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MRI REPORT

Agricultural Activities Influencing Fine Particulate Matter Emissions

Draft Final Report

For U.S. Environmental Protection Agency
Air Quality Strategies and Standards Division

Attn: Mr. Kenneth R. Woodard

Work Assignment No. II-19
EPA Contract No. 68-D3-0031
MRI Project No. 4202-19

March 25, 1996

MIDWEST RESEARCH INSTITUTE 425 Volker Boulevard, Kansas City, MO 64110-2299 • (816) 753-7600

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Agricultural Activities Influencing Fine Particulate Matter Emissions

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For U.S. Environmental Protection Agency
Integrated Policy and Strategies Group
Air Quality Strategies and Standards Division
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

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Preface

This draft final report presents the results of a study performed by Midwest Research Institute (MRI) to estimate emission reduction effectiveness and control cost-effectiveness for agriculturally related sources of fine particulate matter emissions. This draft final report was prepared for Mr. Kenneth R. Woodard of the U. S. Environmental Protection Agency (EPA), under EPA Contract No. 68-D3-0031, Work Assignment No. II-19.

Dr. Chatten Cowherd, Work Assignment Leader for MRI, directed this project. Data for this study were collected, processed, and analyzed by Lance Henning, Mary Ann Grelinger, Richard Heck, and Michael Gay. This report was prepared by Dr. Cowherd, Mr. Henning, Mrs. Grelinger, and Mr. Gay.

MIDWEST RESEARCH INSTITUTE

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March 25, 1996

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Executive Summary

The purpose of this U.S. Environmental Protection Agency (EPA) work assignment was to assemble and analyze information on PM-10 emissions generated by agricultural activities and associated wind erosion. Emphasis was placed on characterizing emission and cost differences resulting from U.S. Department of Agriculture (USDA) recommended conservation practices, as compared to conventional farming.

Twelve model farm pairs were developed for major crops in areas of the United States with high soil erodibility. For each model farm pair, crop, soil and climatic conditions were the same, but one farm illustrated representative use of conventional practices while the other illustrated representative conservation practices. In this manner, estimates of emissions were developed for both conservation and conventional farming practices for a given crop and geographic location. Similarly, annual costs of conventional and conservation farming were developed from data supplied by USDA sources. Also, a model cattle feedlot was developed to illustrate the effects of wet suppression as a conservation measure.

Monthly PM-10 emissions were based on contributions from each agricultural field operation (tilling, fertilizing, burning, and harvesting) and potential wind erosion during each month that the soil is at least partially exposed. The method for characterizing the dustiness of a given field operation was based on the estimated coverage (percentage) of vegetative residue remaining on the surface after passage of the specific agricultural implement, as estimated by the USDA and the Equipment Manufacturers Institute. Similarly, the propensity of a given soil for wind erosion following each operation was reduced in relation to the coverage of the vegetative residue.

For each model farm, the information presented in this report includes:

- Typical acreage, crop rotation system, and information about the region such as terrain, precipitation, temperature, and wind speed.

- Agricultural field operations and associated implements on a month-by-month basis.

- Monthly and annual estimates of PM-10 emissions from tilling, based on scaling the default AP-42 emission factor (5.7 lb/acre) by vegetative residue remaining after each implement pass.

- Monthly and annual estimates of emissions from wind erosion, based on effectiveness of crop residues in reducing soil erosion.

- Annualized costs of crop production, by conservation and conventional farming, as determined from USDA records.

- Cost-effectiveness value associated with yearly agricultural production by conservation farming in comparison with conventional farming, expressed as $/mass of PM-10 emissions reduced.

With only a few exceptions, this study demonstrates that conservation farming costs farmers less than conventional farming, while reducing PM-10 emissions. Thus, the emission reductions and lower costs associated with many conservation practices result in negative cost-effectiveness values for major crop production in the United States.

Other conclusions and recommendations of this study are:

- Annual wind erosion emissions are usually lower than emissions from agricultural field operations. This observation also has been noted in recent annual EPA "Trends" reports, and occurs in part because median wind erosion estimates from the National Acid Precipitation Assessment Program (NAPAP) inventory represent median wind and precipitation conditions for 31 years of record.

- The median wind erosion estimates may be improved by using the 1992 National Resources Inventory (NRI), which contains more data points for land throughout the United States than the 1982 NRI used for the NAPAP inventory.

- Wind erosion estimates should replace PM-20 with PM-10.

- A default silt content of 18% used to estimate tilling emissions for each model farm should be replaced with regionally specific values. Alternatively, a relative "dustiness index" should be developed for particular soil types, as compared to soils tested to develop the AP-42 emission factor for tilling.

- Emission estimates for different agricultural tillage implements should be improved. To date, the emissions from only a few tillage implements have been characterized by field testing.

- Improved characterization of agricultural field operations would better identify specific operations associated with conventional and conservation practices.

- AP-42 emission factors for harvesting should be improved. Based on visible emissions, harvesting emissions are estimated to be of the same order of magnitude as emissions from tilling; but limited test data indicate that harvesting emissions are significantly lower than tilling emissions. Although in this study the AP-42 factor for PM-10 emissions from tilling (5.7 lb/acre) is applied to harvesting, it is anticipated that the harvesting emission factor will be reduced significantly in the final version of this report.

Section 1
Introduction

Seventy U.S. areas have been identified by the 1990 Clean Air Act Amendments (CAAA) as not attaining the National Ambient Air Quality Standard (NAAQS) for PM-10 (airborne particles with aerodynamic diameters of less than or equal to 10 μm). All PM-10 nonattainment areas have been required to prepare inventories of PM-10 emissions to support State Implementation Plans (SIPs) for reducing such emissions in future years. In many cases, the resulting emission inventories have identified agricultural activities and related wind erosion as a primary source of ambient PM-10 in the nonattainment areas. In addition, soil erosion losses have been asserted to be a major threat to the sustainability of agriculture in the United States.[1]

Agricultural activities that take place on much of the rural land areas of the United States and the ways in which they are conducted influence the amount of particulate matter (PM) emitted to the atmosphere. While wind erosion has long been recognized as a significant source, PM-10 emissions from mechanical disturbance of the land have been found to be of similar magnitude. For example, EPA's "National Air Pollutant Emission Trends, 1900-1994" report identified agricultural tilling as producing 14% and wind erosion as producing 6% of the 1994 total PM-10 emissions.[2] Conservation farming practices manage land and operations in a manner that reduces emissions, because of less intensive soil disturbance and protection of the soil by surface residue.

1.1 Information Gathering

Information gathering for this project relied on inputs from numerous agricultural experts at the state and county levels to assure that the common agricultural practices associated with various regions and crops were properly characterized. Also this study integrated the results of many published emission and economic studies by the U.S. EPA and USDA.

Project staff also interrogated the substantial Internet resources on agricultural wind erosion, soils, crops, hydrology, and farming practices. The following organizations are accessible through World Wide Web home pages and Gopher servers:

- USDA, Agricultural Research Service (ARS), Wind Erosion Research Unit (WERU), Kansas State University, Manhattan, Kansas
- USDA, ARS, National Soil Erosion Research Laboratory (NSREL), Purdue University, West Lafayette, Indiana
- USDA, Natural Resources and Conservation Service (and the National Soil Information System [NASIS], a dynamic resource of soils information for a wide range of analysis)

- USDA, Mann Library at Cornell University, a comprehensive agricultural library on the conservation reserve program (enrollment figures), crop production, farm machinery census, soils, and many other agricultural related topics.
- National Tillith Laboratory, Ames, Iowa
- National Climatic Data Center, Ashville, South Carolina

For example, WERU publishes a bibliography of wind erosion on their Internet home page that includes over 1,000 reports, many of which were pertinent to this work assignment. WERU also supports an unmoderated Internet discussion list, "wind_erosion," on wind erosion science.

1.2 Agricultural Emissions

The quantities of PM emitted to the atmosphere depend on how agricultural activities are conducted, especially the number and types of agricultural field operations that disturb the soil and the condition of the soil after each field operation. Agricultural field operations that emit PM-10 include preparing the soil for planting; maintaining a weed-free, yet nutrient-rich environment; and harvesting. Other conventional agricultural activities that contribute to atmospheric levels of PM include burning of crop residues (such as rice straw) and agricultural practices associated with animal husbandry (cattle feedlots).

Additional PM emissions are generated by the wind from any agricultural field operation that results in a newly exposed soil surface. Wind erosion emissions by Major Land Resource Area (MLRA) were estimated by Gillette *et al.* for the National Acid Precipitation Assessment Program (NAPAP).[3,4,5] Gillette used the USDA 1982 National Resources Inventory (NRI) for soil information, land use, and wind erosion parameters. (The current 1992 NRI contains over 840,000 records to give a detailed inventory of U.S. land resources.) Additionally, Gillette used the Wind Energy Resource Information System (WERIS) from the National Climatic Data Center, which contains 31 years (1948-1978) of monthly values of the mean hourly wind speed and the "pattern factor" statistic for each of the 1,432 wind-measuring locations in the United States. A modification of the NAPAP methodology is currently being used to develop the National Particulates Inventory.[6,7]

1.2.1 Conservation Practices

Crop residue management is an acknowledged conservation practice that usually reduces the number of agricultural field operations and eliminates plowing that inverts the surface layer of soil. The result is to keep sufficient vegetative residue on the soil surface and thereby to reduce wind and water erosion. For purposes of a Crop Residue Management (CRM) Survey conducted by the Conservation Technology Information Center, conventional and conservation tillage are defined, as follows:[8]

1. **Conventional tillage** leaves less than 30% surface residue after planting, either using a moldboard plow or other equipment. This class is divided into:

    a. **reduced till** (15%-29% residue), and

    b. **conventional till** (< 15% residue).

2. **Conservation tillage** is designed to maintain at least 30% surface residue after planting, or at least 1,000 lb/acre of flat, small grain surface residue equivalent during critical wind erosion periods. Conservation tillage is divided into:

    a. **mulch till**, which disturbs the soil prior to planting, but leaves at least 30% residue after planting.

    b. **ridge till**, which does not disturb the soil from the previous harvest until planting, except for nutrient injection. Seeds are planted on ridges with residue left on the surface between ridges.

    c. **no-till**, which leaves the soil undisturbed except for soil fertilization, and utilizes planting or drilling equipment that creates a narrow seedbed or slot.

USDA staff at Big Springs, Texas, have characterized the effectiveness of crop residues to reduce wind erosion. Figure 1-1 shows the relationship of soil cover to soil loss ratio (SLR) as ascertained from wind tunnel studies by Bilbro and Fryrear.[9,10]

In order to provide a consistent comparison of the emission impacts and costs of conservation farming practices, the estimates of PM-10 emission reductions must account for the effects of reduced tillage and increased protection against wind erosion that are afforded by conservation tillage as compared with conventional tillage practices. Conservation practices will reduce PM emissions because:

1. Tilling activity levels (number of annual agricultural field operations) will be reduced;

2. Tilling emission factors for some conservation tillage implements such as no-till drills may be lower than the AP-42 emission factor because of less soil agitation, as estimated from remaining surface residue;

3. Wind erosion emissions will be reduced because of the minimum 30% surface residue required by conservation tillage;

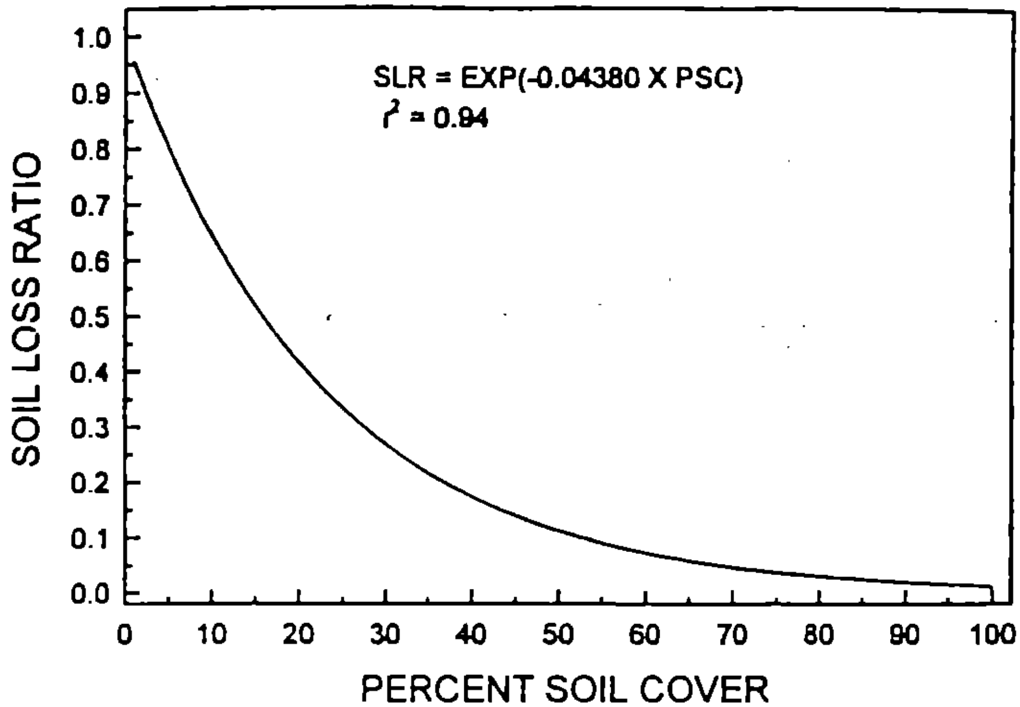

Figure 1-1. Soil Loss Ratio as a Function of Percent of Soil Covered by Nonerodible Materials

4. Limits on burning of crop residues will reduce PM emissions; and

5. Land is taken out of production; e.g., long-term revegetation.

Agricultural conservation practices that reduce PM emissions can include control measures that are not usually applied across farms in a region. These include:

- Wind barriers—natural
  Annual or perennial buffer strips (grasses; sunflowers; etc.)
  Woody or herbaceous (Osage orange; Siberian elm)
  Strip cropping (two or more crops planted together)
  Crop rotations (crops planted 1 year only because of leaving soil in friable condition and not leaving sufficient residue)
- Wind barriers—artificial (wood slats; plastic netting; rock or earthen walls, etc.)
- Emergency tillage (soil ridging and clod formation)
- Soil cover—nonvegetative (rubber "chips;" cotton gin trash)
- Soil cover—temporary vegetative (live or killed to save moisture)
- Operational modifications to soil tillage and implements
- Watering (irrigation, cattle manure, or precipitation—snow/rain)
- Chemical control (asphalts, adhesives, etc.)

- Alternative crops
- Long-term revegetation
- Less frequent than annual burning
- Soil incorporation of crop residues to reduce acres burned
- Mechanical residue removal
- Higher cattle densities

Many of these control technologies were reviewed in emission and cost-effectiveness studies and were considered in this study if they were found to be applicable to the representative farming operations.

1.2.2 Agricultural Equipment

Definitions of agricultural equipment types can be found in ASAE Standard S414.1, *Terminology and Definitions for Agricultural Tillage Implements*, which was adopted and published in 1982 (revised December 1990) by the American Society of Agricultural Engineers Cultural Practices Equipment Committee in cooperation with the Tillage Equipment Council of the Farm and Industrial Equipment Institute, 1950 Niles Road, St. Joseph, Michigan.

A comprehensive list of tillage equipment is presented in Table 1-1, together with the estimated percent surface residue remaining after tilling. Table 1-1 was developed by David Lightle of the USDA National Conservation Resource Service (NCRS) in Lincoln, Nebraska, with the consultation of other agricultural experts, and with support from the Equipment Manufacturers Institute.[11,12] Table 1-1 was originally developed as a guide to help farmers meet residue compliance requirements.

Two additional columns were added to Table 1-1 by the authors of this report to show estimated SLRs for nonfragile and fragile residues. The SLRs were calculated for each type of equipment using the model presented in Figure 1-1.

1.3 Calculation of Cost-Effectiveness of Conservation Practices

Calculation of the PM-10 emission reduction cost-effectiveness of conservation practices requires detailed information on the costs of conservation farming as compared to conventional farming for each crop and geographic area. The USDA uses cost budgets for crop production that are prepared by state agronomists or economists, and district conservationists. These budgets are supplied to the agribusiness community to adjust production, determine financial requirements, and make marketing decisions. In this manner, the cost of each agricultural field operation can be calculated using guidance on cost-sharing in the National Resource Conservation Service (NRCS) General Manual (GM 120, Subpart D).

Table 1-1. Remaining Surface Residues and Soil Loss Ratios for Agricultural Implements

IMPLEMENT	PERCENT RESIDUE REMAINING NON-FRAGILE	PERCENT RESIDUE REMAINING FRAGILE	SOIL LOSS RATIO* NON-FRAGILE	SOIL LOSS RATIO* FRAGILE
PLOWS:				
Moldboard plow	5	2.5	0.8	0.9
Moldboard plow-uphill furrow	35		0.22	
Disk plow	15	10	0.52	0.65
MACHINES WHICH FRACTURE SOIL:				
Paratill/Paraplow	85	80	0.02	0.03
"V" ripper/subsoiler 12-14" deep 20" spacing	80	70	0.03	0.05
Combination tools:				
Subsoil-chisel	60	45	0.07	0.14
Disk-subsoiler	40	15	0.17	0.52
CHISEL PLOWS WITH:				
Sweeps	77.5	55	0.03	0.09
Straight chisel spike points	70	50	0.05	0.11
Twisted points or shovels	60	35	0.07	0.22
COMBINATION CHISEL PLOWS:				
Coulter chisel plow with sweeps	70	45	0.05	0.14
Coulter chisel plow with straight chisel spike points	60	35	0.07	0.22
Coulter chisel plow with twisted points or shovels	50	25	0.11	0.33
Disk chisel plow with sweeps	65	40	0.06	0.17
Disk chisel plow with straight chisel spike points	55	35	0.09	0.22
Disk chisel plow with twisted points or shovels	40	25	0.17	0.33
UNDERCUTTERS:				
Stubble-mulch sweep or blade plows with Sweep/"V"-Blade > 30" wide	90	75	0.02	0.04
Stubble-mulch sweep or blade plows with Sweeps 20-30" wide	85	70	0.02	0.05
DISK HARROWS:				
Offset heavy plowing >10" spacing	37.5	17.5	0.19	0.46
Offset primary cutting >9" spacing	45	30	0.14	0.27
Offset finishing 7"-9" spacing	55	32.5	0.09	0.24
Tandem heavy plowing >10" spacing	37.5	17.5	0.19	0.46
Tandem primary cutting >9" spacing	45	30	0.14	0.27
Tandem finishing 7"-9" spacing	55	32.5	0.09	0.24
Light tandem disk after harvest, before other tillage	75	45	0.04	0.14
One-way disk with 12"-16" blades	45	30	0.14	0.27
One-way disk with 18"-30" blades	30	20	0.27	0.42
Single gang disk	60	50	0.07	0.11
FIELD CULTIVATORS (Including leveling attachments)				
Sweeps 12-20" used as the primary tillage operation	70	65	0.05	0.06
Sweeps or shovels 6-12" used as the primary tillage operation	55	60	0.09	0.07
Duckfoot points used as the primary tillage operation	47.5	42.5	0.12	0.16

Table 1-1 (Continued)

IMPLEMENT	PERCENT RESIDUE REMAINING		SOIL LOSS RATIO*	
	NON-FRAGILE	FRAGILE	NON-FRAGILE	FRAGILE
FIELD CULTIVATORS (continued)				
Sweeps 12-20", 2nd operation following chisel or disk	85	67.5	0.02	0.05
Sweeps or shovels, as 2nd operation following chisel or disk	75	55	0.04	0.09
Duckfoot points, as 2nd operation following chisel or disk	65	42.5	0.06	0.16
FINISHING TOOLS:				
Combination finishing tools w/ disks, shanks, and leveling attchmnts	60	40	0.07	0.17
Combination finishing tools w/ spring teeth and rolling basket	80	60	0.03	0.07
Springtooth (coil tine) harrows	70	60	0.05	0.07
Spike tooth harrows	80	70	0.03	0.05
Flex-tine tooth harrows	82.5	77.5	0.03	0.03
Roller harrow (cultipacker)	70	60	0.05	0.07
Packer roller harrow	92.5	92.5	0.02	0.02
Secondary operation 3" deep rotary tiller	50	30	0.11	0.27
Primary operation 6" deep rotary tiller	25	10	0.33	0.65
RODWEEDERS:				
Plain rotary rod	85	55	0.02	0.09
Rotary rod with semi-chisels or shovels	75	65	0.04	0.06
STRIP TILLAGE MACHINES:				
Rotary tiller, 12" tilled on 40" rows	67.5	55	0.05	0.09
ROW CULTIVATORS: (30" and Wider)				
Single sweep per row	82.5	62.5	0.03	0.06
Multiple sweeps per row	80	60	0.03	0.07
Finger wheel cultivator	70	55	0.05	0.09
Rolling disk cultivator	50	45	0.11	0.14
Ridge Till cultivator	30	15	0.27	0.52
UNCLASSIFIED MACHINES:				
Anhydrous applicator	80	57.5	0.03	0.08
Anhydrous applicator with closing disks	67.5	40	0.05	0.17
Anhydrous applicator with subsurface manure applicator	70	50	0.05	0.11
Anhydrous applicator with rotary hoe	87.5	85	0.02	0.02
Anhydrous applicator with bedders, listers, and hippers	22.5	12.5	0.37	0.58
Anhydrous applicator with furrow diker	80	80	0.03	0.03
Anhydrous applicator with mulch treader	77.5	67.5	0.03	0.05
DRILLS:				
Hoe opener drills	65	50	0.06	0.11
Semi-deep furrow drill or press drill (7"-12" spacing)	80	65	0.03	0.06
Deep furrow drill with >12" spacing	70	65	0.05	0.06
Single disk opener drills	92.5	80	0.02	0.03
Double disk opener drills (conventional)	90	70	0.02	0.05

Table 1-1 (Continued)

IMPLEMENT	PERCENT RESIDUE REMAINING		SOIL LOSS RATIO*	
	NON-FRAGILE	FRAGILE	NON-FRAGILE	FRAGILE
DRILLS: (continued)				
No-till drills and drills w/ following attchmnts in standing stubble:				
Smooth no-till coulters	90	77.5	0.02	0.03
Ripple or bubble coulters	82.5	75	0.03	0.04
Fluted coulters	77.5	70	0.03	0.05
No-till drills and drills w/ following attchmnts in flat residues:				
Smooth no-till coulters	75	60	0.04	0.07
Ripple or bubble coulters	67.5	55	0.05	0.09
Fluted coulters	62.5	50	0.06	0.11
Air seeders: (Refer to appropriate field cultivator or chisel plow depending on the type of ground engaging device used.)				
Air drills: (Refer to corresponding type of drill opener.)				
ROW PLANTERS:				
Conventional planters with runner openers	90	85	0.02	0.02
Conventional planters with staggered double disk openers	92.5	90	0.02	0.02
Conventional planters with double disk openers	90	80	0.02	0.03
No-till planters with smooth cultivators	90	82.5	0.02	0.03
No-till planters with ripple coulters	82.5	77.5	0.03	0.03
No-till planters with fluted coulters	75	67.5	0.04	0.05
Strip till planters with 2 or 3 fluted coulters	70	62.5	0.05	0.06
Strip till planters with row cleaning devices (8-14" wide bare strip w/ brushes spikes, furrowing disks, or sweeps)	70	55	0.05	0.09
Ridge till planter	50	30	0.11	0.27
CLIMATIC EFFECTS:				
Over winter weathering** following summer harvest	80	75	0.03	0.04
Over winter weathering** following fall harvest	87.5	75	0.02	0.04

*95-MP 12.01

** In northern climates with long periods of snow cover and frozen conditions, weathering may reduce residue levels only slightly, while in warmer climates, weathering losses may reduce residue levels significantly.

