THE ADOPTION OF REDUCED TILLAGE SYSTEMS AS A RESPONSE TO CLEAN AIR REGULATIONS

by

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LIST OF ACRONYMS

ACLPI	Arizona Center for Law in the Public Interest
ADA	Arizona Department of Agriculture
ADEQ	Arizona Department of Environmental Quality
BACM	best available control measures
BMP	best management practices
CAA	Clean Air Act
CVM	Contingent Valuation Method
CWA	Clean Water Act
EPA	Environmental Protection Agency
FIP	Federal Implementation Plan
HP	horsepower
IIA	Independence of Irrelevant Alternatives
MAG	Maricopa Association of Governments
NAAQS	National Ambient Air Quality Standards
NAAQTF	National Agricultural Air Quality Task Force
NAMS	National Air Monitoring Stations
NOAA	National Oceanic and Atmospheric Administration
NPP	Nonpoint Pollution
NPV	net present value
NRCD	Natural Resource Conservation District
NRCS	Natural Resource Conservation Service
PAQCD	Pinal Air Quality Control District
PM	particulate matter
RACM	reasonably available control measures
RCTO	reduced conventional tillage operations
ROI	return on investment
SIP	State Implementation Plan
SLAMS	State and Local Monitoring Network Systems
SPMOE	single pass multiple operation equipment
TDM	total design method
TSP	total suspended particulates
UofA	University of Arizona
WTA	willingness to adopt

ABSTRACT

Reduced tillage systems are an approved best management practice for reducing particulate matter 10 micrometers in diameter (PM-10) in the Maricopa County, Arizona PM-10 Non-attainment Area. In addition to reducing PM-10, reduced tillage systems may also reduce costs. This thesis uses partial budgets to estimate the costs savings associated with replacing a conventional tillage system with a reduced tillage system. A semi-log function is used to evaluate the relationship between the per acre net benefits of reduced tillage systems and the percentage of land application. Multinomial logit analysis is used to identify the characteristics of adopters of reduced tillage systems. The study revealed that (1) reduced tillage systems generate costs savings between $16.06 to $25.91 per acre, (2) the ex ante adoption rate of reduced tillage systems that do not require capital investments is higher than those systems that do require an investment, and (3) adoption is influenced by the age and education level of the operator, as well as the size of the operation.

1. The Problems Created by Dust

Airborne dust combined with other particulate matter (PM) such as smoke, soot, and fuel combustion can reach levels that create health problems and damage the environment. PM pollution can aggravate asthma, decrease lung function, and even contribute to premature death (EPA 1997a). High levels of PM impact the environment by reducing visibility and contributing to "hazy" air.

In the United States the severity of dust and PM varies across geographic regions. The Western portion of the United States is more prone to dust problems than the rest of the nation due to the climactic and physical characteristics of the region. The climatic conditions of this area include low rainfall, frequent droughts, and high wind velocities, including dust storms. When these environmental factors combine with the physical features found in the West such as fine textured soils and sparse vegetation, wind erosion of soil occurs and its impact can be substantial (Piper 1989; WERU 2001). Approximately 90 percent of all wind erosion occurs west of the Mississippi River (Piper 1989a).

Some of the dust generated in the West occurs naturally. In fact, "for many thousands of years, wind-borne dust has been emitted from desert areas" (USGS 2000). However, human activity compounds the wind erosion problem. The development of agricultural land and the establishment of cities and towns destabilizes the soil surface and vegetation (USGS 1997). Within urban areas sources of dust include unpaved roads, parking lots, and construction sites. In rural areas, agricultural activities and practices such as tillage and harvest, and the presence of fallow fields during certain times of the year are considered the major sources of wind erosion (Piper 1989b; WERU 2001).

Limited research exists regarding how much dust is generated naturally and by human activity (USGS 2000). The placement of dust monitors in urban areas of central Arizona, and Organ Pipe National Monument indicate dust levels in the urban areas are six to seven times higher than those in the national monument (Table 1.1) (Pitzl 2001). This data indicates that desert areas generate dust, but human activities generate significantly more dust.

TABLE 1.1. Levels of dust in desert and urban areas in Arizona.

Location	Characteristics of the area	Average annual particulate level in 1999*
Organ Pipe National Monument	desert preserve	10
27th Ave., Lower Buckeye Road	freeway, industrial operations	69.4
Higley and Williams Field roads	urbanizing area	61.2
1475 E. Pecos Road, Chandler	mixed land use consisting of agriculture and home building	59.6

*Micrograms/cubic meter, 50 or above exceeds health standards.
Source: Pitzl 2001, Arizona Department of Environmental Quality

Damages caused by wind erosion are generally categorized as on-site or off-site. Because so much soil is lost from cropland, most studies have focused on the on-site damages accruing to crops and farms, with much less research on off-site damages (Piper 1989b; Huszar and Piper 1986). On-site wind erosion causes physical damage to equipment and buildings and can significantly alter productivity and damage crops (Piper

1989a; Huszar and Piper 1986; USDA-ARS 1998). In New Mexico on-site damages have been estimated at $10 million per year (Piper 1989a).

Research on off-site damages is rather limited. What evidence exists indicates on-site losses are small relative to the off-site damages created by wind erosion (Piper 1989a; Huszar 1989). Off-site losses generally include physical damage to nonagricultural property, cleanup costs to households and businesses, and adverse health impacts. Huszar and Piper (1986) conducted the first study of its kind to estimate off-site damages in New Mexico. Piper (1989a) expanded this study to estimate annual off-site damages, primarily clean up costs to Western households (all states west of the Mississippi River). In this later study Piper estimated that off-site damages due to dust were approximately $4 billion annually. This estimate, however, does not include the health damages related to wind erosion and dust which can be substantial.

The health damages caused by dust and other PM include the exacerbation of asthma, chronic pulmonary disease, and even death from cardiovascular causes (heart attacks and strokes) (Donaldson and MacNee 1998). The monetary health damages of these illnesses include medication, hospital and doctor charges, and time off work. These monetary costs are relatively easy to calculate, however, non-monetary damages (i.e. hazy air, reduced outdoor activity) are more difficult to evaluate. In addition, it is difficult to attribute specific illnesses or cause of death to dust alone, as it is usually a combination of different particulates and particle sizes, and it is not always clear which or what combination of particulates affects health the most.

1.1 Clean Air Act (CAA)

The need to improve and protect air quality was recognized by federal legislators in the 1950s. The first air quality legislation passed by Congress was the Air Pollution Control Act of 1955. This Act, which provided research funds and set up a mechanism to provide technical and research assistance to the States to implement control, was the genesis of the present day CAA. The CAA has been amended five times since 1955 (1963, 1967, 1970, 1977, 1990) with the majority of the requirements of the current CAA put in place with the 1970 amendments. In 1972 the Environmental Protection Agency (EPA) was formed and federal administration of the CAA was placed within this agency.

The CAA is implemented throughout the U.S. as a partnership between the states and the EPA (Belden 2001). The EPA is responsible for developing National Ambient Air Quality Standards (NAAQS) and regulatory guidelines. The states use these guidelines to develop State Implementation Plans (SIP) for air quality control regions within the state. SIPs are a collection of strategies and control measures that states develop, implement, and enforce to either prevent air quality deterioration or reduce criteria pollutants that exceed NAAQS. States take the leadership implementation role because pollution control problems are different in each area and require a special understanding of local industries, geography, and housing patterns (EPA 2000).

The EPA has developed NAAQS for six criteria pollutants including PM: carbon monoxide, nitrogen dioxide, ozone, sulfur dioxide, and lead. Currently there are two NAAQS for PM: PM-10 and PM-2.5. PM-10 is made up of "coarse" particulates 10 micrometers in diameter, and sources include windblown dust from the desert, agricultural fields, construction sites, and dust generated by traffic on unpaved roads (EPA 1997b). Although, PM-10 consists of coarse particles, one thousand of these particles could fit in the period at the end of this sentence (EPA 1997a). PM-2.5 are "finer" particles 2.5 microns in diameter and smaller. The components of PM-2.5 include fine dust particles, fuel combustion from industrial and residential sources, and vehicle exhaust.

The EPA is responsible for establishing primary and secondary standards for each of the NAAQS. The primary standards are set at levels to protect public health, while secondary standards serve to protect the environment and public welfare (Belden 2001). The primary standard for both PM-10 and PM-2.5 consists of an annual and 24-hour standard. The two part primary standards exists to protect against long-term (annual) and short-term (24-hour) exposures. The primary PM-10 annual standard is 50 micrograms per cubic meter (ug/m^3) and the primary 24-hour standard is 150 ug/m^3. The PM-2.5 primary annual standard is 15 ug/m^3 and the primary 24-hour standard is 65 ug/m^3. The secondary PM-10 and PM-2.5 standards (annual and 24-hour) are equivalent to their respective primary standards.

Over the years standards have been modified or changed as new information has become available. Before 1987 the NAAQS regulated larger particles, known as total suspended particulates (TSP) which included particles larger than 10 micrometers. The TSP standard was changed to a PM-10 standard when studies found particles equal to and less than 10 micrometers caused adverse health affects by penetrating lung tissue (EPA 1999). The most recent changes to the PM standards went into effect in 1997 when studies indicated the current standards were once again not adequate to protect both the public's health and the environment (EPA 2002). Consequently NAAQS were developed for PM-2.5, the PM is considered to be largely responsible for serious health effects (i.e. premature death, chronic bronchitis, and decreased lung function) and reduced visibility (EPA 1997b).

The EPA chose to retain the PM-10 standard because these particles can aggravate health problems (i.e. asthma) by accumulating in the respiratory system (EPA 1997b). However a minor revision was made in 1997 to the PM-10 standard to simplify data handling requirements. The form of the PM-10 24-hour standard was changed to replace the one-expected-exceedance form with a 99^{th} percentile form averaged over 3 years. The EPA felt that a concentration based measurement (99^{th} percentile) created a more stable target for control programs and eliminated the need for complex data handling of missing values, a problem which existed with the former method of measurement (EPA 1997b).

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 System (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 geographic areas as a non-attainment area when the primary NAAQS in at least one criteria 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. Designations of PM-2.5 non-attainment areas are currently not available. The EPA will designate PM-2.5 non-attainment areas by December 15, 2004 based on air quality data from 2001 through 2003 (EPA 2003).

States with a moderate PM-10 non-attainment area are required to develop an implementation plan, which becomes part of its SIP if approved by the EPA. The implementation plan for a moderate classification must include all of the following requirements: (1) a permit program for construction and operation of new or modified stationary sources of PM-10; (2) a demonstration of attainment by the attainment date or that attainment is impracticable; and (3) provisions assuring reasonably accepted control measures (RACM) for PM-10 in place within four years of non-attainment date (Martineau and Novello 1998).

States with serious non-attainment areas, must develop an implementation plan which includes all the provisions required in the moderate plan as well as demonstrate attainment through air quality modeling. In addition, the state must ensure 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, which yield the maximum degree of PM-10 emissions reductions (Martineau and Novello 1998).

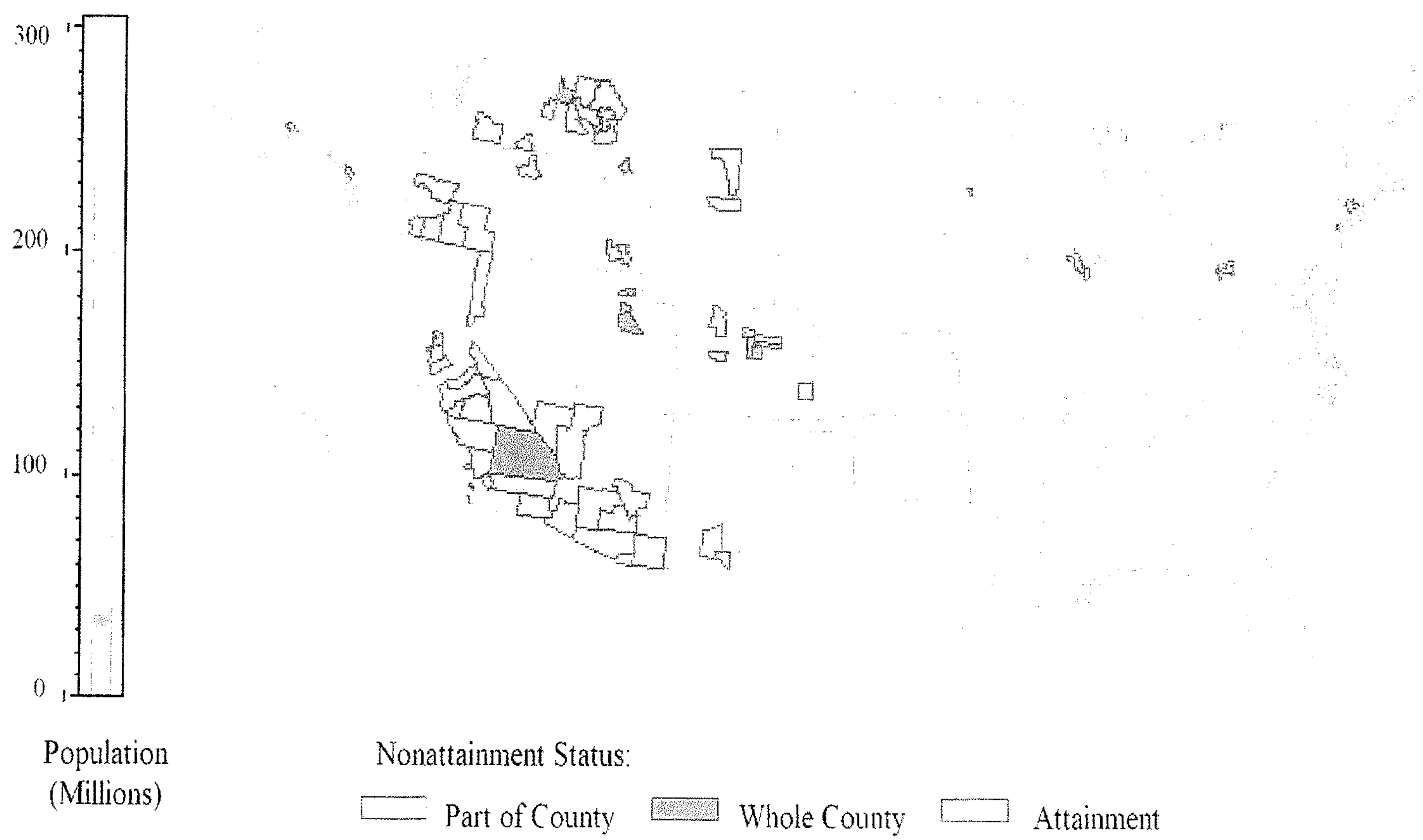
Developing SIPs for the control of PM emissions varies across regions of the U.S. The NAAQS for PM-10 and PM-2.5 are uniform standards that apply to all areas of the U.S., and do not take into account local soil, plant, wind, and topographic conditions. The majority of PM-10 non-attainment areas are located in the western half of the U.S. as illustrated in Figure 1.1. Many areas of the West consists of a dry and arid environment which makes developing and implementing control methods that can achieve the PM-10 NAAQS more challenging for state regulators and PM-10 generating industries. Thus the nature of NAAQS places a greater burden of meeting PM-10 air quality standards in the West. However national air quality standards are set in order to ensure all Americans have the same basic health and environmental protections (EPA 2000; Pella, 2001).

If the moderate or serious area PM-10 implementation plans does not meet the EPA's approval it is sent back to the state or local agency for revisions. In the interim the EPA begins the process of developing a Federal Implementation Plan (FIP). A FIP is composed of federal rules which the EPA implements in order to meet CAA requirements (Belden 2001). A FIP is also developed when states fail to submit implementation plans within a given time period.

1.2 Regulating Agricultural Dust Under the CAA

The CAA originally was intended to control urban sources of pollution. As the urban and rural areas have grown closer in distance, dust generated by agricultural

FIGURE 1.1 PM-10 Nonattaiment Areas in the U.S. as of May 2002.



Source: EPA 2002d

activities and other natural sources is having a greater impact on a larger and more concentrated urban population. Agriculture has long been considered a source of short-term rural particulate loads that are considered a nuisance rather than health or welfare problem (Piper 1989). However, because agricultural dust contributes to PM in the atmosphere over populated areas, the agricultural community is required in some parts of the West to evaluate and adopt dust minimizing practices in order to comply with the CAA (USDA-ARS 1998).

The shift towards regulating rural sources of PM pollution under the CAA has been problematic. Successful pollution control requires accurate identification of the origins of the displaced materials. Identifying sources of dust is a difficult task as it is generated by nonpoint sources. The characteristics of nonpoint pollution (NPP) sources include (1) diffuse emissions, (2) natural variability due to weather related events, (3) site specific characteristics, e.g. soil type, and (4) generally a large number of polluters (Ribaudo 2000). Estimation of source contribution and specifying effective and efficient control measures are difficult.

A variety of control methods have been suggested to reduce NPP. Research has been conducted on hypothetical tax and subsidy schemes that are impractical for operational and political reasons (Segerson 1998; Bunn 1999). Although considered a second best strategy, the voluntary adoption of best management practices (BMP) has been the most common control method for NPP problems. BMPs are practices that are determined to be the most effective practical means for reducing or preventing NPP at the source (Centner et al. 1997). A number of BMPs have been identified for dust control on cropland including reduced tillage systems and multiyear cropping. BMPs have also been evaluated for use on non-cropland areas of farms (i.e. roads and equipment yards) and include the application of synthetic dust suppressants and access restriction to those areas. However, it is uncertain how effective these measures are in reducing overall dust emissions from agriculture.

Congress created the National Agricultural Air Quality Task Force (NAAQTF) to help the agricultural community comply with the PM-10 standards. This group is comprised of agricultural producers, atmospheric scientists, and regional Natural Resource Conservation Service (NRCS) representatives. The task force advises the Secretary of Agriculture on agricultural air quality issues, provides oversight and coordination relating to intergovernmental cooperation in research activities, and ensures accurate data is used by federal agencies conducting air quality studies (NAAQTF 2001).

Large scale and long-term PM studies are being conducted in both the San Joaquin Valley of California and the Columbia Plateau area of Washington State to evaluate PM at the regional level. The goals of these studies are to understand emissions, composition and atmospheric processes of PM-10 (and PM-2.5 in California), and to evaluate control methods that are both efficient and cost effective (CARB 2002; Wash 2000). This type of regional research is essential, because climatic conditions and soil erodibility cannot be modified for a given location (Ferguson et al. 1999).

Regional research has been conducted in central Arizona by engineers and soil scientist from the University of Arizona (U of A) to evaluate dust emissions generated from three reduced tillage systems in cotton. These systems are defined as reducing the number of tillage operations (e.g. disking, ripping, listing) used to produce a crop. The number of tillage operations can be lowered by reducing conventional tillage operations (RCTO), or by adopting single pass, multiple operation equipment (SPMOE). The reduced number of passes in a field by both systems is intended to decrease dust emissions by keeping the soil in a condition that is less likely to erode. This thesis adds to the technical research of reduced tillage systems by evaluating the economic incentives of adopting RCTO and SPMOE systems.

1.3 Objectives

The study area for this thesis is comprised of two counties in central Arizona: Maricopa and Pinal. Cotton growers in these counties experience nearly the same physical characteristics of climate and weather patterns, however the legal institutions under which they operate is quite different. In 1990, Maricopa County violated the PM-10 NAAQS, resulting in a portion of the county being designated as a non-attainment area. Consequently, federal law obligates local and county officials to identify the sources of PM-10 and take appropriate control measures to bring the county into attainment. Agricultural activities produce significant PM-10 pollution (within the Maricopa County PM-10 Non-attainment area) and as a result, federal law requires farmers within the Maricopa non-attainment area adopt dust-reducing BMPs in their operations. RCTO and SPMOE are both BMP options available to growers.[1]

[1] Both RCTO and SPMOE are classified as reduced tillage systems, a BMP category in the Guide to Agricultural PM- Best Management Practices (GABMPC 2001).

A portion of the Maricopa County's PM-10 non-attainment area extends into Pinal County. The majority of growers in this largely agricultural county south of Phoenix are not subject to the PM-10 regulations but were included in the study as a control group to evaluate reduced tillage adoption decisions.

The adoption of new technologies such as reduced tillage systems is more likely to occur when they generate a positive economic benefit. However, other factors also affect a grower's adoption decision. Socioeconomic factors (i.e. age, education level and size of farm) also may influence some growers to adopt when others do not. Current (historically) low prices in the cotton market and a changing rural-urban interface (more so in Maricopa County) also may influence the adoption of reduced tillage systems. Thus the objectives of this study are:

a) identify the per acre net benefits and dust remediation potential of reduced tillage systems,

b) estimate current non-user's willingness to adopt (WTA) for SPMOE systems based on per acre long-term net benefits, and

c) evaluate the socio-economic factors influencing the adoption of reduced tillage systems.

The remainder of this study will proceed as follows. Chapter two reviews the literature on the control methods designed to reduce NPP. Chapter three describes the setting of this study and explains the events which led to the regulation of agricultural activities to reduce dust in Maricopa County. The economic net benefits and dust remediation capabilities of reduced tillage systems are presented in Chapter four. The adoption of conservation tillage literature is reviewed in Chapter five. Chapter six describes the conceptual model, data collection procedures, descriptive statistics, and analytical methods used for the economic evaluation of the adoption of reduced tillage systems. The results of this analysis are presented and discussed in chapter seven. The final chapter discusses the implications and limitations of this study and suggests areas for further research.

2. Mechanisms For Reducing NPP

A major hurdle to cleaner air and water is the development of appropriate control mechanisms that reduce NPP generated by agricultural sources. The effort to reduce NPP in water began in 1972 when amendments to the Clean Water Act (CWA) called for the development of controls to reduce NPP. However, addressing non-point air pollution created by agricultural sources through federal legislation (i.e. CAA) did not begin until the early 1990's. Consequently, the majority of literature pertaining to NPP has addressed improving water quality. Despite the emphasis on non-point source water pollution, the general characteristics of NPP are the same for both water and air. Many of the topics (i.e. policy instruments and implementation) reviewed in non-point water pollution literature can also apply to non-point air pollution.

There are several factors that make developing NPP control mechanisms difficult. First, NPP is created by a group of individual polluters and only the combined (aggregate) ambient pollution of the group is observed (Braden and Segerson 1993). The inability to identify and quantify the pollution generated by each source is considered the most problematic NPP characteristic from a policy standpoint as it complicates targeting and monitoring abatement programs (Ribaudo and Caswell 1999). The second complicating factor is the fluctuation in pollution levels that arise due to random variables such as wind, rainfall and temperature which make the production of NPP a stochastic process - consequently emission levels are difficult to predict. Lastly the process by which the pollution is created is not always understood and/or cannot be easily observed.

2.1 NPP Literature

2.1.1 First Best Mechanisms

The majority of theoretical literature on NPP control has focused on developing first-best mechanisms that create optimal solutions (Helfand and House 1995). The most common optimal instrument discussed in the literature are ambient taxes, which are based on overall pollution levels rather than individual emissions. Segerson (1988) recognized that a range of ambient pollution levels is created as a result of the stochastic nature of NPP. She used a probability density function (pdf) to illustrate the range of ambient pollution levels when no control mechanisms were in place. To reduce the level of pollution (shift the pdf of ambient pollution to the left of the original pdf) Segerson developed an incentive scheme comprised of taxes and subsidies that would encourage polluters to adopt abatement strategies or technologies.[1]

The incentive scheme taxes farmers when ambient water quality falls below a given standard and provides them with a subsidy when the standard is exceeded. The tax and subsidy scheme is given by

$$T(x) = \begin{cases} t(x-\bar{x})+k & \text{if } x > \bar{x} \\ t(x-\bar{x}) & \text{if } x \leq \bar{x} \end{cases}$$

where x is the ambient level of pollution, $\bar{x}$ is the specified ambient pollution cutoff level set by the authorities, t is the tax/subsidy payment that depends on the difference between x and $\bar{x}$, k is a fixed penalty imposed when ambient levels exceed $\bar{x}$, and T(x) is the

[1] The incentive scheme does not require the adoption of any specific abatement practices or technologies. The choice of abatement practices is left to the individual firm who can determine the least-cost pollution abatement techniques.

required payment or subsidy. The fixed penalty, k, is included in order to induce farmers to weigh the additional cost of abatement against the decreasing probability of exceeding the standard after implementing an abatement practice. Without the fixed penalty farmers would choose to gamble on the tax/subsidy, because their tax payment or subsidy received are in part a result of influences (i.e. actions of other polluters and random weather events) outside their control.

Segerson conducted a short and long-run analysis of the tax/subsidy scheme to determine efficiency conditions. In the short run she found that a pure tax/subsidy scheme (no penalty), a pure penalty scheme (no tax/subsidy), or a combination of both could be used to ensure optimal abatement. The flexibility in choosing a program type is a result of the infinite number of combinations of $\bar{x}$, t, and k that could yield short-run efficiency. However, in the long-run both industry output and size influence efficiency and result in reduced program flexibility where only the tax combined with penalty scheme is efficient.[2]

The advantage of Segerson's tax/subsidy scheme is that it requires little interference by the regulating agency in day-to-day firm operations. A major drawback of the incentive scheme is the amount of information required for setting the tax and penalty. The type of information needed includes abatement costs, the costs of damages from ambient pollution, and estimates of each polluter's abatement effects on overall pollution levels.

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[2] A special case of a pure tax program is possible when the benefits of abatement are linear.

Horan et al (1998) expanded Segerson's ambient tax model by introducing additional assumptions regarding ambient pollution. This modified model assumed that the distributions of emissions (individual and ambient levels) were not directly observable by firms or regulators. In addition, they assumed ambient pollution levels (denoted as x in Segerson (1988)) were influenced by a variety of variables including emissions from non-point sources, the natural generation of the pollutant, stochastic environmental variables that influence fate and transport of the pollutant, and watershed characteristics and parameters. The emission generated by each firm was determined by the inputs chosen by the firm, the fate and transport conditions on the farm, and site specific characteristics (i.e. soil type and topography). Horan et al. found that an optimal solution was more difficult to obtain under these modified conditions and only occurred with the firm that had three or less input choices.

