B[d]	6		6	3	
C_T,[g] kg lint cotton	654	654	654	654	
E_L,[e] mg/m^2 or kg/km^2 harvested	0.0699		0.0918	0.0918	0.0560
E_T, mg/m^2 or kg/km^2 harvested	0.427 ± 0.119	0.279 ± 0.078	0.279 ± 0.078	0.279 ± 0.078	0.279 ± 0.078
E_{TOT},[e] mg/m^2 or kg/km^2 harvested	0.952	7.65	2.67	2.68	4.61

[a] Weighted average calculated as explained in text.
[b] From Table C-1.
[c] All confidence limits are for the 95% confidence level (see text).
[d] From field data and Reference 12.
[e] Lack of data precludes assignment of confidence limits.
[f] From Tables 2,3, and 4.
[g] From Reference 35.
Note: Blanks indicate not applicable.

where $(CL)_S$ = overall confidence limit for stripping

f_4, $f_{2,B}$, $f_{2,T}$ = fractions of total strippers that are four-row models, two-row models with baskets, and two-row models pulling trailers, respectively

$(CL)_4$, $(CL)_{2,B}$, $(CL)_{2,T}$ = confidence limits for four-row strippers, two-row strippers with baskets, and two-row strippers pulling trailers, respectively

Equation C-16 is not statistically correct,[43] but it provides a means for estimating overall confidence limits for the weighted averages.

[43]Serth, R. W. (Monsanto Research Corporation, Dayton). Error Propagation Formulas. Internal publication. 22 July 1975. 20 p.

APPENDIX D

SOURCE SEVERITY CALCULATIONS

1. DEFINITION

Source severity is a measure of the air quality impact of source emissions. Of particular interest is the maximum severity from a representative source, defined earlier (in Section IV) as:

$$S \equiv \frac{\overline{\chi}_{max}}{F} \qquad \text{(D-1)}$$

where S = maximum severity from representative source

$\overline{\chi}_{max}$ = maximum time-averaged pollutant concentration to which the public is exposed due to emissions from the representative source, $\mu g/m^3$

F = pollutant hazard factor, $\mu g/m^3$

The hazard factor, F, is the short-term national primary ambient air quality standard, when it exists. Only one such standard applies to cotton harvesting: the 24-hr standard for total suspended particulates, 260 $\mu g/m^3$.[21] For other pollutants, the hazard factor is the TLV adjusted for time of exposure compared to a normal 8-hr workday, and divided by 100 to account for the hazard potential to the general public compared to that for industrial workers. The representative cotton harvesting source operates a maximum of 8 hr/day, so no time adjustment is necessary. Thus the cotton harvesting hazard factors for pollutants other than total suspended particulates are given by:

$$F = 0.01(\text{TLV}) \qquad \text{(D-2)}$$

The concentration, $\bar{\chi}_{max}$, in Equation D-1 must be time-averaged for the same period at the time base of the applicable hazard factor. Since the unit operations in cotton harvesting (harvesting, trailer loading, and field transport) do not operate continuously, the time-averaged concentration is determined by:

$$\bar{\chi}_{max} = (\bar{\chi}_{max})_0 \frac{t_0}{t_F} \tag{D-3}$$

where $(\bar{\chi}_{max})_0$ = maximum average receptor concentration during source operation

t_0 = total time that source operates during a day

t_F = time base of hazard factor, 24 hr for total suspended particulates and 8 hr for other pollutants

The concentrations during operation are calculated with appropriate air pollution diffusion models.

2. CONCENTRATION CALCULATIONS

a. Harvesting and Transport

Harvesting machines and field transport of cotton are moving point sources that make it difficult to model pollutant concentrations at stationary receptors. However, with the coordinate system attached to the source, it becomes a stationary point source with a moving receptor. The integrated cross wind concentration is used to model this case, starting with the Gaussian point source model for ground level concentration from a ground level source:[36]

$$\chi(x,y) = \frac{Q}{\pi \sigma_y \sigma_z \bar{u}} \exp\left(\frac{-y^2}{2\sigma_y^2}\right) \tag{D-4}$$

where $\chi(x,y)$ = concentration at any point (x,y) in the plume, g/m^3

x = distance from source on plume centerline, m

y = distance from plume centerline, parallel to ground, m

Q = source emission rate, g/s

σ_y, σ_z = horizontal and vertical standard deviations, respectively, of the plume concentration distribution from Tables B-2 and B-3, m

