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ABSTRACT

Arizona is the first state in the nation to regulate agricultural practices in order to reduce dust emissions near urbanizing areas. This BMP program requires dust mitigation actions in some combination of tillage and harvest, crop land, and non-crop land activities. Contingent valuation methods were used to estimate the willingness-to-adopt reduced tillage equipment. At $10-26 per acre in long-term net benefits associated with the BMP, adoption generates dust emission reductions on 10-35 percent of the cotton acreage. Most dust mitigation, however, will occur through the reduction of the number of conventional tillage operations and the urbanization of agricultural lands. (JEL Q15, 55)

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I. INTRODUCTION

Airborne dust aggravates cardio-pulmonary conditions leading to illness, higher medical expenses, and an increased number of sick leave days. The Western region of the United States experiences a relatively high number of dust events due to its unique climatic and physical environment: low rainfall, drought, high wind velocity, fine soils, and sparse vegetation. Dust storms have occurred naturally in desert areas for millennia. In recent decades, however, increased human activity associated with agricultural production practices, construction activity on the urban periphery, and the emerging seamlessness of the rural-urban interface have all compounded the overall dust problem in arid and semi-arid regions.

Potential damages from airborne dust or wind erosion generally are categorized as on-site or off-site costs. Physical damage to equipment and buildings, and lower crop yields are the most frequently noted on-site problems for agriculture (Huszar and Piper 1986; Piper 1989a, b). Off-site losses generally include physical damage to nonagricultural property, cleanup costs to households and businesses, and adverse health impacts. Piper (1989a) estimated the annual off-site dust related damages for all states west of the Mississippi River between $4-12 billion—not including health costs. Donaldson and MacNee (1998) argued that the primary health damages caused by airborne dust and other particulate matter (PM) are exacerbation of asthma, chronic pulmonary disease, and death from cardiovascular causes—heart attacks and strokes.

Little empirical research has been reported over the years on the actual health costs of airborne dust.

The Clean Air Act (CAA) represents a federal-state partnership for improving national air quality. The Environmental Protection Agency (EPA) develops national ambient air quality standards (NAAQS) and CAA regulatory guidelines that the states use to develop state implementation plans (SIP). A SIP is a package of strategies and control measures to prevent air quality deterioration or reduce criteria pollutants (i.e., PM, carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide, and lead) that exceed NAAQS. State environmental agencies are the implementation leaders of the CAA because air quality problems are unique to each area of the country (EPA 2000).

There are two NAAQS for PM: PM-10 and PM-2.5. PM-10 represents "coarse" particulates 10 micrometers in diameter—one thousand could fit in the period at the end of this sentence. PM-2.5 are "finer" particles 2.5 microns in diameter and smaller. The primary component of PM-10 is wind blown dust, while vehicle exhaust and fuel combustion from industrial and residential sites represent the dominant sources of PM-2.5. The EPA is responsible for establishing the primary (protecting public health) and secondary (protecting the environment and public welfare) standard for each NAAQS (Belden 2001). The primary standard for both PM-10 and PM-2.5 consists of an annual and a 24-hour standard. The PM-10 annual standard is 50 micrograms per cubic meter (ug/m^3) and the 24-hour standard is 150 ug/m^3. The PM-2.5 annual standard is 15 ug/m^3 and the 24-hour standard is 65 ug/m^3. The primary and secondary standards are the same for both PM-10 and PM-2.5.

A network of monitoring equipment measures the levels of PM-10 and PM-2.5 in both metropolitan and rural areas. The State and Local Monitoring Network (SLAMS) and National Air Monitoring Stations (NAMS) are two types of monitoring stations used to gather air quality data. The size and location of SLAMS monitors are determined by the needs of the state in its efforts to meet SIP requirements. The NAMS monitors are a subset of SLAMS and are located in areas of maximum pollutant concentration and high population density (EPA 2002a).

The EPA designates a geographic area as a non-attainment area when the primary NAAQS in at least one criterion pollutant is not met. With regard to PM-10, an area that does not meet the primary NAAQS is first classified as a "moderate" PM-10 non-attainment area. If attainment is not possible by the end of the sixth calendar year after designation, the area is reclassified as a "serious" non-attainment area. The reclassification extends the attainment date to the tenth calendar year after the initial "moderate" non-attainment designation.