Horan et al. then developed linear and nonlinear tax schemes based on Segerson's adjusted model that achieved optimal solutions without limiting a firm's choice set (i.e. number of inputs). Under both schemes, the tax rate was set equal to the marginal damages that were evaluated at the ex ante efficient level of input usage and conditional on the realization of all random variables. This adjustment in the tax rate changed the expected tax faced by each firm and induced firms to consider the impact each unit of input had on expected damages.

Hansen (1998) developed a damage-based version of Segerson's tax mechanism. The damage-based tax is essentially equivalent to a strict liability rule in which farmers pay for the damages created by water pollution (Segerson 1999). The advantage of this tax was the need for less information as regulators no longer needed to know each polluters' abatement costs or emission functions in order to set the tax. Using Hansen's damage-based tax, the regulator only needed to know the damage function resulting from the pollution. In addition, the damage function was assumed to be non-linear and therefore expected damages were determined as a variance in emissions. Consequently, firms were penalized for the damages resulting from increased emission variance. Although Hansen obtained an optimally efficient short-run outcome for the damage-based tax, he did not ensure long-run entry/exit incentives. In the long-run, knowledge of each firm's cost and emissions functions were necessary in order to ensure that each firm's total expected payment equaled total expected damages.

In contrast to a tax scheme, Xepapadeas (1989) proposed the use of contracts between a pollution control agency and individual polluters to control emission levels and reduce the potential for moral hazard problems. He noted that because individuals cannot be effectively monitored, individual dischargers can increase profits by choosing lower levels of abatement. The contracts he developed include a combination of fines and subsidies that induce dischargers to follow the optimal environmental policies in the absence of individual monitoring. The contract was constructed under a budget-balancing system. Under this mechanism all firms were rewarded if water quality goals were met. However, if the goals were not met one firm would be chosen at random and fined. Given the equity issues inherent in this system its real world application is limited. The development of the contract would also require a great deal of information. In order to determine the optimal fine, information regarding production and abatement technologies and damage from pollution concentrations is necessary. In addition, for the contract system to work all dischargers must participate in the contract. The existence of free riders hampers the enforceability of the contract.

Bunn (1999) is the only study to date that analyzes the use of emission taxes to reduce wind erosion. Bunn applied Segerson's (1988) ambient tax to wind erosion control in a semiarid environment. Bunn determined that a tax could be effective in encouraging farmers to anticipate extreme conditions and take corrective measures in order to avoid increases in their tax burden. However, implementing an ambient tax for the control of wind erosion would be more difficult than for water erosion. Bunn noted the stochastic nature of wind erosion is even more extreme than in water erosion. Thus, developing an optimal tax scheme would be quite difficult, and under certain conditions such as droughts, the tax burden on farmers could make farming economically nonviable.

Bunn concluded that the actual implementation of a ambient tax scheme would not be possible until wind erosion measurements become more sophisticated and the links between measured erosion and particulate size and between particulates and damage were better understood. Meanwhile, the author concludes that it will take a combination of policies that include both mandatory conservation compliance (i.e. best management practices, site-specific standards) and conservation easements (i.e. conservation reserve and land acquisition programs) to curtail wind erosion.

In summary, theoretical tax mechanisms have not been implemented due to their complexity, information demands and/or implementation cost (Horan and Shortle 2001). In addition the use of taxes to address environmental problems has been politically unpopular (Bunn 1999). Given these limitations the potential use of ambient taxes to reduce dust emissions is not likely.

2.1.2 Second Best Mechanisms

Recognizing that theoretically optimal solutions are typically not feasible, policy makers have taken a different approach to reducing NPP through the use of indirect policy instruments also referred to as second-best solutions. Second-best instruments are developed to minimize costs subject to the environmental constraints created by NPP (Horan and Shortle 2001). Examples of indirect instruments includes education and technical assistance, technology standards (i.e. BMPs), performance based standards (i.e. standards regulating runoff or ambient concentrations), and liability. The following sections are a brief overview of these NPP instruments.

2.1.2.1 Education and Technical Assistance

Long-functioning agricultural extension offices and SCS programs facilitated the wide use of education and technical assistance programs that addressed water quality problems (Horan et al 2001). These programs help farmers become more fully aware of alternative practices and their environmental effects (Ribaudo and Caswell 1999). Despite the popularity of educational and technical assistance programs, empirical studies have not validated their effect on adoption of abatement technologies.[3] Current

[3] See Chapter 5 for further discussion of empirical studies on education programs and the adoption of conservation practices.

educational programs, according to Ribaudo and Caswell (1999), have focused on selling the new abatement technology, but failed to provide information about the environmental damages caused by current farming practices.

2.1.2.2 Technology Standards

Technology standards, requiring farmers to adopt conservation plans containing approved BMPs, have been the most commonly used regulatory mechanism to reduce NPP (Ribaudo and Caswell 1999). BMPs are an effective means to reduce NPP because they are implemented on a site specific basis, allowing the characteristics and conditions of the area (of application) to be taken into consideration (Leathers 1991; Murhpy 1979).

Some type of financial incentive or regulatory mechanism must usually be in place to increase BMP adoption rates. Voluntary adoption of BMPs is not typically successful in competitive agricultural markets because the adoption of new technologies can create increased costs and risks (Ribaudo and Caswell 1999). In addition, potential adopters perceive that some BMPs negatively affect yields and farm income (Osteen and Nelson 1979; Stanley 2000; Centner et al YEAR; Mostaghimi et al 2001). To increase the likelihood of BMP adoption federal and state governments have employed cost-sharing mechanisms. Tax incentives (i.e. tax credits and rebates) are another form of subsidy employed to offset investment costs (Batie and Ervin 1999).

Enforcement of BMPs through on site monitoring is cost prohibitive because regulators would be required to inspect each individual source. As a result, the enforcement of technology standards has generally been driven by citizen complaints.

Citizen driven enforcement is a disadvantage of BMPs because the instrument does not provide adequate incentives for farmers to implement efficient levels of control (Ribaudo and Caswell 1999). However, growers/polluters can be induced to comply when the penalty for noncompliance is a relatively large fine.

2.1.2.3 Performance Standards

Performance standards control NPP by regulating observable outcomes of a polluter's decision (Ribaudo et al 1999). The observable outcome that the standard is generally based on is the ambient level of pollution or runoff. However given the natural variability in ambient pollution and runoff levels, setting accurate standards that detect fluctuations from manmade sources versus natural sources is generally not technologically feasible. Consequently the use of performance standards to control NPP is nearly nonexistent. The one example of a performance standard actually being used is in portions of Florida to control runoff from dairies. The ability to measure the runoff from the diaries is made possible by water drainage infrastructure that allows for systematic sampling to identify individual sources of pollution (Ribaudo and Caswell 1999).

2.1.2.4 Liability

The advantage of using liability as a NPP reduction mechanism is that it forces polluters to consider the damages they may cause and thus take precautions to prevent those damages. However, a liability instrument has not proven to be an effective means for controlling agricultural NPP. Ribaudo et al. 1999, determined that using strict liability rules or negligence rules limits the feasibility of achieving efficient levels of NPP control. Strict liability rules hold polluters liable for payment of any damages that occur. However, identifying who caused the damages can be difficult given the complex characteristics of NPP. The liability policy is somewhat easier under negligence rules as a polluter is liable only if the due standard of care is not used and many states accept compliance with BMPs as a defense for negligence actions (Ribaudo et al 1999).

Joint and several liability allows an injured party to sue one or more of the suspected polluters. This form of liability makes it possible to deal with the multiple polluters by making each of the polluters responsible for a portion of the damages. Agricultural sources again would generally be exempt from this type of liability because so long as the polluters are non-negligent (practiced due care) they are not responsible for the pollution created.

In case of groundwater pollution caused by pesticide use Segerson (1990) noted that (pesticide) manufactures can bear the risk of damages or injury better than an individual farmer. Manufactures are generally large firms that can spread the risks created by their products and are considered risk neutral. Farmers are considered risk averse given their relatively small operations and inability to spread risk. Segerson (1990) determined that an efficient liability condition exits when manufactures are held strictly liable for any damages caused by their products while farmers are exempt from any liability.

2.2 Voluntary NPP Policies

The most commonly used mechanisms for reducing NPP has been education and technical assistance, technology standards (BMPs), subsidies and cost sharing. The implementation of these instruments has typically been through voluntary programs. However, despite their wide use in agriculture there remain questions as to how effective voluntary programs have been in terms of their ability to reduce emissions, their reliance on subsidies to increase participation (moral suasion), and whether or not command and control policies would be more effective.

The overall effectiveness of voluntary programs has been tied to program participation rather than reducing NPP. Instead of meeting performance targets (i.e. reducing ambient pollution to a predetermined level), voluntary participation has been the primary objective and determining measure of success. However as noted before, developing performance standards or measurable objectives is complicated by the difficulty of identifying sources and the stochastic nature of the pollutant.

A second issue related to the use of voluntary programs is their reliance on subsidies and cost-sharing. The use of these economic incentives violates the polluter pays principle and often involves large transfers of payments to polluters. Subsidies have been justified for the purpose of offsetting the initial investment cost of alternative technologies or practices and the perceived losses in farm income.

A study by Wu and Babcock (1999) evaluated the relative efficiency of a voluntary conservation program to a mandatory program targeted at reducing agricultural pollution. The voluntary program was defined as a stewardship program where the government provides technical assistance and cost sharing payments to farmers. Under their mandatory program the government did not provide any services and imposed fines for non-compliance. The more efficient program of the two was the one that achieved the environmental objective at the lowest social cost.[4]

The authors found two conditions where voluntary programs were preferred to mandatory programs. Under the first condition voluntary programs were more efficient when deadweight losses were minimized. Deadweight losses are created by distortions in labor, investment, and consumption markets because of the need to raises taxes to pay for the government services and cost-sharing payments under the voluntary program. The deadweight losses had to be less than the difference between the private and public costs of government services plus the additional implementation costs (i.e. formal legal procedures) of mandatory programs.

The second condition affecting the efficiency of voluntary programs was the rivalness of government services. The authors identified three categories of government services according to their marginal costs: non-rival services with zero marginal costs (i.e. gathering and disseminating information), pure private services with constant marginal cost (i.e. cost-sharing), and semi-rival services with marginal cost greater than zero and decreasing (i.e. technical assistance). They found that when government services were less rival and cost less than private services, voluntary programs were likely

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[4] Wu and Babcock only focus on evaluating the efficiency of the two programs and assume that the environmental target has already been determined.

to be more efficient. Their finding supports the incorporation of government services into voluntary programs in order to reduce the duplication of private effort and thus decrease private costs.

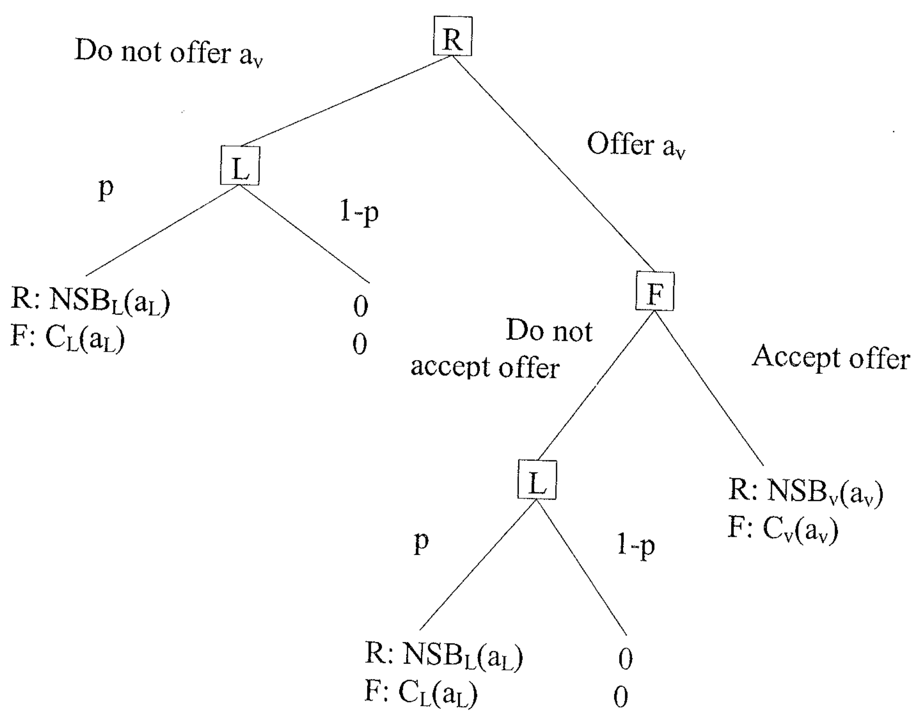
Segerson and Miceli (1998) developed a model that evaluated the role of legislative threats in determining the program type (mandatory or voluntary) resulting from negotiations between regulators and polluters. In addition, they investigated whether an efficient level of environmental protection was possible when a voluntary agreement was the outcome of negotiations. The control of point source pollution (PSP) was the emissions objective of this study, and thus the complex nature of NPP was not addressed.

The authors presented their model in the form of a decision tree (see Figure 2.1) that shows the sequence of decisions between a regulator and a firm as they attempt to develop an abatement program. The initial move is made by the regulator, who decides whether or not to offer a voluntary agreement with an abatement level denoted as, a_v. The regulator will only offer an agreement when the net social benefits (NSB) under the voluntary agreement (denoted as NSB_v) are less the NSB resulting from a legislatively imposed agreement (denoted as NSB_L).

In the case where the regulator chooses to offer the voluntary agreement the firm is left with the decision of accepting or rejecting the agreement. The firm will only accept the regulator's offer when the expected costs of the voluntary agreement are lower than those that would be incurred with a legislatively imposed agreement. The payoffs to the regulator under this scenario are $NSB_v(a_v)$, while the costs to the firm are $C_v(a_v)$.

When the firm chooses not to accept the offer or when the regulator chooses not to make the offer, the threat of a legislative agreement still remains and the regulator has the option of following through on the threat. Depending on the industry the probability of legislation will either be closer to 0 or 1.[5] As the authors note, the agricultural sector would tend to have a low probability of a legislative threat given "there has not been much political support for the imposition of mandatory controls" (p. 112). If the probability of a threat is high and a legislative agreement is imposed the payoffs to the regulator are $NSB_L(a_L)$and the costs to the firm are $C_L(a_L)$. When the legislative threat is low and not carried out there are no payoffs to either the regulator or the firm.

FIGURE 2.1. Sequence of moves by regulator (R), the firm (F), and the legislature (L). Payoffs are for the regulator (top) and the firm (bottom).



Source: Segerson and Miceli (1998) p. 114.

[5] The probability of a legislative threat is assumed to be exogenous and between 0 and 1 (i.e. $0 \leq p \leq 1$).

Segerson and Miceli then evaluated the effects bargaining power had on the outcome of agreement type and abatement level. They note that the "relative bargaining strength of the two parties affected not only the allocation of surplus from the voluntary agreements, but also the efficiency properties of the equilibrium abatement level" (p. 117). At one extreme the regulator had all of the bargaining power while the firm had all of the power at the other extreme. When the regulator had all of the bargaining power there were two types of equilibria that maximize its payoffs: (1) $a_v^{min} < a_v^* < a_v^{max}$, and (2) $a_v^{min} < a_v^{max} < a_v^*$.[6] The outcome of the first equilibrium is a voluntary agreement at the first-best level of abatement. This is because the first-best level of abatement the regulator is willing to offer, a_v^*, an outcome that lies within the minimum and maximum abatement levels. Under the second equilibrium the maximum level of abatement is offered because the firm would reject a_v^* and the outcome would revert to a legislative threat. When the firm had all of the bargaining power the outcome of a voluntary agreement is still possible, however the abatement level is not first best. The firm in this case can make a take or leave it offer, which results in an abatement level that is less the first-best level (a_v^*) as well the level that would have been imposed legislatively (a_L^*). Segerson and Miceli found that equilibrium outcomes that were not first best could be improved (regardless of who had the bargaining power) when the magnitude of the legislative threat was increased.

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[6] a_v^{min}, minimum level of abatement
a_v^*, efficient level of abatement
a_v^{max}, maximum level of abatement

The work by Segerson and Miceli reveals the importance of legislative threats in the development of voluntary programs. Their theoretical work brings to light the effects of bargaining power on the development of voluntary programs and on the resulting levels of abatement. Their results coincide with the work done by Maxwell et al. (1999) who also found that industries facing a high level of regulatory threat and low marginal abatement costs have an incentive to engage in voluntary abatement. Maxwell et al. (1999) evaluated the incentive of interest groups (both firms and consumers) to lobby for their preferred policies. In contrast to Segerson and Miceli (1998), the threat of regulation in the Maxwell et al (1999) study comes from the political pressure generated by environmental groups. A significant finding of this study was that states with initially high emission levels and strong environmental group membership generate more voluntary pollution abatement. This occurs because environmental groups have the capacity to apply political pressure and firms have low marginal abatement costs, therefore voluntary abatement is the best decision for the firm.

2.4 Flexible Incentives

An alternative approach to evaluating NPP control mechanisms is to evaluate them as a policy package rather than as individual tools. Braden and Segerson (1993) note that policy makers have been searching for a combination of second-best instruments to implement, however researchers until recently have not conducted research on this type of pollution control. The use of a multiple control mechanism is referred to as flexible incentives because they use a variety of policy instruments (i.e. education, liability, subsidies, regulation) that give regulators and firms added flexibility in attaining emission targets or standards.

In an effort to evaluate the efficiency of multiple instruments, Braden and Segerson (1993) developed a method that determined whether single or combined set of instruments was more efficient in controlling NPP. The two control mechanisms evaluated in this study were an input tax and a liability rule. Both mechanisms are considered second-best strategies for reducing NPP and inefficient methods for reducing NPP. The authors hypothesized that combining the two instruments would result in increased efficiency.

Braden and Segerson created a scenario where two inputs (X and Y), used by a firm, contributed to NPP damages. To reduce the level of pollution the regulator imposes an input tax on one of the inputs (X) and/or creates a liability rule where the farmer (if found guilty) is held liable for the damages resulting from the pollution.

To evaluate the efficiency of alternative control instruments (input tax, liability rule, or combined approach), the SNB of each was determined and then compared to one another. Braden and Segerson found that combining the two intruments was more efficient than using the input tax alone. The input tax was inefficient because it was levied on only one of the two inputs. Therefore only the efficient level of the taxed input (X) was chosen. Because input Y was not regulated it would be used more excessively, given the level of X, resulting in inefficient use. The liability component of the combined approach induces the farmer to reduce the level of Y (reducing the probability of being held liable), thus creating a level of SNB greater than that achieved with the input tax alone.

The combined approach does not always yield greater SNBs than those generated by a single instrument. In fact it was possible for the combined approach to have a lower level of SNBs. This occurred when the liability rule was compared to the combined approach. The use of the liability rule alone results in imperfect enforcement, producing inefficient levels of X and Y. When the input tax on X was introduced the distortion created by the liability rule was eliminated. However, the increase or decrease in SNB resulting from the addition of the input tax depends on how the tax affects the level of Y chosen (level of Y given level of X) and how Y and X interact in production and pollution processes. Determining efficiency would require detailed empirical knowledge of these interactive processes.

The model Segerson (1999) uses to explain flexible incentives is similar to the negotiation model developed in Segerson and Miceli (1999). The flexible incentives framework is built on the regulator's use of both voluntary and mandatory policy mechanisms as a policy package. The level of abatement is assumed to be a predetermined standard. Under the flexible incentives model the regulator initially offers a voluntary program to the firm. If the firm chooses not to participate in the voluntary program the regulator is left with the option of implementing a mandatory program. As with Segerson and Miceli's (1999) negotiation model, there is uncertainty regarding whether or not the mandatory program would be imposed. According to Segerson (1999), the flexible incentives model allows the regulator to determine the level of the mandatory threat. The certainty of the threat can be built into the policy package by developing the voluntary program with a stipulated mandatory program when the voluntary standard is not met.

An important component in making flexible incentives work is the regulator's ability to ensure that the costs under the mandatory program are higher than those under the voluntary approach. The mandatory program envisioned by Segerson is likely to use instruments such as input taxes or mandate the adoption of certain practices which reduce a farmers ability to meet a pollution standard using least costs methods. Thus, producers must believe that the costs and threat of a mandatory program are large enough so that meeting the performance objectives under the voluntary agreement is in their best economic interest.

2.4 Summary of Literature Reviewed

The literature reviewed in this chapter reveals the variety of policy instruments available to reduce NPP. The key findings of this review are as follows:

(1) First-best instruments, such as ambient taxes can achieve efficient NPP control. However, the need for significant quantities of information and the technological limitations of monitoring prohibit their use.

(2) There are a variety of second-best instruments available to policymakers. Education and technical assistance, as well as technology standards (BMPs) have been the most popular and widely used second-best instruments.

(3) Voluntary NPP control programs are preferred to mandatory programs when (a) the government provides services at lower costs than private services (i.e. gathering and disseminating information; (b) the NSB of the voluntary program are greater than the mandatory program; and (c) the background threat of a mandatory program is high, which can also lead to higher levels of abatement.

(4) Flexible incentives that are comprised of multiple policy instruments can provide both regulators and firms added choices and alternatives in meeting emissions standards or targets. Not all combinations of policies work to improve efficient outcomes, however, because the information requirements necessary to make efficient choices are not available.

To date the NPP literature has not addressed the effects of stakeholder involvement on the development, implementation, and outcome of voluntary or mandatory NPP program/regulations. However, there is the case in Arizona where agricultural producers, as stakeholders, played a key role in developing a mandatory program to reduce PM-10. The following chapter details how the mandatory program came about and how it was developed and implemented.

3. The Study Area and Background

Maricopa and Pinal Counties located in central Arizona are the study areas for this research. In the early stages of this study only Maricopa County was selected as the study site because of the unique regulatory situation facing agricultural producers to reduce PM-10. However, to analyze adoption of reduced tillage systems under a regulatory and non-regulatory conditions, and to increase the number of potential survey respondents, Pinal County was added to the study area. This chapter provides general information regarding population totals, growth rates, and land use changes for both counties. In addition, a significant portion of this chapter describes the history of the Maricopa PM-10 non-attainment conditions, consequences, and plan.

3.1 Study Area

Maricopa and Pinal Counties are located in south central Arizona. The climate in this area is characterized by monthly average temperatures ranging from a high of 105 F to a low of 38 F, and average annual rainfall of 7.83 inches per year (NetState 2002; Sellers and Hill 1974). The high temperatures and low rainfall both contribute to the dry dusty conditions of the area.

Dust generating wind events such as dust storms and dust devils are common. Dust devils, which look like miniature tornadoes, form over the desert floor during the hot dry summer months and are typically short lived. Major dust events occur in the form of dust storms. During the “monsoon season” (July through September), thunderstorms organize into a (squall) line, which can extend more than 100 miles. Each of the cells within the line creates a downdraft of wind that generates dust. The wall of dust that is created can be up to 8000 feet thick with an average visibility of ¼ mile (Ingram 1972). The average wind velocity of the squall lines is 48 mph and has been recorded as high as 72 mph (Ingram 1972). The squall lines typically originate in the Santa Cruz Valley (Tucson, Arizona) and can travel up to 100 miles, reaching the Phoenix area in approximately three and half hours (Ingram 1972). The storms can also originate on the Mogollon Rim and travel to the Phoenix area from the northeast.

In addition to the monsoon season, high wind events can occur from October through April, as a result of storm systems that enter Arizona from the Pacific Ocean via California (GABMPC 2001). The wind speed generated by these storms can reach up to 40 mph. These winds like those generated by monsoon storms have the potential of generating wind blown dust.

People have lived in this desert environment for thousands of years. The Hohokam Indians, known as superb agriculturists, began settling parts of south central Arizona in A.D. 300 and created a civilization that lasted over 1000 years (Weinstein 2000). The Hohokam thrived in the desert by developing irrigation systems as a means of controlling and harvesting water to produce crops. The Hohokam abandoned their dwellings in the 1400s and Spanish settlers moved into the area approximately 150 years later. Americans from the eastern portion of the U.S. followed the Spanish beginning in the mid 1800s. In Maricopa and Pinal Counties the newly arrived American farmers used the ancient Hohokam canals as a foundation for the development of their own irrigation systems (Weinstein 2000; SRP 2002). Controlling and manipulating water in the desert has allowed both agricultural systems and populations to flourish, despite low rainfall and arid conditions.

3.2 Population, Growth and Land Use

Maricopa County has experienced tremendous population growth since the early 1960s. In the last 40 years the population has more than tripled, and as of 2002 the estimated population of Maricopa County was 3,296,250 (ADES 2002). The majority of this growth has been concentrated in the Phoenix metropolitan area. Continued growth is expected in this county and forecasts predict the population will reach 4,516,090 by the year 2020 (ADES 1997).

In contrast, Pinal County is a rural county with several fast growing towns: Casa Grande, Florence, Apache Junction and Maricopa. Over the last decade Pinal was the state's second fastest growing county with a population increase of 55 % (Romero 2001). Population forecasts over the next 20 years project slower growth, with only a 28 % increase in population by the year 2020 (ADES 1997). The growth in Pinal County has been influenced by its close proximity to the Phoenix metro area (Maricopa County). In spite of Pinal County's rapid growth, its population as of 2002 was estimated at 192,395, a small fraction of the population residing in Maricopa County's (ADES 2002).