The Statement of Work for this work assignment stated that costs of implementing various USDA NRCS farming practices were available from an EPA report titled "Guidance Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters," EPA-840-B-92-002, January 1993. This document was reviewed for useful information, but was not found to provide appropriate cost data. Chapter 2 of the EPA coastal waters report describes conservation management measures for agricultural sources that focused on control of water pollution, as distinguished from air pollution. Conservation practices that were costed included (a) water diversions, (b) terraces, (c) waterways, (d) permanent vegetative cover, and (e) conservation tillage. Although conservation tillage costs are of interest in this study, the costs reported in the EPA coastal waters report were not relevant because all 12 states for which costs were reported lie east of the Mississippi valley, which is not usually affected by serious wind erosion problems.. In addition, "reported capital costs ($/acre)" for each state were summarized at the state level. Conservation tillage costs were somewhat out of date (1980 through 1987), but had been inflated to 1991 dollars by the ratio of indices of prices paid by farmers for other machinery, based on a ratio of 1.00 for 1977. Because of these deficiencies, the recommended EPA report was not utilized in this study.

Soil conservation programs that take farmland out of production, such as the Conservation Reserve Program (CRP), were not investigated in this study. The reader is referred to other analyses, including a well-referenced 1995 article in the *Policy Studies Journal*.[13]

1.4 Report Organization

The body of this report is organized as follows:

- Section 2 describes the concept and selection of model farms for characterization of emission reduction and cost-effectiveness studies.
- Section 3 identifies the procedures for emission and cost analyses.
- Section 4 presents the emission and cost results for each pair (conventional vs. conservation practices) of model farms.
- Section 5 summarizes the conclusions and recommendations.

Appendix A contains the survey instrument and letter of instruction used to gather information on the selected model farms and representative agricultural field operations from state agronomists and district conservationists.

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Section 2
Model Farm Development

Model plants have previously been utilized in air pollution studies as a basis for calculation of emissions from representative plant processes within a particular industry. This section describes how pairs of model farms for major crops and animal husbandry in specified areas of the United States were developed to estimate emission reduction effectiveness and cost-effectiveness of conservation practices.

2.1 Concept

The task to develop model farm pairs focused on the ultimate need to base estimated emissions on representative farming scenarios in major crop growing regions. For both the conventional and conservation version of each model farm pair, a typical crop production scenario, i.e., a sequence of specified agricultural field operations, was obtained through surveys of state agronomists and district conservationists.

The model farms represent specific cropping (or rotation) systems in particular geographic regions. Specifications of the model farms matched those already defined in the USDA Field Office Technical Guides (FOTGs) and Crop Enterprise Budgets for the identified states, so that the available farming cost calculations for conventional and conservation tillage of the respective crops could be utilized directly.

Twelve model farms producing crops were identified for calculation of tilling, harvesting, and wind erosion emissions, farming costs, and cost-effectiveness of conservation farming practices as compared to conventional practices. Confined livestock operations, which constituted the 13th model farm pair, were treated separately.

2.2 Selection Criteria

The first step was to identify geographic areas with major crop production and soil propensity for wind erosion. Annual crop production was ranked by harvested acreage.[1] Acreage and geographical areas of major production were identified. Model farm locations were then placed in high production counties with representative soils and climates within the major crop-growing regions.

Crops were ranked by nationally harvested acreage in 1993, and seven crops and one animal husbandry operation were identified for the model farms. The following list also identifies crops and animal husbandry operations that were eliminated from consideration.

Crops (1993 harvest above 1,000 K acres)

Corn	69,752 K	
~~Hay~~	~~59,679 K~~	— Eliminated because of low dust emission impact
Soybeans	57,347 K	
Winter wheat	43,811 K	
Durum, spring wheat	18,901 K	
Cotton	12,783 K	
Sorghum	9,267 K	
~~Barley~~	~~6,753 K~~	— Eliminated because of relatively small impacts
~~Oats~~	~~3,803 K~~	
Rice	2,833 K	— Included to address burning
~~Sunflower~~	~~2,486 K~~	— Eliminated because of relatively small impacts
~~Peanuts~~	~~1,690 K~~	
~~Beans, dry edible~~	~~1,622 K~~	
~~Sugar beets~~	~~1,409 K~~	
~~Potatoes~~	~~1,317 K~~	

Animal Husbandry

Cattle feedlots
~~Dairies~~ — Eliminated because of low dust impacts
~~Swine feedlots~~
~~Poultry farms~~
~~Cattle on pasture~~

2.3 Selected Model Farms

Table 2-1 lists the model farms by crop, state, county, and MLRA. Figure 2-1 indicates the locations of the 13 model farms, as overlaid on a median dust potential map prepared by Gillette and Hansen[2] (1989). Table 2-2 presents Gillette's wind erosion and dust emission results for MLRA 77, "Southern High Plains," located in Kansas, New Mexico, Oklahoma, and Texas. The eroding fraction of acreage in MLRA 77 is identified as 59.9%. Almost all of MLRA 77 is in farms and ranches. About one-third of the area, the smooth uploads, is dry-farmed to winter wheat, grain sorghum, and cotton.

Table 2-1. Model Farm Locations

Model farm	Crop	State	County	MLRA No.	MLRA Name
1	Corn	Indiana	Jasper	110	Northern Illinois and Indiana Heavy Till Plains
2	Corn	Iowa	Carroll	107	Iowa and Missouri Deep Loess Hills
3	Corn	Texas	Castro	77	Southern High Plains
4	Cotton	California	Kings	17	Sacramento and San Joaquin Valleys
5	Cotton	Texas	Lynn	77	Southern High Plains
6	Rice	California	Butte	17	Sacramento and San Joaquin Valleys
7	Sorghum	Kansas	Stevens	77	Southern High Plains
8	Soybeans	Illinois	Livingston	110	Northern Illinois and Indiana Heavy Till Plain
9	Spring wheat	North Dakota	Adams	54	Rolling Soft Shale Plains
10	Winter wheat	Kansas	Sherman	72	Central High Tableland
11	Winter wheat	Texas	Dallam	77	Southern High Plains
12	Winter wheat	Washington	Whitman	8	Columbia Plateau
13	Cattle feedlot	Texas	Deaf Smith	77	Southern High Plains

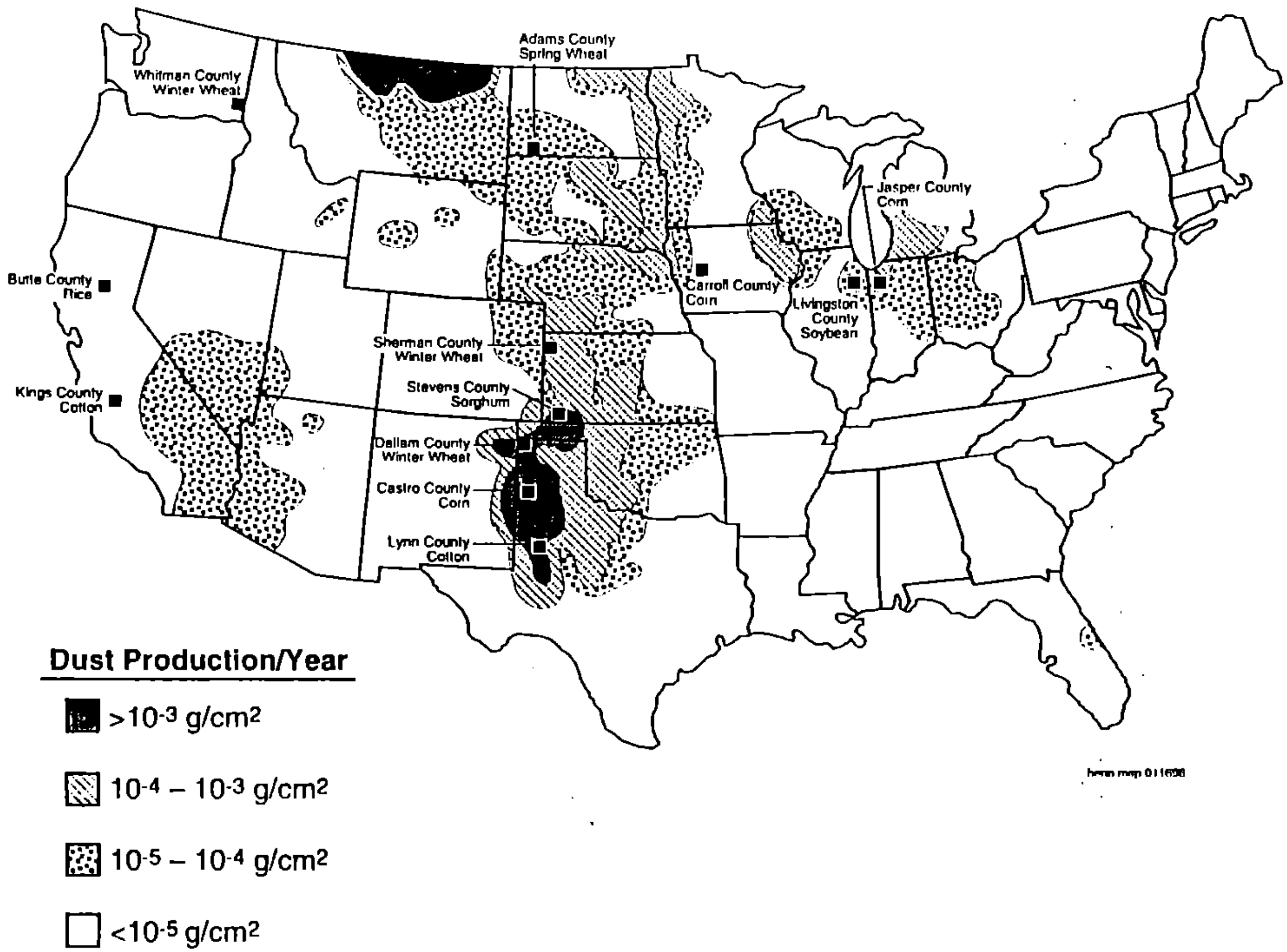

Figure 2-1. Model Farms Overlaid on Map of Median Dust Flux Emissions Developed by Gillette and Hanson[2]

Table 2-2. Example Wind Erosion Data for MLRA 77 from Gillette[4]

December 1987 Wind erosion and Dust Emission Results by MLRA			
mass in grams, area in sq cm	Filename: DUST.PRN		
developed by Dale Gillette.			
MLRA area (cm2	1.26E+15	Eroding area	
MLRA area (acr	31243820	percentage	
MLRA	77	59.9%	
Eroding area (c	7.55E+14		
MEDIAN EROSION (grams)		g/cm2	lb/acre
Jan	2.28E+10	3.02E-05	2.69
Feb	3.64E+10	4.82E-05	4.30
Mar	3.16E+11	4.19E-04	37.34
Apr	3.06E+11	4.05E-04	36.16
May	1.70E+11	2.25E-04	20.09
Jun	5.61E+09	7.43E-06	0.66
Jul	2.85E+08	3.77E-07	0.03
Aug	15810000	2.09E-08	0.00
Sep	5.85E+09	7.75E-06	0.69
Oct	3.05E+10	4.04E-05	3.60
Nov	3.29E+10	4.36E-05	3.89
Dec	3.56E+10	4.72E-05	4.21
Median YR	1.74E+12		113.67
WORST 90th percentile (grams)			
Jan	1.23E+11	1.63E-04	14.53
Feb	1.89E+11	2.50E-04	22.33
Mar	2.14E+12	2.83E-03	252.88
Apr	1.28E+12	1.70E-03	151.26
May	9.09E+11	1.20E-03	107.42
Jun	5.64E+10	7.47E-05	6.66
Jul	4.51E+09	5.97E-06	0.53
Aug	4.88E+09	6.46E-06	0.58
Sep	9.15E+10	1.21E-04	10.81
Oct	7.67E+10	1.02E-04	9.06
Nov	1.48E+11	1.96E-04	17.49
Dec	2.74E+11	3.63E-04	32.38
Median YR	3.70E+12		625.94
BEST 10th percentile (grams)			
Jan	6.32E+08	8.37E-07	0.07
Feb	2.60E+09	3.44E-06	0.31
Mar	8.69E+10	1.15E-04	10.27
Apr	2.96E+10	3.92E-05	3.50
May	2.72E+10	3.60E-05	3.21
Jun	2.17E+08	2.87E-07	0.03
Jul	4640	6.15E-12	0.00
Aug	0	0.00E+00	0.00
Sep	0.6524	8.64E-16	0.00
Oct	241700	3.20E-10	0.00
Nov	5.45E+08	7.22E-07	0.06
Dec	1.18E+09	1.56E-06	0.14
Median YR	4.01E+11		17.59

References—Section 2

1. Agricultural Statistics, United States Department of Agriculture, National Agricultural Statistics Service, Bernan Lanham, Maryland, 1994.

2. Gillette, Dale A., and Kirby J. Hanson. "Spatial and Temporal Variability of Dust Production Caused by Wind Erosion in the United States," *J. Geophys. Res.*, 94, No. D2, 2197-2206, 1989.

3. *Land Resource Regions and Major Land Resource Areas of the United States*, Agriculture Handbook 296, United States Department of Agriculture, Soil Conservation Service, Washington, DC. 1981.

4. Gillette, Dale. Text file DUST.PRN received by C. Cowherd on July 27, 1988.

Section 3
Procedure for Emission and Cost Analysis for Model Farms

This section discusses the procedures used to characterize agricultural field operations, particulate matter emissions, and operating costs for the model farms. The procedures used were consistent for both conventional and conservation farms. While the same procedures were used at all locations, information varied between localities depending on the originating information source.

3.1 Determination of Agricultural Operations

The emissions and costs associated with a particular model farm are directly related to the agricultural field operations practiced on the model farm. Agricultural field operations were determined for each model farm through consultation with local agricultural professionals. These professionals used their best judgment based on field experience to characterize the operations for each model farm. As discussed in Section 2, the local USDA NRCS district conservationists provided assistance to determine the field operations associated with particular farming practices and crops. In some cases, local Agricultural Extension Service agents provided the expertise in determining field operations. In all cases, the local experts identified field operations for the model farms by completing a survey form and/or reviewing and editing the state crop budget.•

Conventional farming practices for a local area were determined by identifying the standard practices used by the majority of farmers. Conservation practices were identified as the best erosion and emission reduction practices in common use. This criterion was loosely defined as practices being used by 10% or more of the growers. The most common conservation practices are management methods that maintain surface crop residue.

• The agriculture operations in the state crop budgets are often based on the best judgments of agricultural professionals, not on statistically gathered data. In some cases, the state crop budget is a worst-case scenario or includes operations that may be appropriate in another region of the state.

3.2 Estimation of Emissions

This section describes procedures used to estimate the emission reduction effectiveness of several USDA NRCS conservation farming practices. This entailed estimating the monthly emissions generated by agricultural field operations and by wind erosion, for both the conventional and conservation farming scenarios associated with each model farm pair.

Because of limited resources, this study was not able to consider waste generated at animal containment units that release ammonia which reacts with nitrogen and sulfur oxides and volatile organic compounds to form secondary PM in the atmosphere.

3.2.1 Estimation of Tilling Emissions

Emissions for PM-10 from agricultural tillage operations were calculated using the emission factor equation from the U.S. EPA AP-42,[1] Section 9.1, "Tillage Operations." Using a default silt content of 18% in the emission factor equation, the tilling emission factor is 5.7 lb PM-10/acre.

Emissions from different agricultural field operations were characterized in terms of their fractional soil disturbance in relation to a standard tillage operation. The technique of scaling the AP-42 emission factor for PM-10 was approximated in this study through a correlation with estimated residues remaining after a single tillage operation. This technique assumed the amount of residue remaining was an indicator of soil disturbance and an indirect indicator of dust emissions.

A one-way disk was used as a standard operation and assigned a multiplier of 1.00 because most AP-42 tests were performed using this type of equipment. For this study, it was assumed no equipment produces PM-10 emissions greater than the 5.7 lb/acre produced by a one-way disk. Tilling equipment multipliers ranged from 0.50 to 1.00 based on an inverse relationship with residue levels. In other words, high residue levels resulted in a lower multiplier. A tillage operation that leaves 100% residue on the surface results in a multiplier of 0.50; a tillage operation that leaves 0% residue results in a 1.00 multiplier for the tillage emission factor. Equipment-specific multiplying factors were applied to the PM-10 emission factor of 5.7 lb/acre and used to calculate emissions for that particular agricultural tillage operation.

Emissions from agricultural field operations other than tillage were estimated using different methods. For spray and spreader operations the unpaved road equation from AP-42 Section 13.2.2[1] was applied to the agricultural equipment traveling over the field. Particulate emissions originating from the spray or spreader material were not estimated.

3.2.2 Estimation of Wind Erosion Emissions

Wind-generated PM-10 emissions (lb/acre) were calculated for each model pair farm, reflecting conventional and conservation tillage, respectively. The median wind erosion values presented by Gillette and Hanson[2] in their file, dust.prn, which is based on 31 years of meteorological data (1948-1978), served as initial estimates of monthly emissions; example data from this file are shown in Table 2-2. The effects of crop residue in affording protection against wind erosion were evaluated in this study using the soil loss ratio shown in Figure 1-1.

Algorithms to estimate monthly median dust production values reported by Gillette and Passi[3] incorporated adjustments for surface residue. Emissions from wind erosion were assumed to be negligible whenever at least 168 g/m^2 (1,500 lb/acre) of surface residue were estimated to be present on land farmed for cotton, peanuts, soybeans, or beets. A residue coverage of at least 84 g/m^2 (750 lb/acre) was required to eliminate erosion for other crops.

Figure 2-1 presents the national median values of dust production the National Acid Precipitation Assessment Program (NAPAP) as described by Gillette and Hanson.[2] These dust fluxes were multiplied times the adjusted soil loss ratio following each agricultural field operation to determine the monthly wind erosion values for the model farms. Note that the "total dust fluxes" estimated for the NAPAP inventory apparently correspond to the particle size fraction less than 20 μm in aerodynamic diameter.

For all crops except winter wheat, it was assumed that the crop was sufficient in height within 30 days of planting to eliminate wind erosion emissions. For winter wheat in Kansas and Washington, it was assumed that the crop does not reach sufficient height before winter dormancy to eliminate wind erosion effects. Once the winter wheat enters spring growth, wind erosion emissions are no longer regarded.

3.2.3 Estimation of Harvesting Emissions

The AP-42 emission factors for Grain Harvesting cited in the Fifth Edition of AP-42,[1] Section 9.3.2, are three orders of magnitude lower than tillage emissions. Based on visible dust emissions, experienced agricultural and air quality professionals consider the harvesting emissions factor suspect. A substitute grain harvesting emission factor equal to the base tillage emission factor of 5.7 lb/acre was used for this study. Within the same crop, the estimated harvesting emissions have little effect on comparisons between farming practices.

New PM-10 emission tests of cotton picking and cotton stalk cutting conducted by the University of California, Davis, report emission factors of 39 kg/km^2 (0.35 lb/acre) and 78 kg/km^2 (0.70 lb/acre), respectively.[4] These new emission factors were applied to both California and Texas cotton farms.

CARB emission estimates from rice chopping are based on the engineering judgment of rice growing professionals to be 1.25 times the CARB/EPA emission factor for tilling.[5] The CARB/EPA adjusted tilling emission factor for PM-10 is equal to 4.1 lb/acre, thus the chopping emission factor equals 5.1 lb/acre.

3.2.4 Estimation of Burning Emissions

For the selected model farms, only California rice farmers burn vegetative residue as part of their agricultural operations. From testing, CARB estimates a PM-10 emission factor of 24 lb/acre for burning dry rice straw. Rice straw is generally burned when dry; however, if the rice straw is wet, the PM-10 emissions increase up to 77 lb/acre.[5]

3.3 Estimation of Costs

Costs were estimated using local crop budgets prepared by district conservationists, state economists, and/or extension service agents, generally with guidance from the USDA National Resource Conservation Service Field Office Technical Guides (FOTGs). Costs were determined for both conventional and conservation farms. As discussed above, the field operations reported in the crop budgets often are not based on actual statistical data, but on the best judgments of the persons compiling the budgets

Costs from the cost budgets for individual field operations and materials were used in this study; however, the field operations and materials were identified by the local district conservationists, as discussed above. The annual cost of crop production, in $/acre, for a particular model farm is the sum of the material costs (seed, chemicals, etc.), the agricultural field operation costs, and interest associated with operating capital.

For this study, many costs were assumed to be the same for both conventional and conservation cropping practices. These costs, such as land costs, equipment storage, management charges, crop-drying costs, and soil tests, were not included in the analysis. Also, costs for some of the minor and irregular operations, such as delivering the seed to the field, spot spraying, and use of an ATV to check fields, were not included.

While the basic format for cost budgets in different states is similar, variations exist in the detailed costs included when comparing crop budgets for different states. Many cost budgets had insufficient information to standardize the data. For example, the tractor size and the width of the implement used for different field operations were not always reported. Also, no adjustments could be made to normalize the year of the costs presented, although all costs were in a 3-year range from 1992 to 1995.

3.4 Cost-Effectiveness

Cost-effectiveness is defined as the ratio of the annualized cost of emission control to the amount of emission reduction achieved. Cost-effectiveness calculations allow an industry to compare and identify suitable the most control methods. Mathematically, cost-effectiveness is calculated by:

$$C* = \Delta C/\Delta PM$$

where:

	$C*$	=	cost-effectiveness, \$/mass of emissions reduced
	ΔC	=	annualized cost of the emission-reducing conservation measure above the cost of the conventional method, \$/year
	ΔPM	=	reduction in annual PM-10 emissions, mass/year

The total cost difference was calculated from a comparison between conventional farming practices and conservation practices for each respective model farm pair. The detailed farming costs developed from the state crop budgets were used to make the comparison. A positive ΔC represents the additional costs of conservation practices; whereas, a negative ΔC indicates that conservation practices reduce the farm operator's costs.

The reduction in annual emissions was calculated as the difference in annual emissions between a conventional and a conservation model farm pair. The emissions for one crop year from agricultural field operations and wind erosion were summed for each model farm pair and compared. The difference in emissions between the conventional and conservation model farm was represented as ΔPM.

References—Section 3

1. "Compilation of Air Pollutant Emission Factors, Volume I: Stationary Point and Area Sources." AP-42 Fifth Edition, U.S. EPA Office of Air Quality Planning and Standards, Research Triangle Park, NC. January 1995.

2. Gillette, Dale A., and Kirby J. Hanson. "Spatial and Temporal Variability of Dust Production Caused by Wind Erosion in the United States," *J. Geophys. Res.*, 94, No. D2, 2197-2206, 1989.

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4. Ashbaugh, Lowell, Robert Matsumura, Terry James, Omar Carvacho, and Robert Flocchini, "Modeling PM_{10} Dust Emissions from Field Harvest Operations," presented at the International Conference on Air Pollution from Agricultural Operations, sponsored by Midwest Plan Service, Kansas City, MO, February 7-9, 1996.

5. "Progress Report on the Phase Down of Rice Straw Burning in the Sacramento Valley Air Basis, 1992-1994." Final draft report to the California Legislature. Submitted by California Air Resources Board and the California Department of Food and Agriculture. September 1995.

Section 4
Results

The following section briefly discusses each of the 13 model farm pairs selected for this study. Conditions and common practices for each model farm location are addressed. Farming operations, estimated costs, and estimated particulate emissions are presented for both conventional and conservation model farms. From the estimated costs and particulate emissions, the cost-effectiveness of reducing particulate emissions by converting from conventional to conservation farming practices was calculated for each of the 13 model farms.

The California cotton farm has only a conventional model, since there are generally no conservation methods currently practiced on California cotton farms. The California rice farm differs from the other farms by focusing its comparison on rice burning versus nonburning. Also, cattle feedlots differ from the other model farms, by focusing on the effects of wet suppression as a conservation method.