States with moderate PM-10 non-attainment areas are required to develop an implementation plan that becomes part of the state's SIP if approved by the EPA. The implementation plan for a moderate classification must include (1) the development of a permit program for construction and other major new and/or modified stationary sources of PM-10, (2) attainment by the attainment date or convincing evidence that attainment is impractical, and (3) the assurance that reasonably accepted control measures (RACM) for PM-10 are in place within four years of the non-attainment date. States with serious non-attainment areas must develop an implementation plan which includes all the provisions required in the moderate plan as well as a demonstration of attainment through air quality modeling. In addition, the state must ensure that best available control measures (BACM) are in place no later than four years after serious area classification. BACMs are production processes and other available methods, systems, and techniques that yield the maximum degree of PM-10 emission reductions (Martineau and Novello 1998). If the moderate or serious area PM-10 implementation plans do not meet the EPA's approval, the plan is sent back to the state for revisions. In the meantime the EPA will develop a Federal Implementation Plan (FIP) that the agency will implement if the state fails to receive approval or fails to submit a revised plan to the EPA.

Until the mid-1990s, agricultural sources of dust were not addressed under the CAA. Agriculture had long been considered a source of dust but its effects were considered more a nuisance than a health problem (Piper 1989a). As the proximity between urban and rural areas has become closer, particularly in some areas in the Western United States agriculture's contribution to PM-10 in the atmosphere has become a source of concern to regulators and environmental activitists. This research evaluates the economics of adopting single pass multiple operation equipment (SPMOE) as a best management practice to reduce dust emissions from agriculture. The analytical setting is central Arizona agriculture on the urbanizing edge of one of the fastest growing areas metropolitan areas (Phoenix, Maricopa County) in the country.

II. CONFLICT ON THE AGRICULTURE-URBAN INTERFACE

In November 1990, 2,880 square miles of Maricopa County, Arizona was designated as a "moderate" PM-10 non-attainment area after violating the 24-hour and annual standards of the CAA (see Table 1 for a detailed chronology of events). This fast growing desert county of over 3 million people contains a large, but shrinking in economic importance, agricultural area of 250,000 field crop acres. The required development of Maricopa County's PM-10 SIP then took 12 years. During that period two SIPs were rejected by the EPA; a third SIP was accepted and approved in 1995, but this federal action led to a lawsuit by the Arizona Center for Law in the Public Interest claiming the SIP failed to mitigate PM-10 problems. In 1996 the EPA reclassified Maricopa County as a "serious" PM-10 non-attainment area and began the development of a FIP.

Agriculture became a major issue in the mid-1990s as a result of a microscale study conducted by the Arizona Department of Environmental Quality (ADEQ). The controversial results from four of the five PM-10 monitoring sites produced 24-hour violations. Agricultural fields were predominant in two of these four sites. ADEQ was not able to demonstrate attainment for the agricultural sources of dust. The EPA decided to use a best management practices (BMP) approach in the FIP with the active participation of key stakeholders within and outside the agricultural community. An agreement was reached in 1999 between the EPA and the State of Arizona that approved the use of acceptable BMPs in agriculture as a substitute for the EPA's FIP. In 2000, regulations for the BMP-based, agricultural PM-10 general permit were promulgated—in doing so Arizona became the first state in the nation to regulate agricultural practices aimed at limiting dust with the approval of the EPA.

The Governor of Arizona's Agricultural BMP Committee (GABMPC) and its ad-hoc technical advisory group developed a comprehensive list of 65 BMPs based on (1) academic literature and technical documents on wind erosion and dust control, (2) their suitability to Arizona soils, (3) their impact on soil erosion, (4) cost, and (5) cost effectiveness (ADEQ 2001; GABMPC 2001)[1]. The Committee reduced this list to 30 BMPs and organized them under three categories: tillage and harvest, crop land, and non-crop land (Table 2).