Urban growth in both counties has played a role in the steady decline of total cropland.[1] Figures 3.1 and 3.2 provide a graphical representation of the decrease in total

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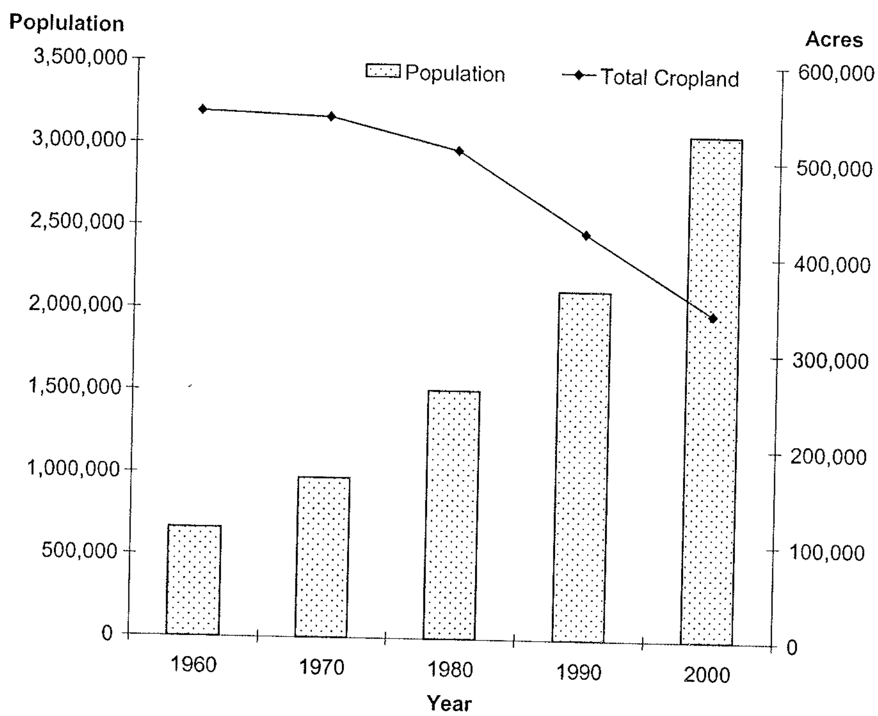
[1] The USDA National Agricultural Statistical Service (NASS) defines total cropland as "land from which crops were harvested or hay was cut; land in orchards, citrus groves, vineyards, nurseries, and greenhouses;

cropland relative to the increasing population in both Maricopa and Pinal Counties. In the past 40 years the amount of cropland in Maricopa County has decreased by approximately 37.8 %, while Pinal County has lost approximately 33 % of its cropland in the last 30 years (cropland acres peaked in the late 1960s) (USDA-NASS Various Years). The decrease in agricultural land is expected to continue as the population in both

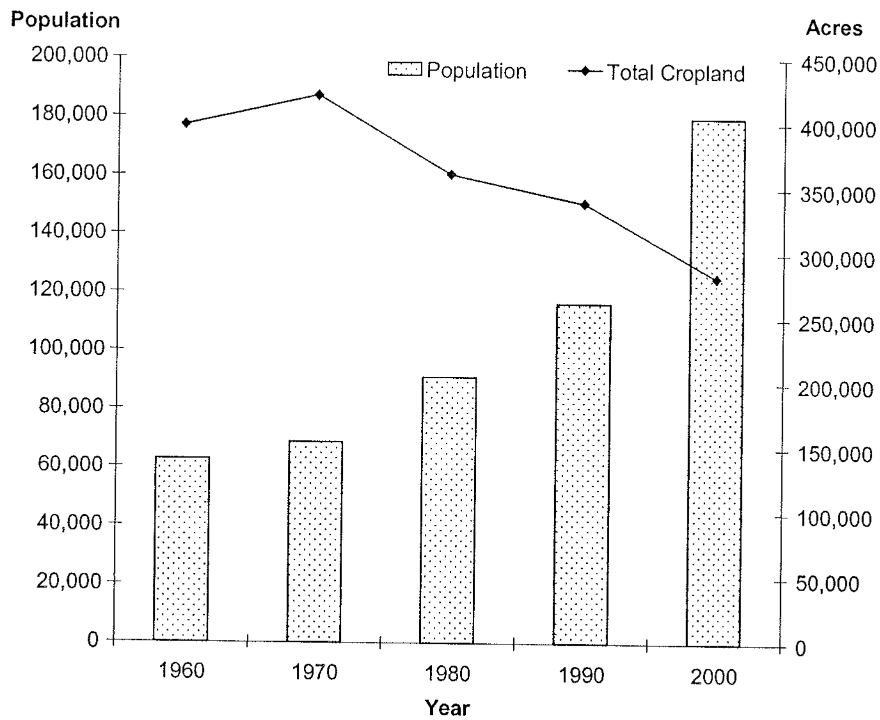
FIGURE 3.1 Maricopa County population and total cropland 1960-2000.*



*Total cropland for the years given in the graph are approximates and were based on USDA Agricultural Censuses for the years 1959, 1969, 1978, 1987, and 1997.
Data sources: USDA-NASS various years; ADES 1997 and 2002

cropland used only for pasture or grazing; land in cover crops; legumes, and soil improvement grasses; land on which all crops failed; land in cultivated summer fallow; and idle cropland" (USDA-NASS 1997 p. A-11).

FIGURE 3.2 Pinal County population and total cropland 1960-2000.*



*Total cropland for the years given in the graph are approximates and were based on USDA Agricultural Censuses for the years 1959, 1969, 1978, 1987, and 1997.
Data sources: USDA-NASS various years; ADES 1997 and 2002

counties increases. It is predicted that approximately 6,000 to 8,000 acres of farmland per year will be converted for urban development in Maricopa County (Roger 2000, FB 1998).

3.3 Pinal County Non-attainment Area History

Pinal County has two PM-10 non-attainment areas, near the towns of Hayden and San Manuel. The sources that caused the exceedances were related to mining activities and fugitive dust emissions (ADEQ 2002). Agricultural sources have not been identified as a significant source of PM-10 in this county. However, several monitors in the county near Stanfield and Cowtown (feedlots along the Maricopa Highway) are close to exceeding the annual PM-10 standard (PAQCD 2002). In addition, the Pinal Air Quality Control District (PAQCD) Director in a recent meeting has identified agriculture as a source of the high dust levels in the county (Aja 2002). Currently the PAQCD is holding meetings with stakeholders (agriculture, construction, off-road vehicle businesses) to inform them of the PM-10 status and begin developing voluntary control measures to mitigate a PM-10 violation.

3.4 Maricopa County PM-10 SIP History

In November of 1990, 2880 square miles of Maricopa County was designated by the EPA as a "moderate" PM-10 non-attainment area after violating the 24-hour and annual standards (ADEQ 2000a; ADEQ 2001). The PM-10 non-attainment area encompasses the entire metro Phoenix area and extends into Pinal County (Figure 3.3).[2] This area is larger than the state of Rhode Island (1045 sq. miles) (Netstate 2003). Due to the large non-attainment area the PM-10 SIP was developed by two entities, the Arizona Department of Environmental Quality (ADEQ) and the Maricopa Association of Governments (MAG).

The Air Assessment Section and Planning Section of the Office of Air Quality of ADEQ develops SIPs for non-attainment areas within the state including municipalities

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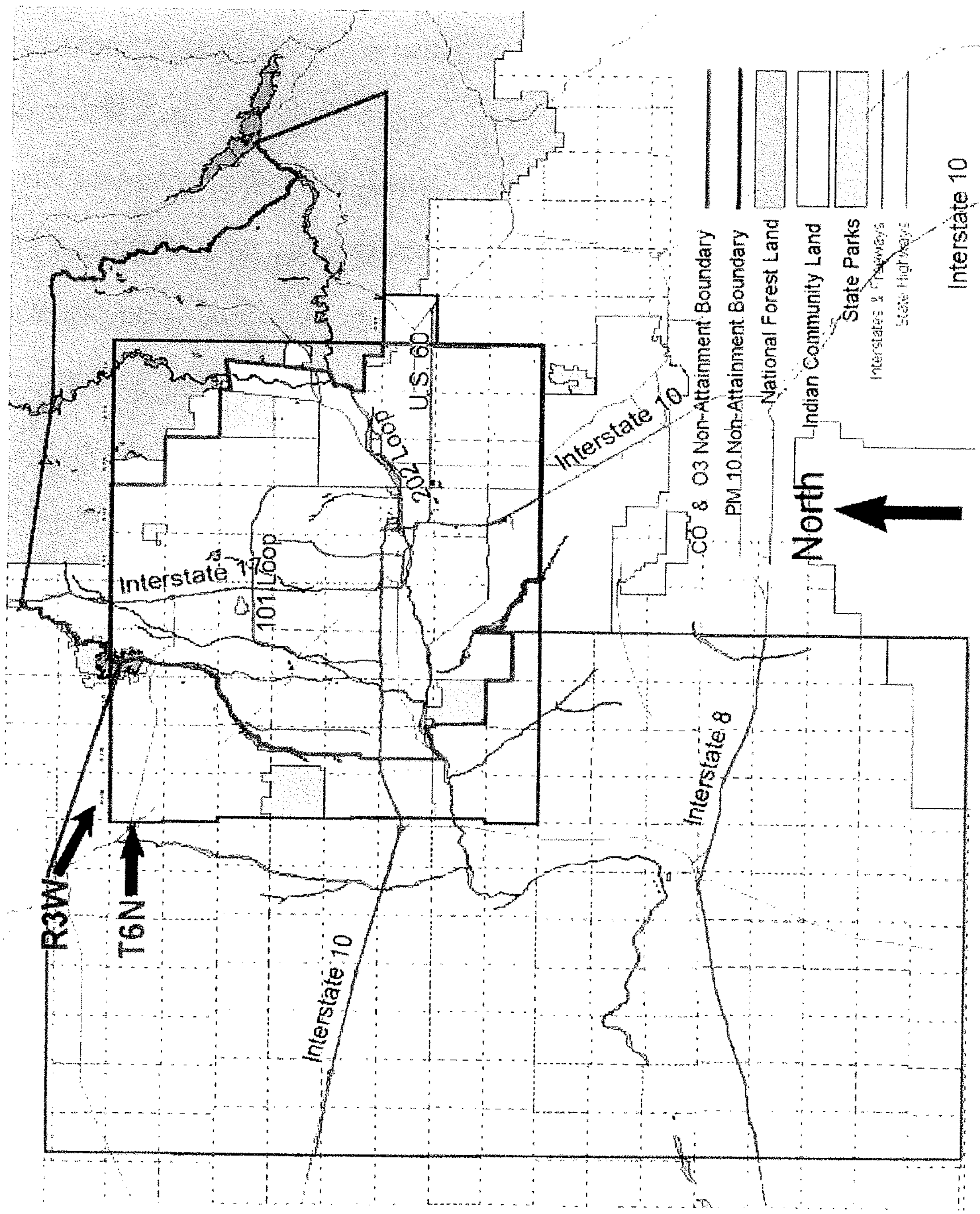
[2] Approximately 36 square miles of Pinal County (town of Apache Junction) are within the Maricopa PM-10 non-attainment area.

FIGURE 3.3 Maricopa County PM-10 Non-attainment Area.*



* Each blue dashed square represents 36 square miles.
Source: MCG 2003

made up of 25 cities and towns within Maricopa County, and includes the Gila River Indian community, the Salt River Pima Maricopa Indian Community, and two ex-officio members (Arizona Department of Transportation and Citizens Transportation Oversight Committee) who serve for transportation related issues (MAG 2002). MAG is the lead air quality planning organization for the Phoenix Metro area and implements SIP requirements within its boundaries (ADEQ 2002). During the development of the Maricopa PM-10 SIP ADEQ was responsible for the 24-hour standard while MAG developed a regional plan to address the annual standard.

The development of Maricopa's PM-10 SIP was a long process that spanned 12 years (Table 3.1). Maricopa County submitted its first SIP in 1991, however the EPA determined that it was incomplete, and began the process of developing a PM-10 FIP which was to be implemented within two years.[3] Maricopa went on to revise and submit its SIP two more times (August 1993 and March 1994), and in 1995 the EPA approved the revised moderate PM-10 SIP.

The SIP submitted to the EPA in 1994 revealed the difficulty ADEQ and MAG had in determining the sources and control measures for PM-10. The report stated that both the annual and 24-hour PM-10 NAAQS would continue to be exceeded despite the implementation of RACMs (ADEQ 2001). ADEQ and MAG were able to demonstrate

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[3] As mentioned earlier (Chapter 1) the EPA is responsible for ensuring the requirements of a SIP are fulfilled. If a SIP is not approved by the EPA it is sent back to the state or local agency for revisions and in the interim the EPA begins the process of developing a FIP.

TABLE 3.1. 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(9th 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 did 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 that attainment of the annual standard was impractical, but were not able to do this for the 24-hour standard. Developing air quality models to determine ambient concentrations associated with meeting the 24-hour standard was not possible due to lack of information regarding the emission sources (ADEQ 2001).

The Arizona Center for Law in the Public Interest (ACLPI), an activist law group based in Phoenix, was dissatisfied with PM-10 SIP approved by the EPA, in part because the SIP did not address sources and controls for the 24-hour PM-10 violations as required under the CAA (Thelander 1999). As a result, ACLPI filed a petition for review in 1995 (Ober v. EPA, 84F .3d 304 (9^{th} Cir. 1996)) and in May of 1996 the 9^{th} Circuit Court ruled in favor of the ACLPI. The Court vacated the Moderate PM-10 NAP and reinstated the EPA's FIP. In response to the Court's ruling, the EPA requested that ADEQ conduct a microscale particulate study to evaluate emission sources suspected of causing the 24-hour PM-10 violations and develop enforceable control measures.

In 1994 ADEQ designed the microscale study and implemented it through 1995 (ADEQ 2000b). ADEQ set up five PM-10 monitoring devices throughout the non-attainment area including Salt River, Maryvale, Gilbert, and West and East Chandler. The Gilbert and West Chandler sites were considered rural-urban interface areas (EPA 1999). Results from four of the five sites determined that fugitive dust created by industrial activities, agricultural fields and aprons, vacant lots, unpaved parking lots and unpaved roads contributed to the 24-hour violations (Table 3.2).

Representatives of the agricultural community in Maricopa County did not agree with the results of the Microscale Study. They felt the study overstated emissions and the results were questionable (FB 1998). Jim Klinker, Executive Secretary of the Arizona Farm Bureau, did not support the claim that field aprons (30 foot turn outs) in an alfalfa field at the Gilbert site were a significant source of PM-10 (Klinker 2001). Klinker also questioned the location of the West Chandler monitor which was placed near an 80 acre

TABLE 3.2. Microscale monitor sites and sources of fugitive dust.

Monitoring Sites	Salt River	Maryvale	Gilbert	West Chandler
Fugitive Dust Sources	Industrial haul roads Unpaved parking lots Earth moving Unpaved roads	Disturbed cleared areas	Agricultural field aprons Unpaved parking lots	Agricultural field aprons Agricultural fields Disturbed cleared areas Vacant lots

Source: ADEQ 2001b

field and a major freeway construction project (Chandler Boulevard and Price Road/101 Freeway) (Klinker 2001). The dust monitor was incapable, according to Klinker, of distinguishing the proportion of dust contributed by each source.

ADEQ was able to show sufficient PM-10 attainment controls at the Salt River and Maryvale sites by making existing municipal dust rules more stringent. However, ADEQ was not able to develop PM-10 controls for agricultural sources at the Gilbert and West Chandler sites. Consequently, the Microscale Plan submitted to the EPA in 1997 was only partially approved. The inability to demonstrate attainment for the agricultural sources resulted in the EPA preparing a FIP to complete the plan.

The EPA began developing its PM-10 FIP by meeting with key stakeholders and touring agricultural sites in Maricopa County. Stakeholders included representatives from the Maricopa and Arizona Farm Bureau who cooperated with the EPA to ensure Maricopa farmers were represented in the regulatory decision-making process. As a result of these meetings, EPA officials decided to use a BMPs approach in developing the FIP. At the state level the EPA worked with both ADEQ and both Farm Bureaus to develop BMPs through a state-led process, which would replace the EPA's FIP if approved by the EPA (EPA 1999).

The state-led process began in 1998, when state legislators passed a law (Arizona Revised Statutes (A.R.S.) §49-457) creating the Governor's Agricultural BMP Committee (the Committee). The Committee was created to develop an agricultural PM-10 general permit and its membership consisted of five local farmers, the director of ADEQ, the director of the Arizona Department of Agriculture (ADA), the state conservationist for NRCS, the vice dean of the U of A, and soil scientists from the U of A. The general permit would require farmers to adopt at least one BMP in each of the following categories: tillage and harvest, crop land, and non-crop land (i.e. farm roads and yards) (GABMPC 2001). The Committee was also responsible for identifying the BMPs used in the general permit.

The Committee recognized that BMPs do not uniformly reduce dust on individual farms or fields due to heterogeneity in soil type, wind, cropping system, location, and management style. In addition there was little research available on which BMPs were most effective in reducing dust. To account for the differences across farms and lack of scientific information on dust mediation practices, the Committee looked for BMPs that would be feasible, effective, and common sense practices that would minimize the negative impacts of increased regulation on local agriculture (ADEQ 2001; GABMPC 2001).

The Committee established an ad-hoc technical group consisting of representatives from the EPA, ADEQ, U of A College of Agriculture and Life Sciences, and Cooperative Extension, Western Growers Association, NRCS, Maricopa and Arizona Farm Bureau, and the Agricultural Research Service to identify the most appropriate BMPs for Maricopa County. The participants developed a comprehensive list of 65 BMPs based on (1) literature and technical documents on wind erosion and dust control, (2) their suitability to Arizona soils, (3) impact on wind reduction, (4) cost, and (5) cost effectiveness (ADEQ 2001). The list was reviewed by the Committee and reduced to 30 BMPs. The selected BMPs were then classified under three categories: tillage and harvest, crop land, and non-crop land (Table 3.3).

To comply with the permit, farmers were required as of December 31, 2001 to (1) adopt at least one BMP in each of the categories, and (2) keep a written record of the BMP adopted for each category. Farmers were (and are) encouraged, but not required, to adopt more than one BMP under each category (ADEQ 2001).

Enforcement of the permit at this time is complaint driven and the responsibility of ADEQ. Although, the EPA would like for ADEQ to verify compliance of all farmers within the PM-10 non-attainment area, ADEQ does not have the resources to do so and therefore has chosen to rely on complaints from individuals (Pella 2001). When a compliant is reported ADEQ inspection personnel visit the farm in question. ADEQ's responsibility is to ensure that the farm operator has abided by the law in verifying that the farmer has adequately maintained records of the BMPs implemented. An example of a permit record sheet provided to farmers in the Governor's Agricultural Best Management Practices Committee Guide (GABMPC 2001) can be found in Appendix A.

TABLE 3.3. Agricultural BMP for the Maricopa County 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

Although compliance with the general permit is straight forward, stiff penalties can be incurred for those who do not comply. The first two offenses do not carry stiff penalties and farmers are given an opportunity to comply with the general permit. Under the first offense a farmer not in compliance with the permit must submit a plan, specifying the BMPs they will use to comply with general permit, to its local Natural Resources Conservation District (NRCD). If a farmer is found not in compliance a second time they must submit an additional plan (like the one submitted to NRCD) to ADEQ. A third non-compliance requires the farmer obtain an individual fee-based permit. This is the same type of permit an industrial business would need to obtain before building a new plant that generates air pollutants regulated under the CAA. Most farmers would not be able to incur the expense of obtaining an individual fee based permit (approximately $25,000) (Rogers 2001).

ADEQ was required to submit a technical report (part of the Microscale Plan) that demonstrated dust reduction due to the use of BMPs to ensure that agricultural BMPs would lead to PM-10 reductions that would meet the 24-hour PM-10 NAAQS by December 31, 2006 (deadline to meet PM-10 NAAQS). Given the time and budgetary constraints ADEQ was working under, the agency used studies from other areas of the country where research had been conducted on BMPs and developed a range (minimum, mid-point, and maximum) of emission reductions. Their methodology for calculating these reductions included determining the applicability of each of the BMPs to the major crops grown in the county, ranking the BMPs most likely to be implemented (by members of the agricultural community), determining the control efficiency of the BMPs, and developing an implementation scenario (ADEQ 2000b).

Using the mid-point level, ADEQ estimated that BMPs would reduce emissions by 36.6 percent, an amount that is below the 58 percent reduction required of agricultural sources by 2006. ADEQ, however, is relying on a reduction in farmland to meet the required reduction. They estimate farm acres to decline by 4 percent per year. Fewer farm acres alone reduces dust emissions by 37 percent. When these reductions are combined with the BMP reductions, overall emissions are reduced by 60.3 percent (ADEQ 2000b).

The use of a range of emissions was important because BMP strategies to control dust are highly dependent on local factors. In determining the control efficiencies of the BMPs the technical report relied heavily on the scientific literature. The majority of the reviewed studies were conducted in other areas of the U.S. and there was some question about the applicability of these controls in Maricopa County (ADEQ 2000b). However, estimating more accurate emission levels would have taken a significant amount of money and years of additional research (ADEQ 2001).

In order to evaluate the BMPs most likely to be implemented by growers in the non-attainment area, the farmers who sat on the Committee ranked the BMPs they felt would most likely be adopted and developed an implementation scenario based on their responses (10 BMPs were selected for the scenario). Some, if not most, of the BMPs which received a high ranking in term of implementation are common practices used on farms. For example, two BMPs commonly used by farmers are combining tractor operations and planting based on soil moisture, and were ranked 1 (scale of 1 to 10, with 1 being the highest level) in implementation. However, no data exists that quantifies what percentage of the farm population or acreage within Maricopa County used these and other practices listed as BMPs before the compliance deadline. Therefore, the implementation scenario may not only have inaccurately predicted the BMP, but also may be overestimating emissions by including reductions in dust emission which may have already taken place.

The implementation of BMPs to control dust from agricultural sources has drawn complaints from the ACLPI. As a result of the flexibility built into the general permit, they feel growers will choose the least cost BMP which may not be the most effective in reducing dust (Fischer 1999). In addition, ACLPIs observes nothing in the general permit that requires a meaningful and quantifiable reduction in dust that can be enforced by ADEQ (Fischer 1999). What the ACLPI fails to realize is the NPP nature of dust emissions, and the technical and budgetary limitations which make "rules with numeric values" impossible to develop.

Despite the ACLIPI's thoughts regarding the use of BMPs and quantifiable reductions, the EPA was satisfied with the use of BMPs to reduce PM-10 emissions to federal standards by December 2006, the federally mandated attainment date. In January 2002, the EPA accepted Maricopa County's plan for attaining both the annual and 24-hour PM-10 NAAQS. Arizona became the first state in the nation to regulate agricultural practices aimed at limiting dust (FB 1998).

4. Evaluation of PM-10 Emissions and the Economic Benefits of Reduced Tillage Systems

Reduced tillage systems are a BMP available to growers in the Maricopa County PM-10 non-attainment area as means for reducing PM-10. By reducing the number of passes across a field, reduced tillage systems preserve the structure of the soil and potentially reduce PM-10 emissions. In addition, reduced tillage systems may also provide an economic benefit (i.e. increased yields, reduced operating costs) to producers who adopt these systems.

The objectives of this chapter are to (1) quantify and compare the PM-10 emissions of reduced tillage systems to a conventional tillage system, (2) evaluate the yields these same tillage systems, and (3) determine if the reduced tillage system generate a positive change in net income over the conventional tillage system. The following section will present the equipment and methods used to quantify and analyze of the PM-10 emissions, yields and fuel usage. The results of these analyses will then be presented and followed by a brief conclusion and statement of the limitations of this analysis.

4.1 Materials and Methods

4.1.1 PM-10 Research

Cotton growers in Arizona are required to comply with state regulations (Arizona Administrative Code R3-4-204) which call for the destruction of cotton stalks and root systems by a specific deadline. The state mandated plow-down controls pink bollworm and cotton boll weevil populations. The cotton harvest in Maricopa and Pinal Counties is generally completed during November- growers then have until February 15th to complete their plow-down activities.[1] As a result of the plow down regulations post harvest tillage operations are conducted during the driest portion of the year, creating dust levels that may affect the EPA's PM-10 standards.

A multi-disciplinary study was conducted to compare a conventional tillage system and three reduced tillage systems with the potential for reducing PM-10 emissions.[2] The objectives of the study were to evaluate the tillage systems in terms of their profitability, sustainability, and particulate emissions (Walsworth et al 2003). The PM-10 analysis took place at two separate UofA locations: the Marana Agricultural Center in Pima County and the Maricopa Agricultural Center located in Pinal County. The tillage systems were operated in fields laid out in a randomized block design.[3] At the Marana location the field was divided into six blocks where a replication of each system was run within each block. In Maricopa, the field was divided into five blocks resulting in five replications of each system. The collection of cotton yields, fuel usage, and PM-10 data began with the plow-down of the 2000 cotton crop.

The conventional method for conducting plow down generally consists of four operations that includes cutting stalks, disking the residue into the soil, ripping the field

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[1] Portion of Pinal County have until March 1 (after each growing season) to comply with the plow-down deadline. See Arizona Administrative Code R3-4-204 for the specific location.
[2] The University of Arizona Departments of Agricultural and Resource Economics; Soil, Water, and Environmental Sciences; Agricultural and Biosystems Engineering; and Plant Sciences participated in the multidisciplinary study.
[3] When using a randomized block design researchers believe that the experimental units (in this case yields) are not homogenous, therefore a blocking factor is used to allow the experimental units to be homogeneous within each block (SAS 1999).

to break up compacted soil, and a second disking to break up large dirt clods (Carter et al 2001). A fifth operation, listing, reshapes the seedbed and is not required under plow down regulations but is a typical operation performed to properly prepare fields for planting.

A single pass of each conventional operation was completed over the sample plots. The use of a single pass may be simplifying the actual number of passes and operations that growers use, as field conditions and/or management choices may result in additional passes or the elimination of an entire operation (i.e. ripping). However, a single pass of each operation is appropriate to serve as a baseline for this analysis because it captures the minimum number of operations that would typically be used under the conventional tillage system.

There are three reduced tillage systems: the Sundance, Paratill, and Pegasus which can either replace the entire conventional system or reduce the number of operations through the use of alternative equipment (Table 4.1). Henceforth the Sundance, Paratill and Pegasus systems will be referred to as single pass multiple operation equipment (SPMOE) as there will be a need in later chapters to distinguish these systems from an alternative type of reduced tillage systems.

The Sundance system consists of equipment primarily designed for use with an underground drip irrigation system developed by Arizona Drip Systems, Incorporated.

TABLE 4.1. Tillage systems, field operations, and implements

Systems	Operations	Implements
Conventional (5 operations)	Cut stalks Disk residue Rip Second disking List (new beds)	Rotary stalk cutter, 4 row 13.5' Offset disk V-ripper, 3 shank 13.5' Offset disk Lister, 5 bottom
Sundance (3 operations)	Cut stalks Pull roots Rip furrow/Disk bed/List (reshape previous beds)	Rotary stalk cutter, 4 row Root-puller, 4 row Disk/Lister, 4 row
Paratill (2 operations)	Cut stalks/ Rip bed/Disk bed/List (reshape previous beds)	Rotary stalk cutter, 4 row Paratill, 4 row
Pegasus (1 operation)	Bury stalks/Disk bed/List (reshape previous beds)	Pegasus, 4 row

Adapted from: Coates 1996 (p. 1596)

However, the Sundance tillage equipment such as the root-puller and wide bed disk can be used with conventional farming systems that do not use drip irrigation. The Sundance implements reduce the number of conventional tillage operations to three, primarily with the use of the wide bed disk that completes three operations in one pass (rip, disk, list). The root-puller pulls the roots from the soil once the stalks have been cut.