4.1 Wheat

Wheat acres harvested in 1993 in the United States totaled nearly 63 million acres. National rankings in total wheat acres harvested for the states selected for model farms were: Kansas ranked first, North Dakota second, Texas fifth, and Washington eighth.[1] North Dakota was first in 1995 and is expected to be first in 1996 due to very dry conditions in Kansas, Oklahoma, and Texas. During dry weather, portions of these states have some of the most severe wind erosion potential in the nation. Farming practices for wheat are similar in different areas of the country. Conservation practices for wheat are tracked under the small grain category. In the United States, conservation practices are used on 25% of all small grain acres.[4]

4.1.1 Kansas Winter Wheat

In 1993, Kansas farmers harvested 11.1 million acres of wheat, which was almost 18% of the wheat acres harvested in the United States.[1] Model farm pair No. 10 is located in MLRA 72 in Sherman County, Kansas. Sherman County is comprised mostly of farmland on which 193,000 acres of wheat were harvested in 1994. Dryland wheat accounts for 87% of the wheat acres in Sherman County and 94% of the wheat acres in Kansas. The average size farm in Sherman County is 1,243 acres, which is larger than the state's average farm size of 735 acres.[5]

The land in Sherman County is comprised of a loess-mantled tableland, and most of the area is level to gently rolling. Ustolls are the most common soil type and are well drained and medium to fine textured. The propensity for wind erosion is high in Sherman County and much of Western Kansas. Precipitation is low and erratic from year to year. It averages 21 in, two-thirds occurring from April through August. The annual average wind speed is 12 mph, and the average temperature is 52°F.[3]

Conventional farming practices, implements/machinery, and associated costs/acre totaling $96.81 are listed in Table 4-1.[6,7] Conventional practices for dryland wheat in Sherman County generally include deep tillage, shallow tillage, and planting. Sherman County farmers used conventional methods on 48% of their wheat acres.[4]

Conservation farming practices, implements/machinery, and associated costs/acre totaling $84.63 are listed in Table 4-2.[6,7] Conservation practices used in Sherman County include no-till and mulch till, but only 2% of the wheat acres used no-till methods. Mulch till accounted for 50% of the wheat acres in Sherman County; therefore, the mulch till practice was selected for the model farm. At the state level, 25% of the wheat acres use conservation practices.[4]

A wheat-fallow rotation is used on a majority of both conservation and conventional wheat acres in Sherman County. It is estimated that 83% of all wheat acres use a wheat-fallow rotation. Cost data in Tables 4-1 and 4-2 represent farming operations for a full wheat season only; therefore, field operations for a continuous wheat crop or other rotations would be similar to the wheat-fallow rotation operations.

Estimated particulate emissions from tillage and wind erosion are presented for conventional practices in Table 4-3[6,7] and for conservation practices in Table 4-4[6,7] Results show annual conventional emissions total 35.3 lb/acre and annual conservation emissions total 21.8 lb/acre. Only a small percentage of emissions are attributed to wind erosion. Wind erosion emissions account for 0.43 lb/acre for conventional practices and 0.24 lb/acre for conservation practices. Total estimated emissions are reduced 38% with conservation practices.

The cost-effectiveness calculation for reduction of particulate emissions per acre is as follows:

$$\$82.21 - \$96.81 / 35.3 \text{ lb/year} - 21.8 \text{ lb/year} = - \$1.08/\text{lb}$$

The negative value of cost-effectiveness indicates a cost savings associated with the emission reduction.

4.1.2 Texas Winter Wheat

In 1993, Texas farmers harvested 3.7 million acres of wheat, which was almost 6% of the wheat acres harvested in the United States.[1] Model farm pair No. 11 is located in MLRA 77 in Dallam County, Texas. Dallam County is comprised mostly of farmland

Table 4-1. Kansas Winter Wheat—Conventional Tillage 1995 Cost[6,7]

Cost category		Cost/acre	
Input			
	Fertilizer—Anhydrous Ammonia	55 lb @ 0.18/lb	$9.90
	Phosphate	20 lb @ 0.18/lb	$3.60
	Potash	12 lb @ $0.13/lb	$1.56
	Wheat Seed	70 lb @ $0.15/lb	$10.50
	Herbicide	2.0 pints	$7.11
	Interest on Operating Capital (9%)		$3.11
		SUBTOTAL	$35.78
Machinery			
	Disk, Offset—16 ft	Weed Control	$6.09
	Disk, Offset—16 ft	Weed Control	$6.09
	Disk, tandem—22 ft	Bed Prep/Weed Control	$5.52
	Anhydrous Ammonia Applicator	Fertilizer Application	$6.66
	Field Cultivator—27 ft (sweep)	Bed Prep	$3.10
	Grain Drill—24 ft	Planting	$5.62
	Fertilizer Spreader—40 ft	Fertilizer Application	$2.11
	Sprayer Pull Type—30 ft	Herbicide Application	$1.78
	Combine—Small Grain (including transportation)	Harvesting	$24.06
		SUBTOTAL	$61.03
Total Costs			$96.81

Table 4-2. Kansas Winter Wheat—Conservation Tillage 1995 Cost[6,7]

Cost category		Cost/acre	
Input			
	Fertilizer—Anhydrous Ammonia	55 lb @ 0.18/lb	$9.90
	Phosphate	20 lb @ 0.18/lb	$3.60
	Potash	12 lb @ $0.13/lb	$1.56
	Wheat Seed	70 lb @ $0.15/lb	$10.50
	Herbicide	2.0 pints	$7.11
	Interest on Operating Capital (9%)		$3.11
		SUBTOTAL	$35.78
Machinery			
	Field Cultivator	Bed Prep/Weed Control	$3.10
	Anhydrous Ammonia Applicator	Fertilizer Application	$6.66
	Field Cultivator—27 ft (sweep)	Bed Prep	$3.10
	Grain Drill—24 ft	Planting	$5.62
	Fertilizer Spreader—40 ft	Fertilizer Application	$2.11
	Sprayer Pull Type—30 ft	Herbicide Application	$1.78
	Combine—Small Grain (including transportation)	Harvesting	$24.06
		SUBTOTAL	$46.43
Total Costs			$82.21

Table 4-3. Calculation of Annual Emissions from Kansas Winter Wheat Farm—Conventional Tillage[6,7]

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
7/94	Disc, Offset	F8	Residue Management	5.7	1.00	38 [85 × 0.45]	0.19	5.70
7/94	Disc, Offset	F8	Bed Prep/Weed Control	5.7	1.00	17 [38 × 0.45]	0.47	5.70
7/94		-	Wind Erosion	0.0080	-	17	0.47	0.004
8/94	Disc, Tandem	F4	Bed Prep	5.7	1.00	6 [17 × 0.375]	0.77	5.70
8/94		-	Wind Erosion	0.0007	-	6	0.77	0.001
9/94	Anhydrous NH_3 Applicator	L1	Fertilizer Application	5.7	0.7	5 [6 × 0.80]	0.8	3.990
9/94	Field Cultivator	E2	Shallow Tillage/Bed Prep	5.7	0.65	4 [5 × 0.85]	0.84	3.71
9/94	Drill	M2	Planting	5.7	0.7	3 [4 × 0.80]	0.88	3.99
9/94	Spreader	-	Fertilizer Application	~ 0.208 lb/acre[c]	-	3	0.88	0.21
9/94		-	Wind Erosion	0.2505	-	3	0.88	0.220
10/94		-	Wind Erosion	0.1007	-	25[d]	0.33	0.033
11/94		-	Wind Erosion	0.1579	-	25[d]	0.33	0.052
12/94		-	Wind Erosion	0.0981	-	25[d]	0.33	0.032
1/95		-	Wind Erosion	0.1084	-	25[d]	0.33	0.036
2/95		-	Wind Erosion	0.1525	-	25[d]	0.33	0.050
3/95 to 7/95		-	Wind Erosion	0	-	100	0	0
3/95	Sprayer	-	Herbicide Application	~ 0.208 lb/acre[c]	-	100	0	0.21
7/95	Combine	T2	Harvesting	5.7	1.0	85	0.02	5.70
Total Annual Estimated Emissions (lb/acre)								35.3

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph.; silt = 18%.
[d] Germinated wheat in dormancy.

Table 4-4. Calculation of Annual Emissions from Kansas Winter Wheat Farm—Conservation Tillage[6,7]

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
8/94		-	Wind Erosion	0.0007	-	95	0.02	0
8/94	Field Cultivator	E2	Bed Prep	5.7	0.65	81 [95 × 0.85]	0.03	3.71
9/94	Anhydrous NH_3 Applicator	L1	Fertilizer Application	5.7	0.7	65 [81 × 0.80]	0.06	3.99
9/94	Field Cultivator	E2	Bed Prep	5.7	0.65	55 [65 × 0.85]	0.09	3.71
9/94	Drill	M2	Planting	5.7	0.7	44 [55 × 0.80]	0.15	3.99
9/94	Spreader	-	Fertilizer Application	~ 0.208 lb/acre[c]	-	44	0.15	0.21
9/94		-	Wind Erosion	0.2505	-	44	0.15	0.038
10/94		-	Wind Erosion	0.1007	-	25[d]	0.33	0.033
11/94		-	Wind Erosion	0.1579	-	25[d]	0.33	0.052
12/94		-	Wind Erosion	0.0981	-	25[d]	0.33	0.032
1/95		-	Wind Erosion	0.1084	-	25[d]	0.33	0.036
2/95		-	Wind Erosion	0.1525	-	25[d]	0.33	0.050
3/95 to 7/95		-	Wind Erosion	0	-	100	0	0
3/95	Sprayer	-	Herbicide Application	~ 0.208 lb/acre[c]	-	100	0	0.21
7/95	Combine	T2	Harvest	5.7	1.0	95	0.02	5.70
Total Annual Estimated Emissions (lb/acre)								21.8

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph.; silt = 18%.
[d] Germinated wheat in dormancy.

on which 106,400 acres of wheat were harvested in 1994. Dryland winter wheat accounts for 26% of the harvested wheat acres in Dallam County and 78% of the harvested wheat acres in Texas. Dryland practices will be characterized for this study, because they have a higher propensity for wind erosion and apply to the majority of wheat acres in Texas. In Texas, the acres of wheat planted are much greater than the acres of wheat harvested. For example, in 1994, Dallam County planted 146,400 acres to wheat, but harvested only 106,400 acres. Most of these unharvested acres were used for livestock grazing. Also, some of the unharvested acres are used as a cover crop on cotton land. The average size farm in Texas is 639 acres.[8]

The land in Dallam County is generally a smooth high plain that gently slopes. The soils are mostly Ustolls and Ustalfs, both well drained.[2] Precipitation is somewhat erratic and moderately low with an annual average of 17 in. The area has a high propensity for wind erosion. The annual average wind speed is 14 mph and the average temperature is 59°F.[3]

Conventional farming practices, implements/machinery, and associated costs/acre totaling $87.96 are listed in Table 4-5.[9,10] Conventional practices for dryland wheat generally include deep tillage, shallow tillage, planting, and cultivating. Dallam County farmers used conventional methods on 46% of their wheat acres.(4)

Conservation farming practices, implements/machinery, and associated costs/acre totaling $73.44 are listed in Table 4-6.[9,10] Since mulch till is the only conservation practice used on wheat acres in Dallam County, it was selected for the model farm. Mulch till accounted for 54% of the wheat acres in Dallam County. Texas has nearly 43% of its wheat acres using conservation practices and 3% using no-till methods.[4]

Crop rotations are estimated to be used by nearly 25% of the wheat farmers.[10] It is estimated that 36% of all harvested wheat acres are continuously cropped and 13% of the harvested wheat acres use a wheat-fallow rotation.[8] A common rotation is a wheat-sorghum-fallow rotation.[10] A wheat-corn rotation is also used regularly.[10] Cost data in Tables 4-5 and 4-6 represent farming operations for a full wheat season only; thus, field operations for the wheat season in a wheat-fallow rotation or other rotations would be similar to the continuous cropping operations.

Estimated particulate emissions from tillage and wind erosion are presented for conventional practices in Table 4-7[9,10] and for conservation practices in Table 4-8.[9,10] Results show annual conventional emissions total 38.1 lb/acre and annual conservation emissions total 21.9 lb/acre. Less than 3% of the emissions are attributed to wind erosion. Wind erosion emissions account for 1.0 lb/acre for conventional practices and 0.6 lb/acre for conservation practices. Total estimated emissions are reduced by 43%.

The cost-effectiveness calculation for reduction of particulate emissions per acre is as follows:

$$\$73.44 - \$87.96 / 38.1 \text{ lb/year} - 21.9 \text{ lb/year} = - \$0.90/\text{lb}$$

The negative value of cost-effectiveness indicates a cost savings associated with the emission reduction.

Table 4-5. Texas Winter Wheat—Conventional Tillage Dryland 1994 Cost[9,10]

Cost category		Cost/acre	
Input			
	Anhydrous Ammonia	275 lb @ $.105/lb	$28.9
	Wheat Seed	.5 bu @ $13.5/bu	$6.63
	Interest on Operating Capital (9%)		$2.21
		SUBTOTAL	$37.74
Machinery			
	Discing	Residue Management	$6.22
	Chisel Plow	Bed Prep	$4.31
	Field Cultivator	Bed Prep	$3.02
	Anhydrous Ammonia Application	Fertilizer	$3.00
	Lister	Bed Prep	$4.30
	Drill	Planting	$9.35
	Field Cultivator	Weed Control	$3.02
	Combine	Harvesting	$17.00
	(including transportation)		
		SUBTOTAL	$50.22
Total Costs			$87.96

Table 4-6. Texas Winter Wheat—Conservation Tillage Dryland 1994 Cost[9,10]

Cost category		Cost/acre	
Input			
	Anhydrous Ammonia	275 lb @ $.105/lb	$28.90
	Wheat Seed	.5 bu @ $13.5/bu	$6.63
	Interest on Operating Capital (9%)		$2.21
		SUBTOTAL	$37.74
Machinery			
	Field Cultivator	Bed Prep	$3.02
	Anhydrous Ammonia	Fertilizer	$3.00
	Rod Weeder	Bed Prep	$3.33
	Drill	Planting	$9.35
	Combine	Harvesting	$17.00
	(including transportation)		
		SUBTOTAL	$35.70
Total Costs			$73.44

Table 4-7. Calculation of Annual Emissions from Texas Wheat Farm—Conventional Tillage[9,10]

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
5/93		–	Wind Erosion	20.0187	–	85	0.02	0.40
6/93		–	Wind Erosion	0.6006	–	85	0.02	0.013
7/93	Disc	F2	Residue Management	5.7	1.05	38 [85 × 0.45]	0.19	5.70
7/93	Chisel Plow	C2	Bed Prep	5.7	0.80	27 [38 × 0.70]	0.31	4.56
7/93		–	Wind Erosion	0.0336	–	27	0.31	0.010
8/93	Field Cultivator	G4	Bed Prep	5.7	0.65	23 [27 × 0.85]	0.37	3.71
8/93		–	Wind Erosion	0.0019	–	23	0.37	0.001
9/93	Anhydrous NH_3 Applicator	L1	Fertilizer Application	5.7	0.70	18 [23 × 0.80]	0.45	4.56
9/93	Lister	L5	Bed Prep	5.7	1.00	4 [18 × 0.23]	0.84	5.70
9/93	Drill	M5	Planting	5.7	0.60	4 [4 × 0.90]	0.84	3.42
9/93	Field Cultivator	G4	Weed Control	5.7	0.65	3 [4 × 0.80]	0.88	3.71
9/93		–	Wind Erosion	0.6889	–	3	0.88	0.61
10/93 to 4/94		–	Wind Erosion	0	–	100	0	0
5/94	Combine	T1	Harvest	5.7	1	85	0.02	5.70
Total Annual Estimated Emissions (lb/acre)								38.10

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.

Table 4-8. Calculation of Annual Emissions from Texas Wheat Farm—Conservation Tillage[9,10]

AFO Date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
5/93		–	Wind Erosion	20.0187	–	85	0.02	0.40
6/93		–	Wind Erosion	0.6606	–	85	0.02	0.013
7/93	Field Cultivator	G1	Bed Prep	5.7	0.80	60 [85 × 0.70]	0.07	4.56
7/93		–	Wind Erosion	0.0336	–	60	0.07	0.002
8/93	Anhydrous NH_3 Applicator	L1	Fertilizer Application	5.7	0.70	48 [60 × 0.80]	0.12	3.99
8/93		–	Wind Erosion	0.0019	–	48	0.12	0.003
9/93	Rod Weeder	I1	Bed Prep	5.7	0.65	41 [48 × 0.85]	0.17	3.71
9/93	Drill	M5	Planting	5.7	0.60	37 [41 × 0.90]	0.20	3.42
9/93		–	Wind Erosion	0.6889	–	37	0.20	0.14
10/93 to 4/94		–	Wind Erosion	0	–	100	0	0
5/94	Combine	T1	Harvest	5.7	1.0	85	0.02	5.70
Total Annual Estimated Emissions (lb/acre)								21.9

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.

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4.1.3 Washington Winter Wheat

In 1993, Washington State farmers harvested 2.8 million acres of wheat, which was almost 4% of the wheat acres harvested in the United States.[1] Model farm pair No. 12 is located in MLRA 8 in Whitman County, Washington. Whitman County is comprised mostly of farmland on which 488,000 acres of wheat were harvested in 1994. Dryland wheat accounts for 99% of the wheat acres in Whitman County and 90% of the wheat acres in Washington. The average size farm in Washington is 469 acres.[11]

The land in Whitman County is generally level to steeply sloping and composed of loess- and ash-mantled plateaus. Xerolls are the most common soil type and are well to excessively drained.[2] Precipitation occurs mostly in the winter months and averages 15 in annually. The average annual wind speed is 5 mph, and the average temperature is 49°F.[3]

Conventional farming practices, implements/machinery, and associated costs/acre totaling \$137.99 are listed in Table 4-8.[12,13] Conventional practices for dryland wheat in Whitman County generally include deep tillage, shallow tillage, and planting. Whitman County farmers used conventional methods on 74% of their wheat acres.[4]

Conservation farming practices, implements/machinery, dates of field operations, and associated costs/acre totaling \$163.28 are listed in Table 4-9.[12,13] Washington winter wheat is one of the few model farm pairs reporting higher costs associated with conservation practices. The differences between conventional and conservation practices may be accounted in part by higher herbicide usage and an aerial application used in the conservation practices. No-till practices are used on 4% of the wheat acres in Whitman County, and mulch till practices are used on 22% of the wheat acres.[4] No-till practices were selected for the model farm.

A crop rotation method is used on a majority of both conservation and conventional wheat acres in Whitman County. The most common rotation is a wheat-pea rotation, but other rotations are used in the county including a wheat-fallow rotation. Actual tillage operations related to wheat are similar in different wheat-cropping rotations. Cost data in Tables 4-9 and 4-10 represent farming operations for a full wheat season only; therefore, field operations for a continuous wheat crop or other rotations would be similar to the wheat-pea rotation.

Estimated particulate emissions from tillage and wind erosion are presented for conventional practices in Table 4-11[27,28] and for conservation practices in Table 4-12.[27,28] Results show annual conventional emissions total 14.1 lb/acre and annual conservation emissions total 10.3 lb/acre. No emissions are attributed to wind erosion based on the NAPAP inventory. This is in part due to the estimate of vegetative residue estimated to be in place by the NAPAP study during the period the wind erosion emissions are calculated.

The cost-effectiveness calculation for reduction of particulate emissions per acre are as follows:

$$\$163.28 - \$137.99 / 14.1 \text{ lb/year} - 10.3 \text{ lb/year} = \$6.66/\text{lb}$$

Table 4-9. Washington Winter Wheat—Conventional Tillage 1995 Cost[12,13]

Cost category		Cost/acre	
Input			
	Fertilizer—Nitrogen	100 lb @ 0.31/lb	$31.00
	Phosphate	15 lb @ 0.45/lb	$6.75
	Sulfur	15 lb @ $0.35/lb	$5.25
	Wheat Seed	85 lb@ $0.14/lb	$11.90
	Herbicide (Buctril, Surfactant, Harmony)		$13.59
	Interest on Operating Capital (9%)		$6.51
		SUBTOTAL	$75
Machinery			
	Fertilizer Applicator	Fertilizer Application	$6.27
	Field Cultivator—36 ft	Bed Prep	$5.37
	Drill, double disc—36 ft	Planting	$8.15
	Sprayer—80 ft	Herbicide Application	$2.51
	Combine—22 ft (including transportation)	Harvesting	$40.69
		SUBTOTAL	$62.99
Total Costs			$137.99

Table 4-10. Washington Winter Wheat—Conservation Tillage 1995 Cost[12,13]

Cost category		Cost/acre[a]	
Input			
	Fertilizer —Nitrogen	110 lb @ 0.31/lb	$34.10
	Phosphate	35 lb @ 0.45/lb	$15.75
	Sulfur	15 lb @ $0.39/lb	$5.85
	Wheat Seed	82 lb @ $0.14/lb	$11.48
	Herbicide (Buctril, Surfactant, Roundup)		$28.37
	Interest on Operating Capital (9%)		$6.51
		SUBTOTAL	$102.06
Machinery			
	Sprayer—60 ft	Herbicide	$3.35
	Fertilizer Applicator	Fertilize	$5.77
	No-Till Planter	Plant	$8.15
	Sprayer—60 ft	Herbicide	$3.35
	Aerial Spray	Herbicide	$4.01
	Combine—22 ft Including Transportation	Harvest	$36.59
		SUBTOTAL	$61.22
Total Costs			$163.28

[a] No-till data was obtained from 1992 Cost Budgets and prices were adjusted using 1995 Cost Budget data.

Table 4-11. Calculation of Annual Emissions from Washington Winter Wheat Farm—Conventional Tillage[27,28]

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
8/94		-	Wind Erosion	0	-	85	0	0
9/94	Spreader	-	Fertilizer Application	~ 0.208 lb/acre[c]	-	85	0.02	0.21
9/94	Field Cultivator	G1	Bed Prep	5.7	0.80	60 [85 × 0.70]	0.07	4.56
9/94	Drill	M5	Planting	5.7	0.60	54 [60 × 0.90]	0.09	3.42
9/94			Wind Erosion	0			0.09	0
10/94		-	Wind Erosion	0	-	79 [54 + 25][d]	0.03	0
11/94		-	Wind Erosion	0	-	79[d]	0.03	0
12/94		-	Wind Erosion	0	-	79[d]	0.03	0
1/95		-	Wind Erosion	0	-	79[d]	0.03	0
2/95		-	Wind Erosion	0	-	79[d]	0.03	0
3/95 to 7/95		-	Wind Erosion	0	-	100	0	0
4/95	Sprayer	-	Herbicide Application	~ 0.208 lb/acre[c]	-	100	0	0.21
8/95	Combine	T1	Harvesting	5.70	1	85	0.02	5.70
Total Annual Estimated Emissions (lb/acre)								14.1

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph.; silt = 18%.
[d] Germinated wheat in winter dormancy, plus remaining surface residue.

Table 4-12. Calculation of Annual Emissions from Washington Winter Wheat Farm—Conservation Tillage[27,28]

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
8/94	Sprayer	-	Herbicide Application	~ 0.350 lb/acre[d]	-	85	0.02	0.35
8/94		-	Wind Erosion	0	-	85	0.02	0
9/94	Spreader	-	Fertilizer Application	~ 0.208 lb/acre[c]	-	85	0.02	0.21
9/94	No-till	M7	Planting	5.7	0.675	70 [85 × 0.825]	0.05	3.85
9/94		-	Wind Erosion	0	-	95 [70 + 25][d]	0.02	0
10/94		-	Wind Erosion	0	-	95[d]	0.02	0
11/94		-	Wind Erosion	0	-	95[d]	0.02	0
12/94		-	Wind Erosion	0	-	95[d]	0.02	0
1/95		-	Wind Erosion	0	-	95[d]	0.02	0
2/95		-	Wind Erosion	0	-	95[d]	0.02	0
3/94 to 7/95		-	Wind Erosion	0	-	100	0	0
4/95	Sprayer	-	Herbicide Application	~ 0.208 lb/acre[c]	-	100	0	0.21
6/95	Aerial Spray	-	Herbicide Application	0	-	100	0	0
8/95	Combine	T1	Harvesting	5.70	1	85	0.02	5.70
Total Annual Estimated Emissions (lb/acre)								10.3

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph.; silt = 18%.
[d] Germinated wheat in winter dormancy, plus remaining surface residue.