$\bar{u}$ = average wind speed, assumed constant, m/s

To find the average ground level concentration on a line parallel to the y-axis at a distance, x, from the source, Equation D-4 is first integrated with respect to y across the plume:

$$\chi_A(x) = \int_{-\infty}^{\infty} \chi(x,y)\,dy = \int_{-\infty}^{\infty} \frac{Q}{\pi\sigma_y\sigma_z\,\bar{u}} \exp\left(\frac{-y^2}{2\sigma_y{}^2}\right) dy \qquad \text{(D-5)}$$

$\chi_A(x)$ is called the crosswind integrated concentration, in g/m^2, and is the area under the concentration distribution curve for ground level. In Equation D-5, Q, π, and $\bar{u}$ are constants, and σ_y and σ_z are functions of x only. Also, the concentration distribution curve is symmetric, so the integral in Equation D-5 is twice the area under one side of the curve. Thus,

$$\chi_A(x) = \frac{2\,Q}{\pi\sigma_y\sigma_z\bar{u}} \int_{0}^{\infty} \exp\left(\frac{-y^2}{2\sigma_y{}^2}\right) dy \qquad \text{(D-6)}$$

The integral in Equation D-6 is solved by integration in the complex plane. Substituting the value of the integral[44]

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[44]Standard Mathematical Tables, 14th Edition. Selby, S.M. (ed.). Cleveland, The Chemical Rubber Co., 1965. p. 345.

and simplifying,

$$\chi_A(x) = \sqrt{\frac{2}{\pi}} \frac{Q}{\sigma_z \bar{u}} \tag{D-7}$$

To find the average ground level concentration across the plume, $\chi_A(x)$ is divided by the plume width. The above derivation assumes that the plume is infinite in width with asymptotic concentrations approaching zero at $\pm \infty$. In reality, the plume has finite width. To estimate the width, the plume edges are defined as those points between which 95% of the area under the concentration distribution curve is contained. These points are at a distance $\pm 1.96\ \sigma_y$ from the plume axis, so the plume width is $3.92\ \sigma_y$. Hence, the average ground level concentration in the plume is

$$\chi_p(x) = \frac{0.95\ \chi_A(x)}{w_p} = \frac{0.95\ \chi_A(x)}{3.92\ \sigma_y} \tag{D-8}$$

where $\chi_p(x)$ = average ground level concentration at distance x from source, g/m^3

w_p = plume width, m

or, substituting Equation D-7 into Equation D-8,

$$\chi_p(x) = \frac{0.95}{3.92} \sqrt{\frac{2}{\pi}} \frac{Q}{\sigma_y \sigma_z \bar{u}} \tag{D-9}$$

The maximum receptor concentration is defined at the representative distance, D, from the source to the edge of the representative harvesting operation. Evaluating σ_y and σ_z for Class C stability (national average) at $x = D$ (for $100\ m < D < 1{,}000\ m$), and using the national annual average wind speed of 4.5 m/s, the average plume concentration at the edge of the field is:

$$(\chi_p)_{max} = \chi_p(D) = \frac{1.82\ Q}{D^{1.814}} \qquad (D-10)$$

where $(\chi_p)_{max}$ = maximum ground level concentration in the plume at the edge of the representative field, g/m^3

This concentration must be time adjusted by the fraction of time that the receptor is actually exposed to the plume. The adjustment will be shown later in this appendix.

b. Trailer Loading

Emissions from cotton trailer loading can be modeled with the Gaussian dose model for maximum ground level concentration from a ground level source:[36]

$$D_L(x) = \frac{Q_L}{\pi \sigma_y \sigma_z \bar{u}} \qquad (D-11)$$

where $D_L(x)$ = total dose at the plume centerline at distance x from the source, $g\text{-}s/m^3$