The Paratill system uses two implements including the rotary stalk cutter and a subsoiler known as the Paratill. A subsoiler is the main component of the Paratill that loosens the soil to depths of 12 to 17 inches while leaving the soil virtually undisturbed and the basic soil structure intact (Bingham Brothers 2001). Additional tillage components consisting of coulters and rear bedding shanks are attached to the Paratill that allows the implement as a whole to complete the ripping, disking and listing operations in one pass.

The Pegasus system consists of one implement, the Pegasus plow, that replaces all of the implements used in the conventional system and completes all five operations in one pass. Instead of shredding the stalks as the other SPMOE systems do, the Pegasus plow buries the stalk and roots in a 6-inch deep trench (created by the implement) (Carter et al 2001). A disk follows the plow to reshape the furrows and beds.

To quantify PM-10 emissions generated by the different tillage systems a dust monitor unit was built to collect dust samples. The monitor used in this study was attached to each tillage implement in order to collect dust samples from the plume created as the implement was pulled across the field. The dust samples were collected at four elevations: 24, 48, 72, and 96 inches (0.6, 1.3, 2.0 and 2.7 m).

Originally, the PM-10 particulates were collected using high volume filters that captured the PM-10 particles on filter paper. The filter paper was coded and changed after each pass over the field. The ADEQ provided the filter papers and were responsible for weighing each filter paper to determine PM-10 emissions. The use of the high volume filters was discontinued after the first year of PM-10 collection (2000) when it was determined that the high volume filters were collecting particles greater than 10 microns in diameter. In 2001, the second year of the study, electronic particle counters were used to quantify PM-10 emissions. The electronic particle counters use a sensor to measure PM-10 emission in micrograms per cubic meter (Mg/M^3).

4.1.1.1 Methodology for PM-10 Analysis

To compare the tillage systems based on the amount of PM-10 created, it was assumed that the tillage systems were substitutes for one another. This assumption was necessary due the different types and number of implements used in the tillage systems. Total average PM-10 emissions were calculated for each of the PM-10 collection elevations (24, 48, 72, and 96 inches). The average PM-10 emissions of each of the implements within a tillage system were summed to determine the total average PM-10 emissions.

4.1.1.2 Methodology for Cotton Yield Analysis

The cotton yield data was analyzed using SAS version 8 software. A one-way analysis of variance (ANOVA) was used to obtain the means and standard deviations for the cotton yields and fuel used by each tillage system. The ANOVA analysis in SAS was used because of its ability to recognize data generated by a randomized block design. In addition, using SAS allowed for a multiple range test (Ryan-Einot-Gabriel-Welsch Multiple Range Test) to evaluate the statistical significance of the reported means.

The cotton data was also analyzed using Microsoft Excel 2000 to obtain the descriptive statistics and in particular the skewness of the cotton yield data for each system. The skewness was obtained in order to determine how the yields within each system were distributed and whether the distribution conformed to a normal frequency distribution.

4.1.2 Economic Analysis

Partial budgets were constructed to evaluate the change in net returns of switching from the conventional system to each of the three SPMOE systems. Partial budgeting is an analytical tool that provides the ability to compare the costs and returns of alternative plans or proposed changes to an ongoing business, but only affect a portion of the business. As a result only those costs and returns that would be affected by the proposed plan are included in the partial budgets.

The prediction accuracy of partial budgets depends on the accuracy of the information and estimates they contain (Pierce 1997). Because the partial budgets constructed for this study were not for a particular farm, much of the information used to prepare the cost estimates were drawn from cotton crop budgets and machinery cost estimates prepared by the UofA (Teegerstrom and Clay 1999; Teegerstrom 2000). All of the formulas used to prepare the partial budgets are presented in Appendix B.

The Arizona Farm Machinery Costs Bulletin provided the ownership and operating costs of implements used in the conventional and SPMOE systems (Teegerstrom 2000). The ownership costs were calculated to correspond with the Straight Line Method of depreciation as opposed to the Modified Accelerated Cost Recovery System. Under the Straight Line Method annual operating costs are calculated based on constant average annual hours of use throughout the life of the item (Teegerstrom 2000).

The cost of the equipment also was obtained from the Arizona Farm Machinery Cost Bulletin (Teegerstrom 2000). The implements reported in the U of A bulletin do not coincide with a particular brand (i.e. Pegasus, Sundance, Paratill) of implement. Despite the generic form in which the equipment is classified in the bulletin, the costs of most of the implements used in the study were obtained from the bulletin. However, the Paratill implement was not adequately represented by any of the equipment classifications in the bulletin. As a result the cost of this implement was obtained from an implement dealer in Casa Grande, Arizona (Carsen 2003). The cost of the implements and systems are reported in Table 4.2.

A single tractor (220 horsepower (HP)) was used during the experimental field operations of this study and had much more power than is required for the four-row tillage implements. Commercial farm tillage implements vary in size and weight and a single tractor is typically not used for all operations. In order to prepare the partial budgets more accurately, the appropriate tractor size for each of the implements was used instead of a single tractor size. The tractor size information was gathered from cotton crop budgets (Teegerstrom and Clay 1999), Ed Eaton (2002c), and a Pegasus Tillage Cost Comparison Worksheet (1996). In several instances the recommended tractor size from each of the sources was not consistent. In these cases, the tractor most likely to be used given the weight and size of the implement was chosen. The tractor selected for each implement can be found in Appendix C.

The partial budgets were prepared on a per acre basis. In order to calculate the per acre ownership and operating costs of each of the implements (and tractor use) the job rate of each implement was required. The job rate specifies the number of acres an implement covers in one hour. The rates for the conventional tillage equipment were available in the crop budgets, however the job rates for the equipment used in the SPMOE systems were not. Therefore the job rates calculated by Ed Eaton (2002a), the mechanical engineer responsible for conducting the field experiments, were used. The job rates can be found in Appendix D.

TABLE 4.2. Cost of reduced tillage implements and system.

Reduced Tillage System	Implement	Cost	Total System Cost
Sundance	Root-Puller	$6,189.00	$25,352.00
	Wide Bed Disk	$19,163.00	
Paratill	Paratill	$13,800.00	$13,800.00
Pegasus	Pegasus	$26,435.00	$33,602.00
	3 Pt. Guidance System	$7,167.00	

Source: Teegerstrom 2000; Carsen 2003.

The partial budgets are composed of four sections: (1) added annual returns, (2) reduced annual costs, (3) added annual costs, and (4) reduced annual returns. In preparing the information for each part of the partial budget a number of assumptions had to be made which are explained in the following sections.

4.1.2.1 Added Annual Returns

The section on added annual returns includes any additional income that would occur as a result of switching from the conventional tillage system to any one of the SPMOE systems. The literature regarding reduced tillage systems and their impact on cotton yields (Coates 1996) and the limited yield information from this study do not indicate any significant increase in yields over the conventional tillage system. As a result, it was assumed that no added income would result from the adoption of SPMOE.

4.1.2.2 Reduced Annual Costs

The variable (i.e. repair) and fixed (i.e. depreciation) costs of the conventional tillage system that are eliminated as a result of the proposed tillage system change are include in the reduced annual costs section. Each partial budget prepared for the alternative SPMOE systems indicates which of the conventional tillage implements were eliminated and their corresponding variable and fixed costs. Additionally, the variable and fixed costs of the tractors used with each of the implements that were eliminated were also included.

4.1.2.3 Added Annual Costs

There are two subsections within the added annual cost component of the partial budgets: (1) investment/ownership costs, and (2) added annual operating costs. The subsection on investment costs allows for the purchase of a new investment to be accounted through depreciation and interest costs instead of the purchase price. However, the interest costs of the reduced tillage equipment were not included in the partial budgets because it was assumed that farmers could finance the purchase of this equipment through their annual operational budgets. The purchase price of this reduced tillage equipment is generally small enough to allow for self-financing.

The added annual operating costs included the new variable and fixed costs that would be incurred with the use of reduced tillage equipment and corresponding tractor use. The variable costs were comprised of the repair and labor costs for both the tractor and implement. The fixed costs consisted of the depreciation of the tractor used with reduced tillage equipment.

4.1.2.4 Reduced Annual Income

Reduced annual income includes any reduction in income that results from a switch to a reduced tillage system. As noted earlier, no significant changes in cotton yields (either positive or negative) that would impact income was expected as a result of the adoption of SPMOE. The only expected reduction in income was associated with foregone interest from the funds used to purchase the reduced tillage equipment. Because this was an opportunity cost and not a direct cash cost it only affected the profitability portion of the partial budgets.

4.1.2.5 Methods for Evaluating the Partial Budgets

The change in net income and the return on investment (ROI) were measures used to evaluate the economic performance of the SPMOE systems. The changes in net income were reported in terms of profitability and cash flow. Under profitability the change in net income includes both cash and non-cash expenses (i.e. depreciation and interest foregone) while the cash flow computation includes only cash expenses.

The profitability measure was used to calculate the ROI, which is calculated by dividing the change in net returns (profitability) by the total added investment. The ROI expresses the average net profits generated each year as a percentage of the initial investment and can be used to compare the profitability performance of the SPMOE systems.

The cash flow measure can be used to calculate the payback period of an investment, which is the amount of time it takes for an investment to generate enough cash to recover the purchase price of the investment. The payback period is calculated by dividing the total added debt of the asset by the cash flow generated by the investment. Because it was assumed that farmers could finance assets through their operating budget their total added debt is equal to their total added investment.

4.1.2.6 Sensitivity Analysis

A sensitivity analysis was prepared to evaluate the impact a reduction in yields would have on the net returns of the SPMOE systems. Cotton production generates both cotton and cottonseed. Ginning generally produces 1.6 to 1.7 pounds of linted whole cottonseed per pound of cotton lint (Hoffman 2003). Thus growers generate an income from the sale of both cotton lint and cottonseed. The Arizona upland cotton lint and cottonseed prices obtained from the Crop Values 2002 Summary prepared by the USDA (2002) were used to prepare the sensitivity analysis. The cotton lint price (0.489 $/acre) was based on the marketing and monthly prices received from August 1, 2002 through December 31, 2002. The 2002 cottonseed price was 138.00 $/ton.

An additional sensitivity analysis was conducted to determine the impact a tax credit resulting from an investment in SPMOE systems would have on net returns. Arizona law (ARS §§ 43-1081 and 43-1170) provides a tax credit for equipment used to control or prevent pollution. The amount of the tax credit is 10% of the purchase price and is applied to an individual's or business's state income tax. In the partial budgets the tax credit results in an increase in added income.

4.2 Results and Discussion

4.2.1 PM-10 Research Results

The PM-10 results were compared to the EPA's 24-hour PM-10 standard of 150 Mg/M^3 to determine if the dust generated by the tillage system were above or below the standard. The graphical results of the PM-10 analysis for the Marana and Maricopa locations are presented in Figures 4.1 and 4.2.

At the Maricopa site the conventional, Sundance, and Pegasus tillage systems each violated the EPA's standard at least once. The conventional system exceeded the EPA's standard at each collection elevation (24, 48, 72, and 96 inches). It generated the highest PM-10 emissions at the 48-inch elevation where emissions were three times greater than the standard. The Sundance system exceeded the standard at the 48 and 72-inch elevations by 30 Mg/M^3 (20%) and the Pegasus system generated PM-10 emissions that were generally 80% below the EPA's standard, except at the 72-inch elevation were emissions spiked to 230 Mg/M^3 (50% above the standard). The only tillage system at the Maricopa site that did not violate the EPA's 24-hour PM-10 standard was the Paratill system. The maximum PM-10 emission generated by the Paratill system was 130 Mg/M^3, which occurred at the 48-inch elevation.

FIGURE 4.1. Total average PM-10 emissions generated by the conventional and SPMOE tillage systems at the Maricopa experiment site.

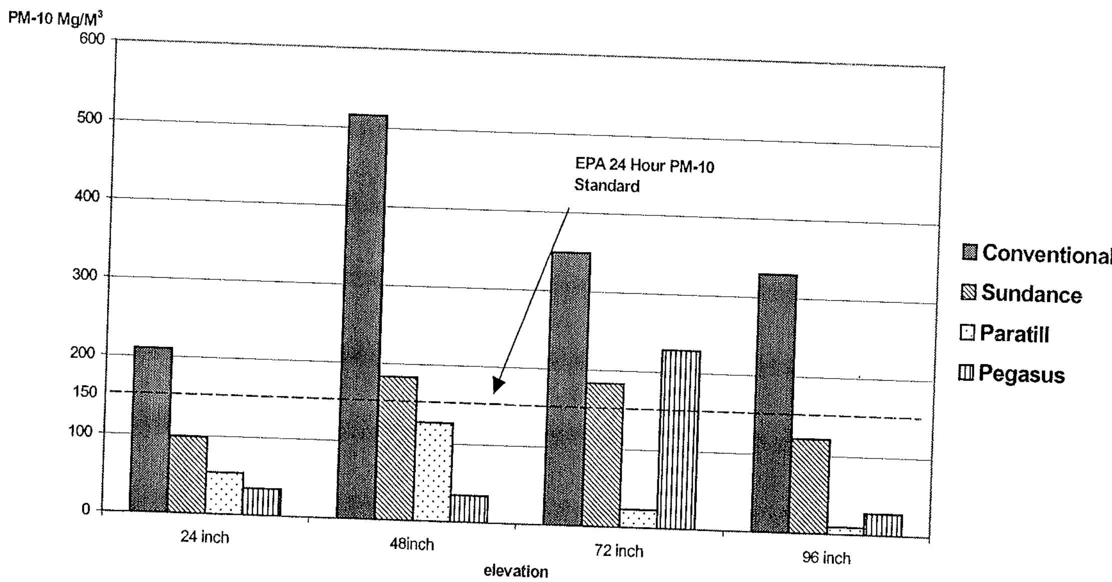
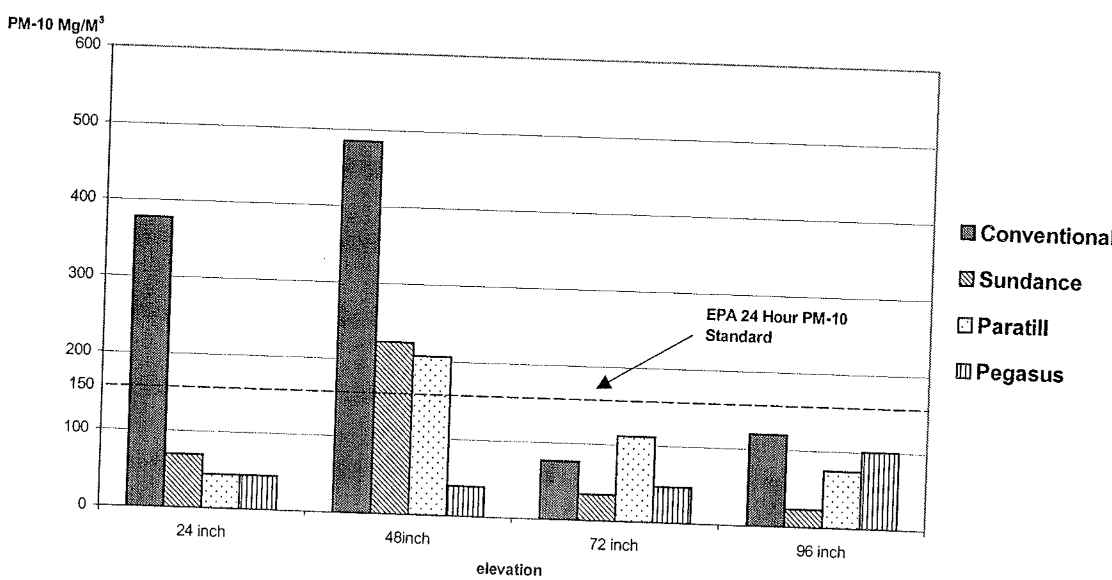


FIGURE 4.2. Total average PM-10 emissions generated by the conventional and SPMOE tillage systems at the Marana experiment site.



PM-10 emissions at the Marana location were relatively lower than those in Maricopa. In Marana the EPA standard was exceeded four times with the majority of exceedances occurring at the 48-inch elevation. At the 48-inch elevation the Sundance system exceeded the standard by 33% while the Paratill system exceeded the standard by 47%. The conventional system surpassed the standard by as much as one and half times the standard at both the 24 and 48-inch elevations. The Pegasus system was the only tillage system in Marana that consistently generated PM-10 emissions below the EPA standard.

The PM-10 results indicate that SPMOE systems generate lower PM-10 emissions than the conventional system. The decrease in the PM-10 emissions by the SPMOE systems is partially due to their use of fewer implements and fewer passes across the field. In fact, at the 24 and 48-inch elevations PM-10 emissions generally decreased as the number of implements was reduced. However, at the 72 and 96-inch elevations there was no consistent pattern that indicated the tillage systems using the fewest implements produced the lowest PM-10 emissions. Eaton (2002b) noted that PM-10 particles do not precipitate easily and this may be one reason why the results at the higher elevations were not consistent with those at the lower elevations. Soil moisture and ambient conditions such as wind and wind speed during the collection time frame may also have affected the amount of PM-10 being collected at the higher elevations.

During the tillage operations at the Maricopa experiment site the soil moisture levels were 4.5%. In Marana the soil moisture levels were approximately 11% for most of the tillage operations. During the shredding and Paratill operations the soil moisture level was 4% and increased to 11% after rain occurred in the area (Walworth et al 2003). The higher moisture levels may partly explain why lower PM-10 levels were found at the Marana experiment site.

It was generally windier at the Marana Agricultural Center than it was at the Maricopa Agricultural Center during the time when the PM-10 data was collected (November and December 2002). The average wind speed at the Marana Agricultural Center during November was 5.5 mph and 5 mph during December while at the Maricopa Agricultural Center the average November wind speed was 4.2 mph and 3.0 mph in December (AZMET 2002). These are general wind conditions, however, specific field wind conditions (i.e.speed and direction) were recorded for each tillage pass during PM-10 collection. This was data was not analyzed with the PM-10 data in this study or in the final project report (Walworth et al 2003).

The PM-10 analysis presented in this thesis is based on one year of data, collected in 2002. PM-10 data was collected in 2001, however there was a substantial number of missing observations. The 2001 data was evaluated in the project report (see Walworth et al 2003). Several years of complete PM-10 data are needed to better understand the reductions in PM-10 created by the SPMOE systems and to determine which of the three SPMOE systems consistently generates lower levels of emissions.

4.2.2 Cotton Yields

The results of the cotton yield analysis from each of the tillage systems showed, as supported by previous research, little statistical difference in the mean yields produced by the tillage systems (Table 4.3). At the Marana site the Paratill system produced the highest overall yields in 2001 and 2002. However, it was only in 2001 that the Paratill system produced a statistically significant higher yield than both the conventional and Sundance systems.[4] The yield of the Paratill system was not statistically different from the Pegasus system. In addition to high yields, the Paratill system had the least variability (as measured by the standard deviation) in yields than any of the other tillage systems. No statistically significant differences in yields were observed in 2002 or in the yields averaged over two years.

At the Maricopa site the conventional systems produced the highest yields in both 2001 and 2002. In 2001 there was no significant difference between the yields produced, however in 2002 the yields of the conventional system were significantly higher than the Paratill systems (at 0.20 level of significance). There were no statistical differences in yield between the conventional system and the Sundance system or the Pegasus system despite a minimum 120 lb/acre difference in yields. The standard deviations for all of the tillage systems were relatively higher in Maricopa during 2002 than any of the other years for which the analysis was conducted and may explain the lack of significance.

All of the yield distributions of the tillage systems were skewed to some degree in all of the time periods analyzed. The results from the individual years show that majority of the skewness of the tillage systems was to the right (positive skewness). The skewness

[4] See section 4.1.1.2 for methodology used to test the difference between means.

TABLE 4.3. Yield means (lb/acre), standard deviations, and skewness for cotton tillage systems, Marana and Maricopa Agricultural Centers.

System	2001			2002			Two year average		
	Mean[1]	SD[3]	Skewness	Mean	SD	Skewness	Mean	SD	Skewness
Marana									
Conventional	1202 b	53.31	-1.75	1455 a	82.17	-0.57	1329 a	147.71	0.19
Sundance	1246 b	50.87	0.51	1470 a	84.15	0.15	1360 a	136.66	0.35
Paratill	1330 a	48.53	0.96	1475 a	93.35	-0.11	1400 a	101.99	0.70
Pegasus	1321 a	74.78	-0.62	1466 a	125.90	-0.33	1394 a	124.48	0.45
Maricopa									
Conventional	1186 a	117.67	0.77	1411 a[2]	190.57	-0.59	1298 a	190.87	0.47
Sundance	1140 a	63.44	0.25	1287 ab	250.42	0.51	1167 a	174.56	0.98
Paratill	1175 a	70.34	-0.77	1193 b	135.50	1.63	1231 a	117.61	1.62
Pegasus	1170 a	107.50	0.57	1291 ab	204.28	0.20	1231 a	166.46	0.83

1. Means with the same letter within a column are not significantly different at a 0.05 level. The Ryan-Einot-Gabriel-Welsch Multiple Range Test was used to evaluate the significance between the means.
2. 0.20 level of significance
3. Standard deviation

of the yields averaged over two years shows skewness directed to the right for all of the tillage systems as well. To a producer right skewness implies they will receive less than the mean yield more than half of the time (FAO 1995).

The skewness values of the two-year averaged yields reveal that the right skewness of the conventional system is less than that of the SPMOE systems at both experimental locations. This implies that all of the tillage systems increase the risk of lower yields relative to the conventional system. Thus the results of the skewness analysis suggest that the SPMOE system increases the probability of lower yields. The results of this section are based on only two years of cotton data. Additional years of data would be needed in order to substantiate the results.

4.2.3 Economic Analysis Results

The results of the partial budgets indicate that replacing the conventional tillage system with any of the three SPMOE systems results an increase in net income under the standard assumptions discussed earlier (Table 4.4).[5] The system with the highest profitability was the Pegasus system followed by the Paratill and Sundance systems (in that order). Replacing the conventional tillage system with Pegasus system resulted in an additional $25.91 per acre while the Sundance and Paratill systems increased income by $16.76 and $16.06 per acre respectively. With respect to cash flow each of the SPMOE systems generated a positive change in net income. The Pegasus system had the highest

[5] A model of the partial budget used to evaluate each of the reduced tillage systems is located in Appendix F. A diskette containing the individual partial budgets is located on the inside of the back cover.

level of cash flow at $20.92 per acre. The Paratill and Sundance systems followed the same pattern they did under profitability. The cash flow of the Sundance system was $13.79 per acre, slightly higher than the cash flow of the Paratill system of $12.21 per acre. [6]

All SPMOE systems generated a relatively high ROI. The Paratill generated the highest ROI of 115 %. The ROIs calculated for the Pegasus and Sundance systems were less than half of the ROI of the Paratill. Following the ROI of the Paratill was the Pegasus system at 76% and the Sundance system at 70 %.

The payback period for each of the SPMOE systems was relatively short. The Paratill system had the shortest payback period at just over a year. The payback period for the Pegasus system was 1.6 years and for the Sundance systems it was 1.7 years.

The changes in net income and the ROIs reported in the partial budgets may be overstated because the SPMOE systems in reality do not adequately replace the ripping operation of the conventional system. Ripping is a deep tillage operation used to break up compacted soil in the top 12 to 18 inches of soil (Silvertooth 1999). Only the Paratill system approximates the conventional ripping operation, as the Paratill implement includes a subsoiler. However, the Paratill implement as used in this study performed the ripping operation beneath the seedbed and not across the entire field (experiment block) as would be done with a conventional ripping operation. A grower who adopts SPMOE would likely still need to rip a cotton field when soil compaction begins to affect yields.

[6] According to the Eaton (2002d) the Paratill implement did not properly reshape the seedbeds and therefore under actual farming conditions the conventional lister would need to be used. Thus for the

Therefore, the partial budgets were re-estimated for the SPMOE with the assumption that they did not replace the conventional ripping operation.

TABLE 4.4. The before tax change in net income and return on added investment.

Tillage System	Change in Net Income ($/acre) Profitability	Repayment Capacity	Return on Added Investment
*Baseline partial budget analysis**			
Sundance	$16.76	$13.79	70%
Paratill	$16.06	$12.21	115%
Pegasus	$25.91	$20.92	76%
Partial budget analysis assuming SPMOE systems do not replace ripping operation			
Sundance	$7.60	$6.61	32%
Paratill	$6.90	$5.03	50%
Pegasus	$16.75	$13.74	49%

*Assumes the ripping operation is replaced by SPMOE systems.

The re-estimated partial budgets indicate the values of the change in net income and the ROIs are reduced when the conventional ripping operation is not replaced (Table 4.4). The values of the re-estimated partial budgets follow the same pattern as the originally computed partial budgets. The re-estimated values may be undervalued since the ripping operation would not take place after each cotton season.[7] The Pegasus system continued to generate the highest level of profitability at $16.75 per acre followed by the Sundance ($7.60 per acre) and Paratill systems ($6.90 per acre). The cash flows of the

purpose of evaluating the economic benefits it was assumed that Paratill system was not capable of replacing the conventional listing operation.

SPMOE systems were all positive. The Pegasus system generated $13.74 per acre in cash flow, while the Sundance and Paratill systems generated $6.61 and $5.03 per acre, respectively. The ROI, although lower, still indicated that the SPMOE systems are a profitable alternative to the conventional system. The ROI of all the SPMOE systems still indicate that they would be profitable investments. The ROI of the Paratill decreased substantially to 50% and was only slightly higher than the ROI of the Pegasus.