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The positive value of cost-effectiveness indicates a cost associated with the emission reduction. Washington winter wheat is the only grain model farm that shows a cost associated with conservation practices. As stated above this is partially accounted for through higher herbicide use and an aerial spray application.

4.1.4 North Dakota Spring Wheat

In 1993, the North Dakota farmers harvested 10.8 million acres of wheat, comprising 17% of the wheat acres harvested in the United States.[1] Spring wheat accounted for 8.8 million of the harvested wheat acres in North Dakota. Model farm pair No. 9 is located in MLRA 54 in Adams County, North Dakota. Adams County is mostly comprised of farmland on which 119,300 acres of total wheat were harvested and 109,000 acres of spring wheat were harvested in 1993. Most of the wheat acres in the region are grown using dryland practices. The average size farm in North Dakota is 1,263 acres.[14]

The land in Adams County is a smooth rolling plain. The soils are mostly Borolls, which are well drained and loamy and clayey.[2] Precipitation averages 16 in annually, although 80% of the precipitation typically falls from April through September. The annual average wind speed is 11 mph, and the average temperature is 42°F.[3]

Conventional farming practices, dates of field operations, and associated costs/acre totaling $78.28 are listed in Table 4-13.[15,16] Conventional practices generally include chisel plowing as a deep-tillage pass, a shallow-tillage pass, and planting. Adams County farmers used conventional methods on 90% of their wheat acres.[4]

Conservation farming practices, implements/machinery, and associated costs/acre totaling $71.35 are listed in Table 4-14.[15,16] No-till, which is the only conservation method practiced in Adams County, is used on 10% of the wheat acres.[4] One farming operation in the North Dakota model farm that is not used on other model farms is the practice of swathing the wheat prior to combine operations. The three other model farms cut and combine the wheat in one operation.

A wheat-fallow rotation is used on both conservation and conventional wheat acres in Adams County. Approximately 70% of the harvested wheat acres use a wheat-fallow rotation. Some farmers use a wheat-wheat-fallow rotation, and the remainder use continuous wheat farming practices. Cost data in Tables 4-13 and 4-14 represent farming operations for a full wheat season only; therefore, field operations for a continuous wheat crop or other rotations would be similar to those presented.

Estimated particulate emissions from tillage and wind erosion are presented for conventional practices in Table 4-15 and for conservation practices in Table 4-16. Results show annual conventional emissions total 26.6 lb/acre and annual conservation emissions total 12.6 lb/acre. Only a small percentage of emissions are attributed to wind erosion. Wind erosion emissions account for 0.10 lb/acre for conventional practices and 0.01 lb/acre for conservation practices.

Table 4-13. North Dakota Spring Wheat—Conventional Tillage 1995 Cost[15,16]

Cost category		Cost/acre	
Input			
	Fertilizer (18-46-0)	100 lb @ $0.11/lb	$11.00
	Wheat Seed	1.0 bu @ $7.00/bu	$7.00
	Herbicide (2,4-D Amine)	1.0 pnt @ $1.38/pnt	$1.38
	Interest on Operating Capital (9%)		$1.30
		SUBTOTAL	$20.68
Machinery			
	Fertilizer Applicator	Fertilizer Application	$2.00
	Chisel Plow—15 ft	Manage Residue	$4.94
	Field Cultivator—18 ft (sweep)	Bed Prep	$3.48
	Tandem Disk—20 ft (9-in sweep)	Bed Prep	$4.58
	Grain Drill—20 ft	Planting	$8.37
	Sprayer Pull Type—50 ft	Herbicide Application	$1.02
	Swather SP—18 ft	Harvesting	$8.24
	Combine—Small Grain (including transportation)	Harvesting	$24.97
		SUBTOTAL	$57.60
Total Costs			$78.28

Table 4-14. North Dakota Spring Wheat—Conservation Tillage 1995 Cost[15,16]

Cost category		Cost/acre	
Input			
	Fertilizer (18-46-0)	100 lb @ $0.11/lb	$11.00
	Wheat Seed	1.0 bu @ $7.00/bu	$7.00
	Herbicide (2,4-D Amine)	1.0 pnt @ $1.38/pnt	$1.38
	Herbicide (Roundup)	1.0 pnt @ $4.75/pnt	$4.75
	Interest on Operating Capital (9%)		$1.60
		SUBTOTAL	$25.73
Machinery			
	Fertilizer Applicator	Fertilizer Application	$2.00
	Sprayer Pull Type—50 ft	Herbicide Application	$1.02
	Grain Drill—20 ft	Planting	$8.37
	Sprayer Pull Type—50 ft	Herbicide Application	$1.02
	Swather SP—18 ft	Harvesting	$8.24
	Combine—Small Grain (including transportation)	Harvesting	$24.97
		SUBTOTAL	$45.62
Total Costs			$71.35

Table 4-15. Calculation of Annual Emissions from North Dakota Spring Wheat Farm—Conventional Tillage[15,16]

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
9/93		-	Wind Erosion	0	-	85	0.02	0
10/93	Spreader	-	Fertilizer Application	~ 0.208 lb/acre[c]	-	85	0.02	0.21
10/93	Chisel Plow	C1	Residue Management	5.7	0.725	66 [85 × 0.775]	0.06	4.13
10/93		-	Wind Erosion	0.0022	-	66	0.06	0
11/93		-	Wind Erosion	0	-	66	0.06	0
12/93		-	Wind Erosion	0	-	66	0.06	0
1/94		-	Wind Erosion	0	-	66	0.06	0
2/94		-	Wind Erosion	0.0088	-	66	0.06	0.001
3/94		-	Wind Erosion	0.0110	-	66	0.06	0.001
10/93 to 4/94		-	Climatic Effects	0	-	58 [66 × 0.875]	0.08	-
4/94	Field Cultivator	G1	Bed Prep	5.7	0.80	41 [58 × 0.70]	0.17	4.56
4/94		-	Wind Erosion	0.2469	-	41	0.17	0.042
4/94	Tandem Disc	F6	Bed Prep	5.7	0.95	23 [41 × 0.55]	0.37	5.42
5/94	Grain Drill	N1	Planting	5.7	0.60	21 [23 × 0.90]	0.40	3.42
5/94	Sprayer	-	Herbicide Application	~ 0.208 lb/acre[c]	-	23	0.37	0.21

Table 4-15 (Continued)

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
5/94		–	Wind Erosion	0.1433	–	21	0.40	0.057
6/94 to 8/94		–	Wind Erosion	0	–	100	0	0
8/94	Swath	–	Harvesting	5.70	0.50	100	0.02	2.85
8/94	Combine	–	Harvesting	5.7	1.0	85	0.02	5.70
Total Annual Estimated Emissions (lb/acre)								26.6

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph.; silt = 18%.

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Table 4-16. Calculation of Annual Emissions from North Dakota Spring Wheat Farm—Conservation Tillage[15,16]

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
9/94		–	Wind Erosion	0	–	85	0.02	0
10/93	Spreader	–	Fertilizer Application	~ 0.208 lb/acre[c]	–	85	0.02	0.21
10/93		–	Wind Erosion	0.0022	–	85	0.02	0
11/93		–	Wind Erosion	0	–	85	0.02	0
12/93		–	Wind Erosion	0	–	85	0.02	0
1/94		–	Wind Erosion	0	–	85	0.02	0
2/94		–	Wind Erosion	0.0088	–	85	0.02	0
3/94		–	Wind Erosion	0.0110	–	85	0.02	0
10/94 to 4/94		–	Climatic Effects	–	–	74 [85 × 0.875]	0.04	–
4/94		–	Wind Erosion	0.2469	–	74	0.02	0.005
5/94	Sprayer	–	Herbicide Application	~ 0.208 lb/acre[c]	–	74	0.04	0.21
5/94	No-till	M6	Planting	5.7	0.6	67 [74 × 0.90]	0.05	3.42
5/94		–	Wind Erosion	0.1433	–	67	0.05	0.007
6/94	Sprayer	–	Herbicide Application	~ 0.208 lb/acre[c]	–	67	0.05	0.21
6/94 to 8/94		–	Wind Erosion	0	–	100	0	0
8/94	Swath	–	Harvesting	5.70	0.5	85	0.02	2.85
8/94	Combine	T1	Harvesting	5.70	1.0	85	0.02	5.70
Total Annual Estimated Emissions (lb/acre)								12.6

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph.; silt = 18%.

The cost-effectiveness calculation for reduction of particulate emissions per acre is as follows:

$$\$71.35 - \$78.28/\ 20.6\ \text{lb/year} - 12.6\ \text{lb/year} = -\$0.50/\text{lb}$$

The negative value of cost-effectiveness indicates a cost savings associated with the emission reduction.

4.2 Corn

Corn acres harvested in 1993 in the United States totaled 78 million acres. National rankings in total corn acres harvested in 1993 for states with selected model farms was: Iowa ranked first, Indiana fifth, and Texas eighth.[1] Farming practices for corn are similar in different areas of the country. They range from the use of traditional moldboard plow and many field passes to newer no-till operations with limited field passes. Wind erosion emissions in Iowa and Indiana are generally less severe than in the Texas Panhandle region, although unprotected dry soil is subject to wind erosion in Iowa and Indiana. The region with the highest percentage of land being farmed using conservation practices is the Corn Belt region (Illinois, Indiana, Iowa, Missouri, Ohio) at 47.5%.[4]

4.2.1 Indiana Corn

In 1993, Indiana farmers harvested 6 million acres of corn, which was almost 8% of the corn acres harvested in the United States. Model farm pair No. 1 is located in MLRA 110 in Jasper County, Indiana. Southern Jasper County is mostly comprised of farmland, and the northern portion of the county is feeling the encroachment of urban sprawl. Total corn harvested acres in the county were 154,100 acres in 1994. Although the average size farm in Indiana is 254 acres, the average size farm in Jasper County is 422 acres.[17]

The land in Jasper County is nearly level to gently sloping. The soils are mostly Udolls (dark and well-drained) and some Aquolls (wet). Water control problems including erosion and drainage are generally more of a concern in this area than wind erosion.[2] The annual precipitation averages 36 in, two-thirds occurring from April through September. The annual average wind speed is 11 mph, and the average temperature is 49°F.[3]

Conventional farming practices, implements/machinery, and associated costs/acre totaling $155.07 are listed in Table 4-17.[18,19] Conventional practices generally include chisel plowing as the deep tillage pass, a shallow tillage pass, planting, and cultivation after emergence. Jasper County farmers used conventional methods on 70% of their corn acres.[4]

Table 4-17. Indiana Corn —Conventional Tillage 1992 Cost

Cost category		Cost/acre[a]	
Input			
	Fertilizer—Phosphate	60 lb @ $0.18/lb	$10.80
	Potash	70 lb @ $0.10/lb	$7.00
	Anhydrous Ammonia (28%)	170 lb @ $0.15/lb	$25.50
	Corn Seed	0.25 bu @ $71.00/bu	$17.75
	Herbicide—Broadleaf	2.5 lb @ $2.15/lb	$5.38
	Herbicide—Grass	2.0 qt @ $5.91/qt	$11.82
	Interest on Operating Capital (9%)		$5.01
		SUBTOTAL	$83.26
Machinery			
	Chisel Plow—12 ft	Bed Prep/Weed	$5.53
	Fertilizer Spreader—40 ft	Fertilizer Application	$2.45
	Anhydrous Ammonia Applicator	Fertilizer Application	$7.22
	Tandem Disc—21 ft	Bed Prep	$4.43
	Conventional Planter	Planting	$7.06
	Sprayer Pull Type—30 ft	Herbicide Application	$1.82
	Row Cultivator	Weed Control	$5.63
	Combine—SP, 6-Row (including transportation)	Harvesting	$37.67
		SUBTOTAL	$71.81
Total Costs			$155.07

[a] Estimated for 130 bushels/acre.

Table 4-18. Indiana Corn—Conservation Tillage 1992 Cost

Cost category		Cost/acre[a]	
Input			
	Fertilizer—Phosphate	60 lb @ $0.18/lb	$10.80
	Potash	70 lb @ $0.10/lb	$7.00
	Anhydrous Ammonia (28%)	170 lb @ $0.15/lb	$25.50
	Corn Seed	0.25 bu @ $71.00/bu	$17.75
	Herbicide—Broadleaf	2.5 lb @ $2.15/lb	$5.38
	Herbicide—Grass	2.0 qt @ $5.91/qt	$11.82
	Interest on Operating Capital (9%)		$5.01
		SUBTOTAL	$83.26
Machinery			
	Fertilizer Spreader—40 ft	Fertilizer Application	$2.45
	No-till Planter	Planting	$8.63
	Anhydrous Ammonia Applicator	Fertilizer Application	$7.22
	Sprayer Pull Type—30 ft	Herbicide Application	$1.82
	Combine—SP, 6-Row (including transportation)	Harvesting	$37.67
		SUBTOTAL	$57.79
Total Costs			$141.05

[a] Estimated for 130 bushels/acre.

Conservation farming practices, implements/machinery, and associated costs/acre totaling $141.05 are listed in Table 4-18.[18,19] Conservation practices used in Jasper County include no-till, ridge till, and mulch till. No-till methods were selected for the Indiana model farm. Indiana ranks fourth in the nation for no-till corn acres planted with 1.4 million acres. In Jasper County, no-till methods were used on 20% of the corn acres, and all conservation practices combined were used on 30% of the corn acres.[4]

A corn-soybean rotation is used on a majority of both conservation and conventional corn acres in Jasper County. It is estimated that 80% of all corn acres use a corn-soybean rotation. Cost data in Tables 4-17 and 4-18 represent farming operations for corn field operations only; therefore, field operations for a continuous corn crop or other rotations would be similar to the corn-soybean rotation operations.

Estimated particulate emissions from tillage and wind erosion are presented for conventional practices in Table 4-19 and for conservation practices in Table 4-20. Results show annual conventional emissions total 27.1 lb/acre and annual conservation emissions total 14.5 lb/acre. Only 1% to 2% of emissions are attributed to wind erosion. Wind erosion emissions account for 0.60 lb/acre for conventional practices and less than 0.15 lb/acre for conservation practices. Total emissions are reduced 46% with conservation practices.

The cost-effectiveness calculation for reduction of particulate emissions per acre is as follows:

$$\$141.05 - \$155.07 / \ 27.1 \text{ lb/year} - \ 14.5 \text{ lb/year} = - \ \$1.11/\text{lb}$$

The negative value of cost-effectiveness indicates a cost savings associated with the emission reduction.

4.2.2 Iowa Corn

In 1993, Iowa farmers harvested nearly 13 million acres of corn, which was 16% of all corn acres harvested in the United States.[1] Model farm pair No. 2 is located in MLRA 107 in Carroll County, Iowa. Carroll County is mostly comprised of farmland on which 147,000 acres of corn were harvested in 1994. The average size farm in Carroll County is 291 acres, which is close to Iowa's average farm size of 329 acres.[20]

The land in Carroll County is comprised of a rolling loess-mantled plain. The upland soils, mainly Udolls and some Orthents, have a high erosion potential.[2] The annual precipitation averages 29 in, two-thirds occurring from June through October. The annual average wind speed is 12 mph and the average temperature is 48°F.[3]

Table 4-19. Calculation of Annual Emissions from Indiana Corn Farm—Conventional Tillage

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
10/94		–	Wind Erosion	0	–	95	0.02	0
11/94	Chisel Plow	C3	Residue Management	5.7	0.90	57 [95 × 0.60]	0.08	5.13
11/94	Spreader	–	Fertilizer Application	~ 0.208 lb/acre[c]	–	57	0.08	0.2
11/94		–	Wind Erosion	0.3501	–	57	0.08	0.028
12/94		–	Wind Erosion	0.3374	–	57	0.08	0.027
1/95		–	Wind Erosion	1.7809	–	57	0.08	0.14
2/95		–	Wind Erosion	1.2076	–	57	0.08	0.097
3/95		–	Wind Erosion	1.7099	–	57	0.08	0.14
10/94 to 4/95		–	Climatic Effects	–	–	50 [57 × 0.875]	0.11	0
4/95		–	Wind Erosion	1.0883	–	50	0.11	0.120
5/95	Anhydrous NH_3 Applicator	L1	Fertilizer Application	5.7	0.70	35	0.29	3.99
5/95	Tandem Disc	G1	Bed Prep	5.7	0.80	20 [28 × 0.70]	0.42	4.56
5/95	Conventional	N3	Planting	5.7	0.60	18 [20 × 0.90]	0.45	3.42
5/95	Sprayer	–	Herbicide Application	~ 0.208 lb/acre[c]	–	18	0.45	0.21
5/95		–	Wind Erosion	0.0476	–	18	0.45	0.021
6/95 to 10/95		–	Wind Erosion	0	–	100	0	0
6/95	Row Cultivator	K2	Weed Control	5.7	0.70	100	0	3.99
10/95	Combine	T1	Harvesting	5.7	1.0	95	0.02	5.70
Total Annual Estimated Emissions (lb/acre)								27.1

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph.; silt = 18%.

Table 4-20. Calculation of Annual Emissions from Indiana Corn Farm—Conservation Tillage

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
10/94		–	Wind Erosion	0	–	95	0.02	0
11/94		–	Wind Erosion	0.3501	–	95	0.02	0.007
12/94		–	Wind Erosion	0.3374	–	95	0.02	0.007
1/95		–	Wind Erosion	1.7809	–	95	0.02	0.036
2/95		–	Wind Erosion	1.2076	–	95	0.02	0.024
2/95	Spreader	–	Fertilizer Application	~ 0.208 lb/acre[c]	–	95	0.02	0.21
3/95		–	Wind Erosion	1.7099	–	95	0.02	0.034
10/94 to 4/95		–	Climatic Effects	-	-	83 [95 × 0.875]	0.03	-
4/95		–	Wind Erosion	1.0883	-	83	0.03	0.033
5/95	Anhydrous NH_3 Applicator	L1	Fertilizer Application	5.7	0.70	66 [83 × 0.80]	0.06	3.99
5/95	No-till	N6	Planting	5.7	0.75	50 [66 × 0.75]	0.11	4.28
5/95	Sprayer	–	Herbicide Application	~ 0.208 lb/acre[c]	–	83	0.03	0.21
5/95		–	Wind Erosion	0.0476	–	50	0.11	0.005
6/94 to 9/95		–	Wind Erosion	0	–	100	0	0
10/95	Combine	T1	Harvesting	5.7	1.0	95	0.02	5.70
Total Annual Estimated Emissions (lb/acre)								14.5

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph.; silt = 18%.

Conventional farming practices, implements/machinery, and associated costs/acre totaling $166.10 are listed in Table 4-21.[21,22] Conventional practices generally include chisel plowing as the deep tillage pass, a shallow tillage pass, planting, and cultivation after emergence. Carroll County farmers used conventional methods on 68% of their corn acres.[4]

Conservation farming practices, implements/machinery, and associated costs/acre totaling $151.85 are listed in Table 4-22.[21,22] Conservation practices used in Carroll County include no-till, ridge till, and mulch till. No-till methods were selected for the Iowa model farm. Iowa leads the nation in no-till corn acres planted with 1.9 million. In Carroll County, no-till methods were used on 13% of the corn acres, and all conservation practices combined were used on 32% of the corn acres.[4]

A corn-soybean rotation was used on a majority of both conservation and conventional corn acres in Carroll County. It is estimated that 80% of all corn acres use a corn-soybean rotation. Cost data in Tables 4-21 and 4-22 represent farming operations for a full corn season only; therefore, field operations for a continuous corn crop or other rotations would be similar to the corn-soybean rotation operations.

Estimated particulate emissions from tillage and wind erosion are presented for conventional practices in Table 4-23[21,22] and for conservation practices in Table 4-24.[21,22] Results show annual conventional emissions total 32.4 lb/acre and annual conservation emissions total 14.2 lb/acre. Less than 1% of the emissions are attributed to wind erosion. Wind erosion emissions account for 0.11 lb/acre for conventional practices and 0.02 lb/acre for conservation practices. Total emissions are reduced by 56% with conservation practices.

The cost-effectiveness calculation for reduction of particulate emissions per acre is as follows:

$$\$151.85 - \$166.10 / 32.4 \text{ lb/year} - 14.2 \text{ lb/year} = -\$0.78/\text{lb}$$

The negative value of cost-effectiveness indicates a cost savings associated with the emission reduction.

4.2.3 Texas Corn

In 1993, Texas farmers harvested 1.5 million acres of corn, which was almost 2% of the corn acres harvested in the United States.[1] Model farm pair No. 3 is located in MLRA 77 in Castro County, Texas. Castro County is mostly comprised of farmland on which 106,500 acres of corn were harvested in 1994. All corn in the region grown for harvest is irrigated. The average size farm in Texas is 639 acres.[8]

Table 4-21. Iowa Corn—Conventional Tillage 1995 Cost[21,22]

Cost category			Cost/acre
Input			
	Fertilizer (Anhydrous Ammonia and P&K)		$38.00
	Corn Seed		$25.00
	Herbicide/Pesticide		$17.00
	Interest on Operating Capital (9%)		$4.80
		SUBTOTAL	$84.80
Machinery			
	Fertilizer Spreader—40 ft	Fertilizer Application	$2.95
	Chisel Plow	Manage Residue	$9.60
	Tandem Disc—21 ft	Bed Prep	$6.85
	Anhydrous Applicator	Fertilizer Application	$6.25
	Field Cultivator	Shallow Tillage	$8.00
	Conventional Planter	Plant	$9.00
	Sprayer Pull Type—30 ft	Herbicide Application	$3.85
	Row Cultivator	Weed Control	$5.70
	Combine (including transportation)	Harvesting	$29.10
		SUBTOTAL	$81.30
Total Costs			$166.10

Table 4-22. Iowa Corn—Conservation Tillage 1995 Cost[21,22]

Cost category			Cost/acre
Input			
	Fertilizer (Anhydrous Ammonia, P&K)		$38.00
	Corn Seed		$25.00
	Herbicide		$27.00
	Interest on Operating Capital (9%)		$4.80
		SUBTOTAL	$94.80
Machinery			
	Fertilizer Spreader—40 ft	Fertilizer Application	$2.95
	Anhydrous Ammonia Applicator	Fertilizer Application	$6.25
	Sprayer Pull Type—30 ft	Herbicide Application	$3.85
	No-Till Planter	Planting	$11.05
	Sprayer Pull Type—30 ft	Herbicide Application	$3.85
	Combine (including transportation)	Harvesting	$29.10
		SUBTOTAL	$57.05
Total Costs			$151.85

Table 4-23. Calculation of Annual Emissions from Iowa Corn Farm—Conventional Tillage[21,22]

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
10/94		-	Wind Erosion	0	-	85	0.02	0
11/94	Spreader	-	Fertilizer Application	~ 0.208 lb/acre[c]	-	85	0.02	0.21
11/94	Chisel Plow	C3	Residue Management	5.7	0.90	51 [85 × 0.60]	0.11	5.13
11/94		-	Wind Erosion	0.0107	-	51	0.11	0.001
12/94		-	Wind Erosion	0.0517	-	51	0.11	0.006
1/95		-	Wind Erosion	0.0793	-	51	0.11	0.009
2/95		-	Wind Erosion	0.0384	-	51	0.11	0.004
3/95		-	Wind Erosion	0.3134	-	51	0.11	0.034
10/94 to 4/95		-	Climatic Effects	-	-	45 [51 × 0.875]	0.14	-
4/95		-	Wind Erosion	0.3073	-	45	0.14	0.043
4/95	Tandem Disc	F5	Bed Prep	5.7	0.95	25 [45 × 0.55]	0.33	5.42
4/95	Anhydrous NH_3 Applicator	L1	Fertilizer Application	5.7	0.70	20 [25 × 0.80]	0.42	3.99
4/95	Field Cultivator	G5	Shallow Tillage	5.7	0.75	15 [20 × 0.75]	0.52	4.28
5/95	Conventional	N3	Planting	5.7	0.60	14 [15 × 0.90]	0.54	3.42
5/95		-	Wind Erosion	0.0249	-	14	0.54	0.013
6/95 to 9/95		-	Wind Erosion	0	-	100	0	0
6/95	Sprayer	-	Herbicide Application	~ 0.208 lb/acre[c]	-	100	0	0.21
6/95	Row Cultivator	K2	Weed Control	5.7	0.70	100	0	3.99
10/95	Combine	T1	Harvesting	5.7	1.0	85	0	5.70
Total Annual Estimated Emissions (lb/acre)								32.4

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995); 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph.; silt = 18%.