Q_L = total pollutant release, g

σ_y, σ_z, $\bar{u}$ = as defined in Equation D-4

The average concentration over the time of exposure to the puff is estimated as:

$$\chi_e(x) \cong \frac{D_L(x)}{60\ t_e} \qquad (D-12)$$

where $\chi_e(x)$ = average concentration at receptor during exposure, g/m^3

t_e = time of receptor exposure to the puff, min

Substituting the representative distance, D, for x, evaluating σ_y and σ_z as above, and combining Equations D-11 and D-12,

$$(\chi_e)_{max} = \chi_e(D) = \frac{0.05\ Q_L}{D^{1.814}\ t_e} \qquad \text{(D-13)}$$

where $(\chi_e)_{max}$ = maximum receptor concentration during exposure

The time required for the harvester to dump one basket, t_B, is greater than the time of exposure, t_e, because of the time consumed in raising and lowering the basket and other related activities. Therefore, the average concentration during the basket dumping operation is

$$(\chi_B)_{max} = (\chi_e)_{max} \frac{t_e}{t_B} \qquad \text{(D-14)}$$

where $(\chi_B)_{max}$ = average maximum receptor concentration during basket dumping

t_B = time consumed in dumping one basket

or, combining with Equation D-13,

$$(\chi_B)_{max} = \frac{0.05\ Q_L}{D^{1.814}\ t_B} \qquad \text{(D-15)}$$

The further time correction that is necessary to account for the fraction of time spent in performing the basket dumping operation will be shown below.

3. TIME AVERAGING

a. Harvesting and Trailer Loading

One harvester pass is completed each time the harvester travels the length of one side of the representative field, L. The number of harvester passes required to fill one harvester basket is found by:

$$n_p = \frac{C_T/n_B}{Lrw_rY} \tag{D-16}$$

where n_p = number of harvester passes required to fill one harvester basket

C_T = capacity of one representative cotton trailer, kg lint cotton

n_B = number of baskets required to fill one cotton trailer

L = length of one side of representative field, m

r = number of rows in harvester swath

w_r = row spacing, m = 1.016 m

Y = lint cotton yield, kg lint cotton/m^2 harvested

The time required for one harvester pass is:

$$t_p = t_L + t_t \tag{D-17}$$

where t_p = time for one harvester pass, min

t_L = time to harvest one length, L, of field, min

t_t = time for harvester to turn after each pass, min $\approxeq$ 0.3 min[a]

---

[a]From field observation.

and t_L is calculated as:

$$t_L = \frac{L}{60\ v_H} \tag{D-18}$$

where v_H = harvester speed while harvesting, m/s

The time to complete one cycle of harvesting and dumping one harvester basket is:

$$t_1 = n_p t_p + t_B \tag{D-19}$$

where t_1 = time to fill and dump one harvester basket, min
t_B = time to dump one harvester basket or change trailers, min

The number of these cycles completed in one 8-hr work day is:

$$n_1 = \frac{480}{t_1} \tag{D-20}$$

The total harvester operating time in a day, $(t_0)_H$, is:

$$(t_0)_H = n_1 (n_p t_p) \tag{D-21}$$

and the total basket dumping time in a day, $(t_0)_B$, is:

$$(t_0)_B = n_1 t_B \tag{D-22}$$

The concentrations derived previously can now be time averaged. For harvesting, the concentration in Equation D-10 is first multiplied by the fraction of time that the receptor is exposed to the plume in one harvester pass, or:

$$f_p = \frac{w_p/60\ v_H}{t_p} \tag{D-23}$$

where w_p = plume width = 3.92 σ_y,[a] m

v_H = harvester speed, m/s

The time averaged maximum concentration from harvesting is calculated by combining Equations D-3, D-10, D-21, and D-23:

$$(\overline{\chi}_{max})_H = \frac{1.82\ Q_H}{D^{1.814}} \left(\frac{w_p}{60\ v_H}\right)\left(\frac{n_1 n_p}{t_F}\right) \tag{D-24}$$

where $(\overline{\chi}_{max})_H$ = time-averaged maximum receptor concentration due to harvesting, g/m^3

Q_H = harvester emission rate while operating, g/s

For basket dumping, the time-averaged maximum concentration is calculated by combining Equations D-3, D-15, and D-22:

$$(\overline{\chi}_{max})_B = \left(\frac{0.05\ Q_L}{D^{1.814}}\right) \frac{n_1}{t_F} \tag{D-25}$$

where $(\overline{\chi}_{max})_B$ = time-averaged maximum receptor concentration due to trailer loading, g/m^3