Given that the Pegasus system ranked highest in profitability and repayment capacity it would be anticipated that cotton growers would favor this system. Despite the potential $25.91 per acre increase in net income, the Pegasus system has not been widely accepted by cotton growers in Arizona. One reason why the Pegasus has not been adopted is due in part to the system's inability to work under a variety of soil types and moisture conditions (Eaton 2002). For example, in soils with high clay content the Pegasus can leave large dirt clods that must later be worked with additional tillage operations before planting can take place. In addition, during the field experiment portion of this study the Pegasus implement was not able to destroy voluntary cotton stalks and had difficulty staying within the track of the existing beds. A grower would be in violation of the cotton plow down regulations if the operation did not destroy all of the cotton stalks and root systems.

As noted earlier, the results of the cotton yield analysis showed that SPOME systems are more likely to result in lower yields more often than the conventional tillage

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[7] A grower adopting a SPMOE system would most likely not conduct a ripping operation each year, since SPMOE tillage systems preserve the original seedbed. A ripping operation would destroy the seedbed

system. The potential revenue loss per acre can be determined by preparing a sensitivity analysis of the change in net revenues when yields are decreased. Assuming the average cotton yield is 1227 lb/acre a 5% decrease in yields is equivalent to a 61.2 lb/acre decrease.[8] The results of the sensitivity analysis show that at a 5% decrease in yields could potentially reduce net income by as much as $20.81 per acre using the Paratill system, by $20.11 with the Sundance system, and $10.96 with the Pegasus system (Table 4.5).

When a 5 % decrease in yields is applied to the partial budgets prepared under the assumption that the ripping operation is not replaced by SPMOE systems, the reduction in net returns is even greater. The net revenues losses of the Paratill and Sundance systems are nearly $30.00 per acre and the Pegasus system losses are approximately $20.00 per acre.

Despite the positive change in net income and relatively high ROIs of SPMOE, these systems potentially increase the risk of obtaining lower yields. The lower yields as noted in the sensitivity analysis can significantly reduce net income. Given the tradeoff between the increased revenues and the risk of the lower yields, the risk preference of the individual grower will partially determine their willingness to adopt SPMOE.[9]

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requiring additional disking and listing operations.

[8] The 1227 lb/acre cotton yield was obtained from the Maricopa County Bt. upland cotton crop budget (Teegerstrom and Clay 1999).

[9] As reported in Chapter 5 there are additional factors (i.e. socioeconomic) that explain the decision to adopt new technologies as well.

TABLE 4.5. Sensitivity analysis of net returns when revenues decrease ($/acre)[1]

Tillage system	Change in net returns		
	-5% and ripping not replaced by SPMOE	-5%	Baseline[2]
Sundance	-$29.27	-$20.11	$16.76
Paratill	-$29.97	-$20.81	$16.06
Pegasus	-$20.12	-$10.96	$25.91

1. Reduction in revenues based on decreases in both cotton and cottonseed revenues.
2. Assumes the ripping operation is replaced by SPMOE systems.

The sensitivity analysis evaluating the effect of an environmental tax credit indicates an increase in net returns over the baseline partial budget analysis, but not by a significant margin (Table 4.6). The Pegasus continued to yield the highest increase in net returns among the SPMOE systems, followed by the Sundance and Paratill systems. However, the increase in net returns resulting from the tax credit is also not sufficient to cover the potential yield losses that may arise as a result of the adoption of SPMOE systems. Consequently, the environmental tax credit provided by Arizona may not be a sufficient incentive for the adoption of SPMOE systems.

A realistic scenario can be evaluated by combining the assumptions that a farmer would take advantage of the environmental tax credit and continues to use the conventional ripping operation (not on an annual basis) despite adopting a SPMOE system (Table 4.6). The results of such a partial budget analysis reveals that changes in net income are still positive, but the values (change in net income) are less than those in the baseline scenario. Again the net income values of the realistic scenario are likely undervalued because the ripping operation would not take place every year.

TABLE 4.6 Sensitivity analysis of net returns when an environmental tax credit is applied.

Tillage System	Change in Net Income ($/acre) Profitability	Repayment Capacity	Return on Added Investment
Partial budget analysis with pollution control tax credit			
Sundance	$19.15	$13.79	80.3%
Paratill	$17.45	$12.21	125.3%
Pegasus	$29.31	$20.92	86.3%
Baseline partial budget analysis			
Sundance	$16.76	$13.79	70%
Paratill	$16.06	$12.21	115%
Pegasus	$25.91	$20.92	76%
Partial budget analysis with pollution control tax credit and ripping operation replacement assumption:			
Sundance	$9.99	$8.99	41.9%
Paratill	$8.29	$6.42	59.5%
Pegasus	$20.15	$17.13	59.4%

*Assumes the ripping operation is replaced by SPMOE systems and does not include environmental tax credit.

4.3 Conclusion

This chapter compares the PM-10 emissions, yields, fuel usage and profitability of SPMOE systems to a conventional tillage system. The results of the study indicate that overall SPMOE systems generate lower levels of PM-10 emissions than the conventional system while increasing net revenues to the farming operation. The cotton yield analysis demonstrates that use of SPMOE increases the likelihood of lower yields relative to the conventional system. In addition to yield risks, these systems may be more difficult to operate and growers might not want to deal with the "hassle" factor of learning how to operate these newer technologies.

The results reveal some limitations. First, there are not enough years of data for the PM-10 emissions and cotton yields to produce conclusive results. The data that is available and evaluated in this study has provided some initial insights which must be further substantiated. Second the size of the equipment used in the partial budgets is smaller (implements- row size) than what would normally be used on a typical farm. The disadvantage of calculating the costs of the equipment used in the field experiments is that it may not accurately represent the equipment used on a commercial cotton farm. The equipment on most commercial farms is larger (i.e. 6 row) in order to cover more acreage per hour. Finally, the preparation of the partial budgets relied heavily on county level crop budgets and state level farm machinery costs. However, the construction of the partial budgets allow for an individual farmer to enter their own data to determine the profitability of a SPMOE system on their own farm. A diskette provided in this thesis contains the partial budgets that were constructed in Excel 97. The change in net benefits and profitability measures are automatically recalculated when changes are made to items that add to and/or reduce net income.

5. Literature Review: Adoption of Conservation Practices

In the previous chapter the economic feasibility of reduced tillage systems was evaluated along with the PM-10 emissions they produce. The partial budget analysis of the reduced tillage systems revealed that the adoption of these systems produced a positive change in net returns over the conventional tillage system. It could easily be assumed that farmers would automatically be willing to adopt any one of the reduced tillage systems because of the additional profits they can generate. However the literature on the adoption of conservation practices says otherwise. There are number of different theoretical models used for explaining adoption behavior. In addition various factors (i.e. personal and resource characteristics) have been found to affect a adoption decision. In this chapter the theory used to explain adoption behavior will be presented and followed by a brief review of the empirical literature on the adoption of conservation practices.

5.1 Theory of Adoption

The literature on the adoption of conservation practices is based on more than one theory. Some studies use economic theory to explain adoption, where farmers are assumed to make adoption choices based on utility or profit maximization, while others use innovation diffusion theory. The following is a brief explanation of the three theoretical methods of explaining adoption behavior.

Under profit maximization an individual chooses the technology which yields the highest returns. Upadhyay et al (2002) note that “the strength of this approach lies in understanding the role played by one of the major factors that motivate or inhibit innovation: changes in income" (page 3). However, using profit maximization to model adoption behavior is a narrow approach, because it does not recognize individual preferences or values. For instance a farmer with low income may value an additional dollar in revenues differently than an individual with a high income (Robison and Barry 1987).

The second method of explaining adoption behavior, utility maximization, is capable of incorporating the values and preferences of individuals in its models. Utility models allows for a broader set of factors, including the profitability of a technology, to determine the adoption decision. In terms of conservation practices a farmer chooses the technology that maximizes their utility subject to constraints such as prices, personal characteristic (i.e. age), policies (i.e. participation in soil conservation programs), and natural resource assets (i.e. soil erosion potential).

The third method of evaluating adoption is with the innovation-diffusion-adoption paradigm. This paradigm was developed by Rogers (1962) and is based on social psychology, cultural anthropology, sociological theory, and the traditions of diffusion research. Rogers described adoption as a process consisting of five major stages; (1) the individual becoming aware of the innovation, (2) forming an opinion about the innovation, (3) deciding whether to adopt or reject the innovation, (4) (if adopted) implementing the innovation, and (5) the individual either reinforces their adoption decision (all ready made) or rejects it. The characteristics of the individual (i.e. socioeconomic) making the adoption decision are hypothesized to affect the first stage of the decision-making process, while perceived characteristics of the innovation (i.e.

complexity) affect the second stage. The paradigm focuses on individual characteristics and adoption choices within a society. Thus it recognizes that individuals, as defined by diffusion theory, can be identified as early to late adopters.

An important contribution from innovation-diffusion-adoption paradigm is that it allows adoption to be expressed as a decision making process with stages. In addition, it helps explain psychological processes that determine the preferences used in utility maximization (Lynne et al 1988). The use of the paradigm has allowed a number of empirical studies to evaluate the factors that affect the decision making stages prior to the adoption decision.

Explaining the adoption of conservation practices is complex and all three theoretical methods for explaining adoption behavior have been used for empirical analyses. The following section is a review of the empirical literature. The majority of the literature addresses conservation practices used to mitigate soil erosion. However, there are two studies which address soil erosion in the context of this study (air pollution). In addition not all of the studies specifically examine the adoption of conservation (reduced) tillage practices, but they do reveal important factors that affect the adoption of conservation practices in general.

5.2 Review of Empirical Literature

Featherstone and Goodwin (1993) constructed a conceptual model where a farmer's objective was to maximize the net present value (NPV) of a conservation practice investment given by:

$$(1) \quad \text{Maximize} \quad \sum_{j=1}^{J} NPV_j \left[\frac{r}{1-e^{-rTj}} \right] x_j$$

Where NPV_j is the net present value of project j, the term in brackets is the continuous time amortization factor (T is the time horizon and r is the discount rate), and x_j is a binary variable indicating if the investment was made (0,1). Maximizing the NPV of the conservation investment was subject to constraints including credit rationing, site characteristics such as land quality, and program participation (i.e. conservation requirements in government programs). The credit constraint captures the effect of limited financial resources where farmers must choose which technology to invest in. Technical and program constraints can also affect an investment choice by either limiting the application of certain technologies or imposing restrictions on the choice of technology. Formally the constraints are described as:

$$(2) \quad \sum_{j=1}^{J} I_j x_j \leq AVAIL \qquad \text{(credit constraint)}$$

$$(3) \quad \sum_{j=1}^{J} A_{ij} X_j \leq b_i \quad \text{for all i} \qquad \text{(technical and program constraints)}$$

Under the credit constraint I_j is the investment amount for the j^{th} project and AVAIL is available funds for investment. In the second constraint i is the i^{th} constraint, A is a matrix of technical coefficients for the i^{th} constraint and the j^{th} investment, and b_i is the resource limit for the i^{th} constraint. An empirical analysis of the conceptual model was conducted using a simultaneous equation tobit model.

The results of the empirical analysis indicated that credit constraints (debt level, capital assets, and total non-farm assets) had a positive effect on the adoption of conservation technologies, implying that larger capitalized farms were more likely to invest in long-term conservation practices. The technical and program constraints that took into account cropping efficiency, amount of land rented, and total government payments were also found to significantly affect the adoption decision. Farmers receiving government payments were more likely to adopt, while cropping efficiency and percentage of land rented decreased the likelihood of adoption. Cropping efficiency was predicted to be negative because it was hypothesized that the economic benefits of conservation technologies would be greater on less and non-eroded land.

Another study that used the profitability approach to modeling farmer adoption behavior was conducted by Soule, Tegene, and Wiebe (2000). The purpose of their study was to show how land tenure (owners, and cash- and share-renters) affected the adoption of conservation practices. The conservation practices evaluated in the study ranged from conservation tillage, hypothesized to offer short-term gains, to medium-term practices such as contour farming which would most likely be adopted by owner-operators. The authors used a present value model where farmers chose a conservation practice that maximized the present value of their current returns plus a terminal land value.[1]

Soule, Tegene, and Wiebe found that tenure type did affect a farmers decision to adopt conservation practices. The use of conservation tillage was most likely among

[1] The terminal land value is expected to be greater when conservation practices are employed.

owner-operators and share-renters. Owner-operators were also more inclined to use medium-term practices. The authors noted that over 40% percent of U.S. farmland is leased and therefore they conclude that encouraging the adoption of conservation practices should be targeted to those who rent land.

An example of the second analytical approach to adoption decision making is Cooper (1997) who conducted a study using a random utility model to explain farmer behavior. This study analyzed cost-sharing programs and their effect on the adoption decision, and determined the most effective cost share payment that achieves some desired level of adoption (usually defined by a government conservation program). Cost sharing is used to offset farmers' costs of improving the environment (Heffernan 1982). Additionally, conservation practices are often perceived to have high initial costs, low economic profitability, and high risk (Korsching, et al 1983). According to Cooper, in determining cost share values the government can only guess what the necessary amounts should be.

In Cooper's analysis a farmer will accept a cost share payment ($C) to switch to a new production practice if their utility from adopting the new practice and the incentive payment are at least as great as their original state. An indirect utility model was used to express the decision faced by an individual farmer. The functional form of the model is given by:

(4) $$V(0, y; x) + \varepsilon^0 \le V(1, y + C; x) + \varepsilon^1$$

Where 0 is the base state, 1 is the state with the conservation practice, y is farmer i's income, x is a vector of other attributes of the farmer that could potentially affect their willingness to adopt decision, ε is an independently and identically distributed random variable with a zero mean, and C is the cost share payment.

Cooper conducted an empirical analysis based on his conceptual model to evaluate the adoption and the cost-share payments of six conservation practices (conservation tillage, manure testing, integrated pest management, legume crediting, and soil moisture testing). Cooper combined the hypothetical incentive payment required by non-adopters with the $0 incentive of those who had adopted (did not require any cost-share payment). The dichotomous choice contingent valuation method (CVM) was used to collect the hypothetical payment values. Non-adopters were asked if they would adopt a practice based on a specified per acre cost share amount.

Cooper found that the value of the cost share payment and land value were the most significant predictors of adoption. With respect to the significance of land value, Cooper explained that those with higher land values may view conservation practices as detrimental to profitability, but only by a small amount. However, the predicted median cost share payments ranged in value which was a result consistent with Cooper's hypothesis that the optimal rates of adoption would vary among the different practices.

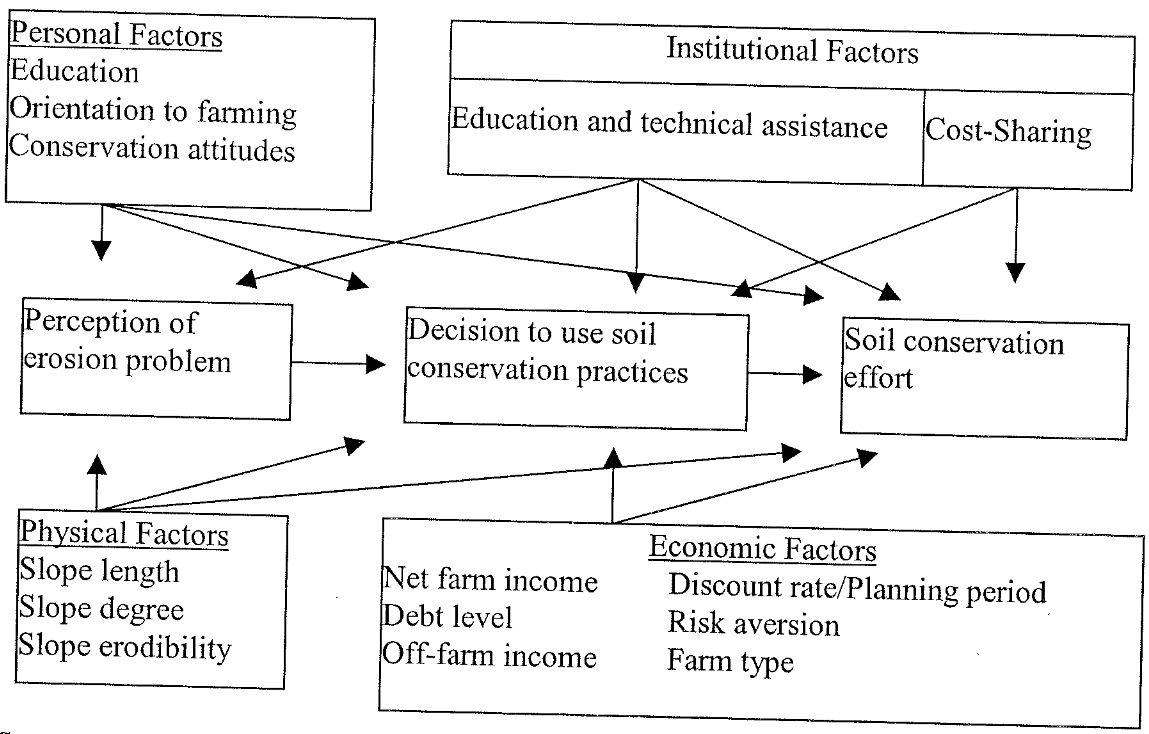
Cooper also found that using the combined incentive payment data resulted in more conservative cost-share values than using the hypothetical data alone. When using the combined data nearly 50 % of the farmers adopted soil moisture testing at cost share values less than $30 per acre. However, achieving the same level of adoption when only the hypothetical data was used required cost share payments up to $80 per acre. Cooper concluded that using the hypothetical data alone to determine payments to attain a given level of adoption could result in overpayment.

Cost share payments did not have a significant impact on increasing the adoption of conservation tillage because 70 % of the survey respondents had already adopted the practice. An increase in the cost-share payment from $0 to $10 only resulted in an additional 2.6 % of the acres added to conservation tillage practices.

Ervin and Ervin (1982) were the first to develop a conceptual model based on the third approach, innovation-diffusion theory. The Ervin study captured the decision making process of adopting conservation practices associated with reducing soil erosion (See Figure 5.1). Their decision making process began with a farmer recognizing the existence of an erosion problem. Once recognized the farmer decides on whether to adopt or not to adopt a conservation practice. Lastly the farmer determines how widely the conservation practice would be applied. The degree of perception helps explain the decision to adopt, which then leads to determining the level of application. Other variables hypothesized to affect each stage of the decision making process included personal, physical (i.e. slope, soil type), institutional (i.e. cost sharing), and economic factors. The economic factors such as debt level and off-farm income were not perceived to have an affect on the perception of an erosion problem and were included only in the last two decision making stages.

An empirical analysis of the Ervin conceptual model was conducted on farm level data of farmers who owned and operated their own cropland. Multiple regression analysis was used to test each of the three decision making stages as separate models. The results indicated that the perception of an erosion problem positively affected the number of conservation practices adopted and the intensity of adoption. They also found

FIGURE 5.1. Decision making process for the use of soil conservation practices.



Source: Ervin and Ervin (1982) p. 281

that farmers with land having higher erosion potential and who participated in cost-sharing programs were more likely to use conservation practices more intensely. Factors such as involvement in conservation programs and the economic factors of debt concern, and the transfer of the farm to a child (used to identify farmers planning period) were not significant in any of the decision making stages.

The authors also conducted a separate analysis on the different conservation practices to determine the factors that influenced each practice. The conservation practices ranged from structural practices, such as the construction of terraces, to the rotation of row crops and pasture. They found that in general cost-sharing was an important factor in the adoption of structural practices while education and perception were more likely to affect the decision to adopt minimum tillage, contouring, and crop rotation.

Subsequent studies have used Ervin and Ervin's (1982) framework to analyze the adoption of conservation practices. Gould, Saupe, and Klemme (1989) built on the Ervin three stage framework by examining various factors that affect the adoption of conservation tillage practices. The authors used an integrated model to evaluate the three stage decision making process. In this integrated model the predicted probability of perceived soil erosion was determined with a single equation probit model which was then used as an explanatory variable in the adoption model. The likelihood of adoption and the intensity (effort) of conservation tillage were then determined using a tobit model.

Gould, Saupe, and Klemme found education, age, contact with soil conservation agencies, and cropland on steeper soils all played a significant role in identifying an erosion problem in the perception model. In the adoption model they found young farmers and large farms were more likely to adopt conservation practices, despite the fact that older farmers and small farm operators were more likely to recognize an erosion problem. They also found that as the amount planted acreage increased so did the proportion of land planted under conservation tillage.

Traore, Landry and Amana (1998) used Ervin and Ervin's framework to establish a link between the perceived health hazards of chemical use and a farmers adoption of innovations that reduce the use of these chemicals (i.e. BMPs). This study evaluated how a farmers' perception of health hazards affects their behavior towards the environment. The authors incorporated the recognition of the health hazards as a factor in the adoption model. Their results indicated that farmers were aware of health hazards due to their current use of chemicals. However they were not willing to modify their current practices becuase they perceived that an adjustment would negatively affect their crop productivity. The perceived negative impact reveals the importance of profitability in the decision to adopt conservation technologies and/or BMPs.

A study by Cary and Wilkinson (1997) considered how the perception of profitability of certain conservation practices affected farmers adoption behavior. The perceptions of increases in long-term profits and the short-term costliness of conservation practice served as the variables for evaluating farmers perceived profitability. Their findings suggest that long-term profitability has a greater affect than short-term investment costs on the adoption decision.

A study more closely related to the environmental problem addressed in this study was conducted by Wang, Young, and Camara (2000). In their study the adoption of conservation practices to reduce wind erosion problems was addressed. They noted that the damages caused by wind erosion may not be as easy to identify as those created by water erosion. Ervin and Ervin's (1982) framework was employed to evaluate the perception of damages and the adoption of practices that reduce wind erosion, however their econometric analysis was conducted differently. Wang, Young, and Camara used two separate single equation binomial logit models to determine a farmer's probability of adopting (1) minimum/no till systems and (2) continuous spring cropping. An ordered probit model was employed to evaluate the number of changes in practices made by a farmer due to wind erosion. Two variables were used to determine the perception of wind erosion problems: (1) the number of wind erosion problems noticed over the last ten years and (2) whether a farmer was familiar with PM-10.

The results of this analysis found that knowledge of PM-10 had a positive and significant effect on the adoption of the two conservation practices and the number of changes made. The number of identified wind erosion problems had no significant effect in either of the adoption models. In addition, there were few socioeconomic factors that were significant in the models. Wang, Young, and Camara note that this lack of significance may be due to the fact that the theory underlying socioeconomic variables are premised on the adoption of profitable technologies. The conservation practices used in their study have not been conclusively shown to be profitable. In addition, research on the adoption of conservation practices to reduce wind erosion, specifically PM-10, is fairly new.

A study that has used the innovation-diffusion-adoption paradigm to explain farmers' adoption behavior with respect to technologies that reduce wind erosion was conducted by Upadhyay et al. (2002). The impetus of this study was to determine how three categories of adopters (based on the number of practices adopted), ranging from zero, single, and multiple adopters, differed from one another. The authors believed their study was most closely associated with the innovation-diffusion-adoption paradigm due to their classification of adopters and the belief that multiple adopters were more innovative than those adopting a single practice or none at all. In their sample of 266 farms in Washington they found that a majority of farmers had not adopted any conservation tillage practices (zero practice adopters). Only 40 % of the farmers sampled had adopted conservation practices with 26 % having adopted a single practice (single practice adopters) and 14 % adopting at least two practices (multiple practice adopters). Between the zero-adopters and single-adopters the researchers found no statistical difference between the characteristics of the two groups. Multiple practice adopters were found to have significantly larger farms and higher levels of education than zero practice adopters.

Upadhyay et al used logit regression models to determine which factors influenced the adoption of conservation practices, specifically continuous cropping and no-till practices. Here they contrasted the adoption of the two practices between (1) adopters (of the specific practice) and zero adopters and (2) adopters (of the specific practice) with adopters of other conservation practices (referred to as "rest" and includes zero adopters). In their study farmers had a menu of conservation practices to choose from, therefore not adopting the specific practices of no-till and/or continuous cropping did not necessarily translate into a non-adopter.

They found that knowledge of PM-10, size of farm, off-farm income and level of education positively influenced the adoption decision of both single practice adopters and "rest" adopters. Among single practice adopters and zero-adopters only knowledge of PM-10 and size of farm positively and significantly influenced the adoption decision.

Given these results the authors concluded that adopters of a specific practice differed more from zero adopters than those who had adopted other conservation practices.

Upadhyay et al. also found that the perception of wind erosion problems had a negative, but statistically insignificant affect on adoption. The researchers explain that this result may be due to the farmers' inability to recollect erosion problems over the last ten years. This result is consistent with Wang, Young, and Camara who also found that that number of wind erosion problems did not significantly affect adoption of conservation practices.

5.3 Significant Findings

The adoption behavior of individuals can be explained either through profit maximization, utility maximization, or as a decision making process derived from innovation-diffusion theory. The use of all three methods is evident in the empirical literature reviewed in this chapter. Although they evaluate adoption behavior differently, there are some general results.

The findings of Traore, Landry and Amara (1988), and Cary and Wilkinson (1997) indicate that profitability plays an important role in the decision to adopt. Therefore despite the fact that a farmer recognizes an environmental problem, the environmental costs created may be less than the cost of investing in a new technology. When this occurs there may be no incentive for the farmer to adopt conservation practices. In addition the benefits of adopting a conservation technology extend beyond the farm, but the costs are borne solely by the farmer (Heffernan 1982).

For the reasons mentioned above, the government has provided cost sharing programs. Ervin and Ervin(1982) found that cost sharing increased the adoption of conservation practices. Featherstone and Goodwin (1993) determined that farmers receiving government payments were also more likely to adopt conservation practices. However, this was more likely a result of participation criteria rather than providing a monetary incentive. Cooper's (1997) study found that the government can increase adoption rates among certain practices using lower incentive cost share values when it is recognized that some farmers adopt conservation practices without any incentive payments.

The size of farms and education levels were also found to positively influence adoption in these studies. Larger farms have more financial resources to facilitate adoption, while highly educated farmers more readily obtain and understand information regarding benefits conservation practices. Education was also found to significantly increase the likelihood of perceiving soil erosion problems.

The perception of an environmental problem was shown in these studies to positively influence adoption when included as an explanatory variable in the adoption models. However, among the studies involving wind erosion perception of an environmental problem was not a significant explanatory variable. This overall finding supports the claim that farmers are less responsive when the visual damages created by wind erosion are less noticeable than those damages associated with water erosion.