Table 4-24. Calculation of Annual Emissions from Iowa Corn Farm—Conservation Tillage[21,22]

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
10/94		-	Wind Erosion	0	-	85	0.02	0
11/94	Spreader	-	Fertilizer Application	~ 0.208 lb /acre[c]	-	85	0.02	0.21
11/94		-	Wind Erosion	0.0107	-	85	0.02	0
12/94		-	Wind Erosion	0.0517	-	85	0.02	0.001
1/95		-	Wind Erosion	0.0793	-	85	0.02	0.002
2/95		-	Wind Erosion	0/0384	-	85	0.02	0.001
3/95		-	Wind Erosion	0.3134	-	85	0.02	0.006
10/94 to 4/95		-	Climatic Effects	-	-	74 [85 × 0.875]	0.04	0
4/95		-	Wind Erosion	0.3073	-	74	0.04	0.012
4/95	Anhydrous NH_3 Applicator	L1	Fertilizer Application	5.7	0.70	59 [74 × 0.80]	0.08	3.99
4/95	Sprayer	-	Herbicide Application	~ 0.208 lb/acre[c]	-	59	0.08	0.21
5/95	No-till	N5	Planting	5.7	0.675	49 [59 × 0.825]	0.12	3.85
5/95		-	Wind Erosion	0.0249	-	49	0.12	0.003
6/95 to 10 /95		-	Wind Erosion	0	-	100	0	0
6/95	Sprayer	-	Herbicide Application	~ 0.208 lb/acre[c]	-	100	0	0.21
10/95	Combine	T1	Harvesting	5.7	1.0	85	0.02	5.70
Total Annual Estimated Emissions (lb/acre)								14.2

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph.; silt = 18%.

The land in Castro County is generally a smooth high plain that gently slopes. The soils are mostly Ustolls and Ustalfs, both well-drained.[2] Precipitation is somewhat erratic and moderately low with an annual average of 17 in. The area has a high propensity for wind erosion. The irrigation water is obtained from wells, and the water table is gradually declining. The annual average wind speed is 14 mph, and the average temperature is 59°F.

Conventional farming practices, implements/machinery, and associated costs/acre totaling $247.08 are listed in Table 4-25.[9,10] Approximately 25% of the costs are associated with irrigation practices. Conventional practices generally include chisel plowing as the deep tillage pass, a shallow tillage pass, planting, and cultivation after emergence. Castro County farmers used conventional methods on only 15% of their corn acres; however, 70% of the corn acres in Texas use conventional methods.[4]

Conservation farming practices, implements/machinery, and associated costs/acre totaling $235.59 are listed in Table 4-26.[9,10] Again, over 25% of the costs were associated with irrigation. Since mulch till is the only conservation practice in use in Castro County, it was selected for the model farm. In Castro County, mulch till methods were used on 75% of the corn acres.[4]

A corn-wheat rotation is used on some of both conservation and conventional corn acres in Castro County; however, there are no data to indicate that crop rotations are followed by the majority of the farmers. Corn costs in Castro County are significantly higher than the other model farms. Some of these costs can be attributed to irrigation and shredding. Approximately 25% of the costs in Tables 4-25 and 4-26 are associated with irrigation. In addition, corn stalks are typically shredded to prevent corn bore in Castro County, but shredding is uncommon in Indiana and Iowa. The reported cost of harvesting corn in Texas is also more than 40% greater than harvesting costs in Indiana or Iowa.

Estimated particulate emissions from tillage and wind erosion are presented for conventional practices in Table 4-27[9,10] and for conservation practices in Table 4-28.[9,10] Results show annual conventional emissions total 46.5 lb/acre and annual conservation emissions total 26.0 lb/acre. Only a small percentage of emissions are attributed to wind erosion. Wind erosion emissions account for 0.11 lb/acre for conventional practices and 0.02 lb/acre for conservation practices. Total emissions are reduced by 44% using conservation practices.

The cost-effectiveness calculation for reduction of particulate emissions per acre is as follows:

$$\$235.59 - \$247.08 / 46.5 \text{ lb/year} - 26.0 \text{ lb/year} = -\ \$0.56/\text{lb}$$

The negative value of cost-effectiveness indicates a cost savings associated with the emission reduction.

Table 4-26. Texas Corn—Irrigated Conservation Tillage 1994 Cost[9,10]

Cost category		Cost/acre	
Input			
	Fertilizer P&K	40 lb @ $0.25/lb	$10.00
	Anhydrous Ammonia	275 lb @ $0.105/lb	$28.90
	Corn Seed	0.35 bag @ $80/bag	$28.00
	Herbicide		$16.00
	Interest on Operating Capital (9%)		$6.98
		SUBTOTAL	$89.88
Machinery			
	Shredding	Shred Stalks	$8.90
	Chisel	Weed Control	$4.30
	Irrigation	Irrigation	$12.78
	Anhydrous Ammonia Applicator	Fertilizer Application	$6.00
	Sprayer, Pull Type	Herbicide Application	$3.75
	Fertilizer Spreader—40 ft	Fertilizer Application	$3.00
	Planter—12 Row	Planting	$2.66
	Irrigation	Irrigation	$12.78
	Irrigation	Irrigation	$12.78
	Irrigation	Irrigation	$12.78
	Irrigation	Irrigation	$12.78
	Combine (including transportation)	Harvesting	$53.20
		SUBTOTAL	$145.71
Total Costs			$235.59

Table 4-25. Texas Corn—Irrigated Conventional Tillage 1994 Cost[9,10]

Cost category		Cost/acre	
Input			
	Fertilizer P&K	40 lb @ $0.25/lb	$10.00
	Anhydrous Ammonia	275 lb @ $0.105/lb	$28.90
	Corn Seed	0.35 bag @ $80/bag	$28.00
	Herbicide		$16.00
	Interest on Operating Capital (9%)		$6.98
		SUBTOTAL	$89.88
Machinery			
	Shredding	Shred Stalks	$8.90
	Chisel	Weed Control	$4.30
	Irrigation	Irrigation	$12.78
	Field Cultivator	Bed Prep/Weed	$4.17
	Anhydrous Ammonia Applicator	Fertilizer Application	$6.00
	Sprayer, Pull Type	Herbicide Application	$3.75
	Fertilizer Spreader—40 ft	Fertilizer Application	$3.00
	Lister	Bed Prep	$4.30
	Planter—12 Row	Planting	$2.66
	Row Cultivator	Weed Control	$3.02
	Irrigation	Irrigation	$12.78
	Irrigation	Irrigation	$12.78
	Irrigation	Irrigation	$12.78
	Irrigation	Irrigation	$12.78
	Combine (including transportation)	Harvesting	$53.20
		SUBTOTAL	$157.20
Total Costs			$247.08

Table 4-27. Calculation of Annual Emissions from Texas Corn Farm—Conventional Tillage[9,10]

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
9/93		-	Wind Erosion	0.6889	-	95	0.02	0.014
10/93		-	Wind Erosion	3.592	-	95	0.02	0.072
11/93		-	Wind Erosion	3.874	-	95	0.02	0.077
12/93		-	Wind Erosion	4.192	-	95	0.02	0.084
1/94		-	Wind Erosion	2.685	-	95	0.02	0.054
1/94	Shredder	-	Shred Stalks	5.7	0.50	95	0.02	2.85
2/94		-	Wind Erosion	4.286	-	95	0.02	0.086
3/94		-	Wind Erosion	37.21	-	95	0.02	0.74
3/94	Chisel Plow	C2	Bed Prep/ Weed Control	5.7	0.80	67 [95 × 0.70]	0.05	4.56
9/93 to 3/94		-	Climatic Effects	-	-	59 [67 × 0.875]	0.08	-
4/94	Field Cultivator	G4	Bed Prep/ Weed Control	5.7	0.65	50 [59 × 0.85]	0.11	3.71
4/94	Anhydrous NH_3 Applicator	L1	Fertilizer Application	5.7	0.70	40 [50 × 0.80]	0.17	3.99
4/94	Spray Applicator	-	Herbicide Application	~ 0.208 lb/acre[c]	-	50	0.11	0.21
4/94		-	Wind Erosion[d]	36.03 × 0.5	-	40	0.17	3.06
5/94	Lister	L5	Bed Prep	5.7	1.0	9 [40 × 0.225]	0.67	5.70
5/94	Conventional	N1	Planting	5.7	0.60	8 [9 × 0.90]	0.70	3.42

Table 4-27 (Continued)

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
5/94	Row Cultivator	G1	Weed Control	5.7	0.80	6 [8 × 0.70]	0.77	4.56
5/94		-	Wind Erosion[d]	20.01 × 0.5	-	6	0.77	7.70
6/94 to 9/94		-	Wind Erosion	0	-	100	0	0
9/94	Combine	T1	Harvest	5.7	1.0	95	0.02	5.70
Total Annual Estimated Emissions (lb/acre)								46.5

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph.; silt = 18%.
[d] Wind erosion reduced 50% in April and May due to irrigation.

Table 4-28. Calculation of Annual Emissions from Texas Corn Farm—Conservation Tillage[9,10]

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion period	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
9/93		-	Wind Erosion	0.6889	-	95	0.02	0.014
10/93		-	Wind Erosion	3.5916	-	95	0.02	0.072
11/93		-	Wind Erosion	3.8742	-	95	0.02	0.077
12/93		-	Wind Erosion	4.1921	-	95	0.02	0.084
1/94		-	Wind Erosion	2.6849	-	95	0.02	0.054
1/94	Shredder	-	Shred Stalks	5.7	0.50	95	0.02	2.85
2/94		-	Wind Erosion	4.2864	-	95	0.02	0.086
3/94		-	Wind Erosion	37.2112	-	95	0.02	0.74
3/94	Chisel Plow	C2	Bed Prep/ Weed Control	5.7	0.80	67 [95 × 0.70]	0.05	4.56
9/93 to 3/94		-	Climatic Effects	-	-	59 [67 × 0.875]	0.08	0
4/94	Anhydrous NH_3 Applicator	L1	Fertilizer Application	5.7	0.70	47 [59 × 0.80]	0.13	3.99
4/94		-	Wind Erosion[c]	36.0336 × 0.5	-	47	0.13	2.34
5/94	Sprayer		Herbicide Application	~ 0.208 lb/acre[d]	-	47	0.13	0.21
5/94	Spreader	-	Fertilizer Application	~ 0.208 lb/acre[d]	-	47	0.13	0.21
5/94	Conventional	N1	Planting	5.7	0.60	42 [47 × .090]	0.16	3.42
5/94		-	Wind Erosion[c]	20.0187 × 0.5	-	42	0.16	1.60
6/94 to 9/94		-	Wind Erosion	0	-	100	0	0
9/94	Combine	T1	Harvesting	5.7	1.0	95	0.02	5.70
Total Annual Estimated Emissions (lb/acre)								26.0

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Wind erosion reduced 50% in April and May due to irrigation.
[d] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph.; silt = 18%.

4.3 Soybeans

Soybeans acres harvested in 1993 in the United States totaled over 57 million acres.[1] Illinois harvested the largest area of soybeans in the nation in 1993. Farming practices range from the traditional moldboard plow and many field passes to newer no-till operations with limited field passes. The propensity for wind erosion exists but is less severe than the dust bowl region including Kansas and Texas. The majority of the soybeans acres in the Midwest use a soybean-corn rotation. Approximately 50% of planted soybean acres in the United States use conservation tillage practices.[4]

4.3.1 Illinois Soybeans

In 1993, Illinois harvested 9 million acres of soybeans, or 16% of the nation's total.[1] Model farm pair No. 7 is located in MLRA 110 in Livingston County, Illinois. Livingston County is mostly comprised of farmland on which 276,300 acres of soybeans were harvested in 1994. The average size farm in Livingston County is 408 acres, which is greater than the Illinois average farm size of 365 acres.[23]

The land in Livingston County is nearly level to gently sloping. The soils are mostly Udolls (dark and well drained) and some Aquolls (wet). Water control problems including erosion and drainage are generally more of a concern in this area than wind erosion.[2] The annual precipitation averages 35 in, two-thirds occurring from April through September. The annual average wind speed is 11 mph and the average temperature is 50°F.[3]

Conventional farming practices, implements/machinery, and associated costs/acre totaling $142.70 are listed in Table 4-29.[24,25] Conventional practices generally include chisel plowing as the deep tillage pass, a shallow tillage pass, planting, and cultivation after emergence. Livingston County farmers used conventional methods on 69% of their soybean acres.[4]

Conservation farming practices, implements/machinery, and associated costs/acre totaling $127.54 are listed in Table 4-30.[24,25] Conservation practices used in Livingston County include no-till and mulch till. No-till methods were selected for the Illinois model farm. Illinois leads the nation in no-till soybean acres planted with 3.2 million acres planted. In Livingston County, no-till methods were used on 12% of the soybean acres and all conservation practices used on soybean acres totaled 31%.[4]

A soybean-corn rotation is used on a majority of both conservation and conventional soybean acres in Livingston County. It is estimated that greater than 90% of all soybean acres in Livingston County use a rotation. Cost data in Tables 4-29 and 4-30 represent soybean field operations for a full soybean season, but field operations for a continuous soybean crop or other types of rotation would be similar to the soybean-corn rotation operation.

Table 4-29. Illinois Soybeans—Conventional Tillage 1992 Cost[24,25]

Cost category		Cost/acre[a]	
Input			
	Fertilizer—Phosphate	34 lb @ $0.25/lb	$8.50
	Potash	52 lb @ $0.14/lb	$7.28
	Soybean Seed	1.2 bag @ $15.00/bu	$18.00
	Herbicide, Pre-emerge		$22.41
	Interest on Operating Capital (9%)		$3.55
		SUBTOTAL	$59.74
Machinery			
	Fertilizer Spreader—40 ft	Fertilizer Application	$3.50
	Chisel Plow	Manage Residue	$15.50
	Tandem Disc—21 ft	Bed Prep	$6.00
	Field Cultivate	Bed Prep	$5.00
	Sprayer Pull Type—30 ft	Herbicide Application	$3.25
	Conventional Planter	Planting	$9.50
	Row Cultivator	Weed Control	$6.25
	Row Cultivator	Weed Control	$6.25
	Combine (including transportation)	Harvesting	$27.71
		SUBTOTAL	$82.96
Total Costs			$142.70

[a] Calculated for 40 bushels/acre.

Table 4-30. Illinois Soybeans—Conservation Tillage 1992 Cost[24,25]

Cost category		Cost/acre[a]	
Input			
	Fertilizer—Phosphate	70 lb @ $0.12/lb	$8.50
	Potash	80 lb @ $0.09/lb	$7.28
	Soybean seed	1.4 bag @ $15.00/bag	$21.00
	Herbicide, pre		$6,27
	Herbicide, post		$29.31
	Interest on Operating Capital (9%)		$4.57
		SUBTOTAL	$76.93
Machinery			
	Fertilizer Spreader—40 ft	Fertilizer Application	$3.50
	Sprayer	Herbicide Application	$3.50
	Drill Soybeans	Planting	$13.25
	Sprayer Pull Type—30 ft	Herbicide Application	$3.25
	Combine (including transportation)	Harvesting	$27.11
		SUBTOTAL	$50.61
Total Costs			$127.54

[a] Calculated for 40 bushels/acre.

Estimated particulate emissions from tillage and wind erosion are presented for conventional practices in Table 4-31[24,25] and for conservation practices in Table 4-32.[24,25] Results show annual conventional emissions total 34.2 lb/acre and annual conservation emissions total 9.9 lb/acre. Only a small percentage of emissions are attributed to wind erosion. Wind erosion emissions account for 1.31 lb/acre for conventional practices and 0.14 lb/acre for conservation practices. Total emissions are reduced by 71% using conservation practices.

The cost-effectiveness calculation for reduction of particulate emissions per acre is as follows:

$$\$127.54 - \$142.70 / 34.2 \text{ lb/year} - 9.9 \text{ lb/year} = -\ \$0.63/\text{lb}$$

The negative value of cost-effectiveness indicates a cost savings associated with the emission reduction.

4.4 Cotton

Cotton acres harvested in 1993 in the United States totaled nearly 12.8 million acres.[1] Nationally, Texas ranks first and California ranks third in total cotton acres harvested in 1993.[1] Farming practices between dryland cotton in Texas and irrigated cotton in California are considerably different. California has a mandatory plowdown of residue remaining after harvest. Texas upland cotton farms have an extremely high propensity for wind erosion, thus requiring the farm operators to maintain surface residues to reduce wind-generated emissions. Only 10% of all cotton acres in the United States use conservation practices as defined by remaining surface residue.[4]

4.4.1 Texas Cotton

In 1993, Texas farmers harvested 5.1 million acres of cotton, which was 40% of all cotton acres harvested in the United States.[7] Model farm pair No. 5 is located in MLRA 77 in Lynn County, Texas. Lynn County is mostly comprised of farmland on which 233,200 acres of cotton were harvested in 1994. Dryland cotton is grown on 81% of the cotton acres in Lynn County, and the remaining 19% of the acres are irrigated. Upland cotton is the only type of cotton grown in Lynn County, and 99% of all cotton grown in Texas. A majority of the cotton acres are used in a continuous cropping situation. The average size farm in Texas is 639 acres.[8]

The land in Lynn County is generally a smooth high plain that gently slopes. The soils are mostly Ustolls and Ustalfs both well drained.[2] Precipitation is somewhat erratic and moderately low with an annual average of 14 in. The area has a severe propensity for wind erosion. The annual average wind speed is 14 mph and the average temperature is 59°F.[3]

Table 4-31. Calculation of Annual Emissions from Illinois Soybean Farm—Conventional Tillage[24,25]

AFO Date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
10/94	Spreader	–	Fertilizer Application	~ 0.208 lb/acre[c]	–	95	0.02	0.21
10/94	Chisel Plow	D6	Bed Prep	5.7	1.0	38 [95 × 0.40]	0.19	5.70
10/94		–	Wind Erosion	0	–	38	0.19	0
11/94		–	Wind Erosion	0.3501	–	38	0.19	0.067
12/94		–	Wind Erosion	0.3374	–	38	0.19	0.064
1/95		–	Wind Erosion	1.7809	–	38	0.19	0.34
2/95		–	Wind Erosion	1.2076	–	38	0.19	0.23
3/95		–	Wind Erosion	1.7099	–	38	0.19	0.32
10/94 to 4/95		–	Climatic Effects	–	–	33 [38 × 0.875]	0.24	0
4/95		–	Wind Erosion	1.0883	–	33	0.24	0.26
5/95	Tandem Disc	F6	Bed Prep	5.7	0.95	18 [33 × 0.55]	0.45	5.42
5/95	Field Cultivator	G5	Shallow Tillage	5.7	0.75	14 [18 × 0.75]	0.54	4.28
5/95	Sprayer	–	Herbicide Application	~ 0.208 lb/acre[c]	–	14	0.54	0.21
5/95	Double-Disc	N3	Planting	5.7	0.60	13 [14 × 0.90]	0.57	3.42
5/95			Wind Erosion	0.0476		13	0.57	0.027
6/95 to 9/95		–	Wind Erosion	0	–	100	0	0

Table 4-31 (Continued)

AFO Date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
6/95	Row Cultivator	K2	Weed Control	5.7	0.70	100	0	3.99
6/95	Row Cultivator	K2	Weed Control	5.7	0.70	100	0	3.99
9/95	Combine	T2	Harvesting	5.7	1.0	95	0.02	5.70
Total Annual Estimated Emissions (lb/acre)								34.2

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph.; silt = 18%

Table 4-32. Calculation of Annual Emissions from Illinois Soybean Farm—Conservation Tillage[24,25]

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion period	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
10/94	Spreader	-	Fertilizer Application	~ 0.208 lb/acre[c]	-	95	0.02	0.21
10/94		-	Wind Erosion	0	-	95	0.02	0
11/94		-	Wind Erosion	0.3501	-	95	0.02	0.007
12/94		-	Wind Erosion	0.3374	-	95	0.02	0.007
1/95		-	Wind Erosion	1.7809	-	95	0.02	0.036
2/95		-	Wind Erosion	1.2076	-	95	0.02	0.024
3/95		-	Wind Erosion	1.7099	-	95	0.02	0.034
10/94 to 4/95		-	Climatic Effects	-	-	83 [95 × 0.875]	0.03	0
4/95		-	Wind Erosion	1.0883	-	83	0.03	0.033
5/95	Sprayer	-	Herbicide Application	~ 0.208 lb/acre[c]	-	83	0.03	0.21
5/95	Drill	M5	Planting	5.7	0.60	75 [83 × 0.90]	0.04	3.42
5/95	Sprayer	-	Herbicide Application	~ 0.208 lb/acre[c]	-	75	0.04	0.21
5/95		-	Wind Erosion	0.0476	-	75	0.04	0.002
5/95 to 9/95		-	Wind Erosion	0	-	100	0	0
9/95	Combine	T2	Harvesting	5.7	1.0	95	0.02	5.70
Total Annual Estimated Emissions (lb/acre)								9.9

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph; silt = 18%.

Conventional farming practices, implements/machinery, and associated costs/acre totaling \$110.64 are listed in Table 4-33.[9,26] For this study, dryland cotton was selected for model cotton farm calculations in Texas . Conventional practices generally include chisel plowing as the deep tillage pass, a shallow tillage pass, bed shaping, planting, sand fighting, and cultivation after emergence. Lynn County farmers use conventional methods on 99% of their cotton acres.[4]

In Texas, approximately 9% of the cotton acres use conservation methods, but Lynn County only has 1% of the cotton acres in conservation methods.[4] Minimum-tillage, however, is used in the Texas South Plains District on an estimated 20% of the cotton acres.[10] Cover cropping is a conservation management practice used to reduce wind erosion, but not reported in the reference cited for the above statistics. Wheat, other small grains, or grasses are planted immediately after the cotton harvest. The cover crop is terminated chemically in early spring, and the residue managed so that soil protection exists after seedbed preparation. Use of a cover crop is becoming more common and was used on 9% of the cotton acres in Texas in 1994.[26]

Conservation practices using a cover crop, implements/machinery, and associated costs/acre totaling \$118.28 are listed in Table 4-34.[9,26,31] This model farm shows the cover crop management to cost \$7.64/acre more than conventional practices. A 3-year study, 1990-92, by the USDA-SCS reported the cover crop costs \$4.90/acre more than conventional methods based on annual net returns.[27] Several of the benefits of a cover crop were not measured in the study including reduced soil erosion, reduced soil compaction, reduced crop replantings, increased soil moisture retention, and increased water infiltration.

Other practices to maintain a surface residue are likely to be less expensive than cover cropping and less effective at reducing wind erosion. Another method to reduce wind erosion in the region is strip cropping, where wind strips are planted with small grains or grasses. Also, an estimated 5% of the cotton acres use a cotton-wheat rotation and less than 5% use a cotton-sorghum rotation.[10] The residues from the rotated crops (sorghum or wheat) are managed to help prevent wind erosion. A majority of the cotton acres in Texas still follow continuous cotton practices.

Estimated particulate emissions from tillage and wind erosion are presented for conventional practices in Table 4-35 and for conservation practices in Table 4-36. Results show annual conventional emissions total 126.5 lb/acre and annual conservation emissions total 22.8 lb/acre. Texas cotton has the largest wind erosion emissions of all model farm pairs with 86.7 lb/acre for conventional practices and 5.1 lb/acre for conservation practices. Cover cropping practices reduce wind erosion emissions by 94%.

The cost-effectiveness calculation for reduction of particulate emissions per acre is as follows:

$$\$118.28 - \$110.64/\ 126.5\ \text{lb/year} -\ 22.8\ \text{lb/year} = \$0.07/\text{lb}$$

The positive value of cost-effectiveness indicates the cost of developing a cover crop to reduce emissions; however, the cost per pound of reduced emissions is relatively low. Other less tangible benefits of a cover crop are stated above.