Q_L = total pollutant release in dumping one harvester basket, g

b. Field Transport

The number of cotton trailers filled in 1 day is:

[a] As shown in Equation D-8. σ_y calculated from Table B-2 at x = D.

$$n_T = \frac{n_1}{n_B} \quad \text{(D-26)}$$

where n_T = number of trailers filled in one day

n_1 = number of harvester baskets dumped in one day, from Equation D-20

n_B = number of harvester baskets required to fill one trailer

The fraction of time, f_T, that the receptor is exposed to the plume in one transport pass is:

$$f_T = \frac{w_p}{D} \quad \text{(D-27)}$$

where w_p = plume width = 3.92 σ_y evaluated at x = D, m

D = representative transport distance = one-half of the length of one side of the representative field, m

The total time devoted to transport in 1 day is:

$$(t_0)_T = \frac{2\ n_T\ D}{60\ v_T} = \frac{n_T\ D}{30\ v_T} \quad \text{(D-28)}$$

where v_T = transport vehicle speed, m/s

The factor 2 in Equation D-28 accounts for the fact that two passes are made for each trailer filled: one to pull the empty trailer onto the field and one to pull the filled trailer out. Combining Equations D-3, D-10, D-27, and D-28:

$$(\overline{\chi}_{max})_{TR} = \frac{1.82\ Q_{TR}\ w_p n_T}{30\ D^{1.814}\ v_T t_F} \quad \text{(D-29)}$$

where $(\bar{\chi}_{max})_{TR}$ = time-averaged maximum receptor concentration due to field transport, g/m^3

Q_{TR} = transport emission rate while operating, g/s

4. RESULTS

Source severities were calculated by combining Equations D-24, D-25, and D-29 with Equation D-1, using the supporting equations presented and representative source parameters. The calculations are presented in tabular form in Table D-1 for total suspended particulates (TSP) and inert dust (ID).

Severities can be calculated for other pollutants by applying their hazard factors to the appropriate 8-hr average particulate concentrations in Table D-1, using the pollutant composition fraction. Care must be taken to apply pollutant composition fractions to the proper unit operations. For example, raw cotton dust is 100% of the composition of harvester and trailer loading emissions but is not present in transport emissions, which are all soil dust. Another case is free silica, where the only available measurement of composition fraction is for total particulate from all harvesting operations.

Raw cotton dust severities, S_{RCD}, are presented in Table D-2. Eight-hour average respirable particulate concentrations from Table D-1 were divided by the cotton dust hazard factor of 2 $\mu g/m^3$.

Free silica (S_iO_2) severities are presented in Table D-3. The 8-hr average respirable particulate concentrations from Table D-1 were divided by the respirable free silica hazard factor, given by:[22]