Only two known studies (Wang, Young, and Camara; Upadhyay et al.) have addressed the adoption of conservation practices to reduce PM-10. More research is needed to develop an understanding of the factors that affect the adoption of the technologies that reduce dust. This thesis will attempt to make a small contribution to the current body of literature by analyzing adoption practices associated with PM-10 abatement.

6. Analytical Procedures and Data Acquisition

The two analytical procedures used to analyze the adoption of reduced tillage systems are presented in this chapter. The first method uses a semi-log function that evaluates the relationship between the net benefits of SPMOE and RCTO and the percentage of land on which the systems are applied. The semi-log function is based on a mean-variance adoption model where the growers objective is to maximize profits by optimally allocating the conventional and reduced tillage technologies between the total land farmed. The second analytical procedure uses a multinomial logit model that evaluates the decision to adopt SPMOE, RCTO, both SPMOE and RCTO, or not to adopt as a function of farm and operator characteristics. This chapter also explains the data acquisition procedures and survey design.

6.1 Analysis Procedures

6.1.1 Mean-variance Model and Semi-log Function

A conventional mean-variance model provides insight on the adoption decision between reduced tillage (R) and conventional (C) technologies facing the grower.[1] Although this model was not formally estimated in this analysis, the framework does provide a more complex explanation of the decision making process. Suppose the reduced tillage technology and the conventional tillage system are represented by scale-neutral per acre production functions, f (R) and g(C), respectively, where f', $g' > 0$, and

f'', g'' <0. Assume that the grower produces only one crop (y) which is sold at price p, where yield per acre associated with conventional tillage is known, but where $y_s = f(R) + \varepsilon$, and $\varepsilon \sim N(0,\sigma^2)$. The decision-maker allocates the two technologies between the total land farmed (L_T). Assume that the decision maker 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:

(1) $$\max_{L,R,C} \Pi_{ce} = p[Lf(R) + (L_T - L)g(C)] - p_L L - p_R LR + p_C(L_T - L)C - \frac{\lambda}{2p^2L^2(1+\theta)\sigma_\varepsilon^2}$$

where L is the cropped acreage utilizing the new tillage system at the cost of p_L, and p_R and p_C are the costs 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) $$L^* = \frac{p[f(R) - g(C)] - p_L - p_c C + p_R R}{\lambda p^2(1+\theta)\sigma_\varepsilon^2} \qquad \text{for } 0 \le L \le L_T$$

The numerator of this optimal condition 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

[1] The mean-variance model was used by Anderson et al (1999) to describe the decision making process of farmers adopting laser leveling. The model is also described in detail by Robison and Barry (1987 pp. 284-93).

operational costs. The denominator notes that risk preferences, information, and variability associated with the new technology will drive the adoption decision as well.

In this study only the allocation of new or alternative PM-10 reducing technologies was analyzed. From a policy standpoint knowing the cumulative area of application of the new technology by those who have adopted or would adopt is important since any meaningful reduction of PM-10 requires widespread usage. In addition understanding the level of net benefits required to obtain a large percentage of application would be useful to policy makers. For example, if the net benefits are low and the acres of application are low there may be a need to develop cost sharing mechanism to increase adoption and application. Thus information was gathered regarding the ex post (realized) and ex ante (perceived) net benefits of adopting SPMOE and RCTO (ex post only) and the percentage of cotton acreage on which the technology was or would be applied.

A semi-log function was used to evaluate the relationship between technology benefits and the percentage of land application.[2] A semi-log function can be represented by:

(1) $$Y = B_1 + B_2 \log(x) + \varepsilon \qquad \text{and } \varepsilon \sim N(0, \sigma^2)$$

In this study Y represents the percentage of cotton acreage on which the new technology is used, x is the natural logarithm of per acre net benefit related to the adoption of the new technology and B_1 and B_2 are parameter estimates. The semi-log function is useful

[2] More specifically the semi-log model used in this study is a lin-log model, because the independent variable is linear and the dependent variable(s) is logrithmic.

because of the way in which the slope parameter, B_2, is interpreted. Formally B_2 is given by:

$$(2) \qquad B_2 \frac{\Delta Y}{\Delta \ln x}$$

where the numerator is the change in Y divided by a relative change in x (a change in the log of a number is a relative change) (Gujarati 1995). According to Gujarati (1995) equation (2) can be rewritten as:

$$(3) \qquad B_2 \frac{\Delta Y}{\Delta x / x}$$

and rearranged as:

$$(4) \qquad \Delta Y = B_2 (\Delta x / x)$$

From equation (4) the absolute change in Y can be found by multiplying slope (B_2) by the relative change in x. Because equation (1) was estimated using ordinary least squares (OLS), the value of the estimated slope coefficient (B_2) is multiplied by 0.01 – the relative change in x (Gujarati 1995). Thus the semi-log function is used to determine the increase in Y (percentage of cotton acreage) when x (log of net benefits) increases by 1%. The semi-log functions were estimated with the software package Excel 97.

6.1.2 Random Utility and Multinomial Choice Models

A separate model was used to evaluate cotton growers adoption choice of reduced tillage systems. The adoption decision in this study is more than a binary choice between "yes" or "no" , because growers have four different adoption choices: none, SPMOE, RCTO, and both (SPMOE and RCTO). A multinomial choice adoption model is required when there is a single decision among more than two alternatives (Greene 2000).

Wu and Babcock (1998) detail a multinomial choice model that is easily applied to the adoption of reduced tillage systems. The multinomial model is motivated by a random utility model where a farmer has m possible reduced tillage systems to choose from. Let u_j^* be the farmer's expected utility from choosing system j:

(5) $u_j^* = \beta' x_j + \varepsilon_j$

where x is the set of physical and socioeconomic characteristics of the farm and operator, β is a set of estimated parameters, and ε_j is a residual capturing errors in perception and optimization by the farmer. The farmer's utility from choosing alternative systems is not observable, but the choice of system is. Therefore, let I be a polychotomous index denoting the farmer's choice of system and,

(6) $I = j$ if and only if

$u_j^* = \max(u_1^*, \ldots, u_m^*)$

Thus a farmer is expected to choose the reduced tillage system that maximizes their expected utility.

From this point there are two empirical models that can be used to evaluate the analytical framework described. The two models differ in their definition of the residuals, ε_j. If the residuals are independently and identically distributed with Weibull distribution (type I extreme value distribution in standard form) (Greene 2000; Cramer 1991),[3]

(7) $F(\varepsilon_j) = \exp(-e^{-\varepsilon j})$

then the adoption choice can be represented by a multinomial logit model described as (Maddala 1983):

$$(8) \qquad P_{ij} = \frac{\exp(\beta_j{}'x_i)}{\sum_{k=0}^{m} \exp(\beta_k{}'x_i)}, \quad j = 1,2,\ldots,m.$$

where k is the number of alternatives. When estimated equation (4) provides a set of probabilities for the J+1 choices for a farmer with characteristics x_i (Greene 2000). However the model must be normalized, as it has too many parameters (one vector of k parameters is redundant) (Cramer 1991). Thus the model is solved using a set of m-1 equations of the form (Caffey and Kamierczak 1994)

$$(9) \qquad \sum_{1=1}^{n} (f_{ik} - P_{ik})x_i = 0, \quad k = 1,2,\ldots,m$$

where $f_{ik} = 1$ if the ith individual chooses the kth technology and zero otherwise.

The multinomial logit model has been the most widely used model for analysis of polychotomous choices (Greene 2000; Wu and Babcock 1998). However the multinomial logit model is limited by a property referred to as the independence of irrelevant alternatives (IIA). Modes of transportation are the most common example used

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[3] See Cramer (1991) p. 51 for thurther discussion of the Weibull distribution.

in the literature to describe the IIA problem (Maddala 1983; Cramer 1991). A commuter has the choice between a car, bus, and train. Then a second bus is added to the choice set but is only different from the original bus in color. The commuter is described as treating the choice between the two buses as equivalent. When a new choice which is nearly identical to an existing choice is added to the set one would expect that the probability of choosing the similar alternatives to be cut in half and the probabilities of choosing the other alternatives to be unaffected. Instead the multinomial logit produces a new set of probabilities that preserves the original relative probabilities and predicts a too high joint probability for the two similar alternatives (Kennedy 1998; Maddala 1983).

An alternative to the multinomial logit model is the multinomial probit model. Under the latter model the residuals have a multivariate normal distribution and the IIA property does not exist. Because of the normal distribution, computing the probability of choosing any of the choices involves evaluating multiple integrals. Consequently an analytical solution cannot be found and the model must be evaluated by numerical methods in order to solve the integrals (Cramer 1991). The multinomial probit can be estimated with the LIMDEP (version 8.0) econometric software package.

Of the two multinomial choice models, the multinomial logit model was chosen to evaluate the adoption of reduced tillage systems.[4] The IIA property does not apply in this analysis as a farmer would not perceive RCTO and SPMOE or the combination of the

[4] The multinomial probit model could not be used given the small number of observations and the low response rate to one of the adoption choices. An attempt was made to estimate the multinomal probit model using LIMDEP (version 8.0), however it was not able to compute any results due to the limited observations in one of the adoption choices.

two systems as equivalents. The systems differ in aspects such as cost savings, investment expenditures, and ease/complexity of application.

All of the variables used in the model were taken directly from the survey questions. The variables specified in the model are classified either as operator or farm characteristics (Table 6.1). The operator characteristics included age, years of post high school education, perception of dust, and decision to transfer ownership of the farm to a family member. The perception of dust and transfer decision were both dichotomous dummy variables. The dust perception question was modified to fit one dichotomous dummy variable (i.e. 0,1). Instead of using six different dummy variables for each of the perception levels, one variable was used to capture perception of dust as a nuisance. The farm characteristics included the acreage of the farm, number of full time employees, the farms proximity to an urbanized area, and the county where the farm was located.

The coefficients that are calculated from the multinomial logit model are difficult to interpret (Greene 2000; Wu and Babcock 1998). Marginal effects are estimated in order to explain the policy relevant information produced by the multinomial logit model (Dorfman 1996). These are the marginal effects of the explanatory variable on the choice of alternative management strategies. The marginal effects from the estimated multinomial logit model employ the following formulation (Greene 2002)

(10) $$\frac{\partial P_j}{\partial X} = P_j(\beta_j - \sum_{i=1}^{m} P_i \beta_i),$$
$$j = 0,1,\ldots,m$$

TABLE 6.1. Definitions of variables.

Variable	Description	Type
Operator characteristics		
Age	Age of the respondent	Continuous
Educ	Years of formal education beyond a high school diploma	Continuous
FarmT	Respondents plan to transfer ownership of farm to family member (1 = yes, 0 otherwise)	Dummy
DustP	Perception of dust as a nuisance (1 = yes, 0 otherwise)	Dummy
Farm characteristics		
Acres	Total number of acres farmed	Continuous
Employees	Number of full time employees	Continuous
FarmL	Location of farm is within two miles of an urban, commercial or planned housing development (1 = yes, 0 = otherwise)	Dummy
County	Location of farm (1 = Maricopa County, 2= Pinal County)	Dummy

The signs and magnitudes of the marginal effects depend on the signs and magnitudes of many coefficients and have no direct relationship with any specific coefficient (Wu and Babcock 1998). The maximum likelihood method of estimation is used to estimate the multinomial logit models. The statistical package LIMDEP version 8.0 was used to estimate the model and calculate the marginal effects.

Evaluating the goodness of the fit is done by presenting the log likelihood ratio test and the prediction accuracy of the estimated model. The log likelihood value reflects the probability that data would be observed given the parameter estimates (Pampel 2000). The likelihood ratio test uses the likelihood values from the estimated model and a restricted model where the β coefficients equal zero. Multiplying the difference by -2 yields the chi-square value with degrees of freedom equal to the number of independent variables (Pampel 2000). Using a chi-square table, the null hypothesis that all coefficients other than the constant equal zero can be tested.

The prediction accuracy of the model reveals the number choices made that were predicted correctly. This information is generally presented as a prediction success table (see Chapter 7) where the diagonal terms are the correct prediction of choice i and the off-diagonal terms are the number of individuals who chose alternative i, but were predicted to choose alternative j (Maddala 1983).

6.2 Survey Methods

6.2.1 Target Population

As reported in Chapter 5, the tillage systems used in this study to evaluate PM-10 emissions were conducted in cotton fields at the experiment stations. The analysis of the adoption of the reduced tillage systems is based on data collected from a survey of cotton farmers operating in Maricopa and Pinal Counties. The population of cotton growers in both counties is relatively small therefore an effort was made to carry out a census in each county.

The list of cotton growers compiled for this study was obtained from various sources. The ADA's list of farm operations that had obtained pesticide permits served as the master list. It was assumed that the majority of commercial cotton growers in Arizona would be on this list. The name of the farm business, its owner, mailing address, and telephone number were listed for each pesticide license. However, the ADA list contained statewide information and did not specify the type of farming operation for which the pesticide permit was obtained. A small proportion of the cotton growers were identified in ADA's list due to the researcher's knowledge of the agricultural community in both counties. The majority of cotton growers were identified by cross-referencing ADA's list with the Maricopa and Pinal County Extension mailing lists supplied by the Cotton Specialists in each county (Pat Clay and Steve Husman). Interviews were held with each of the Cotton Specialists to review the final list of cotton growers and ensure its accuracy. The final number of cotton growers identified for the survey was 237 with 119 growers located in Maricopa County and 118 in Pinal County.

6.2.2 Survey Instrument Design

The questionnaire consisted of three pages and was arranged as a booklet (see Appendix F and G). The booklet format was used with the intention of making the questionnaire easier to handle, read, and complete. In addition, the questionnaire was designed to be completed in 10 minutes and without any consultation of farm records.

There were some differences between the questionnaires sent to each county and differences within the questionnaires as well. The differences between the county questionnaires were a result of an introductory paragraph that was specific to each county. The background setting for the adoption of reduced tillage systems was different in each county requiring separate introductory paragraphs that accounted for these differences. Within each county six different questionnaires were prepared to accommodate the range of willingness to adopt (WTA) values. The WTA values were informed by the partial budget estimates. Table 6.2 identifies the combination of WTA values used in each of the six questionnaires and the breakdown of the number sent in each county.

The first question in the questionnaire was used to determine if the respondents were actively engaged in the day-to-day operation of a cotton farm. The purpose of this question was to ensure that the person responding to the survey operated a cotton farm. There are a number of reasons why a person identified on the mailing list as a cotton

TABLE 6.2. Combination of WTA values used in questionnaires.

Questionnaire WTA Code	WTA values (estimated long-term net benefits ($/acre) of SPMOE*)	Number of questionnaires sent to each county	
		Maricopa	Pinal
A	$10, $20, $30	19	19
B	$10, $25, $40	20	19
C	$10, $30, $50	20	21
D	$15, $25, $35	20	20
E	$15, $30, $45	20	20
F	$15, $35, $55	20	19

grower would no longer be actively engaged in cotton farming including retirement, sale of farm, or simply no longer growing cotton. If the respondent answered "no" to this question, they were thanked for participating in the survey and asked to return the questionnaire.

The second question was included to determine cotton growers' perception of dust as an environmental nuisance. Originally the question was worded using environmental damages, but because this study evaluated reductions in PM-10 emissions rather than soil erosion it was felt that word nuisance rather than damages was more accurate.[5] With soil erosion there are both on-site and off-site damages, however the dust generated by tillage operations and the resulting PM-10 generally result in off-site (i.e. cleaning cost and increased respiratory problems) damages. Farmers may or may not recognize the nuisance they create for others. A scale of answers was provided to determine whether the cotton growers believed the dust they generated through their tillage operations created an environmental nuisance and how they perceived the nuisance level.

Questions three through seven were used to determine the type of reduced tillage systems adopted and the estimated long-term net benefits per acre from adopting the systems. Question three served as the "road map" that directed the respondent to the subsequent question based on their response to the type of reduced tillage system adopted (or not adopted). The reason for the "road map" was that more than one type of reduced tillage system could be adopted. For instance a grower may have adopted both SPMOE and RCTO or they may have adopted only one of the systems. Depending on the answer to the type of system adopted, respondents were directed to the corresponding questions that asked for the estimated long-term net benefits of adopting reduced tillage systems. Question three also asked those who had adopted either SPMOE or RCT their reason(s) for choosing to adopt the system (i.e. reduced costs, dust control). For the respondents who had adopted RCTO question five asked them to identify which of the five

[5] Dust and PM-10 can create an annoyance for nearby residents and communities.

conventional tillage operations they had reduced or eliminated and what percentage of cotton acreage it was applied to.[6]

The cotton growers who had not adopted SPMOE (including those who had only adopted RCTO) were asked to answer questions seven, eight, and nine. These three questions were used to elicit cotton growers WTA SPMOE. The estimated per acre long-term net benefits were arranged in the combinations noted in Table 6.1. The WTA values ranged from $10 to $55. The range was selected to encompass the per acre net benefits calculated in the partial budgets in Chapter 4. If the respondent answered "yes" to any of the values they were asked to specify the percentage of the cotton acreage or which they would apply SPMOE. The responses of "no" or "don't know" were also included as possible answers to the WTA questions. If either of these two answers was chosen the respondent was directed to question ten, which asked them to explain the reason for answering "no" or "don't know".

The format of the WTA questions were generally consistent with National Oceanic and Atmospheric Administration (NOAA) recommendations (NOAA 1993). They suggest that valuation questions be posed as a vote on a referendum. In addition, they recommend that a "no-answer" option be given to a "yes" and "no" vote option, however in this study the "no-answer" option was worded as "don't know". Although the wording is different it did give respondents an alternative to the "yes" or "no" answers. An open-ended follow-up question was provided for the "no" and "don't know" responses which was consistent with NOAAs recommendations. Follow up questions for

[6]See Chapter 4 for a description of the conventional tillage operations.

the "yes" and "no" responses were also recommended to determine why the respondent voted the way they did. However, these later follow up questions were not included in the questionnaire.

The last set of questions, eleven through seventeen, were included to gather socioeconomic data from each of the respondents. Individuals often perceive such questions to be intrusive and an invasion of privacy, therefore preceding the last set of questions was a statement that explained the importance of these answers for understanding adoption behavior.

The personal characteristics of the cotton growers were obtained in questions twelve, fourteen, fifteen, and sixteen. The age of the grower and their level of education (years of formal education beyond a high school diploma) were asked in questions twelve and thirteen. The second two personal characteristic questions were used to determine the planning horizon of the farmer. It was hypothesized that those with a longer planning horizon were more likely to invest in conservation practices. To elicit this information the respondents were asked how long (years) they planned to continue farming and if they planned to transfer ownership of the farm to a family member.

Question seventeen was included to determine the proximity of the farm to a developed urban area, which also might also be considered a proxy variable for determining the farmers planning horizon. The hypothesis is farmland near developed urban areas may be converted to non-agricultural uses sooner than land in more rural areas (Soule et al 2000). Thus a farmer may be less inclined to adopt practices that require capital investments.

6.2.3 Survey Procedures

The questionnaire was reviewed in early January 2002 with the Pinal County cotton specialist and pre-tested in February 2002 with four cotton growers, two from each county. The pre-testing revealed components of the questionnaire that created confusion and were difficult to understand, verified the time necessary to complete the questionnaire, and the acceptance of the subject matter. Revisions to improve the questionnaire were made based on the comments of the five individuals.

The questionnaire developed for the study was implemented as a mail survey rather than a telephone survey or through personal interviews due to the number of cotton farmers and the limited resources (personnel, time, and financial) of the study. To increase the response rate of the survey the Dillman method for administering mail surveys was followed.

Dillman (2000) developed a total design method (TDM) for administering mail and telephone surveys. The portion of the TDM that applies to implementing a mail survey was used in this study and consists of two parts, (1) preparation of the survey packets and (2) procedures for conducting follow-up mailings.

The survey packet mailed to the cotton growers consisted of a cover letter, questionnaire, and self-addressed stamped return envelope. The information in the cover letter included an explanation of the study, the anticipated benefits of the study, and the importance of each person's response. Information pertaining to the cotton growers consent to participate in the study and how their information would be kept confidential was also included.[7]

Each cover letter was hand signed in accordance with the Dillman method by the principle investigator and graduate research assistant who prepared and administered the questionnaire. The signatures of the U of A cotton specialists were also included in the cover letters mailed to their respective counties. The U of A Cotton specialists spend a significant amount of time interacting with the cotton growers in their particular counties, therefore their names and signatures were included to provide the cotton growers with a name they recognized. Copies of the cover letters are available in Appendix H and I.

An identification number was placed on each of the questionnaires before they were mailed. The purpose of the identification number was to keep track of the questionnaires as they returned and to facilitate follow up mailings. The cover letter, questionnaire, and stamped reply envelope were folded and arranged as a packet rather than inserted separately.

The data collection process began with the first mailing on April 5, 2002. One week later a follow up thank you/reminder post card was mailed. The response rate after the first mailing and post card follow up was 31 percent. After the third follow up mailing, which was sent on April 26, 2002, the response rate increased to 54 percent (127 questionnaires). A fourth follow up and third mailing of the entire survey packet was not conducted as it was felt that it would not significantly increase the response rate.

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[7] Including the consent and confidentiality information was required by the UofA Human Subjects Committee.

The goal in this study was to obtain a response rate between 50 and 70 percent. Admittedly the response rate achieved was in the lower bounds of the goal, however the follow up mailings did increase the response rate. In addition keeping the completion time if the survey to under 10 minutes and not requiring the respondents to consult their records may have also contributed to the overall response rate.[8]

[8] Pennings et al (2002) found that without compensation farmers are only willing to spend a minimum of 10 minutes completing a questionnaire and are more likely to answer questions that do not require them to consult their records.

7. Analysis of Results

The survey response rate of 54% (128 questionnaires) reported in Chapter 6 can be deceiving as not all of the questionnaires were used to conduct the data analysis in this study. A total of 54 questionnaires had to be eliminated leaving 74 with which to conduct the data analysis (Table 7.1). The reasons for eliminating questionnaires included missing information, inconsistent responses, and duplication of information.

The majority of the questionnaires not used in the data analysis was a result of respondents reporting they were no longer engaged in the day-to-day operation of a cotton farm. Twenty-eight such responses were from Maricopa County, while an additional five were obtained from Pinal County. Although a follow up question was not provided to determine why the respondent was no longer growing cotton, eight individuals did provide this information. The reasons indicated for not growing cotton included the elimination of cotton from the cropping mix, retirement, and conversion of land to urban uses. These results are not surprising given relatively low cotton prices, the aging of the farm operator population, and increased urbanization pressures on adjacent farmland. Two respondents indicated that they were involved in the production of other crops (i.e. hay or vegetables) and not cotton. It is difficult to determine if these individuals were ever involved in the production of cotton (specialized from the start) or if they transitioned out of cotton production to other crops.

Thirty-five questionnaires contained missing data (i.e. WTA and socioeconomic responses). In order not to eliminate all 35 questionnaires, an attempt was made to contact by telephone each of the respondents who did not adequately complete their surveys. The 15 questionnaires listed as not usable represent the respondents who could not be reached. Two surveys missing socioeconomic data were also eliminated. Three surveys were eliminated as result of inconsistent responses to (1) the hypothetical WTA questions and (2) estimated net benefits of reduced conventional tillage system.

TABLE 7.1. Survey validation for adoption and WTA analysis.

Total surveys collected		128
Not actively engaged in growing cotton	(33)	
Missing WTA responses and/or estimated net benefits	(10)	
Inconsistent responses	(3)	
More than one survey from the same farm	(1)	
Listwise deletion		
Application of reduced tillage systems on cotton acreage (% of cotton acreage)	(5)	
Socioeconomic data	(2)	(54)
Usable surveys		74

One survey was eliminated because using it would have duplicated the information from one farm. A problem that arose in developing the list of cotton growers was individuals from the same family who potentially were farming together as a partnership. Generally the same information regarding tillage practices would be reported by these individuals. There were two individual surveys returned by family members operating the same farm. One of these surveys noted that the "son" was responsible for managing the majority of the farm and therefore only the survey prepared by the son was used.

7.1 Dust Perception

Nearly 71 % of cotton growers acknowledge that the dust generated by their tillage activities creates an environmental nuisance, however the majority believed the problem was not severe (Table 7.2). Using a range from very severe to not severe to determine the level of environmental nuisance, 38.7 % identified the nuisance as not severe, 16 % believed it was moderately severe, and only 6.7 % felt it was severe or very severe. Of the remaining respondents, 36 % felt that the dust generated by tillage operations did not create an environmental nuisance and less than 3 % responded that they did not know whether or not an environmental nuisance was created.

TABLE 7.2. Survey respondents perception of dust an environmental nuisance.

Perception level	Maricopa County		Pinal County		Total	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Very severe	1	3.3	2	4.5	3	4.1
Severe	0	0	2	4.5	2	2.7
Moderately severe	4	13.3	8	18.1	12	16.2
Not severe	12	40	16	36.3	28	37.8
Not a nuisance/ problem	13	43.3	14	31.8	27	36.5
Don't know	0	0	2	4.5	2	2.7

7.2 Adoption Breakdown

From the 74 usable questionnaires a total of 51 respondents were classified as having adopted at least one type of reduced tillage system and 23 were classified as non-adopters. Among the adopters 2 adopted SPMOE only, 22 adopted RCTO only, and 28 adopted both SPMOE and RCTO (referred to as BOTH) (Table 7.3). The respondents classified as non-adopters were individuals who had not adopted either SPMOE or RCTO.

The breakdown of adoption type was nearly evenly split between Maricopa and Pinal Counties. The greatest difference occurred among the non-adopters where the majority of the non-adopters in the sample (69.6%) were located in Pinal County.

TABLE 7.3. Adoption of reduced tillage systems in Maricopa and Pinal Counties.

	Maricopa County		Pinal County		Total	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Adopted SPMOE only	1	3.3	1	2.3	2	2.7
Adopted RCTO only	10	33.3	12	27.2	22	29.7
Adopted both SPMOE and RCTO	12	40	15	34.1	27	36.5
Non-adopters	7	23.3	16	36.4	23	31.2

The descriptive statistics of adopters within each adoption classification are presented in Table 7.4. When the adopters are grouped together they had larger farms (based on acreage and number of employees), were younger operators, and had more years of formal post high school education than non-adopters. These same results also describe the adopters of SPMOE and both SPMOE and RCTO. On average the RCTO adopters had smaller farms and were nearly the same age as non-adopters, but had more years of formal education.