Table 4-33. Texas Cotton—Dryland Conventional Tillage 1994 Cost[9,26]

Cost category		Cost/acre	
Input			
	Fertilizer—P&N	50 lb @ $0.25/lb	$12.50
	Cotton Seed	28 lb @ $0.46/lb	$12.88
	Herbicide		$12.00
	Defoliant included below[a]		
	Interest on Operating Capital (9%)		$5.96
		SUBTOTAL	$43.34
Machinery			
	Shredding	Shred Stalks	$8.90
	Chisel	Bed Prep/Weed	$4.30
	Disc and Spray, Tandem	Bed Prep/Weed	$6.60
	Fertilizer Spreader—40 ft	Fertilizer Application	$3.00
	Listing	Bed prep	$4.30
	Bedding	Bed Shaping	$2.38
	Rotary Hoe	Weed/Crust Break	$3.28
	Planting and Spray	Planting	$7.31
	Rotary Hoe	Weed Control	$3.28
	Sand Fighter	Roughening	$1.49
	Cultivator—8 Row	Weed Control	$3.02
	Defoliant and Application	Harvesting	$3.12
	Strip and Module (including transportation)	Harvesting	$16.32
		SUBTOTAL	$67.30
Total Costs			$110.64

[a] Cost of defoliant included with application cost.

Table 4-34. Texas Cotton—Dryland Conservation Tillage with a Cover Crop 1994 Cost[9,26,31]

Cost category		Cost/acre	
Input			
	Wheat Seed	.5 bu @ $13.5/bu	$6.63
	Fertilizer—N&P	50 lb @ $0.25/lb	$12.50
	Herbicide		$17.00
	Cotton Seed	18 lb @ $0.46/lb	$8.28
	Defoliant included below[a]		
	Interest on Operating Capital (9%)		$6.28
		SUBTOTAL	$50.69
Machinery Costs			
	Shredding	Shredding Stalks	$8.90
	Drill, Wheat	Planting Wheat	$9.35
	Herbicide Application	Terminating Wheat	$6.00
	Fertilizer Application	Fertilizer Application	$6.00
	Listing	Bed Prep	$4.30
	Planting and Spraying	Planting/Herbicide Application	$7.31
	Cultivator—8 Row	Weed Control	$3.02
	Hoeing	Weed Control	$3.27
	Defoliant and Application	Harvesting	$3.12
	Strip and Module (including transportation)	Harvesting	$16.32
		SUBTOTAL	$67.59
Total Costs			$118.28

[a] Cost of defoliant included in application.

Table 4-35. Calculation of Annual Emissions from Texas Cotton Farm—Conventional Tillage[9,26]

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
11/93		–	Wind Erosion	3.874	–	70	0.02	0.077
12/93	Shredding	–	Shredding Stalks	0.208 lb/acre[c]	–	35	0.22	0.69
12/93		–	Wind Erosion	4.1921	–	35	0.22	0.922
1/94		–	Wind Erosion	2.6849	–	35	0.22	0.591
2/94	Chisel	C2	Bed Prep	5.7	0.80	25 [35 × 0.70]	0.33	4.560
2/94		–	Wind Erosion	4.286	–	25	0.33	1.415
3/94	Disc, Tandem	F3	Bed Prep; Weed Control	5.7	0.95	14 [25 × 0.55]	0.54	5.415
3/94	Spreader	–	Fertilizer Application	~ 0.208 lb/acre[c]	–	14	0.54	0.21
3/94	Lister	L5	Bed Prep	5.7	1.0	3 [14 × 0.225]	0.88	5.70
3/94		–	Wind Erosion	37.21	–	3	0.88	32.746
4/94		–	Wind Erosion	36.03	–	3	0.88	31.710
5/94	Bedder	G1	Bed Shaping	5.7	0.80	2 [3 × 0.70]	0.92	4.56
5/94	Rotary Hoe	L4	Crust Breaking; Weed Control	5.7	0.625	1 [2 × 0.875]	0.96	3.56
5/94	Conventional	N1	Planting	5.7	0.60	1 [1 × 0.90]	0.96	3.42
5/95		–	Wind Erosion	20.02	–	1	0.96	19.2
6/94 to 11/94		–	Wind Erosion	0	–	100	0	0

Table 4-35 (Continued)

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
6/94	Rotary Hoe	L4	Weed Control	5.7	0.625	88 [100 × 0.875]	0	3.56
6/94	Sand Fighter	B5[e]	Roughening	5.7	0.60	79 [88 × 0.90]	0	3.42
7/94	Cultivator	G5	Weed Control	5.7	0.75	100	0	4.28
11/94	Sprayer	–	Defoliant	~ 0.208 lb/acre[d]	–	100	0	0.21
11/94	Strip; Module	T3	Harvesting	0.26 lb/acre[c]	1.0	70	0.02	0.26
Total Annual Estimated Emissions (lb/acre)								126.5

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Ashbaugh, et al., *Modeling PM-10 Dust Emissions from Field Harvest Operations* (1996).
[d] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph; silt = 18%.

Table 4-36. Calculation of Annual Emissions from Texas Cotton Farm—Conservation Tillage with a Cover Crop[9,26,31]

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
11/93		-	Wind Erosion	3.874	-	70	0.05	0.194
12/93	Shredder	-	Shred Stalks	0.690 lb/acre[c]	-	35	0.22	0.690
12/93	Drill	M5	Plant Wheat Cover	5.7	0.60	32 [35 × 0.90]	0.25	3.42
12/93		-	Wind Erosion	4.1921	-	32	0.25	1.05
1/94 to 4/94		-	Wind Erosion	0	-	100	0	0
4/94	Sprayer	-	Herbicide Application	~ 0.208 lb/acre[d]	-	100	0	0.21
4/94	Spreader	-	Fertilizer Application	~ 0.208 lb/acre[d]	-	100	0	0.21
4/94	Field Cultivator	G1	Bed Prep	5.7	0.80	70 [100 × 0.70]	0.05	4.56
5/94	Planter and Spray Applicator	N1	Planting	5.7	0.60	63 [70 × 0.90]	0.06	3.42
5/94		-	Wind Erosion	20.02	-	63	0.06	1.201
6/94 to 11/94		-	Wind Erosion	0	-	100	0	0
7/94	Row Cultivator	K1	Weed Control	5.7	0.675	83 [100 × 0.825]	0.03	3.85
8/94	Rotary Hoe	L4	Weed Control	5.7	0.625	73 [83 × 0.875]	0.04	3.56
11/94	Sprayer	-	Defoliant	~ 0.208 lb/acre[d]	-	100	0	0.21
11/94	Strip; Module	T3	Harvesting	0.26 lb/acre[c]	1.0	70	0.05	0.26
Total Annual Estimated Emissions (lb/acre)								22.8

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Ashbaugh, et al., *Modeling PM-10 Dust Emissions from Field Harvest Operations* (1996).
[d] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph; silt = 18%.

4.4.2 California Cotton

In 1993, California farmers harvested 1.1 million acres of cotton, which was 9% of all cotton acres harvested in the United States.[1] Model farm No. 4 is located in MLRA 17 in Kings County, California. Kings County is mostly comprised of farmland on which 249,000 acres of cotton were harvested in 1994.[28] All cotton acres are irrigated, and a majority of the cotton acres are used in a continuous cropping situation. It is important to note that California has a mandatory plow down of cotton crop residue for boll weevil control. Due to the mandatory plow down, no farmers follow conservation practices by leaving surface residue on the cropland. The average size farm in California is 378 acres.[28]

Cotton cropland is located in the flat land of the San Joaquin Valley. A high hazard of wind erosion exists for sandy soils in the San Joaquin Valley where vegetative cover is not maintained, particularly on sloping soils.[2] Cotton acres in Kings County, which are irrigated regularly, are located in the flat valley, which is often not composed of sandy soils and is covered with crop during dry periods. These factors significantly reduce the potential for wind erosion on cotton acres. Water for irrigation comes from streams, wells, and canals of organized irrigation districts. The annual precipitation averages 20 in, 70% occurring from December through March. The annual average wind speed is 5 mph, and the average temperature is 63°F.[3]

Conventional farming practices, implements/machinery, and associated costs/acre totaling $392.00 are listed in Table 4-37.[29,30] All farmers must plow down cotton crop residue by December 20 of each year. Planting is allowed to begin March 1 of each year. Generally, most farmers use the farming practices listed in Table 4-37, with slight variations in farming practices followed for different locations in the San Joaquin Valley and for different soil types. Different methods of bed prep and requirements for weed control can increase or decrease the number of field operations by one or two passes.[29] Emissions from conventional California cotton farming, presented in Table 4-38, total 40.2 lb/acre annually.

No conservation farming practices are used in California cotton farming as defined by crop residue. There also are no recorded practices for other reduction methods such as reduced field passes. Practices to reduce the number of field passes could become more common in the near future through methods such as tandem implement operations and new herbicides. Larger tractors and/or new implement equipment will allow some implement operations to be combined into a single field pass. A herbicide new on the market in 1995 reduces weed populations after crop emergence and will reduce the total number of cultivator passes required.[29] No cost-effectiveness in reduction of particulate emissions per acre have been calculated for cotton in California. Data focusing on reduced implement passes would need to be collected to perform cost-effectiveness calculations.

Table 4-37. California Cotton—Irrigated Conventional Tillage 1994 Cost[29,30]

Cost category		Cost/acre
Input Material[a] and Machinery		
Flailer	Chopping Cotton Stalks	$5.00
Discing	Disc Residue	$6.00
Deep Subsoil	Bed Prep/Aeration	$7.00
Primary Discing/Herbicide Application	Bed Prep/Herbicide Application	$7.00
Lister	Bed Prep	$4.00
Irrigation	Irrigation	$40.00
Planter	Planting Cotton	$26.00
Cultivator	Weed/Aeration	$2.00
Cultivator	Weed/Aeration	$2.00
Irrigation	Irrigation	$29.00
Cultivator	Weed/Aeration	$2.00
Irrigation	Irrigation	$29.00
Irrigation	Irrigation	$29.00
Fertilize—Side-Dressing N	Fertilizer Application	$67.00
Irrigation	Irrigation	$29.00
Defoliant and Application	Harvesting	$48.00
Strip and Module (including transportation)	Harvesting	$31.00
Interest on Operating Capital (9%)		$29.00
Total Costs		$392.00

[a] Cost budget presents input materials with operation costs.

Table 4-38. Calculation of Annual Emissions from California Cotton Farm—Conventional Tillage[29,30]

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
11/94	Flailer	-	Shred Stalks	0.69 lb/acre[c]	-	35	0.22	0.69
11/94	Disc	F5	Disc Residue	5.7	1.0	18 [35 × 0.50]	0.45	5.70
12/94		-	Wind Erosion		-	18	0.45	0
1/95	Subsoiler	-	Bed Prep/Aeration	5.7	0.9	11 [18 × 0.60]	0.62	5.13
1/95	Disc/Herbicide	F5	Bed Prep/Herbicide Application	5.7	1.0	6 [11 × 0.50]	0.77	5.70
1/95		-	Wind Erosion	0	-	6	0.77	0
2/95	Lister	L5	Bed Prep	5.7	1.25	1 [6 × 0.25]	0.96	7.13
2/95	Planter	N1	Cotton Planting	5.7	0.6	1 [1 × 0.90]	0.96	3.42
2/95		-	Wind Erosion	0	-	1	0.96	0
3/95 to 11/95		-	Wind Erosion	0	-	100	0	0
4/95	Row Cultivator	K1	Weed Control	5.7	0.7	100	0	3.99
5/95	Row Cultivator	K1	Weed Control	5.7	0.7	100	0	3.99
6/95	Row Cultivator	K1	Weed Control	5.7	0.7	100	0	3.99
10/95	Sprayer	-	Defoliant	~ 0.208 lb/acre[d]	0.625	100	0	0.21
11/94	Strip; Module	T3	Harvesting	0.26 lb/acre[c]	1.0	70	0.02	0.26
Total Annual Estimated Emissions (lb/acre)								40.2

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Ashbaugh, et al., *Modeling PM-10 Dust Emissions from Field Harvest Operations* (1996).
[d] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph; silt = 18%.

4.5 Sorghum

Sorghum acres harvested in 1993 in the United States totaled nearly 9 million acres.[1] Farming practices range from the use of traditional moldboard plow and many field passes to newer no-till operations with limited field passes. Approximately 36% of planted grain sorghum acres in the United States use conservation tillage practices.[4] Kansas, the largest sorghum producing state in 1993 and an area with a high propensity for wind erosion, was selected as the location of the model sorghum farm.

4.5.1 Kansas Sorghum

In 1993, Kansas farmers harvested nearly 2.8 million acres of sorghum, which was 31% of all sorghum acres harvested in the United States.[1] Model farm pair No. 7 is located in MLRA 77 in Stevens County, Kansas. Stevens County is mostly comprised of farmland on which 79,500 acres of sorghum were harvested in 1993. Most of the sorghum acres are used in a continuous cropping situation. The average size farm in Stevens County is 1,530 acres, which is more than twice the state average farm size of 735 acres.[5]

The land in Stevens County is generally a smooth high plain that gently slopes. The soils are mostly Ustolls and Ustalfs, both well-drained. The area has a very high propensity for wind erosion. The annual precipitation averages 19 in, two-thirds occurring from May through September.[2] The annual average wind speed is 15 mph, and the average temperature is 55°F.[3]

Conventional farming practices, implements/machinery, and associated costs/acre totaling $90.26 are listed in Table 4-39.[32,33] The most typical farming practice for Stevens County is mulch till and this was selected for use as a baseline for conventional farming practices. Mulch till generally includes a tillage pass, planting, and cultivation after emergence. Stevens County farmers used mulch till methods on 90% of their sorghum acres. For the state of Kansas, 26% of the sorghum acres use mulch till and 41% use conservation methods.[4]

Conservation farming practices, implements/machinery, and associated costs/acre totaling $89.08 are listed in Table 4-40.[32,33] Conservation practices above the baseline conventional practice used in Stevens County include no-till and ridge till. No-till methods were selected for the Kansas conservation model farm. In Stevens County, no-till methods were used on 7% of the sorghum. Including mulch till, 100% of all sorghum acres in Stevens County are being farmed using conservation practices as defined by remaining surface residue.[4]

Estimated particulate emissions from tillage and wind erosion are presented for conventional practices in Table 4-41 and for conservation practices in Table 4-42. Results show annual conventional emissions total 51.8 lb/acre and annual conservation emissions total 18.4 lb/acre. Wind erosion emissions for Kansas sorghum are much larger than other model farms; however, it is still only 13% to 17% of total estimated emissions.

Table 4-39. Kansas Sorghum—Conventional Tillage 1995 Cost[32,33]

Cost catgegory		Cost/acre	
Input			
	Fertilizer—Potash	15 lb @ $0.13/lb	$1.95
	Phosphate (P205)	27 lb @ $0.18/lb	$4.86
	Anhydrous Ammonia	57 lb @ $0.18/lb	$10.26
	G. Sorghum Seed	5.0 lb @ $1.00/lb	$5.00
	Herbicide—Atrazine	2 lb @ $1.55/lb	$3.10
	Interest on Operating Capital (9%)		$1.51
		SUBTOTAL	$26.68
Machinery			
	Anhydrous Ammonia Applicator	Fertilizer Application	$6.66
	Chisel—18 ft	Bed Prep	$4.86
	Disk, Tandem—22 ft	Bed Prep	$5.52
	Fertilizer Spreader	Fertilizer Application	$2.11
	Field cultivator—27 ft	Bed Prep	$3.10
	Sprayer Pull Type—30 ft	Herbicide Application	$1.78
	Planter	Planting	$6.36
	Row Cultivator	Weed Control	$5.70
	Combine, Small Grain (including transportation)	Harvesting	$27.49
		SUBTOTAL	$63.58
Total Costs			$90.26

Table 4-40. Kansas Sorghum—No-Till 1995 Cost[32,33]

Cost category		Cost/acre	
Input			
	Fertilizer—Potash	15 lb @ $0.13/lb	$1.95
	Phosphate (P205)	27 lb @ $0.18/lb	$4.86
	Anhydrous Ammonia	57 lb @ $0.18/lb	$10.26
	G. Sorghum Seed	5.0 lb @ $1.00/lb	$5.00
	Herbicide—Bladex 90DF	1.5 lb @ $5.95/lb	$8.93
	Atrazine	2 lb @ $1.55/lb	$3.10
	Buctril	1 lb @ $6.16/lb	$6.16
	Interest on Operating Capital (9%)		$2.70
		SUBTOTAL	$42.96
Machinery Costs			
	Anhydrous Ammonia Applicator	Fertilizer Application	$6.60
	Fertilizer Spreader	Fertilizer Application	$2.11
	Sprayer Pull Type—30 ft	Herbicide Application	$1.78
	Planter, No-Till	Planting	$6.36
	Sprayer Pull Type—30 ft	Herbicide Application	$1.78
	Combine, Small Grain (including transportation)	Harvesting	$27.49
		SUBTOTAL	$46.12
Total Costs			$89.08

Table 4-41. Calculation of Annual Emissions from Kansas Sorghum Farm—Conventional Tillage[32,33]

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
10/93		-	Wind Erosion	3.5916	-	95	0.02	0.072
11/93		-	Wind Erosion	3.8742	-	95	0.02	0.077
12/93		-	Wind Erosion	4.1921	-	95	0.02	0.084
1/94		-	Wind Erosion	2.6849	-	95	0.02	0.054
2/94		-	Wind Erosion	4.2864	-	95	0.02	0.086
3/94		-	Wind Erosion	37.2112	-	95	0.02	0.74
3/94	Anhydrous NH_3 Applicator	L1	Fertilizer Application	5.7	0.70	76 [95 × 0.80]	0.04	3.99
3/94	Chisel	C1	Bed Prep	5.7	0.75	59 [76 × 0.78]	0.08	4.28
3/94	Disc	F3	Bed Prep Weed Control	5.7	0.95	32 [59 × 0.55]	0.25	5.42
11/93 to 4/94		-	Climatic Effects	-	-	28 [32 × 0.875]	0.29	-
4/94		-	Wind Erosion	36.0336	-	28	0.29	10.45
4/94	Spreader	-	Fertilizer Application	~ 0.208 lb/acre[c]	-	28	0.29	0.21
4/94	Field Cultivator	G4	Weed Control	5.7	0.65	24 [28 × 0.85]	0.35	3.71
5/94	Sprayer	-	Herbicide Application	~ 0.208 lb/acre[c]	-	24	0.35	0.21
5/94	Conventional	N3	Planting	5.7	0.60	22 [24 × 0.90]	0.38	3.42

Table 4-41 (Continued)

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
5/94		-	Wind Erosion	20.0187	-	22	0.38	7.61
6/94 to 10/94		-	Wind Erosion	0	-	100	0	0
7/94	Row Cultivator	K5	Weed Control	5.7	1.0	100	0	5.70
10/94	Combine	T1	Harvesting	5.7	1.0	95	0.02	5.70
Total Annual Estimated Emissions (lb/acre)								51.8

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph; silt = 18%.

Table 4-42. Calculation of Annual Emissions from Kansas Sorghum Farm—Conservation Tillage[32,33]

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
10/93		–	Wind Erosion	3.5916	–	95	0.02	0.072
11/93		–	Wind Erosion	3.8742	–	95	0.02	0.077
12/93		–	Wind Erosion	4.1921	–	95	0.02	0.084
1/94		–	Wind Erosion	2.6849	–	95	0.02	0.054
2/94		–	Wind Erosion	4.2864	–	95	0.02	0.086
3/94		–	Wind Erosion	37.2112	–	95	0.02	0.74
4/94		–	Wind Erosion	36.0336	–	95	0.02	0.72
11/93 to 4/94		–	Climatic Effects	–	–	83 [95 × 0.875]	0.03	–
5/94	Anhydrous NH_3 Applicator	–	Fertilizer Application	5.7	0.70	55 [83 × 0.80]	0.06	3.99
5/94	Spreader	–	Fertilizer Application	~ 0.208 lb/acre[c]	–	66	0.06	0.21
5/94	Sprayer	–	Herbicide Application	~ 0.208 lb/acre[c]	–	66	0.06	0.21
5/94	No-till	N2	Planting	5.7	0.575	61 [66 × 0.925]	0.07	3.28
5/94		–	Wind Erosion	20.0187	–	61	0.07	1.40
6/94	Sprayer	–	Herbicide Application	~ 0.208 lb/acre[c]	–	100	0	0.21
6/94 to 10/94		–	Wind Erosion	0	–	100	0	0

Table 4-42 (Continued)

AFO date	Machinery	Agricultural implement code	AFO or intervening wind erosion	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
7/94	Sprayer	–	Herbicide Application	~ 0.208 lb/acre[c]	–	100	0	0.21
10/20/94	Combine	T1	Harvesting	5.7	1.0	95	0.02	5.70
Total Annual Estimated Emissions (lb/acre)								18.4

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18%; uses emission factor for wind erosion from Gillette (1988).
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft sprayer or spreader weighs 15 tons and travels at 8 mph; silt = 18%.

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Wind erosion emissions account for 19.2 lb/acre for conventional practices and 3.2 lb/acre for conservation practices. Total emissions are reduced by 65% with conservation practices.

The cost-effectiveness calculation for reduction of particulate emissions per acre is as follows:

$$\$89.08 - \$90.26 / 51.8 \text{ lb/year} - 18.4 \text{ lb/year} = -\$0.04 / \text{lb}$$

The negative value of cost-effectiveness indicates a cost savings associated with the emission reduction. The increased chemical costs of no-till practices make the overall cost difference between conventional and conservation practices small; however, no-till practices reduce wind erosion emissions by 83%.

4.6 Rice

The California State ambient air quality for ozone and PM-10 has historically been violated during the time period that rice straw is typically burned. The Sacramento Valley in California often exceeds the national air quality standards for several reasons. First, rice is the primary cash crop grown in the Sacramento Valley with approximately 484,000 acres planted in 1994-1995. Second, rice growers prefer to burn the rice straw remaining after harvest due to the ease, low cost, and prevention of rice diseases. Third, rice straw is typically burned from September 15 through November 30, a period when unfavorable air dispersion conditions exist in the Sacramento Valley.

Violations of the state ambient air quality standards have led to the Connelly-Areias-Chandler Rice Straw Burning Reduction Act of 1991 (the Act), which requires the phasedown of rice straw burning. The burning reduction schedule mandated by the Act is summarized in Table 4-43. To date, the phasedown schedule has been achieved. However, as the 50% level is approached, the Air Pollution Control District (APCD) offices are challenged with administering an optional field trading policy. This provision of the Act, requested by the growers, is considered one of the most costly portions of the district programs. In addition to the increased cost of the field trading, district revenue has decreased as fewer burn fees are collected with reduced burned acreage.

Table 4-43. Mandated Phasedown of Rice Straw Burning

Year	Burnable acres (%)
1992	90%
1993	80%
1994	70%
1995	60%
1996	50%
1997	38%
1998	25%
1999	25%
2000	25% or 125,000 acres whichever is least

Rice growers are also presented with a variety of problems as the phasedown approaches the 50% tier, due primarily to the lack of off-field disposal alternatives to rice straw burning. Lack of off-field alternatives is clearly demonstrated by the fact that 95% of the unburned rice straw is currently incorporated into the soil, requiring additional agricultural field operations. Moreover, there are an assortment of difficulties associated with incorporating rice straw into the soil:

- Growers are concerned about increased incidence of rice diseases. The University of California currently is conducting studies to investigate risks of rice disease associated with not burning rice straw.
- Incorporation of rice straw is costly and time consuming, especially for those soils which have a high clay content.
- Rice straw is of such a coarse texture that it is particularly wearing on cutting and shredding equipment. This is in part due to rice straw's high silica content, approximately four times higher than other cereal straws such as wheat.

4.6.1 Rice Farming Practices and Costs

For this study, conventional and conservation farming practices differ only in the disposal of rice straw. Farming operations for both the conventional farm and the conservation farm are presented in Tables 4-44 and 4-45.