By December 31, 2001 farmers in the PM-10 non-attainment area were required to adopt at least one BMP in each category and keep a written record of the actions taken. Enforcement is complaint driven, due to the lack of resources to verify compliance, and is the responsibility of ADEQ (Pella 2001). Violators have two opportunities to comply with the PM-10 regulations. With a third non-compliance violations the farmer must obtain an individual fee based permit, similar to those obtained by air pollutant emitting manufacturing plants, in order to remain in operation. Few growers can afford the expense of an individual fee based permit. ADEQ is required to submit a compliance report by December 31, 2006, based on technical data from a microscale study, certifying that PM-10 reductions have met the 24-hour PM-10 NAAQS. ADEQ plans to rely on a combination of BMPs and reduced cropped acres (due to urbanization) to meet the dust mitigation target (URS and ERG 2001).

[1] The Committee consisted of five farmers, the Director of ADEQ, the Director of the Arizona Department of Agriculture (ADA), the State Conservationist for the National Resource Conservation Service (NRCS/USDA), the Vice Dean of the University of Arizona's (UA) College of Agricultural and Life Sciences, and a soil scientist from the UA's Department of Soil, Water and Environmental Sciences. The

III. THE BMP CHALLENGE

The characteristics of nonpoint pollution (NPP), such as dust, include (1) diffuse emissions, (2) natural variability due to weather related events, (3) site specific characteristics such as soil type, and (4) the large number of potential polluters (Ribaudo, Horan and Smith 1999). Identifying source contribution is difficult, if not impossible (Ribaudo and Caswell 1999). Shogren (1993) argues that the aforementioned physical and behavioral factors surrounding NPP are complicated further by the interdependencies that exist between the multiple players thereby making the proposed tax and subsidy schemes for controlling NPP developed by economists (e.g., Segerson 1988; Helfand and House 1995; Hansen 1998; Horan and Shortle 2001;and Bunn 1999) impractical in both operational and political senses.

Due to the impracticality of optimal solutions, indirect or second best strategies and instruments have been applied to NPP. Education and technical assistance, technology standards (e.g., BMPs), performance based standards (i.e., taxes on inputs or subsidies), and liability rules have been implemented by regulatory agencies. The voluntary adoption of BMPs has become the most frequently used remediation strategy for reducing or preventing emissions at the source (Centner et al. 1997). However, the adoption of BMPs generally requires some type of financial incentive or regulatory mechanism to increase adoption rates. Pollution reducing technologies may in fact be profitable in the long run but their adoption is impeded by capital requirements and

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ad hoc technical committee was made up of representatives from the EPA, ADEQ, UA, Western Growers The Association, NRCS, Farm Bureau, and the U.S. Water Conservation Lab (ARS/USDA).

transaction costs. Finally, enforcement of compliance through on-site monitoring is cost prohibitive so the enforcement of technology standards generally has been through citizen complaints.

SPMOE meets two BMPs under the tillage and harvest category: combining tractor operations and reduced tillage systems. The Sundance, Paratill, and Pegasus reduced tillage systems represent different degrees of operational consolidation (See Kennedy et. al for a detailed discussion of these systems). Only the Pegasus system combines all tillage operations in one trip over the field (Table 3). Partial budgeting analysis indicates that the adoption of these BMP systems has the potential to improve net income by $12-26 per acre. This set of mandatory BMPs exists with the background threat of even stricter mandatory EPA regulations and enforcement.

IV. REDUCED TILLAGE AS A POTENTIAL ECONOMIC RESPONSE

Conceptual and applied analyses of the adoption of conservation technologies have utilized profit maximization models (Featherstone and Goodwin, 1993; Soule, Tegene, and Wiebe, 2000), utility maximization (Robison and Barry, 1987; Cooper, 1997) and innovation-diffusion theory (Ervin and Ervin, 1982; Gould, Saupe, and Klemme, 1989; Traore, Landry and Amana, 1998). In the aggregate, this collection of studies reveals that adoption decisions are multi-dimensional, with profitability serving as a necessary but not sufficient condition for adoption. Credit constraints, government programs (i.e., regulations, cost-sharing), land tenure, farm size, risk, age, education, land value, land characteristics (i.e., slope, soil type), contact with soil conservation agencies, knowledge of potential health and environmental damages, and the perceptions associated with all these factors determine adoption decisions.