The comparison between the RCTO adopters and the other two adoption classifications (SPMOE and BOTH) indicate that RCTO adopters have smaller farms, are older in age, but have nearly the same level of education. Usually non-adopters are identified as older operators with less years of education operating smaller farms. One explanation for the smaller farm size of the RCTO adopters is that they generally have less capital to invest in SPMOE and thus rely on reducing the number of tillage operations using currently owned equipment. Although RCTO adopters had smaller farms, they did have a higher level of education than non-adopters who were nearly the same age.

TABLE 7.4 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.

The RCTO adopters did not differ from the SPMOE adopters with respect to their reasons for adopting their respective reduced tillage systems (Table 7.5). The two reasons most commonly chosen were "to reduce costs" and "to reduce cost and dust", however the response of reducing costs always exceeded the response of reducing costs and dust but not by a wide margin. The two SPMOE only respondents both indicated reducing costs was their only reason for adopting these systems. None of the survey respondents chose "to reduce dust" as the sole reason for adopting reduced tillage systems.

TABLE 7.5. Reasons for adopting SPMOE and/or RCTO.

Reason for adoption	Adoption Choice			
			Both	
	SPMOE only	RCTO only	SPMOE	RCTO
Reduce costs	2	12	13	15
Reduce dust	0	0	0	0
Reduce costs and dust	0	10	14	12

The RCTO adopters (from RCTO and BOTH categories) also reported the conventional tillage operations they had reduced or eliminated. Few of the RCTO adopters reported reducing or eliminating the shredding operation. The majority of reductions occurred with the disking, ripping, and listing operations.[1] The disking operation was reduced or eliminated by 84 % of the RCTO adopters and 52 % reduced or eliminated the ripping operation. The listing operation was reduced by 32% of the RCTO adopters.

[1] The landplaning operation was included in the questionnaire as one of the conventional tillage operation that could be reduced. However, it was not defined as part of the conventional tillage system in this study

7.3 Ex ante and Ex post Adoption Results

The respondents who adopted SPMOE and RCTO reported their estimated (ex post) per acre long-term net benefits that resulted from the adoption of these systems and the percentage of cotton acreage on which the reduced tillage systems were used. The ex post value is the per acre net benefit a grower believes has been produced as result of adopting SPMOE and/or RCTO. This information was used to estimate a semi-log function where 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 the net benefits. A similar semi-log function was estimated to evaluate the hypothetical net benefits (WTA) of SPMOE and percentage of cotton acreage reported by non-adopters and RCTO adopters. A growers WTA SPMOE is based on their perception that adopting the system will produce a given value of per acre long-term net benefits. The hypothetical net benefit value is the ex ante adoption expectation of the grower. The results of the semi-log model estimations can be found in Table 7.6.

Because the semi-log function was used, the slope coefficient of the logged net benefits variable measures the absolute change in the percentage of cotton acreage on which the reduced tillage systems are applied to a relative change in net benefits. Thus a one percent increase in net benefits results in an 0.0028 increase in the percentage of

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and was only included in the questionnaire to facilitate the respondents answer to the question that asked them which operations they had reduced (question 5).

TABLE 7.6 Estimated semi-log model results of technology benefits affect 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 (-12.857)	-1.283 (-14.062)	-0.641 (-16.942)
ln(Benefits)	0.283 (22.164)	0.505 (18.954)	0.325 (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.

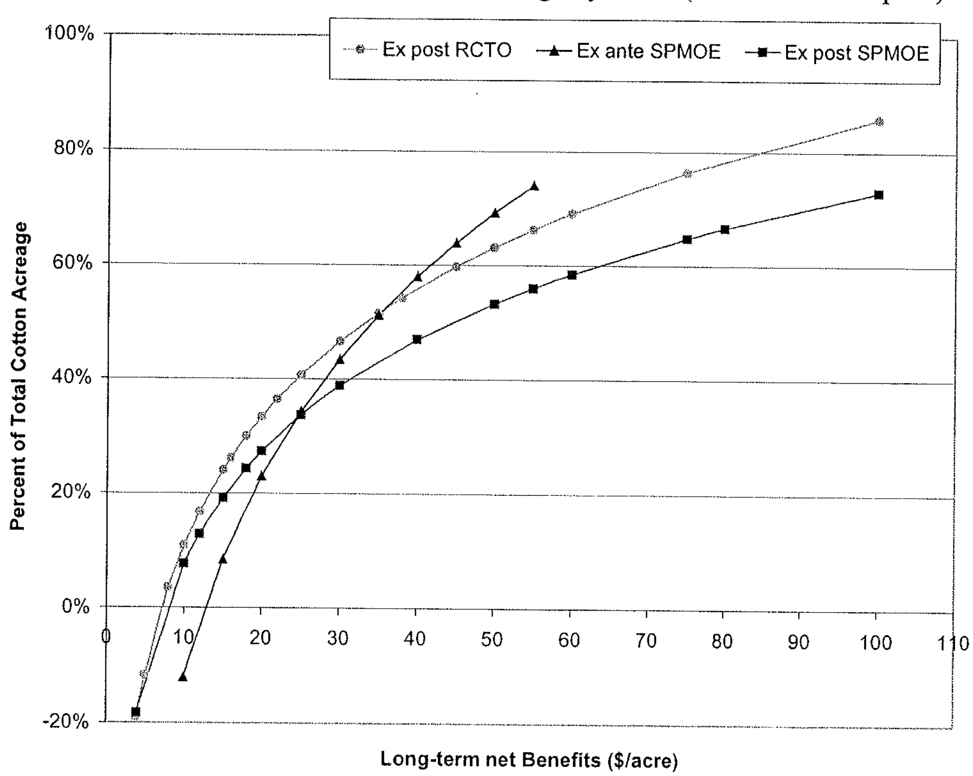
cotton acreage using SPMOE and a 0.0033 increase in the acreage using RCTO.[2] Applying these results to a 1000 acre cotton farm where 40% of the acreage uses SPMOE during tillage operations, the 1% increase in net benefits raises the use of SPMOE to 40.28% (an additional 2.8 acres). If a RCTO system were applied to 40% of the 1000 acre cotton farm, a 1% increase in net benefits would result in additional 3.3 acres using RCTO tillage. In the WTA SPMOE model, which used the hypothetical CVM data a one percent increase in net benefits increased the percentage of cotton acreage using SPMOE by 0.0051. Willingness to adopt "elasticity" for SPMOE exceeds the ex ante measures of adoption elasticity for either ex ante SPMOE and RCTO. This result is analogous to CVM studies that have shown the tendency of respondents to overestimate willingness to

[2] When semi-log functions are estimated using OLS the slope coefficients need to be multiplied by 0.01 (Gujariati 1995, page 172)

pay measures for environmental amenities relative to actual financial payments to protect natural resources (NOAA 1993).

Figure 7.1 illustrates the estimated functions from Table 7.6. The slope of the ex ante SPMOE adoption function exceeds the two ex post functions over most estimates of long-term net benefits indicating a more rapid application rate as net benefits increase. Acreage on which RCTO is applied exceeds the SPMOE acreage for the same level of net benefits. The realized difference between RCTO and SPMOE may be due to the 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 unfamiliar new technology requiring a learning period.

FIGURE 7.1 Adoption rate of reduced tillage systems (ex ante and ex post).



The baseline results from the partial budget analysis indicated that the net benefits associated with switching from the conventional tillage system were between $16.06 and $25.91. Based on these net benefit values the percentage of cotton acreage using SPMOE systems would be between 21% and 35% (when compared to ex post SPMOE function). The percentage of cotton acreage on which SPMOE would applied is even less (up to 27%) when the estimated partial budget values that include effects of an environmental tax credit and the ripping operation assumption are used (between $8.29 and $20.15). In order to obtain at least 50% percent of the cotton acreage using SPMOE the net benefits would need to be at least $45 per acre.

7.4 The Adoption Decision

Before running the multinomial logit model, a test for multicollinearity among the independent variables was preformed. Multicollinearity exists when there is an approximate linear relationship between independent variables. Estimation procedures do not breakdown when there is multicolliniearity but estimation problems arise (difficult to obtain coefficients with small standard errors) (Kennedy 1998; Gujarati 1995). The correlation values of the independent variables were estimated using Excel 97 and the results are reported in Appendix J.

A high correlation value (degree of linear relationship) is 0.8 and higher (Kennedy 1998). The highest degree of correlation occurred between the acres and employees variables at 0.92. The remaining correlation values were well below 0.8. There are several methods available for dealing with multicollinearity, however they are not perfect solutions (Gujariti 1995). One of the simplest methods for dealing with multicollinearity is to drop one of the variables identified as highly correlated. However dropping a variable can result in specification bias or error, because economic theory may say that the two correlated variables should both be included in the model (Gujariti 1995). In this study both acres and number of employees were variables used as proxy measures for the income generated by the farm. Thus as a result of their high degree of correlation the acres variable was dropped. The employee variable was used because the multinomial logit model performed better, as measured by the log likelihood test.[3]

The multinomial logit model was used to evaluate the adoption of the four reduced tillage system options: no adoption, SPMOE only, RCTO only, and BOTH. However, because very few observations were available for SPMOE only, this decision was dropped from the adoption choice set.

The goodness-of-fit of the estimated model was evaluated using the likelihood ratio test and the prediction accuracy of the model. The likelihood ratio test determined that the reduced model (B=0) be rejected in favor of the full model. The chi-square value calculated from the likelihood ratio statistic was 21.87. The critical value from the chi-square table at the 0.10 significance level is $X^2_{0.10}(14)=21.06$.

The prediction accuracy of the model is presented in Table 7.7. The model accurately predicted at least half of each of the actual adoption choices, correctly predicting 13 out of 23 (56.5 %) of the no adoption choice and 9 out of 21 (42.8 %) of the

[3] The multinomial logit model was also run using the acres variable. The remaining coefficient estimates and marginal effects were nearly the same (no significant change in sign or level of significance) as those

RCTO. The choice of both SPMOE and RCTO had the highest prediction accuracy with 18 out 28 (64.3 %) correct predictions. Thus the model provides some, but limited accuracy in predicting the observed choices.

TABLE 7.7. Predicted versus actual adoption choice of reduced tillage systems.

Observed adoption choice	Predicted adoption choice: No adoption	RCTO	SPMOE and RCTO	Observed count
No adoption	13	5	5	23
RCTO	4	9	8	21
RCTO and Both	5	2	18	28
Predicted Count	22	19	31	72

Few of the coefficients estimated by the model were significant (Table 7.8). In fact only two operator characteristics variables were significant; the age of the operator and their education level. In the case of adopting both SPMOE and RCTO systems older farmers were significantly less likely to choose this option versus the choice of no adoption. Older farmers tend to have a shorter planning horizon (unless transferring ownership) and are less likely to adopt new technologies. Older farmers were also less likely to adopt RCTO systems versus no adoption, however age was not significant for this choice.

Additional years of post high school education was expected to have a positive affect on the adoption of reduced tillage systems. Individuals with higher levels of education are more likely to obtain and understand information regarding environmental problems and the technologies available to mitigate the damages created (Traore et al.

produced by the model which used the employee variable. The results of the model using the acres variable

1998). Growers with higher levels of education were found to be significantly more likely to adopt RCTO systems versus no adoption. Although higher levels of education had a positive influence on the adoption of both SPMOE and RCTO versus no adoption, it was not statistically significant.

TABLE 7.8. Parameter estimates for the multinomial logit model of reduced tillage system adoption.

Variables	RCTO Only vs. No Adoption	BOTH vs. No Adoption
Constant	-0.796	0.857
	(1.799)	(1.681)
Age	-0.007	-0.053*
	(0.079)	(0.286)
Educ	0.315*	0.233
	(0.195)	(0.189)
FarmT	0.735	0.701
	(0.753)	(0.797)
DustP	0.188	0.900
	(0.69)	(0.678)
Employees	-0.136	0.047
	(0.079)	(0.048)
FarmL	0.248	-0.218
	(0.715)	(0.649)
County	0.937	0.754
	(0.717)	(0.705)
N		72
Log likelihood		-67.63
Log likelihood, restricted		-78.57
Model chi-square (14 D. F.)		21.87
Significance Level		0.08

Note: Standard errors are in parentheses. * Indicates statistical significance at the 10% level.

The decision to transfer ownership of the farm to a family members and the perception of dust were the remaining variables under operator characteristics. Growers

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is available in Appendix K.

planning to transfer ownership of their farm to a family member were hypothesized to be more likely to adopt reduced tillage systems that both preserve the soil structure and potentially reduced costs. The coefficient estimates for the farm transfer variable were positive for the RCTO and BOTH choices but not statistically significant. The perception of dust as nuisance was predicted to be positive since growers who believed a dust nuisance was created by their activities would be more willing to adopt dust abating technologies. The estimated coefficients were both positive but not statistically significant. The majority of growers (responding to the survey) who thought a nuisance was created also reported that it was not a severe problem and this may explain why the parameter was not significant.

The farm coefficient, employees, had a negative effect on the adoption of RCTO and positive effect on the adoption of both SPMOE and RCTO. Because the adoption SPMOE requires an investment it was expected that large farm operators would be able to invest in this technology (in addition to RCTO) since they would have a greater ability to finance such a purchase and spread its costs over a large area.

The location of a farm was also expected to influence a growers' decision to adopt reduced tillage systems. Grower's farming land within a two mile radius of an urbanized area would be expected to adopt RCTO rather than SPMOE if they believed that their farmland would be sold within a short time frame. The proximity of a farm to an urbanized area affects a grower's planning horizon by increasing the pressure to sell their land. The estimated farm location coefficient from the model supports this hypothesis where growers are more likely to adopt RCTO versus no adoption and are less likely to adopt both SPMOE and RCTO versus no adoption, however these results are not statistically significant.

County was the second farm location variable estimated in the adoption model. Growers' farming in Maricopa County were believed to be more likely to adopt reduced tillage systems in order to comply with the county's BMP regulations as opposed to growers in Pinal County. For RCTO and both SPMOE and RCTO choices growers in Maricopa County were in fact more likely to adopt these systems versus no adoption. Once again however, the estimated coefficients were not statistically significant.

The marginal effects of the independent variables on the choice of no adoption, RCTO, and both SPMOE and RCTO are shown in Table 7.9. The results show that education was the only significant variable affecting the choice of no adoption. Growers' with more years of post high school education were less likely to choose the option of not adopting any reduced tillage system technology(s). The adoption of RCTO was significantly affected by the number of full time employees with larger farm operators less likely to only adopt RCTO systems. However the marginal effect was quite small (-0.03). The number of employees also had a positive and significant yet small marginal effect on the adoption choice of both SPMOE and RCTO. As mentioned earlier a capital investment is required in the adoption of SPMOE and larger farms are generally better able to support new investment costs. The second significant marginal effect under the choice of both SPMOE and RCTO was age. Older farmers were found to be significantly less likely to adopt both SPMOE and RCTO systems.

TABLE 7.9. Estimated marginal effects for the adoption choices of no adoption, RCTO, and both SPMOE and RCTO.

Variable	No Adoption	RCTO	Both SPMOE and RCTO
Age	0.792	0.004	-0.012*
	(0.005)	(0.005)	(0.006)
Educ	-0.06**	0.036	0.023
	(0.036)	(0.033)	(0.04)
FarmT	-0.159	0.067	0.093
	(0.139)	(0.122)	(0.143)
DustP	-0.14	-0.056	0.198
	(0.131)	(0.145)	(0.145)
Employees	0.052	-0.03*	0.026**
	(0.01)	(0.012)	(0.012)
FarmL	0.008	0.07	-0.078
	(0.139)	(0.121)	(0.138)
County	-0.184	0.10	0.084
	(0.138)	(0.117)	(0.145)

Note: Standard errors are in parentheses. * Indicates statistical significance at the 5% level; ** indicates a statistical significance at the 10% level.

In summary, very few of the variables had a statistically significant effect on the adoption of three reduced tillage system choices. The age of the grower, their level of post high school education, and the size of their farm given in number of employees were the three variables that significantly explained the characteristics behind the adopters of RCTO, both SPMOE and RCTO, and non-adopters. Interestingly, all the estimated signs of the adoption models matched the hypothesized signs. Yet in the majority of the variables the sign was statistically insignificant. The low number of significant variables is likely due to the small number of observations available for the analysis.

8. Summary, Implications, and Lessons Learned

PM-10 in high concentrations can aggravate health conditions such as asthma and negatively effect the environment by reducing visibility and contributing to hazy air in urbanized areas. As a result, PM-10 is regulated under the CAA. Congress initially enacted the CAA in 1954 to protect and improve air quality in the U.S. The majority of current the clean air regulations were legislated in 1970 and in successive amendments.

The EPA is responsible for implementing and administering the CAA. This agency sets NAAQSs for six criteria pollutants, including PM-10. The PM-10 NAAQSs are composed of a two-part primary standard set to protect human health and a secondary standard that protects the environment and public welfare. The primary standard consists of an annual standard (50 mg/m^3) that protects against long-term exposures to PM-10 and a 24-hour standard (150 mg/m^3) that protects against short-term exposures.

Areas exceeding the PM-10 standard are classified as non-attainment areas. In 1990 the EPA designated 2,880 square miles of Maricopa County, Arizona as a PM-10 non-attainment area. In order to bring the area back into attainment the ADEQ was required to develop a SIP consisting of control strategies and methods for reducing PM-10. It took ADEQ over 12 years to develop a SIP that met all the requirements of the CAA. The ADEQ's inability to develop a SIP that ensured the 24-hour standard would not continue to be exceeded contributed to the extended timeline. In 1995 the EPA accepted a SIP from ADEQ despite this shortcoming. The activist law group, ACLPI, considered the approved SIP incomplete and as a result sued the EPA. The Ninth Circuit Court ruled the EPA failed to include an analysis of the 24-hour PM-10 violations. As a result of the court's decision the EPA required that the ADEQ conduct a microscale study to determine the significant sources of PM-10 contributing to the 24-hour standard violations and develop control measures for those sources.

The microscale study revealed that construction sites, unpaved roads, grinding and crushing operations, and agricultural activities all produced significant levels of PM-10 within the non-attainment area. The ADEQ was able to develop control measures for each of the sources except agriculture. Generally agricultural activities are not regulated under the CAA, as it is not an urban source of pollution. However in Maricopa County there has been a steady increase population since the 1960's. Currently there are approximately 3.3 million people living in the county with the majority residing within the PM-10 non-attainment area. The population growth in this area has left virtually no buffer zone between urban and rural areas, therefore any dust/PM-10 created by agricultural activities impacts a large and concentrated urban population.

Because the ADEQ was unable to address the agricultural sources of PM-10, the EPA stepped in to develop a FIP containing abatement methods and controls for reducing agricultural PM-10 emissions. The EPA chose to use a BMPs approach to reducing agricultural sources of PM-10 as a result of meetings with agricultural stakeholders in the non-attainment area. Concurrently the Arizona Legislature passed legislation to establish the Governor's Agricultural BMP Committee. The Committee was charged with developing the agricultural PM-10 general permit. The general permit required farmers within the PM-10 non-attainment area to adopt at least three BMPs to reduce PM-10 generated on cropland, non-cropland (i.e. equipment yards), and during tillage and harvest activities. An ad hoc technical committee identified 30 BMPs that growers can choose from to comply with the PM-10 general permit.

Reduced tillage systems are a BMP available to growers under the tillage and harvest category. These systems help preserve the soil structure by reducing the number of tillage operations/passes across a field. As a result, large soil particles are less likely to break down into smaller PM-10 particles. In addition to potentially reducing PM-10 emissions, reduced tillage systems also reduce costs (i.e. fuel and labor costs). The objectives of this thesis were to (1) identify the per acre net benefits of reduced tillage systems; (2) estimate current users and non-users WTA SPMOE systems based on per acre long-term net benefits; and (3) evaluate the socio-economic factors influencing the adoption of reduced tillage systems.

The field research (PM-10 and yield analysis) portion of the study was conducted in cotton fields at the UofA Maricopa and Marana Experiment Stations. The conventional tillage system consisted of five tillage operations: shredding, disking, ripping, second disking, and listing. The three reduced tillage systems (Sundance, Paratill, and Pegasus) each reduced the number of tillage operations through the use of SPMOE. An alternative of SPMOE systems is RCTO, where a farmer reduces or eliminates conventional tillage operations. RCTO was only evaluated in the WTA sections of this thesis.

A dust collector was used to monitor PM-10 emissions at four different elevations (24, 48, 72, and 96 inches). Due to changes in monitoring equipment only one year of data was available for analysis. PM-10 emissions were generally higher at the Maricopa site than at the Marana site. This difference is likely due to the higher soil moisture levels present at the Marana site. At both locations there was a pattern at the 24 and 48 inch elevations where PM-10 emissions decreased as the number of tillage operations decreased. Additional years of data are required in order to adequately evaluate the environmental benefits of reduced tillage systems.

Cotton yield data was collected for two years beginning in 2001 after the tillage systems had been used the prior year. A multiple range test was used to evaluate the statistical significance of the reported yield means. The results indicated little statistical difference among the yield means. Only in 2001 at the Marana site did the Pegasus and Paratill systems have statistically significant higher mean yields than the conventional and Sundance systems. In Maricopa the conventional tillage system had statistically significant higher yields than the Paratill system in 2002.

The skewness of the yield distributions was also evaluated. Under the two year cotton yield distributions the skewness coefficients were all positive for all systems indicating a farmer on average would receive less than mean yield. The skewness values were greater for the reduced tillage systems than the conventional system, indicating reduced tillage systems may increase the risk of lower yields over the conventional tillage system. Because the yield analysis is based on only two years of data other factors may be the cause of the higher skewness values associated with the reduced tillage systems.

The profitability of each of the SPMOE systems was evaluated using partial budgets. The budgets were prepared on a per acre basis using cost data (i.e. equipment, labor, fuel and oil costs) taken from county level cotton crop budgets and machinery cost estimates prepared by the UofA (Teegerstrom and Clay 1999; Teegerstrom 2000). Several key assumptions were made under the baseline scenario partial budgets: (1) no increase or decrease in net revenues and (2) the purchase of SPMOE financed through the annual operating budget. All of the SPMOE systems generated a positive increase in net income both in terms of profitability and repayment capacity. The change in net income (profitability) ranged from $16.06 per acre for the Paratill to $25.91 per acre for the Pegasus system.

Additional separate partial budgets were prepared using the following assumptions: (1) the ripping operation is not replaced by SPMOE, (2) a 5% reduction in yields (decrease in net returns), (3) an increase in net returns as a result of an environmental tax credit, and (4) the ripping operation is not replaced by SPMOE *and* the use of environmental tax credit. Each of these partial budgets resulted in a positive increase in the net income except for the 5% decrease in yields. The per acre revenue losses associated with the 5% yield decrease were -$10.96 for the Pegasus system, -$20.11 for the Sundance system, and -$20.81 for the Paratill system. Under the most realistic scenario where the ripping operation was not replaced by the SPMOE systems and the environmental tax credit was used the partial budget values were less than those calculated under the baseline scenario. The per acre values ranged from $8.29 for the Paratill to $20.15 for the Pegasus system.

Evaluating the relationship between per acre net benefits and percentage of land application and the analysis of factors that influence the adoption of reduced tillage systems was done using data collected by a mail survey of the population of cotton growers in Maricopa and Pinal Counties. Pinal County growers were included as a control group to determine whether the PM-10 general permit had any significant influence on the decision to adopt reduced tillage systems.

A semi-log function was used to evaluate the relationship between the per acre net benefits of reduced tillage systems and percentage of land application. I found that the ex post acreage on which RCTO was applied exceeded the ex post SPMOE acreage for the same level of net benefits. This is most likely due to the uncertainty associated with adopting new technology, as it is easier to make adjustments to familiar technologies. The ex ante adoption function of SPMOE exceeded the two ex post adoption functions (SPMOE and RCTO) indicating a more rapid application rate as the net benefits increase. The ex ante SPMOE respondents are likely overestimating their WTA SPMOE system, contributing to the more rapid adoption rate.

The adoption decision was analyzed using a multinomial logit model. There were few statistically significant variables either in the estimated coefficients or marginal effects. Other studies (Wang et al 2000; Upadhyay et al 2002) investigating the adoption of practices and technologies that reduce PM-10 have had similar results. In this study we found education, age, and number of employees influenced in a statistically significant way the adoption of reduced tillage systems. Growers with more years of post high school education were less likely to choose the option of not adopting any reduced tillage system. Larger farms were more likely to adopt both RCTO and SPMOE systems and less likely to adopt RCTO systems only. Younger growers were more likely to adopt both SPMOE and RCTO systems. Thus air quality agencies may have more success in inducing the adoption of abatement practices and technologies that require a financial investment by targeting younger farmers with higher levels of education who operate farms with higher value crops (e.g. vegetables).

8.1 Implications for Agricultural Dust Mitigation

The results of this study provide both air quality agencies and cotton growers new information regarding the adoption of reduced tillage systems as a means for reducing PM-10 in central Arizona. First, there is the potential for improved air quality through the adoption of both RCTO and SPMOE. However, relying solely on SPMOE systems will not significantly affect air quality. Only two of the survey respondents indicated having adopted only SPMOE. At estimated long-term net benefits of $12-26 per acre, the analysis indicates that SPMOE alone may be adopted on 10-28 percent of the cotton acreage in Maricopa and Pinal counties. Given the same level of net benefits as SPMOE, the application of RCTO to cotton acreage is greater (between 10% and 35%).

Second, market forces may play a greater role in the adoption of reduced tillage systems than clean air regulations. The survey respondents indicated that their reason(s) for adopting reduced tillage systems was either to reduce costs or reduce costs and dust, but never just to reduce dust. The results from the partial budgets indicate that growers can save between $16.06 and $25.91 per acre by adopting SPMOE systems. However, the census of cotton growers in these two central Arizona counties revealed that 14% 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 of low cotton prices and the demand by large local dairy industry for 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.

Finally, urbanization, the very driver that precipitated agricultural regulations in the Phoenix area in the first place, 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% and 46% decrease in farmland, respectively. Some predict that in Maricopa County alone 6,000 to 8,000 acres of farmland per year will be converted to urban development (Roger 2000, Farm Bureau 1998). This trend alone will mitigate dust problems significantly except for residents on the urban fringe.