$$F_{S_iO_2} = \frac{100\ \mu g/m^3}{(\%\ S_iO_2) + 2} \qquad \text{(D-30)}$$

Table D-1. TABULAR SEVERITY CALCULATIONS FOR TOTAL SUSPENDED PARTICULATES AND INERT DUST

Parameter[a]	Type of harvester			
		Stripper		
	Picker, two-row	Two-row, pulled trailer	Two-row, with basket	Four-row, with basket
Operating Basis				
n_B	6	1	6	3
r	2	2	2	4
Y, kg/m^2	0.0630	0.0412	0.0412	0.0412
n_P	0.961	8.82	1.47	1.47
v_H, m/s	1.34	2.23	2.23	2.23
t_L, min	11.0	6.62	6.62	6.62
t_p, min	11.3	6.92	6.92	6.92
t_B, min	2	5	2	2
t_1, min	12.9	66.0	12.2	12.2
n_1	37.2	7.27	39.3	39.3
Harvesting				
Q_H, mg/s[b]	1.24 ± 2.01	33.4 ± 75.8	10.4 ± 3.7	20.9 ± 7.4
$(\bar{x}_{max})_H$, $\mu g/m^3$				
24-hr average	0.00222	0.0644	0.0181	0.0363
8-hr average	0.00665	0.193	0.0542	0.1089
S_H				
TSP[c]	8.54×10^{-6}	2.48×10^{-4}	6.96×10^{-5}	1.40×10^{-4}
ID[d]	1.65×10^{-5}	1.93×10^{-3}	5.42×10^{-4}	1.09×10^{-3}
Trailer Loading				
Q_L, mg[e]	121		243	486
$(\bar{x}_{max})_B$, $\mu g/m^3$				
24-hr average	0.00247		0.00525	0.0105
8-hr average	0.00742		0.01575	0.0315
S_L				
TSP	9.50×10^{-6}		2.02×10^{-5}	4.04×10^{-5}
ID	7.42×10^{-5}		1.58×10^{-4}	3.15×10^{-4}
Field Transport				
n_T	6.20	7.27	6.55	13.1
Q_{TR}, mg/s[b]	22.4 ± 6.3	22.4 ± 6.3	22.4 ± 6.3	22.4 ± 6.3
$(\bar{x}_{max})_{TR}$, $\mu g/m^3$				
24-hr average	0.00416	0.00488	0.00440	0.00880
8-hr average	0.0125	0.0146	0.0132	0.0264
S_{TR}				
TSP	1.60×10^{-5}	1.88×10^{-5}	1.69×10^{-5}	3.38×10^{-5}
ID	1.25×10^{-4}	1.46×10^{-4}	1.32×10^{-4}	2.64×10^{-4}
Total				
S_{TOTAL}				
TSP	3.40×10^{-5}	2.67×10^{-4}	1.07×10^{-4}	2.14×10^{-4}
ID	2.66×10^{-4}	2.08×10^{-3}	8.32×10^{-4}	1.67×10^{-3}

[a]The following quantities are common to calculations for all types of harvesters:

C_T = 654 kg
L = 886 m
w_r = 1.016 m
t_t = 0.3 min
D = 443 m
$w_p = 3.92(0.2089) \times D^{0.9031} = 201$ m
$D^{1.814} = 6.318 \times 10^4$
v_T = 4.47 m/s
$(t_F)_{8\text{-hr}}$ = 480 min
$(t_F)_{24\text{-hr}}$ = 1,440 min
F_{TSP} = 260 $\mu g/m^3$
F_{ID} = 100 $\mu g/m^3$

[b]With 95% confidence limits.
[c]Total suspended particulates.
[d]Inert dust.
[e]Confidence limits not available.
Note: blanks indicate not applicable.

Table D-2. RAW COTTON DUST SEVERITIES

Harvester type	Unit operation: Harvesting	Unit operation: Trailer loading	Total
Picker, two-row	0.00332	0.00371	0.00703
Stripper			
Two-row, trailer	0.0965		0.0965
Two-row, basket	0.0271	0.00790	0.0350
Four-row, basket	0.0544	0.0158	0.0702
Weighted average[a]	0.0547	0.00498	0.0597

[a]Based on 59% two-row with trailer, 39% two-row with basket, 2% four-row with basket.

Note: Blanks indicate not applicable.

Table D-3. FREE SILICA SEVERITIES

Harvester type	Free silica content, mass %	Hazard factor, μg/m³	Source severity
Picker	7.9	10.1	0.00263
Stripper	2.3	23.3	–[a]
Two-row, trailer	–[b]	–[b]	0.00891
Two-row, basket	–[b]	–[b]	0.00357
Four-row, basket	–[b]	–[b]	0.00716
Weighted average[c]			0.00572

[a]Not applicable.

[b]Not available

[c]Based on 59% two-row with trailer, 39% two-row with basket, 2% four-row with basket.

SECTION IX

GLOSSARY OF TERMS

ABSCISSION - The process by which leaves detach from plants by cell division or cleavage; defoliation.

AMERICAN-EGYPTIAN - A type of cotton grown in the U.S., predominantly in arid areas of the Southwest. It's lint is dark cream or buff in color with strong fibers 38 to 44 millimeters in length. Also called American-Pima.

BALE - Product unit of cotton gins. A bale is 218 kilograms (480 pounds) net weight of compressed lint cotton.

BASKET - Screen cage mounted on cotton harvester to collect harvested cotton.

BASKET DUMPING - Operation of unloading harvested cotton from a harvester basket into a cotton trailer.

BOLL - Capsule containing the seed and lint of a cotton plant; the end result of ovary development.