Two recent studies more closely capture the adoption issues surrounding dust pollution from on-farm sources. Wang, Young, and Camara (2000) evaluated the perception of damages and the adoption of mitigation practices associated with wind erosion in Washington state. Two variables were used to evaluate the perception of wind erosion problems: (1) the number of wind erosion problems noticed over the last ten years, and (2) whether the respondent was familiar with the PM-10 standard. Knowledge of PM-10 had a positive and statistically significant impact on the adoption of conservation practices. However, the number of wind erosion problems, profitability, and standard socioeconomic variables used to predict adoption lacked explanatory power. The authors imply that standard adoption models and our understanding of the adoption process is challenged by adoption decisions of "unprofitable" conservation practices.

Upadhyay, et al. (2002), also working in Washington state, sampled 266 farms to determine non-adoption, single practice adoption, and multiple practice adoption of conservation tillage practices. Forty percent of the farmers sampled had adopted conservation practices with 26 percent adopting a single practice and 14 percent adopting at least two practices. Larger farms and operators with higher education levels were more likely to adopt multiple conservation practices as opposed to non-adopters. Single practice adopters and non-adopters were not distinguishable from one another. The authors discovered that farmers adopt conservation practices that may not be no-till related—these "rest" adopters are significantly different from non-adopters but statistically similar to the specific practice no-till adopter. Knowledge of PM-10, farm size, off-farm income, and level of education all had a positive influence on adoption decisions.

A conventional mean-variance model provides insight on the adoption decision between reduced tillage and conventional technologies facing the grower (Robison and Barry 1987). Suppose the reduced tillage technology and the conventional tillage system are represented by scale-neutral per acre production functions, $f(\mathbf{x_f})$ and $g(\mathbf{x_g})$, respectively, where f', $g' > 0$, and f'', $g'' < 0$, and $\mathbf{x}$ is the vector of inputs. Assume that the grower produces only one crop (y) which is sold at price p, where yield per acre associated with conventional tillage is relatively known, but where $y_f = f(\mathbf{x_f}) + \varepsilon$, and $\varepsilon \sim N(0,\sigma^2)$. The decision-maker allocates the two tillage technologies between the total land farmed (L_T). Assume the grower overestimates σ_ε^2 by the factor $(1+\theta)$ due to inadequate information and/or personal hesitance to adopt the new tillage system (note that $\theta>0$).

The adoption decision can be written as follows:

$$(1) \quad \max_{L,x} \Pi_{ce} = p[Lf(\mathrm{x_f}) + (L_T - L)g(\mathrm{x_g})] - p_L L + \mathrm{p_x}\left[L\mathrm{x_f} + (\bar{L} - L)\mathrm{x_g}\right] - \frac{\lambda}{2} p^2 L^2 (1+\theta)\sigma_\varepsilon^2$$

where L is the cropped acreage utilizing the new tillage system at the cost of p_L, and p_x is the vector of prices associated with the operating inputs of the reduced tillage and conventional systems respectively. The Arrow-Pratt risk-aversion coefficient, λ, is assumed to be greater than zero and reflect decreasing absolute risk aversion. By taking the derivative of (1) with respect to L, the optimal acreage devoted to reduced tillage systems is

(2) $$L^* = \frac{p[f(\mathrm{x}_\mathrm{f}) - g(\mathrm{x}_\mathrm{g})] - p_L + p_\mathrm{x}(\mathrm{x}_\mathrm{g} - \mathrm{x}_\mathrm{f})}{\lambda p^2 (1+\theta)\sigma_\varepsilon^2} \quad \text{for } 0 \leq L \leq L_T.$$

The quadratic nature of the risk factor in equation (1) guarantees that L* is an optimal value. The numerator in (2) reveals that the adoption decision is influenced by the relative difference in expected yield per acre, the per acre investment cost of the reduced tillage technology, and the difference between the two technologies in per acre energy (operational) costs. The denominator notes that risk preferences, information, and variability associated with the new technology will drive the adoption decision as well.

V. REDUCED TILLAGE ADOPTION DECISIONS

Data Acquisition and Description

A mailing list of all cotton growers in Maricopa and Pinal counties was assembled from pesticide permit records from the Arizona Department of Agriculture (ADA) and cross-referenced with extension mailing lists utilized by the cotton specialists in each county. Growers in Pinal County were included in the surveyed group because part of the Maricopa non-attainment area extends into Pinal County and growers in this largely agricultural county south of Phoenix act as a control group for the reduced tillage adoption decisions. Two hundred and thirty seven growers were surveyed: 119 in Maricopa and 118 in Pinal.