Table 4-44. California Rice—Conventional Tillage 1993 Cost

Cost category		Cost/acre	
Input			
	Fert 16-20-00	Fertilize	$26.00
	Anhydrous Ammonia	Fertilize	$16.90
	Zinc Sulfate	Fertilize	$13.55
	Boxes & Labor	Irrigation	$5.20
	Irrigation	Field Flooding	$11.50
	Rice	Aerial Application	$37.43
	Ordram	Insecticide	$19.70
	Londax DF	Herbicide	$39.90
	Irrigation	Field Flooding	$5.00
	Irrigation	Field Flooding	$5.00
	Irrigation	Field Flooding	$5.00
	Irrigation	Field Flooding	$5.00
	Drying		$62.30
	Storage		$42.83
	Burn Straw		$5.00
	Rice Checkoff	Promotion and Research	$6.00
	Interest (9%) on Operating Capital purchase of inputs until harvest		$34.89
		SUBTOTAL	$341.20
Machinery			
	Mower, Flail	Soil Preparation	$11.78
	D7 Bulldozer	Removing Levees	$22.50
	Chisel Plow—15 ft	Soil Preparation	$5.33
	Disc, Offset/Heavy Duty—19 ft	Soil Preparation	$7.92
	Disc, Tandem/Regular—19 ft	Soil Preparation	$6.73
	Leveler, Land-Plane	Land Leveling	$13.36
	Blade—10 ft	Constructing Levees	$8.81
	Roller, Rice	Constructing Furrows	$17.33
	Combine, Self-Prop	Harvesting	$12.26
	Pickup—3/4 ton	Transfers	$5.79
	Mower, Sickle	Burning Preparation	$9.50
		SUBTOTAL	$121.31
Total Costs			$462.51

Table 4-45. California Rice—Conservation Tillage 1993 Cost

Cost category		Cost/acre	
Input			
	Fert 16-20-00	Fertilize	$26.00
	Anhydrous Ammonia	Fertilize	$16.90
	Zinc Sulfate	Fertilize	$13.55
	Boxes & Labor	Irrigation	$5.20
	Irrigation	Field Flooding	$11.50
	Rice	Aerial Application	$37.43
	Ordram	Insecticide	$19.70
	Londax DF	Herbicide	$39.90
	Irrigation	Field Flooding	$5.00
	Irrigation	Field Flooding	$5.00
	Irrigation	Field Flooding	$5.00
	Irrigation	Field Flooding	$5.00
	Drying		$62.30
	Storage		$42.83
	Burn Straw		$5.00
	Rice Checkoff	Promotion and Research	$6.00
	Interest (9%) on Operating Capital from purchase of inputs until harvest		$34.89
	Irrigation	Field Flooding	$5.00
		SUBTOTAL	$346.20
Machinery			
	Disc	Extra Operation	$9.00
	Disc	Extra Operation	$9.00
	Mower, Flail	Soil Preparation	$11.78
	D7 Bulldozer	Removing Levees	$22.50
	Chisel Plow—15 ft	Soil Preparation	$5.33
	Disc, Offset/Heavy Duty—19 ft	Soil Preparation	$7.92
	Disc, Tandem/Regular—19 ft	Soil Preparation	$6.73
	Leveler, Land-Plane	Land Leveling	$13.36
	Blade—10 ft	Constructing Levees	$8.81
	Roller, Rice	Constructing Furrows	$17.33
	Combine, Self-Prop	Harvesting	$12.26
	Pickup—3/4 ton	Transfers	$5.79
	Mower, Flail	Incorporation Preparation	$9.50
	Stubble Disc	Incorporation	$9.00
	Stubble Disc	Incorporation	$9.00
		SUBTOTAL	$157.31
Total Costs			$503.51

The field preparations, planting, irrigation, and harvesting are generally the same for both conservation and conventional methods, with an estimated grand total of $451.49 per acre to grow and harvest the rice. The difference between conventional and conservation farming practices is the method of handling rice straw remaining after harvest.

The conventional practice is to burn rice straw at an average cost of $4.50 per acre while conservation practices typically incorporate rice straw into the ground at an average cost of $55.00 per acre, excluding the cost of extra field operations in the spring for wet incorporation.. Most growers start the field preparation by bulldozing the levees that separate the rice fields because it is easier to work a few large fields than it is to work severla small fields. The levees are reconstructed later. The fields are then disrupted with a chisel plow to further prepare the soil for planting, The soil is then disced to help achieve uniformity throughout, and finally the soil is leveled to a specific grade by using a plane leveler. It is important to note that ever 3 to 4 years the soil is leveled using a laser leveler, which provides a more precise grade. This is slightly more expensive than using a plane leveler and costs $18.75 per acre.

After the soil has been properly prepared, which normally occurs during April, the three conventional fertilizers are applied and the irrigation system is constructed before rice seed is aerially applied in mid-May. After the rice is planted, the field is subjected to its first flooding. Herbicides and insecticides are applied aerially according to manufacturer's recommendations or as needed, with the insecticide being applied shortly after the rice is planted and the herbicide being applied a few days before the field is flooded for the second time.

The fields are flooded four more times after the initial flooding at one-month intervals. The rice, which is harvested with a self-propelled combine, is ready for harvesting around the beginning of October.

For the purposes of this study, conservation practices include baling rice straw at an estimated expense ranging from $45.00 to $200.00 per acre depending on bale size and field location. This wide range of costs occurs because there are no significant off-field alternatives. Rice growers are unlikely to bale rice straw if no market for the rice straw exists. Regardless of the no-burn option, additional costs exist to implement conservation practices. This extra expense does not include possible yield reductions or loss of premium crop.

4.6.2 Alternatives to Rice Straw Burning

Soil incorporation exists in two forms, wet and dry, and soil incorporation is the sole alternative that is currently practiced. Although many alternatives to burning rice straw have been identified, only a limited number, such as manufacturing or energy conversion, appear to have real potential before the year 2000. Presently burnable acres can be traded between growers, which helps those who find incorporation very difficult and cost prohibiting. However, field trading is dependent on each individual APCD, and may be in danger because of the combination of high costs associated with regulating field trading and the decreased income of burning fees used to support each district. The following subsections summarize each alternative along with other pertinent information including the current status and the alternative advantages or disadvantages.

4.6.2.1 Wet Incorporation

Wet incorporation procedures include first chopping the rice straw with a flail mower, followed by incorporation with two field passes of a stubble disc, and finally flooding the field to facilitate rice straw decomposition. One advantage of wet incorporation over dry incorporation is better decomposition rates of the rice straw. The average cost of the wet incorporation process is $55.90 per acre.

Several concerns over the wet incorporation process have been noted, including the initial cost of the equipment that must be purchased to incorporate rice straw in the soil. The average 1995 cost of a chopper, which cuts the straw into fine pieces, is reported at $14,000, and the average cost of the stubble disc implement is approximately $35,000. Another concern suggests that constant incorporation will increase the incidence of rice disease, thus causing a significant yield reduction. Microorganisms responsible for rice diseases will multiply in the remaining rice straw, where burning will destroy them. The final concern is the inability to properly plant and obtain a premium crop due to the extra spring field operations required after incorporation. Extra field operations, yield reductions, and loss of premium crop are estimated to cost an additional $65.69 per acre—making a total of $121.59 per acre to wet incorporate rice straw.

4.6.2.2 Dry Incorporation

Dry incorporation procedures include chopping the rice straw with a flail mower, followed by incorporation with two passes of a stubble disc, and finally passing a roller across the field to ensure sufficient rice straw contact with the soil. Some growers add 100 lb of urea per acre prior to the rice chopping to aid in the decomposition process. The average cost of the dry incorporation process is $52.00 per acre. Again, as with wet incorporation, a major concern is the initial cost of the needed equipment. The cost is the same as wet incorporation with the addition of a rice roller estimated at $6,000. Another common concern is the increased incidence of rice diseases, which may be more prevalent with dry incorporation than wet because of lower decomposition rates. The impact of dry incorporation on yield loss is not yet known. Dry incorporation has no effect on delaying spring operations as compared to wet incorporation.

4.6.2.3 Bale and Remove Alternative

"Bale and remove" is a viable alternative if a market for the rice straw can be found or created. The cost of baling and removing the rice straw ranges from $45.00 to $200.00 per acre, depending on the bale size and the field location. It is important to note that all off-field alternatives to burning require the bale and remove procedure.

4.6.2.4 Manufacture of Rice Straw Construction Materials

Manufacturing of non-wood-based construction material is a promising off-field alternative with the major barrier being public acceptance of compressed rice straw paneling for buildings. One company, Pyromod, has designed a complete building system using modules consisting of lightweight compressed straw paneling, latex adhesives, and coatings. A second company, Bio Fab, offers a compressed rice straw panel using a similar process, but their product is primarily for interior walls in place of the studs and drywall. It is worthwhile to note that Stramit, a Texas company, produces a similar product using wheat straw that is currently available in the Texas area.

4.6.2.5 Energy Conversion

Energy conversion is another viable off-field alternative. It exists in two forms: ethanol production and direct combustion. Ethanol production for use in transportation markets would lessen air pollution on two counts. First, the rice straw would not be burned in the field or in a direct conversion process. Second, ethanol fuel blends result in cleaner burning vehicles. The major by-products of ethanol conversion, silica and lignin, also have the potential to be marketed as secondary products. There are currently plans for two ethanol conversion plants in the Sacramento Valley area. Both projects are scheduled to be in operation by 2000, but face concerns of scaling the process from development to commercial levels and the need for enhanced project funding.

4.6.2.6 Combustion of Rice Straw

Direct combustion of rice straw at an off-field location does not appear to be a viable option for many reasons. First, rice straw would have to compete against more suitable biomass products in the market. Many biomass plants have been closed or converted to other uses, both in California and other areas of the United States. Second, when rice straw is used for direct combustion, the high silica content causes heavy slagging to quickly accumulate in the boilers, resulting in high ash content. Third, the ash that is produced from direct combustion is classified as a hazardous waste. The use of rice straw for energy conversion is limited, by practical considerations, to ethanol production.

4.6.2.7 Environmental Mitigation

Environmental mitigation, for protection from wind and water erosion is a promising use for rice straw. The characteristics that prohibit the use of rice straw in other processes are actually desired for environmental mitigation. The high silica content of rice straw makes it a dense substance in comparison to other cereal straws. This higher density helps keep the product in place, where other cereal straws would be blown away. The high silica content is also responsible for the slow decomposition of rice straw, which again benefits environmental mitigation through longer life. Finally, the weeds associated with rice are aquatic in nature and will not be introduced to the areas treated with rice straw. Prominent barriers involved in diverting rice straw to environmental mitigation uses are (1) an unpredictable demand, (2) a deficient infrastructure to transport the rice straw, and (3) expected high costs.

4.6.2.8 Other Off-field Alternatives

Composting and livestock feed have been identified as off-field alternatives for rice straw, but barriers exist in each case. The rough abrasive texture, the slow decomposition, and the competition of other proven cereal straws make composting an unlikely diversion for rice straw. Rice straw as a component of livestock feed has similar problems as the coarse structure and limited nutritional value make it unappealing for feed material. It is unlikely that a significant amount of rice straw will be diverted to either of these alternatives.

4.6.3 Cost-Effectiveness of Emission Reductions

The cost-effectiveness of emission reductions for rice growing has been calculated for four scenarios: The worst-case, the best-case, minimized emissions for both, and maximized emissions for both. All of the scenarios were calculated using wet incorporation, which requires additional water to flood the field and usually two extra discing operations in the spring.

Tables 4-46 and 4-47 present the estimated annual emissions for conventional and conservation practices. As is shown, PM-10 annual emissions from conventional practices total 63.5 lb/acre, of which 24.0 lb/acre results from burning of rice straw. In comparison, conservation practices are estimated to produce 57.6 lb/acre of PM-10 emissions.

Scenario One—Worst-case: The worst-case scenario is an emissions reduction cost of $13,899/ton. This calculation assumes that the emissions from conventional burning of rice straw are at the minimum value, with the cost and emissions maximized for conservation practices. Note that the values used to calculate the worst-case scenario are the values reported in Tables 4-44 to 4-47.

Table 4-46. Calculation of Annual Emissions from Sacramento Valley Rice Growing—Conventional Practices

AFO date	Machinery	Agricultural implement code	AFO	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
4/93	Flail Mower	–	Soil Preparation	4.1	1	100	0.01	4.10
4/93	Bulldozer	–	Removing Levees	~ 0.673 lb/acre[d]	1	100	0.01	0.67
4/93	Chisel Plow	C2	Soil Preparation	4.1	1.15	35	0.22	4.70
4/93	Offset Disc	F1	Soil Preparation	4.1	1.32	6	0.77	5.40
4/93	Tandem Disc	F6	Soil Preparation	4.1	1.17	2	0.92	4.80
4/93	Land Leveler	–	Soil Preparation	4.1	1	2	0.92	4.10
4/93	Spreader	–	Fertilizer Application	~ 0.208 lb/acre[c]	1	2	0.92	0.21
4/93	Anhydrous NH_3 Applicator	L1	Fertilizer Application	4.1	0.92	1	0.96	3.80
4/93	Spreader	–	Fertilizer Application	~ 0.208 lb/acre[c]	1	1	0.96	0.21
4/93	Bulldozer	–	Constructing Levees	~ 0.673 lb/acre[d]	1	1	0.96	0.67
5/93	Rice Roller	H7	Constructing Furrows	4.1	0.63	1	0.96	2.60
5/93	Aerial Application	–	Planting	0	1	1	0.96	0
5/93	Aerial Application	–	Insecticide and Herbicide Application	0	1	1	0.96	0

Table 4-46 (Continued)

AFO date	Machinery	Agricultural implement code	AFO	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
10/93	Combine	-	Harvesting	4.1	1	1	0.96	4.10
10/93	Sickle Mower	-	Burning Preparation	4.1	1	1	0.96	4.10
10/93	Fire Starter	-	Burning	24[e]	1	1	0.96	24.0
Total Annual Estimated Emissions (lb/acre)								63.5

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18% and CARB PM-10 scaling factor of 15%; no wind erosion emissions calculated; assumed minimal.
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft spreader travels at 8 mph, weighing 15 tons.
[d] Uses AP-42 factor for bulldozing overburden from Section 11.9 USEPA (1995): moisture = 20% and silt = 18%.
[e] Progress Report on the Phasedown of Rice Straw Burning in the Sacramento Valley Air Basin, CARB (1995).

Table 4-47. Calculation of Annual Emissions from Sacramento Valley Rice Growing—Conservation Practices

AFO date	Machinery	Agricultural implement code	AFO	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
3/93	Disc	F6	Extra Field Operation due to Incorporation	4.1	1.17	33	0.24	4.80
3/93	Disc	F6	Extra Field Operation due to Incorporation	4.1	1.17	11	0.62	4.80
4/93	Flail Mower	NA	Soil Preparation	4.1	1	11	0.62	4.10
4/93	Bulldozer	NA	Removing Levees	~ 0.673 lb/acre[d]	1	4	0.84	0.67
4/93	Chisel Plow	C2	Soil Preparation	4.1	1.15	1	0.96	4.70
4/93	Offset Disc	F1	Soil Preparation	4.1	1.32	0	0	5.40
4/93	Tandem Disc	F6	Soil Preparation	4.1	1.17	0	0	4.10
4/93	Land Leveler	NA	Soil Preparation	4.1	1	0	0	4.10
4/93	Spreader	NA	Fertilizer Application	~ 0.208 lb/acre[c]	1	0	0	0.21
4/93	Anhydrous NH_3 Applicator	L1	Fertilizer Application	4.1	0.92	0	0	3.80
4/93	Spreader	NA	Fertilizer Application	~ 0.208 lb/acre[c]	1	0	0	0.21
4/93	Bulldozer	NA	Constructing Levees	~ 0.673 lb/acre[d]	1	0	0	0.67
5/93	Rice Roller	NA	Constructing Furrows	4.1	0.63	0	0	2.60
5/93	Aerial Spray	NA	Planting	0	1	0	0	0
5/93	Aerial Spray	NA	Insecticide and Herbicide Application	0	1	0	0	0
10/93	Combine with chopper	NA	Harvest and Incorporation Preparation	4.1	1	0	0	4.10
10/93	Flail Mower	NA	Chop Rice Straw	4.1	1.25	0	0	5.10

Table 4-47 (Continued)

AFO date	Machinery	Agricultural implement code	AFO	Base PM-10 emission factor[a] (lb/acre)	Tillage emission factor ratio[b]	Remaining surface residue (%)	Soil loss ratio	PM-10 emissions (lb/acre)
10/93	Stubble Disc	NA	Incorporation	4.1	1	0	0	4.10
10/93	Stubble Disc	NA	Incorporation	4.1	1	0	0	4.10
Total Annual Estimated Emissions (lb/acre)								57.6

[a] Uses AP-42 factor for tilling from USEPA (1995) with silt content = 18% and CARB scaling factor of 15%; no wind erosion emissions calculated; assumed minimal.
[b] Assumes that relative emissions from specific tilling operation are inversely proportional to percentage of surface residue remaining.
[c] Uses AP-42 factor for travel on unpaved surfaces from USEPA (1995): 30-ft spreader travels at 8 mph weighing 15 tons.
[d] Uses AP-42 factor for bulldozing overburden from Section 11.9 USEPA (1995): moisture = 20% and silt = 18%.

Scenario Two—Best-case: The best-case scenario produced an emissions reduction cost of $339/ton. This calculation assumes that the rice straw is burned when wet which maximizes the emissions for conventional growing, and that the costs and emissions are minimized for conservation practices. Maximized conventional emissions are calculated using 77 lb/acre for burning rather than the 24 lb/acre reported in Table 4-46.[34] This means that three agricultural field operations would be eliminated: One chopping, one incorporation discing, and one extra spring discing, as these field operations are performed only as needed.

Scenario Three—Minimized emissions: This scenario is calculated using minimized emissions and costs for both conventional and conservation growing, and yields an emissions reduction cost of $1,357/ton.

Scenario Four—Maximized emissions: This scenario is calculated using maximized emissions and costs for both conventional and conservation growing, and yields an emissions reduction cost of $1,250/ton.

4.6.4 Summary

In summary, the only viable alternatives to burning the rice straw are dry or wet incorporation into the soil, manufacturing building materials, and energy conversion by way of ethanol production. Best estimates suggest the off-field alternatives will divert approximately 30% of the rice straw by the year 2000. However, costs may prove to be prohibitive because of the extra agricultural implements required and new transportation costs. As it stands now, the cost-effectiveness of emissions reduction cost is bounded by $13,899/ton and $339/ton. The actual cost-effectiveness is likely not at either of the two extremes. As the off-field alternatives begin to divert portions of the rice straw from incorporation, costs of alternatives to burning will decrease.

4.7 Texas Cattle Feedlot

4.7.1 Background

A beef cattle feedlot is an area in which beef animals are confined for fattening prior to marketing. This fattening, or finish feeding, typically lasts 4 to 5 months. As shown in Figure 4-1, air pollution from beef cattle feedlots originates from multiple points in a feedlot operation, including holding pens (cattle movement and manure decomposition), roads and alleyways, manure windrows and stockpiles, feed grain spillage and decomposition, and settling ponds and lagoons.

A major source of the particulate matter emissions from feedlots is the open feedlot pen surface, which is usually a native soil surface. The feedlot surface becomes a padded mixture of soil and manure because of animal movement, which stirs up

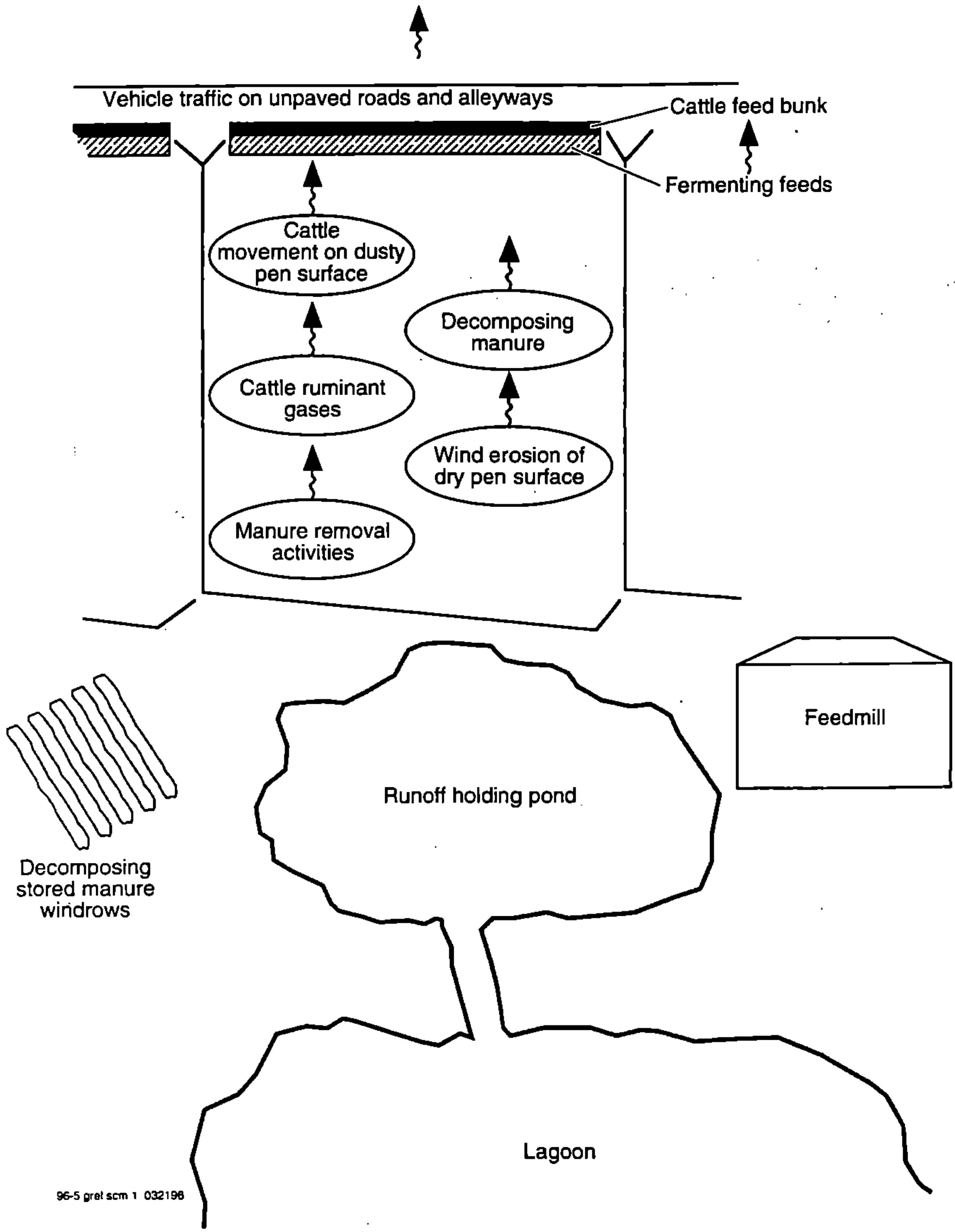

Figure 4-1. Emission Sources Associated with Cattle Feedlots

particulate emissions from the pen surface. Feedlot roads and alleyways also are sources of significant PM from vehicle traffic.

Particulate emissions are dependent on animal density (e.g., spacing), time of day, manure production, and other parameters such as soil silt and moisture contents. Feedlot surfaces are observed to produce more PM emissions when dry and dusty, especially in the early evening hours of summer when cattle are more active. Feedlot emissions of PM are also suspected to be dependent on such factors as silt content of the soil. However, the current AP-42 factor for PM is a single value because of lack of sufficient test data for more complex emission factor development.

The following (alternative) particulate emission factors for cattle feedlots were published by EPA (AP-42) in July 1979:

280 lb/day per 1,000 head capacity, or
27 ton per 1,000 head throughput

These emission factors originated from 1972 test data[36] obtained at over 20 California feedlots using a high volume Staplex sampler. The factors were actually developed in a 1977 study by Peters and Blackwood[37] that used dispersion modeling to estimate the PM emission rate by applying a continuous line source algorithm to the 1972 data.