BRACT - Small scalelike modified leaf growing at the base of a flower, or in cotton, at the base of the boll.

BUR - Split wall of open boll.

BYSSINOSIS - Chronic bronchial disease caused by prolonged exposure to raw cotton, flax, or hemp dust. Symptoms are chest tightness and shortness of breath; symptoms are worst upon renewed exposure after a few days of nonexposure. Bract, stem, and leaf fragments believed to be source of causal agents.

CONFIDENCE LEVEL - Probability that a value falls within specified limits.

CONFIDENCE LIMITS - Plus-or-minus (±) value defining the limits between which a value is expected to lie, with a specified confidence level.

COTTON GIN - Facility which separates trash and seeds from lint cotton and compresses it into bales.

COTTON-TYPE FARM - A farm with at least $10,000 of annual cotton sales or at least 50% of all farm sales from cotton, excluding farms with total annual sales under $2,500.

CYCLONE - Device used to separate particles from a gas stream with centrifugal force.

DEFOLIANT - Chemical applied to plants to cause abscission.

DEFOLIATION - Process that induces abscission.

DESICCANT - Chemical applied to plants to cause desiccation.

DESICCATION - Process that kills leaves, permitting tissue drying and inhibiting abscission.

DOFFER - Part of a mechanical cotton picker which removes cotton from the picking spindles.

DOSE - Pollutant concentration multiplied by exposure time.

ELEVATOR - Mechanism of a cotton harvester which lifts harvested cotton and deposits it in a basket or trailer.

EMISSION BURDEN - Fraction of total annual mass of emissions contributed by a specific source type, by state or nationwide.

FIELD TRANSPORT - The movement of empty cotton trailers into a field and loaded trailers out of a field, within the confines of the field.

FREE SILICA - As used in this document, crystalline silicon dioxide as quartz.

GLEANER - Mechanical harvester used to salvage cotton from the ground after mechanical cotton picking.

GRADE - Classification of the quality of cotton based on color, leaf fragments and other foreign matter, and ginning preparation.

HARVEST EFFICIENCY - Fraction of cotton in a field that a harvester retrieves.

HARVEST RATE - Area harvested per unit time.

HAZARD FACTOR - Concentration used to denote the relative toxicity of a pollutant.

INERT DUST - Particulate matter with less than 1% quartz that does not produce disease or toxic effects when exposure is kept under reasonable control; also called nuisance dust.

LINT - Cotton fibers.

LINT COTTON - Harvested cotton from which seeds and trash have been removed by a cotton gin.

LINTERS - Short fibers remaining on seeds after cotton ginning.

LOCK - Distinct, separate tuft of cotton lint and seeds developed in a locule formed by the two halves of adjacent carpels in a boll. Bolls of most cultivated varieties of cotton contain three to five locks.

PICKER - Mechanical cotton harvester which picks locks of cotton from open bolls by means of rotating spindles that poke into the plants perpendicular to the plant row.

POINT SOURCE - Pollutant emitter with a definable pollutant outlet point.

RAW COTTON DUST - Dust from mechanical handling of cotton which has had no chemical or physical treatment other than mechanical cleaning.

RECEPTOR - As used in dispersion modeling, a hypothetical sensor of pollutant concentration.

RESPIRABLE PARTICULATE - In this document, particles less than 7 μm in diameter.

ROW SPACING - Centerline to centerline distance between planted rows.

SEED COTTON - Harvested cotton prior to ginning.

SEVERITY - Ratio of pollutant concentration to a hazard factor.

SILICOSIS - Chronic lung disease caused by prolonged exposure to free silica dust.

SKIMMER - Device which removes particles from a gas stream by passing the stream through a short radius π radian (180°) bend and "skimming" off the particles thrown to the outside of the bend.

SPINDLE - One of many barbed, toothed, or fluted and tapered or straight spinning cylinders that a mechanical cotton picker uses to pick locks from open bolls.

STAPLE - Fiber of cotton, wool, flax, etc., with reference to length and fineness.

STRIPPER - Mechanical cotton harvester which strips bolls from plants with pairs of rotating cylinders or stationary fingers and slits.

TOTAL SUSPENDED PARTICULATE - Airborne particles collected on a glass fiber filter with a high-volume air sampler.