A mail questionnaire was developed to gather information on current farming operations, perceptions of dust as an environmental problem, reduced conventional tillage operations (RCTO) (e.g. reduce the number of diskings), estimated benefits of RCTO and SPMOE, the willingness to adopt SPMOE, and basic socioeconomic information including the distance of the center of the farm to the edge of the nearest residential housing area.[2] The design of the willingness to adopt (WTA) questions followed the general recommendations for contingent valuation studies (NOAA 1993). The questionnaire was reviewed several times by the Pinal County cotton specialist and pre-tested with four cotton growers, two from each county.

The mail survey was implemented following the total design method (Dillman 2000). The research team and the appropriate cotton specialist signed each cover letter. Follow-up procedures included a reminder postcard and a second mailing of the survey packet. One hundred and twenty eight respondents (54%) returned their "completed" questionnaires. Thirty-three growers responded that they were no longer farming cotton. Twenty additional responses were eliminated from the data set due to incomplete or inconsistent responses to specific questions.

Sixty-two percent of the responding cotton growers acknowledged that dust generated by tillage operations can create an environmental nuisance. A majority of these respondents, however, believed this nuisance was not a severe problem. Only seven percent of the growers labeled the problem as very severe or severe. Thirty-six percent of all respondents classified their tillage operations as not creating a dust problem while the

[2] A copy of the questionnaire can be obtained from the authors.

remaining three percent did not know if tillage activities created an environmental nuisance or not.

Table 4 classifies the basic respondent information by adoption decision. Among the adopters of some form of reduced tillage, two growers reported adopting SPMOE only, 22 adopted RCTO only, and 28 reported adopting both SPMOE and RCTO. RCTO adopters reported eliminating some disking, ripping, and listing operations. One or more disking operations were eliminated by 84 percent of the RCTO adopters and 52 percent reported eliminating ripping their fields. Thirty-two percent of the RCTO adopters eliminated one listing operation. Smaller operations and older operators tended to rely on RCTO alone to compete in the current economic and regulatory environment. Only education differentiates the adopter and non-adopter groups, with adopters having a statistically significant higher level of post-secondary education.

The two reasons most commonly chosen for both SPMOE and RCTO adopters were "to reduce costs" and "to reduce cost and dust." The two sole SPMOE adopters indicated that reducing costs was their only reason for adopting these tillage systems. None of the survey respondents chose "to reduce dust" as a reason for adopting reduced tillage systems.

Ex Post and Ex Ante Adoption Results

The growers who adopted SPMOE and/or RCTO reported their estimated realized long-term net benefits per acre associated with their decision. In addition, the respondents estimated the percentage of their cotton acreage on which the reduced tillage systems were used. Growers who had not adopted SPMOE were asked to estimate the expected long-term net benefit per acre that would induce them to adopt this type of reduced tillage systems (i.e., Pegasus, Sundance, Paratill). These growers also were asked to estimate the expected percentage of their cotton acreage they would farm with this technology.

All three estimates (ex post SPMOE, ex post RCTO, ex ante SPMOE) were analyzed using a semi-log function to evaluate the relationship between technology benefits and the percentage of cotton acreage on which the technology was or would be applied. In this formulation the slope coefficient of the explanatory variable, long-term net benefits, measures the absolute change in the percentage of cotton acreage relative to a change in net benefits (Table 5). So a one percent increase in net benefits associated with SPMOE produces a 0.0028 increase in the percentage of cotton acreage using SPMOE.[3] Willingness to adopt "elasticity" for SPMOE exceeds the ex post measures of adoption elasticity for either SPMOE or RCTO. This result is analogous to contingent valuation studies that have shown the tendency of respondents to overestimate willingness to pay measures for environmental amenities, relative to actual financial payments, to protect a natural resource.