8.2 Insights for Future Related Research: Lessons Learned

The issue of agricultural clean air regulations in Maricopa County was (and is) a politically sensitive issue. As a result, it was important to meet with agricultural stakeholders before the questionnaire was developed to get an understanding of clean air regulations from their perspective as well as an awareness of what information cotton growers would be willing to voluntarily provide (privacy concerns). Based on the information provided the questionnaire was developed in such a way that cotton growers would be willing to respond to the questions and yet the questions would still enable the researcher to meet the objectives of the thesis. By taking the time to meet with industry representatives and members I was able to ensure the target population (cotton growers) would accept the questionnaire and simultaneously I was able to obtain the necessary data for my research.

The collection of primary data in this thesis was implemented as a mail survey. Although the overall response rate was 54%, when the number of unusable questionnaires was taken into account the response rate dropped to 31%. A more extensive analysis of the adoption of reduced tillage systems may have been possible with more data, in other words a higher response rate. However, obtaining a higher response rate using a mail survey is not likely. In general people are busier and do not have time or will not take the time to fill out a questionnaire. In addition many are distrustful of how personal information they provide will be used. A survey using personal interviews may be better suited to studies that collect sensitive environmental and firm level data as it gives the researcher and respondent the opportunity to personally interact. A disadvantage of using personal interviews is the amount of time and money that would be required to survey a population of 237 cotton growers in Maricopa and Pinal Counties.

Additional research is needed to determine the reductions in PM-10 emissions created by reduced tillage systems. The field research component of multi-department study provided some preliminary information that indicates PM-10 emissions decrease as the number of tillage passes are reduced. However more analysis is needed to determine/predict how soil moisture, wind conditions, and soil type impact emission levels. More research also is needed to quantify dust/PM-10 pollution generated by conventional agricultural activities. This latter type of research would help determine whether agricultural activities are truly a significant source of PM-10.

In conclusion, BMPs aimed at reducing dust will be primarily adopted for economic reasons, with some considerations of clean air regulations. Market forces, however, will likely have the greatest impact on improving air quality in the Maricopa PM-10 Non-attainment Area. Farmers will continue to reduce their cotton acreage replacing it with it alfalfa, a BMP cover crop, but the greatest reduction in agricultural PM-10 will be through the conversion of productive agricultural land to urbanized uses. Thus the ever increasing population in Maricopa County will lead to the most permanent of cover "crop(s)": houses, malls, and freeways.

Appendix A. Agricultural BMP General Permit Record

Agricultural Best Management Practices General Permit Record

The following is an example of a form that you can use or duplicate. You are not required to use this form.

Name of commercial farmer____________________ Date__________

Mailing or physical address of the commercial farm

____

____

City__________ State______ Zip_____

Selected Best Management Practices. A commercial farmer must implement at least one practice from each category.

Tillage and Harvest

- ☐ Chemical irrigation
- ☐ Combining tractor operations
- ☐ Equipment modification
- ☐ Limited activity during a high-wind event
- ☐ Multi-year crop
- ☐ Planting based on soil moisture
- ☐ Reduced harvest activity
- ☐ Reduced tillage system
- ☐ Tillage based on soil moisture
- ☐ Timing of a tillage operation

Notes:

Non-Cropland

- ☐ Access restriction
- ☐ Aggregate cover
- ☐ Artificial wind barrier
- ☐ Critical area planting
- ☐ Manure application
- ☐ Reduce vehicle speed
- ☐ Synthetic particulate suppressant
- ☐ Track-out control system
- ☐ Tree, shrub, or windbreak planting
- ☐ Watering

Notes:

Cropland

- ☐ Artificial wind barrier
- ☐ Cover crop
- ☐ Cross-wind ridges
- ☐ Cross-wind strip cropping
- ☐ Cross-wind vegetative strips
- ☐ Manure application
- ☐ Mulching
- ☐ Multi-year crop
- ☐ Permanent cover
- ☐ Planting based on soil moisture
- ☐ Residue management
- ☐ Sequential cropping
- ☐ Surface roughening
- ☐ Tree, shrub, or windbreak planting

Notes:

Signature____________________

Appendix B. Partial Budget Formulas

F & O($/acre) = (Annual Fuel and Oil/Hours Used)/Job Rate(acres/hr)

Repairs[1] ($/acre) = (Annual Repairs/Hours Used)/Job Rate(acres/hr)

Labor[2] ($/acre) = 9.75($/hr) *Labor Hours (hr/acre)

T, I, H($/acre) = (Annual T, I, H/Hours Used)/Job Rate(acres/hr)

Depreciation($/acre) = (Annual Depreciation/Hours Used)/Job Rate(acres/hr)

Total Added Investment($/acre) = Total Investment/(Hours Used*Job Rate(acres/hr))

Pollution Control Tax Credit($/acre) = Total Added Investment($/acre) * .10

Calculating machine hours (MH) using UofA Crop Budgets (Bt. Upland Cotton, 1998) formula:

MH = Machine Rate[3]/Job Rate

Calculating labor hours (LH) using UofA Crop Budgets (Bt. Upland Cotton, 1998) formula:

LH = MH*1.11

Abbreviations:

F & O	fuel and oil
T, I, H	taxes, insurance, and housing
MH	machine hours
LH	labor hours

[1] Same formula for tractor and implements.
[2] The labor costs of $9.75 per hour was obtained from the 1999-2000 Maricopa County Bt. upland cotton crop budget (Teegerstrom and Clay 1999).
[3] Machine rate of .90 obtained from the 1999-2000 Maricopa County Bt. upland cotton crop budget (Teegerstrom and Clay 1999).

Appendix C. Tractor Size Selection

Tractor size suggestions for implements evaluated in the partial budgets.

Equipment	Tractor Size Suggestions			Selected tractor size
	Eaton[1]	Crop Budgets[2]	Pegasus Information Sheet[3]	
Rotary Stalk Cutter, 4 row	50-60 HP*	100HP	--	100HP
13.5' Offset Disk	130 HP	100 HP	150HP	130HP
Ripper, 3 shank	130 HP	150 HP (for 5 shank)	--	130HP
Lister, 5 bottom	--	125 HP (for 7 bottom)	70 HP	100HP
Pegasus, 4 row	130 HP	--	150 HP	150HP
Root Cutter-Puller, 4 row	50-60 HP	--	80 HP	80HP
Disk Lister, 4 row	130 HP	--	--	150HP
Paratill, 4 row	--	--	150 HP	150HP

* horsepower
1. Eaton 2002c
2. Teegerstrom and Clay 1999
3. Pegasus 1996

Rationale for selection of tractor size:

Rotary Stalk Cutter, 4 row
Tractor size chosen for partial budgets: 100HP
Although, a 50-60 HP tractor may be sufficient for use with a 4 row stalk cutter Arizona cotton crop budgets use a larger tractor (100HP) for this operation and with this piece of equipment.

13.5' Offset Disk
Tractor size chosen for partial budgets: 130 HP*
The tractor sizes suggested for this implement ranged from 100HP (crop budgets) to 150HP (Pegasus Info. Sheet). Given this range the midpoint sized tractor of a 130HP (as suggested by Ed Eaton) was selected for the partial budgets.

Ripper, 3-shank
Tractor size chosen for partial budgets: 130 HP*

A tractor pulling a ripper needs adequate horsepower to pull the implement across a field. Given that a 5-shank ripper uses a 150 HP tractor (according to Crop Budgets), a smaller sized tractor (130 HP) suggested by Eaton was chosen.

Lister, 5 bottom
Tractor size chosen for partial budgets: 100 HP
Given that the range of suggested tractors is 70-125 HP (for 7 bottom), the 100HP tractor was selected. As noted previously, a smaller sized tractor should be sufficient to pull a smaller sized implement.

Pegasus, 4 row
Tractor size chosen for partial budgets: 150 HP
Eaton (2002) noted the weight of the Pegasus implement was substantial. Eaton used a 220 HP tractor with all of the implements, but noted that a 130 HP tractor could have pulled the Pegasus with limited speed because of its weight. Given that the Pegasus Information Sheet recommends a 150 HP tractor and the weight issues noted by Eaton, the 150 HP tractor was selected.

Root Cutter-Puller, 4 row
Tractor size chosen for partial budgets: 80HP
The Paratill Information Sheet suggested an 80HP tractor while the manufacturer of this equipment (AZ Drip Systems, Inc.) suggested a 100HP for the larger 6 row version. Therefore, the Paratill information makes sense less HP for a smaller piece of equipment. In addition, this size tractor is listed in the cotton crop budgets as a tractor used in a growing season.

Disk Lister, 4 row
Tractor size chosen for partial budgets: 150HP
Eaton (2002) noted that the disk-lister could be pulled with a 130HP tractor with limited speed due to the weight of the implement. However the 150HP tractor was chosen, as it would most likely handle the weight of the disk-lister.

Paratill, 4 row
Tractor size chosen for partial budgets: 150HP
Eaton did not provide a HP estimate for this implement. However, given the fact that it disks and rips in one pass (eliminating 3 operations) and that a regular 3 shank ripper requires at least 130HP tractor, using a tractor with more than 130 HP makes sense. Therefore, suggested by the Pegasus Information Sheet the 150HP tractor was selected for the partial budgets.

*The AZ Farm Machinery Cost 2000/2001 bulletin did not include cost information for the 130HP tractor; therefore the cost data of the 125 HP tractor was used in its place.

Appendix D. Implement Job Rates

Implement job rates (acres/hour)

System	Implement	Job Rate[1]	Job rate reduced by 15 %[2]
Conventional	Rotary stalk cutter	5.82	4.95
	Offset disk	5.82	4.95
	V-ripper	4.36	3.71
	Lister	5.82	4.95
Sundance	Rotary stalk cutter	5.82	4.95
	Root-puller	8.10	6.88
	Disk/Lister	5.82	4.95
Paratill	Rotary stalk cutter	5.82	4.95
	Paratill	5.82	4.95
Pegasus	Pegasus	5.82	4.95

1. Source: Ed Eaton 2002a.
2. Job rates theoretical and must be reduced by at least 10 percent for actual field capacity. A reduction of 15 % was used because of the short rows and number of turns used in the test plots (Eaton 2002a).

Appendix E. Partial Budget Model

Partial Budget: (Proposed Plan)

CREDIT
Added Return and/or Reduced Cost

	Profitability	Repayment Capacity
Added Return		
Added Income From Proposed Plan		
Total Annual Added Returns	(1a) $	(1b) $
Reduced Costs		
Reduction in Costs From Proposed Plan		
Total Annual Reduced Cost	(2a)$	(2b)$
TOTAL CREDITS (1 + 2)	(3a)$	(3b)$
TOTAL DEBITS (From 7a and 7b)	(7a)$	(7b)$
CHANGE IN NET INCOME (3 - 7)	(8a)$	(8b)$
Total Added Investment	(9)$	
Return/$ Added Investment (8a/9) x 100	(10)%	
Total Added Debt		(11)$
Years to Pay Back Added Debt (11/8b)		(12)Yrs.

DEBIT
Added Cost and/or Reduced Return

	Profitablity	Repayment Capacity
Added Cost		
New Investment and Added Annual Investment Costs from Proposed Plan		
Interst on Added Debt		
Total Added Annual Investment Cost	(4a)$	(4b)$
Added Annual Operating Costs From Proposed Change		
Total Added Annual Operating Cost	(5a)$	(5b)$
Reduced Return		
Reduced Income from Proposed Plan		
Interest Foregone		
Total Annual Reduced Return	(6a)$	(6b)$
TOTAL DEBITS (4 + 5 + 6)	(7a)$	(7b)$

Appendix F. Maricopa County Questionnaire

Reduced Tillage Study

Departments of Agricultural and Resource Economics; Soil, Water, and Environmental Sciences; Agricultural and Biosystems Engineering; and Plant Sciences

College of Agriculture and Life Sciences
University of Arizona

Questionnaire

Introduction

Growers in the Maricopa County Nonattainment Area were required to adopt Best Management Practices (BMP) by December 31, 2001 to reduce dust generated by agricultural practices. Reduced tillage systems are an approved BMP option available to growers. These systems are defined as reducing the number of tillage operations used to produce a crop. The number of operations can be reduced by eliminating some conventional operations or by adopting single pass, multiple operation equipment. The University of Arizona is conducting research to compare levels of dust emitted by both conventional and reduced tillage systems. The purpose of this study is to evaluate growers' willingness to adopt reduced tillage practices.

Please respond to the following questions.

1. Are you actively engaged in the day-to-day operations of a cotton farm?

   Yes ____
   No ____

   If you answered "Yes" to Question 1 please go to Question 2.

   If you answered "No" to Question 1 please return the questionnaire in the enclosed self-addressed stamped envelope. Thank you for your cooperation.

2. Does dust generated by tillage operations cause an environmental nuisance and how do you perceive this nuisance? (please check one)

   Yes, very severe ____
   Yes, severe ____
   Yes, moderately severe ____
   Yes, not severe ____
   No ____
   Don't Know ____

3. Please complete the following table by circling the reduced tillage practice(s) you have adopted and checking (√) the reason for its adoption.

Reduced Tillage Practices	Please circle	Reason: Reduce Cost	Dust Control	Both cost reduction and dust control	Other
(a) I have adopted single pass, multiple operation equipment.	Yes No	____	____	____	____
(b) I have reduced the number of tillage operations using conventional equipment or no-till practices.	Yes No	____	____	____	____
(c) I have done none of the above.	Yes				

If you answered "Yes" to part "a" only please go to Question 4.
If you answered "Yes" to parts "a" and "b" please go to Question 4.
If you answered "Yes" to part "b" only please go to Question 5.
If you answered "Yes" to "c" please go to Question 7.

4. What is your best estimate of the long-term net benefit to you of adopting single pass, multiple operation equipment? Long term net benefit is the cost savings of replacing current equipment/practices with new equipment/practices. (Please assume no increase in yields from the adoption of new technology.)

$_____ per acre On what percent of your cotton acreage is this equipment used? ____%

→ **If you answered "Yes" to only "a" on Question 3, please go to Question 11. Otherwise continue to Question 5.**

5. Please complete the following table for the conventional tillage practices you have reduced or eliminated.

Operation	Number of passes prior to change	Current number of passes	Applicable to what percentage of your cotton acreage?
Shred			
Disk			
Rip			
Landplane			
List			

6. What is your best estimate of the long-term net benefits of adopting all the above reduced tillage operations you specified in Question 5? Long term net benefit is the cost savings of replacing current equipment/practices with new equipment/practices. (Please assume no increase in yields from the adoption of new technology.)

$_____per acre

→ **If you completed Questions 4, 5, and 6 (all three questions), please go to Question 11. Otherwise continue with Question 7.**

7. If the long-term net benefit to you of using reduced tillage equipment (single pass, multiple operation systems) over your current practices was $10 per acre, would you adopt the reduced tillage equipment? Long term net benefit is the cost savings of replacing current equipment/practices with new equipment/practices. (Please assume no increase in yields from the adoption of new technology.)

   Yes ____ On what percent of your cotton acreage? ____%
   No ____
   Don't Know ____

8. If the long-term net benefit to you of using reduced tillage equipment (single pass, multiple operation systems) over your current practices was $20 per acre, would you adopt the reduced tillage equipment?

   Yes ____ On what percent of your cotton acreage? ____%
   No ____
   Don't Know ____

9. If the long-term net benefit to you of using reduced tillage equipment (single pass, multiple operation systems) over your current practices was $30 per acre, would you adopt the reduced tillage equipment?

   Yes ____ On what percent of your cotton acreage? ____%
   No ____
   Don't Know ____

10. If you answered "No" or "Don't know" to Questions 7, 8, or 9 please explain your reason for doing so.

   ____
   ____
   ____

The last few questions ask about you and your business. They are essential to helping us understand adoption decisions.

11. How many total acres do you farm? ________ acres
12. How old are you? _____ years old
13. How many full-time, annual employees work for your farming operation(s)? ____ employees
14. How many years of formal education have you completed beyond a High School diploma? ____ years
15. How many years do you plan to continue farming? ____ years (best estimate)
16. Do you plan on transferring ownership of your farm to a family member?

   Yes____ No____ Don't Know____

17. Is your farm located within two miles of an urban, commercial or planned housing development?

   Yes____ What percentage of the farmland is within 2 miles of one of these areas? ____%

   No____

Thank you for completing this survey. Please return the completed survey in the enclosed stamped envelope. Contact Ana Kennedy ((520)621-4319, aken@ag.arizona.edu) or Paul Wilson ((520)621-6258, pwilson@ag.arizona.edu) if you have any questions concerning this survey or research project.

Appendix G. Pinal County Questionnaire

Reduced Tillage Study

Departments of Agricultural and Resource Economics; Soil, Water, and Environmental Sciences; Agricultural and Biosystems Engineering; and Plant Sciences

College of Agriculture and Life Sciences
University of Arizona

Questionnaire

Introduction

Urbanization in Pinal County is proceeding directly into prime agricultural land. This expansion has left little buffer between rural and urban populations. The dust generated by agricultural practices can create poor visibility and can aggravate health conditions of the elderly, young children, and asthmatics. The University of Arizona is conducting research to compare levels of dust emitted by both conventional and reduced tillage systems. The reduced tillage systems are defined as reducing the number of tillage operations used to produce a crop. The number of operations can be reduced by eliminating some conventional operations or by adopting single pass, multiple operation equipment. The purpose of this study is to evaluate growers' willingness to adopt reduced tillage systems.

Please respond to the following questions.

1. Are you actively engaged in the day-to-day operations of a cotton farm?

   Yes ____
   No ____

   If you answered "Yes" to Question 1 please go to Question 2.

   If you answered "No" to Question 1 please return the questionnaire in the enclosed self-addressed stamped envelope. Thank you for your cooperation.

2. Does dust generated by tillage operations cause an environmental nuisance and how do you perceive this nuisance? (please check one)

   Yes, very severe ____
   Yes, severe ____
   Yes, moderately severe ____
   Yes, not severe ____
   No ____
   Don't Know ____

3. Please complete the following table by circling the reduced tillage practice(s) you have adopted and checking (√) the reason for its adoption.

Reduced Tillage Practices	Please circle	Reason: Reduce Cost	Reason: Dust Control	Reason: Both cost reduction and dust control	Reason: Other
(a) I have adopted single pass, multiple operation equipment.	Yes No	____	____	____	____
(b) I have reduced the number of tillage operations using conventional equipment or no-till practices.	Yes No	____	____	____	____
(c) I have done none of the above.	Yes				

If you answered "Yes" to part "a" only please go to Question 4.
If you answered "Yes" to parts "a" and "b" please go to Question 4.
If you answered "Yes" to part "b" only please go to Question 5.
If you answered "Yes" to "c" please go to Question 7.

4. What is your best estimate of the long-term net benefit to you of adopting single pass, multiple operation equipment? Long term net benefit is the cost savings of replacing current equipment/practices with new equipment/practices. (Please assume no increase in yields from the adoption of new technology.)

$_____ per acre   On what percent of your cotton acreage is this equipment used? ____%

If you answered "Yes" to only "a" on Question 3, please go to Question 11. Otherwise continue to Question 5.

5. Please complete the following table for the conventional tillage practices you have reduced or eliminated.

Operation	Number of passes prior to change	Current number of passes	Applicable to what percentage of your cotton acreage?
Shred			
Disk			
Rip			
Landplane			
List			

6. What is your best estimate of the long-term net benefits of adopting all the above reduced tillage operations you specified in Question 5? Long term net benefit is the cost savings of replacing current equipment/practices with new equipment/practices. (Please assume no increase in yields from the adoption of new technology.)

$_____per acre

If you completed Questions 4, 5, and 6 (all three questions), please go to Question 11. Otherwise continue with Question 7.

7. If the long-term net benefit to you of using reduced tillage equipment (single pass, multiple operation systems) over your current practices was $10 per acre, would you adopt the reduced tillage equipment? Long term net benefit is the cost savings of replacing current equipment/practices with new equipment/practices. (Please assume no increase in yields from the adoption of new technology.)

Yes ____ On what percent of your cotton acreage? ____%
No ____
Don't Know ____

8. If the long-term net benefit to you of using reduced tillage equipment (single pass, multiple operation systems) over your current practices was $20 per acre, would you adopt the reduced tillage equipment?

Yes ____ On what percent of your cotton acreage? ____%
No ____
Don't Know ____

9. If the long-term net benefit to you of using reduced tillage equipment (single pass, multiple operation systems) over your current practices was $30 per acre, would you adopt the reduced tillage equipment?

Yes ____ On what percent of your cotton acreage? ____%
No ____
Don't Know ____

10. If you answered "No" or "Don't know" to Questions 7, 8, or 9 please explain your reason for doing so.

____

____

____

The last few questions ask about you and your business.
They are essential to helping us understand adoption decisions.

11. How many total acres do you farm? ________ acres
12. How old are you? _____ years old
13. How many full-time, annual employees work for your farming operation(s)? ____ employees
14. How many years of formal education have you completed beyond a High School diploma? ____ years
15. How many years do you plan to continue farming? ____ years (best estimate)
16. Do you plan on transferring ownership of your farm to a family member?

Yes____ No____ Don't Know____

17. Is your farm located within two miles of an urban, commercial or planned housing development?

Yes____ What percentage of the farmland is within 2 miles of one of these areas? ____%

No____

Thank you for completing this survey. Please return the completed survey in the enclosed stamped envelope. Contact Ana Kennedy ((520)621-4319, aken@ag.arizona.edu) or Paul Wilson ((520)621-6258, pwilson@ag.arizona.edu) if you have any questions concerning this survey or research project.

Appendix H. Maricopa County Questionnaire Cover Letter

THE UNIVERSITY OF
ARIZONA
TUCSON ARIZONA

College of Agriculture
Department of Agricultural & Resource Economics

P.O. Box 210023
Economics Building
Tucson, AZ 85721-0023
(520) 621-6241
FAX: (520) 621-6250

April 5, 2002

«First_Name» «Last_Name»
«Business_Name»
«Address_1»
«City_St» «Zip_Code»

Dear «Prefix» «Last_Name»:

The University of Arizona is conducting a multi-department study on reduced tillage practices to analyze their potential benefits from a technical, environmental and economic standpoint. We are evaluating cotton growers' willingness to adopt reduce tillage practices, either eliminating one or more conventional tillage operations, or adopting single pass, multiple operation equipment. The information gathered for this study will serve as the basis for Ana Kennedy's Master's thesis and the results will be shared with the cotton community.

The information you provide is extremely valuable. Completing the enclosed survey gives you the opportunity to share your experience and opinions on this issue. Please take the time to complete the brief survey in its entirety and return it in the self-addressed stamped envelope. This should take approximately 10 minutes of your time. Your participation is voluntary. It is essential that we hear from as many cotton growers as possible to produce a balanced and representative analysis.

By completing this questionnaire, consent for use of this survey information is granted. Please be assured that your answers are strictly confidential and will only be used for the analysis of this study. There are no risks associated with completing the survey. Reported results will only include averages over all survey respondents. You can obtain further information from the principal investigator, Paul Wilson, Ph.D., at (520)621-6258. If you have questions or concerns about your rights as a research subject you may call the University of Arizona Human Subjects Committee office at (520)626-6721.

The anticipated completion date for this study is September 2002, at that time we will be happy to send you a copy of the final report. Thank you for participating in this important project.

Sincerely,

Pat Clay	Ana M. Kennedy	Paul N. Wilson
Extension Specialist	Research Assistant	Professor
Tel. (602)470-8086 x313	Tel. (520)621-4319	Tel. (520)621-6258
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Appendix I. Pinal County Questionnaire Cover Letter

College of Agriculture
Department of Agricultural & Resource Economics

THE UNIVERSITY OF
ARIZONA
TUCSON ARIZONA

P.O. Box 210023
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The anticipated completion date for this study is September 2002, at that time we will be happy to send you a copy of the final report. Thank you for participating in this important project.

Sincerely,

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Professor
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Appendix J. Muticollinearity Results (Correlation Matrix)

	County	DustPercep	Acres	Age	Employee	Educ	FarmTrnsfr	FarmLctn
County	1.00							
DustPercep	-0.03	1.00						
Acres	0.22	-0.06	1.00					
Age	0.02	0.18	-0.18	1.00				
Employee	0.32	0.00	0.92	-0.08	1.00			
Educ	-0.10	0.14	-0.10	-0.30	-0.16	1.00		
FarmTrnsfr	-0.06	0.05	0.04	0.33	0.06	-0.31	1.00	
FarmLctn	0.20	0.04	-0.03	-0.05	-0.02	0.19	-0.19	1.00

Appendix K. Multinomial Logit Results Using Acres Variable

Parameter estimates for the multinomial logit model of reduced tillage system adoption.

Variables	RCTO Only vs. No Adoption	BOTH vs. No Adoption
Constant	-0.902	0.759
	(1.67)	(1.748)
Age	-0.008	-0.05*
	(0.028)	(0.284)
Educ	0.322*	0.217
	(0.187)	(0.183)
FarmT	0.728	0.724
	(0.775)	(0.797)
DustP	0.093	0.915
	(0.697)	(0.669)
Acres	-0.0003	0.0002
	(0.0002)	(0.0002)
FarmL	0.298	-0.229
	(0.711)	(0.662)
County	0.808	0.853
	(0.683)	(0.697)
N		72
Log likelihood		-69.63
Log likelihood, restricted		-78.57
Model chi-square (14 D. F.)		17.88
Significance Level		0.21

Note: Standard errors are in parentheses. * Indicates statistical significance at the 10% level.

Estimated marginal effects for the adoption choices of no adoption, RCTO, and both SPMOE and RCTO.

Variable	No Adoption	RCTO	Both SPMOE and RCTO
Age	0.007	0.004	-0.011*
	(0.005)	(0.005)	(0.006)
Educ	-0.06**	0.041	0.015
	(0.033)	(0.035)	(0.04)
FarmT	-0.159	0.067	0.092
	(0.156)	(0.116)	(0.144)
DustP	-0.125	-0.083	0.208
	(0.128)	(0.121)	(0.138)
Acres	0.00001	-0.00009*	0.00007**
	(0.00004)	(0.00004)	(0.00004)
FarmL	0.002	0.086	-0.088
	(0.126)	(0.133)	(0.143)
County	-0.182	0.069	0.113
	(0.13)	(0.121)	(0.143)

Note: Standard errors are in parentheses. * Indicates statistical significance at the 5% level; ** indicates a statistical significance at the 10% level.

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