TRAILER - Wagon with screen or slatted sides used to collect harvested cotton and transport it from the field to a gin.

TRAILER LOADING - Process of dumping harvested cotton from a harvester basket into a trailer.

TRASH - Plant fragments, soil dust, and other foreign matter in harvested cotton.

UPLAND - Cotton species comprising more than 99% of all cotton grown in the U.S. It's lint is almost pure white with fibers 19 to 38 millimeters long that adhere strongly to the seeds.

YIELD - Weight of lint cotton harvested per unit area.

SECTION X

CONVERSION FACTORS AND METRIC PREFIXES[45]

CONVERSION FACTORS

To convert from	to	Multiply by
gram/kilogram (g/kg)	grain/pound	7.000
gram/meter^3 (g/m^3)	grain/foot^3	4.370×10^{-1}
gram/second (g/s)	pound/hour	7.937
kilogram (kg)	bale (480-pound net weight)	4.593×10^{-3}
kilogram (kg)	pound-mass (lb mass avoirdupois)	2.205
kilogram/kilometer^2 (kg/km^2)	pound/acre	8.922×10^{-3}
kilogram/kilometer^2 (kg/km^2)	pound/mile^2	5.710
kilogram/metric ton	pound/ton	2.000
kilometer^2 (km^2)	acre	2.470×10^{2}
kilometer^2 (km^2)	mile^2	3.861×10^{-1}
meter (m)	foot	3.281
meter (m)	mile	6.215×10^{-4}
meter^2 (m^2)	acre	2.470×10^{-4}
meter^2 (m^2)	foot^2	1.076×10^{1}
meter^3 (m^3)	foot^3	3.531×10^{1}
meter/second (m/s)	mile/hour	2.237
metric ton	bale (480-pound net weight)	4.594
metric ton	pound (mass)	2.205×10^{3}
metric ton	ton	1.102
metric ton/kilometer^2	bale/acre	1.860×10^{-2}
milligram (mg)	grain	1.543×10^{-2}
person/kilometer^2	person/acre	4.047×10^{-3}
person/kilometer^2	person/mile^2	2.590
radian (rad)	degree (angle)	5.730×10^{1}

[45]Metric Practice Guide. American Society for Testing and Materials. Philadelphia. ASTM Designation: E 380-74. November 1974. 34 p.

METRIC PREFIXES

Prefix	Symbol	Multiplication factor	Example
micro	μ	10^{-6}	1 μm = 1×10^{-6} meter
milli	m	10^{-3}	1 mm = 1×10^{-3} meter
kilo	k	10^{3}	1 kg = 1×10^{3} grams

SECTION XI

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TECHNICAL REPORT DATA
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15. SUPPLEMENTARY NOTES IERL-RTP project officer for this report is Dale A. Denny, Mail Drop 61, 919/541-2547. Similar previous reports are in the EPA-600/2-76-032 series.

16. ABSTRACT The report summarizes reported data on air emissions from the mechanical harvesting of cotton, including the machine removal and collection of seed cotton from mature plants and the transport of this cotton from the field. Machine harvesting and field transport cause air pollution in the form of respirable dust, from soil and raw cotton, and agricultural chemicals contained in the cotton dust. Mechanical cotton harvesting accounted for 0.002% of the national respirable particulate emissions in 1972. Highest state contributions were 0.046% in Texas and 0.025% in Oklahoma. The air quality impact of cotton harvesting emissions was assessed in terms of source severity (the ratio of the time-averaged maximum pollutant concentration from defined representative picking and stripping sources to the primary ambient air quality standard for particulate, or to a corrected TLV for noncriteria pollutants). The highest source severity was for raw cotton dust: 0.00703 for picking, and 0.035 for stripping. Severities for other pollutants were less than 0.001. No emission control technology is applied to cotton harvesting, and no voluntary future application is expected. Average annual harvested area is expected to remain constant.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Air Pollution	Soils	Air Pollution Control	13B	08M,08G
Assessments	Agricultural Chemistry	Source Assessment	14B	
Cotton Plants		Raw Cotton	02D,06C	02A
Cottonseed	Agricultural Machinery	Cotton		
Dust		Particulate	11G	02C
Harvesting		Source Severity		

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