Figure 1 illustrates the estimated functions from Table 5. The ex ante SPMOE adoption function exceeds the two ex post functions over most estimates of long-term net benefits. Acreage on which RCTO is applied exceeds the SPMOE acreage for the same level of new benefits. We hypothesize that this realized difference is due to the

[3] When semi-log functions are estimated using OLS procedures, the slope coefficient is multiplied by 0.01 to obtain the elasticity measure (absolute change in independent variable for a percentage change in a dependent variable) (Gujariati 1995, p. 172).

uncertainty associated with the new technology. Equivalent cost savings for the risk-averse grower can be obtained from reducing conventional practices as opposed to adopting an unfamiliar new technology requiring a learning period.

VI. IMPLICATIONS FOR AGRICULTURAL DUST MITIGATION

Urbanization, the very driver that precipitated agricultural regulations in the Phoenix area, may prove to be the dominant force for mitigating dust pollution associated with agriculture. In the last 40 years Maricopa County and Pinal County have experienced a 72 percent and 46 percent decrease in farmland, respectively. Some predict that in just Maricopa County alone 6,000 to 8,000 acres of farmland per year is being converted to urban development (Rogers 2001, Farm Bureau 1998). This regional economic trend will mitigate dust problems caused by agricultural operations.

Our survey of the population of cotton growers in these two central Arizona counties revealed that 14 percent of the farmers are no longer growing cotton. A significant number of farmers in recent years have modified their cropping pattern to reflect more alfalfa production because the large local dairy industry relies on a dependable, timely, and high quality source of feed. Alfalfa, a BMP cover crop under the ADEQ guidelines, produces more cash flow than cotton and reduces the dust-related environmental nuisance problem.

The survey results also show that RCTO have been adopted widely by cotton growers to reduce costs, sometimes in combination with SPMOE. Any dust reduction benefits emerging from fewer tillage operations become an added bonus to the grower and society. SPMOE alone does not represent a panacea to the agricultural dust problems in the Phoenix non-attainment area however. Only two growers adopted SPMOE solely to reduce costs and control dust. At estimated long-term net benefits of $12-26 per acre, our analysis indicates that SPMOE alone may be adopted on 10-35 percent of the cotton acreage in Maricopa and Pinal counties. However, a combination of RCTO and SPMOE has the potential to significantly reduce costs and reduce dust emissions on a significant percentage of acreage in both counties.

Growers will continue to sell their land to the developers of residential and industrial projects, shift their cropping pattern to more profitable crops, and search for cost savings by adopting some combination of RCTO and SPMOE. A reduced number of conventional tillage operations alone could prove to be the most important BMP in the Phoenix non-attainment area. Current market forces in agriculture may unwittingly create a considerable environmental benefit for the neighboring urban population.

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Table 1: A Brief Chronology of Events Surrounding Maricopa County's (Arizona) PM-10 Non-Attainment Designation by the EPA

Date	Event
November 1990	The EPA designated approximately 2,880 square miles of Maricopa County and 36 square miles of Pinal County as moderate PM-10 non-attainment area.
November 1991	Maricopa County submits moderate PM-10 non-attainment area SIP to the EPA.
March 1992	EPA deems PM-10 SIP incomplete which requires the EPA promulgate a FIP within two years.
August 1993	Maricopa County submits revised PM-10 SIP.
March 1994	Maricopa County submits addendum to the revised PM-10 SIP, which concludes both the annual and 24-hour PM-10 NAAQS would continue to be exceeded despite implementation of RACMs.
April 1995	The EPA approves the revised moderate PM-10 SIP.
April 1995	Arizona Center for Law in the Public Interest (ACLPI) formally files suit against EPA (Ober v. EPA, 84F .3d 304(9^{th} Cir. 1996)), contending 24-hour PM-10 violations were not addressed in the moderate area plan.
May 1996	Court rules moderate PM-10 SIP incomplete because the state failed to include analysis of and address 24-hour PM-10 violations. Court vacates Moderate Area PM-10 plan and renews EPA's FIP.
May 1996	The EPA reclassifies Maricopa County PM-10 non-attainment area to serious, effective June 1996.
November 1996	ADEQ agrees to submit a Microscale Plan to the EPA, which evaluates emission sources suspected of causing 24-hour violations and control measures.
May 1997	ADEQ submits Microscale Plan to the EPA, but does not demonstrate attainment for 2 of the 4 microscale sites.
August 1997	EPA promulgates partial disapproval of Microscale Plan and obligates itself to prepare FIP for sources that did not demonstrate attainment in the Microscale Plan.
May 1998	Arizona Governor Hull signs into law Senate Bill 1427 (SB 1427) establishing an Agricultural BMP Committee.
August 1998	EPA promulgates FIP to address unpaved roads, unpaved parking areas, vacant lots, and agricultural sources.
August 1998	Agricultural BMP Committee process begins per Senate Bill 1427.
June 1999	EPA publishes its Final Notice of Rulemaking approving Arizona's Agricultural BMP process.
April 2000	The EPA approves and promulgates Maricopa County PM-10 Serious Area Plan for attainment of the annual PM-10 standard.
May 2000	Agricultural BMP Committee adopts agricultural PM-10 general permit (AZ Administrative Code, R18-2-610 and 611).
December 2001	Compliance deadline for agricultural sources.
January 2002	The EPA approves PM-10 SIP for attaining the annual and 24-hour NAAQS and grants a 5-year extension of the attainment date for both standards from December 31, 2001 to December 31, 2006.
December 2006	Latest possible deadline for attainment of PM-10.