A proposed revision to AP-42 that is now underway will recommend a PM-10 multiplier of 0.25, based on test data obtained by Sweeten et al. in 1988[38] at three cattle feedlots in West Texas. Consequently, the current study utilizes a PM-10 emission factor of 70 lb/day per 1,000 head capacity.

There are several approaches to dust control, but water application is the most effective, economical, and reliable means of reducing dust from feed pens.[39] Water application controls are discussed in detail in several reports, including research by Elam et al.,[40] Algeo et al.,[36] and Sweeten et al.[38] Cattle stocking rate as a dust control measure is discussed by Lott.[42] He found that manure can be dried under ambient feedlot conditions to moisture contents between 6% to 9% (wb), which increases dust emissions from the pen surface, as cattle pulverize the dry manure.

In a study of feedlot dust controls during August and September 1990, dust concentrations were measured inside 65 pens at 10 California feedlots containing a total of 9,581 head of cattle located in the San Joaquin and Imperial Valleys. Two hundred and forty-two measurements were made using a Staplex air sampler sampling at 60 to 70 cfm. Pen surface moisture samples were taken simultaneously. Temperature, relative humidity, and wind velocities also were monitored. Dust samples also were collected on adhesive strips.

The San Joaquin experiments explored the effects of cattle density and chemicals to control dust; the Imperial Valley experiments emphasized both water application and chemical agents having dust palliative properties. Chemical agents included calcium sulfate (gypsum), ligno sulfonate, sodium carbonate, calcium nitrate, and a surface wetting agent.

Particulate concentrations (24-hr time averaged) increased from 3,150 to 23,300 $\mu g/m^3$ when daily water sprinkling was discontinued for 7 days, implying that watering could achieve over 85% control efficiency. Water application of 0.5 to 0.75 gal/yd^2 was recommended for effective dust control, with initial doubling of water application rates until loose manure becomes packed and the moisture content reaches approximately 20% to 30%. Water application was recommended in the evening hours beginning at 1800 PDT because of the need to hold humidity to low conditions to avoid heat stressing the cattle in the California environment. Increasing cattle density to 70 to 80 ft^2/head also decreased measured dust concentrations by increasing soil moisture from manure water. Application of straw and other bedding materials may also be effective and economically viable in controlling dust emissions from cattle pens but have not been investigated to date.

Previous fugitive dust studies associated with moisture content of soil surfaces have shown that emission rates are lower when colder temperatures and higher humidities prevail.[43] Natural dust mitigation from precipitation is increased in winter months because of freezing and less rapid evaporation of soil moisture.

4.7.2 Model Feedlot

The model cattle feedlot in West Texas has a capacity of 25,000 head with an animal density of 200 ft^2/head and a total area of 115 acres. Located in Deaf Smith County, the potential for dust generation is greatly increased during prolonged dry, hot periods (e.g., from late spring through the summer) when a loose, dry pad of soil and manure builds up in the pens.

The scenario for the conventional model feedlot assumes no air pollution control measures are in effect. A PM-10 emission factor of 70 lb PM-10/day per 1,000 head of capacity is used with no control measures to reduce emissions. This value is obtained by multiplying the AP-42 emission factor of 280 lb TSP/day per 1,000 head capacity by 0.25, the average fraction of PM-10 to TSP measured by Sweeten et al.[38]

In comparison, the conservation model feedlot assumes that water is sprayed on the feedlot surface areas during the dustiest 6 months of a year to maintain sufficient moisture levels throughout the night and early morning to effectively reduce dust emissions. Water is applied at a daily rate of 0.75 gal/yd^2 to the dry feedlot pens using a permanent sprinkling system. Total water applied to the 115-acre feedlot is calculated as 417,000 gal/day. The water supply for the model feedlot sprinkler system is adequate in this West Texas region at this time, but may be a problem in the future because of aquifer depletion.

Cattle density, if increased from 200 ft^2/head to less than 100 ft^2/head, could also help maintain high enough moisture levels in the pens to limit particulate generation. However, increasing cattle density would likely exacerbate the problem with odors, a major citizen complaint in some areas. Consequently, it is assumed that cattle density does not differ between conventional and conservation feedlots.

Based on the previously described California tests, an average PM control efficiency of 80% for watering is estimated for the conservation model feedlot. In contrast to California, where researchers declined to apply water sprays during the day to avoid heat stressing the cattle, low humidities and relatively high winds in West Texas allow daytime water sprays to assist cattle to tolerate heat better and potentially improve weight gains. Cattle health and production issues will be studied by Texas agricultural researchers in the summer of 1996, and are not discussed in this section because of lack of data.

PM-10 emissions from the conventional feedlot of 25,000 head capacity are estimated at 1,750 lb/day. Because of water sprays from the permanent sprinkler system, an estimated PM control efficiency of 80% is applied to the uncontrolled emissions. This results in a controlled PM-10 emission factor of 14 lb/day per 1,000 capacity for the conservation feedlot. The daily PM-10 emissions for the conservation feedlot is 350 lb/day, resulting in an estimated PM-10 emission reduction of 1,400 lb/day.

The water sprinkler system must be purged with compressed air during November and remains out of operation during the winter months when water lines will freeze. The system is reactivated in April. Assuming that a watering program is conducted only during the warmest, driest 6 months of each year, annual PM-10 emissions could be reduced by as much as 128 tons through a watering program.

Investment costs of a California sprinkler system for a 640-acre, 100,000-head feedlot in the San Joaquin valley were reported at $1 million and included a pumping station (three pumps), reservoir tank, main water line, secondary water supply lines, 750 sprinkler heads with risers, and time clocks to control watering cycles.[42] The normal cycle was a 5-min spray period six times a day. The cost per head was estimated at $7.50 in 1985.

Installation costs of a permanent sprinkler system in Texas in 1996 have been estimated by industry experts at $500,000 to $1,000,000. The annualized cost of a feedlot watering program in West Texas is estimated for the conservation model feedlot at $75,000/yr, but because of the lack of sufficient data is considered only a crude estimate at this time.

In contrast, no control costs are associated with the conventional feedlot. Consequently, conservation feedlot operations are estimated to cost $75,000 more each year for the model feedlot employing a watering program than for a conventional feedlot without a watering program. By dividing the annualized cost of $75,000 by the annual emission reduction of 128 tons of PM-10, the model feedlot pair indicates a cost-effectiveness of $586/ton PM-10. This figure may be reduced if new studies show that cattle weight gains and health are improved through a water spray program, or may be increased if the PM-10 emission factor, now being revised by U.S. EPA, is reduced.

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Section 5
Conclusions and Recommendations

The purpose of the study reported herein was to compare the emission and cost differences between conventional and conservation farming practices. Thirteen model farm pairs were developed for major crops and a cattle feedlot in the United States. Emissions were estimated for both conservation and conventional farming practices, with the results shown in Table 5-1. Annual costs of agricultural crop production were developed from data supplied by USDA sources. The data on emissions and costs were consolidated to produce cost-effectiveness values for conservation farming practices. Cost-effectiveness was calculated as annualized cost of control per unit of reduced PM-10 emissions.

As shown in Table 5-1, the annual emissions of PM-10 for the model farms are produced largely from agricultural field operations, as compared to wind erosion. This observation is consistent with recent annual EPA "Trends" reports. Wind erosion emissions for the individual model farms generally account for less than 20% of the estimated total emission rate, with Kansas sorghum and Texas cotton being the exceptions. These results reflect the median (or 50th percentile value) wind erosion estimates in the NAPAP emission inventory that were used in this study. If the 90th percentile values of wind erosion emissions are used, the annual wind erosion estimates will increase substantially and in some cases will exceed emissions from agricultural field operations. The 90th percentile values, which are more representative of dusty conditions in dry, windy years range from 100 times less to 5 times greater than tillage emissions depending on the model farm.

As indicated in Table 5-2, conservation practices reduce total emissions from 9% to 82%, led by Texas cotton, which has the highest emission density (lb/acre) for conventional farming practices. Conservation practices successfully reduce wind erosion in all cases, from 30% to 97%, depending on the model farm operations.

As shown in Table 5-3, results from eight of the eleven model farm pairs compared demonstrate that cost savings rather than additional expenses accrue to the switching from conventional to conservation practices throughout the country. The emission reductions and lower costs associated with conservation practices typically result in negative cost-effectiveness values for major crop production in the United States.

Several refinements in the calculations methodology have been identified in this study, and are recommended for future consideration, as follows:

- Wind erosion emission estimates would be improved by using the 1992 National Resources Inventory (NRI) that contains more data points for land throughout the United States than the 1982 NRI used by Gillette for the NAPAP study.
- Estimates of emissions from wind erosion should be adjusted from PM-20 to PM-10. Also the nationwide estimates of wind erosion emissions used by EPA in trends analysis should incorporate information on numbers and types of agricultural implements and amounts of surface residue remaining after tillage operations.

Table 5-2. Emission Reductions

Number of model farm pair	Crop	State	Conventional agricultural emissions (lb/acre)	Conservation agricultural emissions (lb/acre)	Total emission reduction (%)	Reduction in wind erosion (%)
1	Corn	Indiana	27.1	14.5	45.8	61.5
2	Corn	Iowa	32.4	14.2	56.2	78.0
3	Corn	Texas	46.5	26.0	44.1	32.3
4	Cotton	California[a]	40.2	NA	NA	NA
5	Cotton	Texas	126.5	22.8	82.0	97.2
6	Rice	California	63.5	57.6	9.31	100.0[b]
7	Sorghum	Kansas	51.8	18.4	64.5	61.5
8	Soybeans	Illinois	34.2	9.9	71.1	89.1
9	Spring Wheat	North Dakota	26.6	12.6	52.6	87.9
10	Winter Wheat	Kansas	35.3	21.8	38.2	52.5
11	Winter Wheat	Texas	38.1	21.9	42.5	29.4
12	Winter Wheat	Washington	14.1	10.3	27.0	NA

[a] No emissions calculated for conservation practices for California cotton due to mandatory plowdown by the state.
[b] For California rice only, percent reduction in burning emissions.

Table 5-3. Cost-Effectiveness

State	Crop	Conventional agricultural emissions		Conservation agricultural emissions		Cost-effectiveness ($/lb)
		lb/acre	$/acre	lb/acre	$/acre	
Indiana	Corn	27.1	$155.07	14.5	$141.05	($1.11)
Iowa	Corn	32.4	$166.10	14.2	$151.85	($0.78)
Texas	Corn	16.5	$247.08	26.0	$235.59	($0.56)
California	Cotton	40.2	$392.00	NA	NA	NA
Texas	Cotton	126.5	$110.64	22.8	$118.28	$0.07
California	Rice	63.5	$462.51	57.6	$503.51	$6.95
Kansas	Sorghum	51.8	$90.26	18.4	$89.08	($0.04)
Illinois	Soybeans	34.2	$142.70	9.9	$127.54	($0.63)
North Dakota	Spring Wheat	26.6	$78.28	12.6	$71.35	(0.50)
Kansas	Winter Wheat	35.3	$96.81	21.8	$82.21	($1.08)
Texas	Winter Wheat	38.1	$87.96	21.9	$73.44	($0.90)
Washington	Winter Wheat	14.1	$137.99	10.3	$163.28	$6.66

Appendix A

Survey Packet Sent to Local Agricultural Authorities

ATTACHMENT 1

Project Background

Project Information:

- Funded by EPA Office of Air Quality Planning and Standards (OAQPS).
- EPA Work Assignment Manager, Mr. Ken Woodard.
  Phone: (919) 541-5697
- USDA Liaison. Mr. Roel Vining, ARS Office
  West Lafayette, IN. Phone: (317) 494-0330
- Other USDA contacts: Mr. David Lightle and Mr. Gary Tibke, NRCS Office
  Lincoln, NE. Phone: (402) 437-5318

Background

From the ranking of crops by nationally harvested acreage in 1993, MRI has identified corn. soybeans. winter wheat, durum spring wheat. cotton, sorghum. and rice as the major crops that will be studied on the basis of dust emission impact. This study will rely on previously estimated wind erosion and tilling emission data. farming practices identified by District Conservationists, and associated cost data. The purpose is to determine the effects of conservation tillage on dust emissions with respect to costs.

Areas with a propensity for wind erosion have been determined by Gillette and Hanson (J. Geophy. Res..Vol 94:D2. 1989) in support of the National Acid Precipitation Assessment Program (NAPAP). Dust emission flux, as calculated for each county, were plotted to identify regions in the United States with a high likelihood of wind erosion. Dust production in the Gillette and Hanson model is dependent on rainfall, soil conditions such as surface texture, ridging and clodiness, land use such as cropping, and wind energy distribution. Wind erosion threshold velocity varies according to precipitation.

A model farm concept will be used to identify the farming practices associated with each of the seven target crops in major growing regions of the United States. The crop rotation system, date of agricultural field operations on the primary crop, types of field equipment used (list included). and conservation measures employed, if any. will be identified for each model farm. Agricultural field operations will be specified by date. including soil tillage. fertilizer. herbicide. and pesticide applications. planting. harvesting, and residue burning.

Once the geographic areas are identified where the harvested acreage of the primary crop is greatest and where the soil and climatic conditions create a high propensity for wind erosion. the specific model farms will be selected. In constructing model farms in the identified geographical areas. **actual farms** must be selected. rather than hypothesizing about realistic combinations of the above conditions. In each geographical area. two model farms (of approximately average acreage) representing two levels of conservation practice: conventional tillage and conservation tillage. Economic data also will be obtained to compare the costs associated with each practice.

ATTACHMENT 2

Example Crop Budget Cost Data
From North Dakota
Field Office Technical Guide

WHEAT
CONVENTIONAL TILL
NORTH DAKOTA

				RECEIPT OR COST/ACRE	YOUR ESTIMATE
PRODUCTION					
WHEAT	27.4 BU	@ $4.00/BU	1/	$109.60	
				ACRE	ESTIMATE
INPUT COSTS					
WHEAT SEED	1.0 BU	@ $7.00/BU		$7.00	
FERTILIZER (18-46-0)	100 LBS	@ $0.11/LB		$11.00	
2,4-D AMINE	1.0 PT	@ $1.38/PT		$1.38	
INTEREST ON OPERATING CAPITAL (10%) 2/				$1.00	
			SUBTOTAL	$20.38	
MACHINERY COSTS 3/					
CHISEL PLOW - 15 FT				$4.94	
FIELD CULTIVATOR 18 FT				$3.48	
TANDEM DISK 20 FT				$4.58	
SPRINGTOOTH DRAG 30 FT				$1.58	
GRAIN DRILL - 20 FT				$8.37	
SPRAYER PULL TYPE - 50 FT				$1.02	
SWATHER SP 18 FT				$8.24	
COMBINE - SM GRAIN - LARGE				$24.97	
			SUBTOTAL	$57.18	
TOTAL COSTS				$77.56	
RETURN TO LAND AND MANAGEMENT				$32.04	
ENTERPRISE COSTS					
OWNERSHIP COSTS PER ACRE (FIXED COSTS)				$31.60	
OPERATING COSTS PER ACRE (VARIABLE COSTS)				$45.96	
TOTAL ENTERPRISE COSTS				$77.56	
LABOR USED					
MACHINERY LABOR	HOURS			1.04	
OTHER LABOR	HOURS			0.07	
FUELS USED					
DIESEL	GALLONS			4.33	

FOOTNOTES

1/ PRICE DOES NOT INCLUDE DEFFICIENCY PAYMENT.
2/ BASED ON TIME FROM WHICH MONEY IS BORROWED TO PURCHASE INPUTS UNTIL HARVEST.
3/ INCLUDES LABOR; AND OWNERSHIP COSTS (DEPRECIATION, INTEREST, AND INSURANCE) AND OPERATING COSTS (FUEL, LUBRICANT, AND REPAIRS) FOR THE IMPLEMENT AND TRACTOR.

WHEAT
CONSERVATION TILL
NORTH DAKOTA

			RECEIPT OR COST/ACRE	YOUR ESTIMATE
PRODUCTION				
WHEAT	27.4 BU @ $4.00/BU 1/		$109.60	________
			ACRE	ESTIMATE
INPUT COSTS				
WHEAT SEED	1.0 BU @ $7.00/BU		$7.00	________
FERTILIZER (18-46-0)	100 LBS @ $0.11/LB		$11.00	________
ROUNDUP RT	1.0 PT @ $4.75/PT		$4.75	________
2,4-D AMINE	1.0 PT @ $1.38/PT		$1.38	________
INTEREST ON OPERATING CAPITAL (10%) 2/			$1.10	________
		SUBTOTAL	$25.23	________
MACHINERY COSTS 3/				
SPRAYER PULL TYPE - 50 FT			$1.02	________
GRAIN DRILL - 20 FT			$8.37	________
SPRAYER PULL TYPE - 50 FT			$1.02	________
SWATHER SP 18 FT			$8.24	________
COMBINE - SM GRAIN - LARGE			$24.97	________
		SUBTOTAL	$43.62	________
TOTAL COSTS			$68.85	________
RETURN TO LAND AND MANAGEMENT			$40.75	________
ENTERPRISE COSTS				
OWNERSHIP COSTS PER ACRE (FIXED COSTS)			$25.08	
OPERATING COSTS PER ACRE (VARIABLE COSTS)			$43.77	
TOTAL ENTERPRISE COSTS			$68.85	
LABOR USED				
MACHINERY LABOR	HOURS		0.63	
OTHER LABOR	HOURS		0.04	
FUELS USED				
DIESEL	GALLONS		2.88	

FOOTNOTES

1/ PRICE DOES NOT INCLUDE DEFFICIENCY PAYMENT.
2/ BASED ON TIME FROM WHICH MONEY IS BORROWED TO PURCHASE INPUTS UNTIL HARVEST.
3/ INCLUDES LABOR; AND OWNERSHIP COSTS (DEPRECIATION, INTEREST, AND INSURANCE) AND OPERATING COSTS (FUEL, LUBRICANT, AND REPAIRS) FOR THE IMPLEMENT AND TRACTOR.

ATTACHMENT 3

Sample MRI Survey Forms
- Farming Practices
- Equipment Usage and Codes
- Soil Management System Description

FARMING PRACTICES FOR

State: ______________ County: ______________ Crop: ______________

District Conservationist: ____
Phone: ______________________
Fax: ______________________

Farm ID: ____________________________ (Use identifier provided by DC)

Total Farm Area (acres): ________________ 1994 Crop Production: ____________

Irrigated (Y/N): _____ Soil Type (or Silt/Sand/Clay %s) __________ MLRA __________

1994 ________ Planted (acres): __________ 1994 Harvested (acres): __________

Cropping System:

____

____

____

Tillage Practice (circle one) Conventional / Conservation / Other

Tilling, Planting, Fertilizing, Harvesting, Burning, and Pesticide Application Dates and Equipment: (see attached survey form, "Equipment Usage")

Conservation Cost Data:

____

____

____

Table 2. *(continued)*

	IMPLEMENT	PERCENT RESIDUE REMAINING NON-FRAGILE	FRAGILE
	ROW CULTIVATORS: *(30" and wider)*		
K1	Single sweep per row	75-90	55-70
K2	Multiple sweeps per row	75-85	55-65
K3	Finger wheel cultivator	65-75	50-60
K4	Rolling disk cultivator	45-55	40-50
K5	Ridge Till cultivator	20-40	5-25
	UNCLASSIFIED MACHINES:		
L1	Anhydrous applicator	75-85	45-70
L2	Anhydrous applicator with closing disks	60-75	30-50
L3	Subsurface manure applicator	60-80	40-60
L4	Rotary Hoe	85-90	80-90
L5	Bedders, listers & hippers	15-30	5-20
L6	Furrow diker	85-95	75-85
L7	Mulch Treader	70-85	60-75
	DRILLS:		
M1	Hoe opener drills	50-80	40-60
M2	Semi-deep furrow drill or press drill (7"-12" spacing)	70-90	50-80
M3	Deep furrow drill with >12" spacing	60-80	50-80
M4	Single disk opener drills	85-100	75-85
M5	Double disk opener drills (conventional)	80-100	60-80
	No-till drills and drills with the following attachments *in standing stubble*:		
M6	Smooth no-till coulters	85-95	70-85
M7	Ripple or bubble coulters	80-85	65-85
M8	Fluted coulters	75-80	60-80
	No-till drills and drills with the following attachments *in flat residues*:		
M9	Smooth no-till coulters	65-85	50-70
M10	Ripple or bubble coulters	60-75	45-65
M11	Fluted coulters	55-70	40-60
M12	Air seeders: (Refer to appropriate field cultivator or chisel plow depending on the type of ground engaging device used.)		
M13	Air drills: (Refer to corresponding type of drill opener.)		
	ROW PLANTERS:		
	Conventional planters with:		
N1	Runner openers	85-95	80-90
N2	Staggered double disk openers	90-95	85-95
N3	Double disk openers	85-95	75-85
	No-till planters with:		
N4	Smooth coulters	85-95	75-90
N5	Ripple coulters	75-90	70-85
N6	Fluted coulters	65-85	55-80
	Strip till planters with:		
N7	2 or 3 Fluted coulters	60-80	50-75
N8	Row cleaning devices (8-14" wide bare strip using brushes, spikes, furrowing disks, or sweeps)	60-80	50-60
N9	Ridge-till planter	40-60	20-40

Table 2. *(continued)*

IMPLEMENT	PERCENT RESIDUE REMAINING NON-FRAGILE	FRAGILE
CLIMATIC EFFECTS:		
Over winter weathering**		
Following summer harvest	70-90	65-85
Following fall harvest	80-95	70-80

***In northern climates with long periods of snow cover and frozen conditions, weathering may reduce residue levels only slightly, while in warmer climates, weathering losses may reduce residue levels significantly.*

ESTIMATES OF RESIDUE COVER REMAINING AFTER SINGLE OPERATION OF SELECTED TILLAGE MACHINES

Developed jointly by the Soil Conservation Service, U.S.D.A. and the Equipment Manufacturers Institute

First Edition February, 1992

AGRICULTURAL SOIL MANAGEMENT SYSTEMS

from *Agricultural Resources and Environmental Indicators*
USDA ERS Agricultural Handbook 705, December 1994

Crop Residue Management (CRM) reduces the number of passes over a farm field with tillage implements or the intensity of tillage operations. Inversion of the surface lay of soil (plowing) is usually avoided. CRM is designed to leave sufficient residue on the soil surface to reduce wind and water erosion. CRM also includes the use of cover crops that may be grown to prevent erosion during critical periods.

Conservation tillage is designed to maintain at least 30% surface residue after planting, or at least 1,000 lb/acre of flat, small grain surface residue equivalent during critical wind erosion periods. Key factors influencing CRM are:

1. Previous crop, including initial residue amount and fragility
2. Types of tillage operations prior to and including planting

DEFINITIONS

Conventional Tillage

Moldboard plow - Any tillage system that includes the use of a moldboard plow.

Without moldboard plow - Any tillage system that leaves less than 30% surface residue, but does not use a moldboard plow.

Conservation Tillage (must maintain at least 30% surface residue after planting)

Mulch till - The soil is disturbed prior to planting with chisels, field cultivators, disks, sweeps, or blades. (If >30% residue is present (and no-till or ridge-till is not present), then operation is mulch till.)

Ridge till - The soil is left undisturbed from harvest to planting except for nutrient injection. Crops are planted in a seedbed prepared on ridges with sweeps, disk openers, coulters, or row cleaners. Residue is left on the surface between ridges.

No till - The soil is left undisturbed from harvest to planting except for nutrient injection. Crops are planted or drilled in a narrow seedbed or slot created by coulters, row cleaners, disk openers, inrow chisels, or roto-tillers.

Other Tillage

Reduced till - Tillage that leave 15 - 30% surface residue after planting, or 500-1,000 lb/acre of small grain residue equivalent throughout the critical wind erosion period.

Conventional till - Tillage that leaves less than 15% residue cover after planting, or less than 500 lb/acre of small residue equivalent throughout the critical wind erosion period.

Each year, a CRM survey is conducted by the Conservation Technology Information Center to provide State and national statistics on adoption of alternative CRM systems for all U.S. planted cropland. The CRM provides estimates of acres for each tillage system used.