Sources: Thelander 1999; ADEQ 2001; EPA 2002b

Table 2: Approved Agricultural BMPs for the Maricopa County (Arizona) PM-10 Non-attainment Area

Tillage and Harvest	Non-Cropland	Cropland
Chemical irrigation	Access restriction	Artificial wind barrier
Combining tractor operations	Aggregate cover	Cover crop
Equipment modification	Artificial wind barrier	Cross-wind ridges
Limited activity during a high wind event	Critical area planting	Cross-wind strip-cropping
Multi-year crop	Manure application	Cross-wind vegetative strips
Planting based on soil moisture	Reduced vehicle speed	Manure application
Reduced harvest activity	Synthetic particulate suppressant	Mulching
Reduced tillage system	Track-out control system	Multi-year crop
Tillage based on soil moisture	Tree, shrub or windbreak planting	Permanent cover
Timing of a tillage operation	Watering	Planting based on soil moisture
		Residue management
		Sequential cropping
		Surface roughening
		Tree, shrub, or windbreak planting

Source: GABMPC 2001

Table 3: Comparable Conventional and SPMOE Tillage Systems, Field Operations, and Implements

System	Operations	Implements
Conventional	Cut stalks	Rotary stalk cutter, 4 row
	Disk residue	13.5 foot offset disk
	Rip	V-ripper, 3 shank
	Second disking	13.5 foot offset disk
	List	Lister, 7 bottom
Single Pass Multiple Operation Equipment		
Sundance	Cut stalks	Rotary stalk cutter, 4 row
	Disk residue	Root-puller, 4 row
	Rip/Second disking/List	Wide bed disk, 4 row
Paratill	Cut stalks	Rotary stalk cutter, 4 row
	Disk residue/Rip/Second disking/ List	Paratill, 4 row
Pegasus	Cut stalks/Disk residue/Second disking/List	Pegasus, 4 row

Adapted from Coates 1996 (p. 1596).

Table 4: Descriptive Statistics of Adopters and Non-adopters of Reduced Tillage Systems

	SPMOE only	RCTO only	Both SPMOE and RCTO	All adopters	Non-adopter
Acres	2500	1294.2	2362.6	1915.87	1803.43
Age	45	54.6	48	50.7	54.5
Employees	11	4.2	9.9	7.5	7.26
Education*	3	3.4	3.2	3.3	2.4
Number of observations	2	22	28	52	23

*Number of formal years of education beyond a high school diploma.

Table 5: Estimated Semi-log Model Results of Technology Benefits on the Percentage of Cotton Acreage on Which Reduced Tillage Technologies Were or Would Be Applied

	Ex Post SPMOE	*Ex Ante* SPMOE	*Ex Post* RCTO
Constant	-0.576	-1.283	-0.641
	(-12.857)	(-14.062)	(-16.942)
ln(Benefits)	0.283	0.505	0.325
	(22.164)	(18.954)	(28.682)
N	30	44	49*
R^2	0.946	0.895	0.946

Note: t-statistic in parentheses.
*There were 50 total observations. One observation was dropped because the net benefits reported was $0, which cannot be transformed into a log coefficient.

Figure 1: Adoption Rate of Reduced Tillage Systems (*Ex Post* and *Ex Ante*)