THESIS

CONSERVATION AGRICULTURE: IMPACTS ON SOIL N_2O EMISSIONS AND ADOPTION BY FARMERS

Submitted by

Amy Swan

Graduate Degree Program in Ecology

In partial fulfillment of the requirements

For the Degree of Master of Science

Colorado State University

Fort Collins, Colorado

Spring 2012

Master's Committee:

Advisor: Keith Paustian
Co-Advisor: Stephen Ogle

Kathleen Sherman

ABSTRACT

CONSERVATION AGRICULTURE: IMPACTS ON SOIL N_2O EMISSIONS AND ADOPTION BY FARMERS

Agriculture is vulnerable to the effects of and a contributor to climate change, as a net source of anthropogenic greenhouse gases (GHG). However, agriculture has potential to reduce emissions and perhaps even become a net sink for GHG, through implementation of improved management practices. Previous research has shown that improved practices that reduce soil disturbance may sequester atmospheric carbon (C) in the form of soil organic matter. However, the impact of these practices on emissions of soil N_2O, a potent GHG, are not as well understood. It is important to assess the effects of these practices on GHG emissions, as well as the potential of these practices to be used widely by farmers. I examined the effects of reduced soil disturbance from two conservation practices, no-till (NT) and conversion of cultivated cropland to perennial grassland, on N_2O emissions, and evaluated adoption of NT by farmers in the Great Plains region of the U.S.

I used a meta-analysis approach to evaluate changes in soil N_2O emissions after a shift from full-inversion tillage (FT) to no-till (NT) on cropland and conversion of cultivated croplands to grasslands. Data were collected from published literature and analyzed with a linear mixed-effect modeling method, in which management practices, soil texture and climate were tested as fixed effect. After adoption of NT, soil N_2O emissions were predicted to increase in humid climates by 0.4-0.8 kg N_2O-N ha^{-1} yr^{-1}, and decrease in dry climates, especially on soils with low clay contents, by as much as 1 kg N_2O-N ha^{-1} yr^{-1}. Changes in emissions after

conversion of cropland to grassland were largely related to changes in N fertilizer rates. When lower rates of N were applied to grasslands, emissions were reduced by as much as 2 kg N_2O-N ha^{-1} yr^{-1}. When there was no change in N fertilizer, emissions were predicted to be higher than cropland rates, especially on moderate clay soils. Though the analysis predicted some clear changes in emissions after NT adoption and conversion of croplands to grasslands, further research is needed to better understand the interacting effects of management, climate and soil texture on soil N_2O emissions.

The practice of NT has been associated with many environmental benefits, including reduced soil erosion, lower run-off rates, increased soil organic matter, and improved soil structure. In addition to the potential of NT to sequester atmospheric C, results from my research show potential for NT to reduce N_2O emissions in dry climates. Furthermore, the ability of NT to increase soil moisture retention may be a great benefit to crop production in dry climates, such as found in the Great Plains, U.S. However, NT is only used on about 17% of all croplands in this region.

To evaluate the factors affecting NT adoption in the Great Plains, I conducted a regional analysis using county-level statistics and a local-level analysis using household surveys. Environmental variables, climate, slope, and soil texture, were predictors of adoption at the regional scale. High rates of adoption were predicted in dry, cool climates, which was consistent with the finding in the household surveys that NT farmers were more likely to cite soil moisture conservation as an important issue. Counties with more erodible soils (i.e. steep slopes (water) or high sand (wind)) had higher rates of NT adoption, possibly indicating that farmers in these counties were using NT to control soil erosion. Components of farm structure were also important, with ownership, cropping system, and Conservation Reserve Program (CRP) enrollment influencing NT adoption. Increased ownership rates and higher proportions of wheat cropping, led to lower rates in NT adoption. According to the household surveys, farmers with land enrolled in the CRP were more likely to use NT. Some operator characteristics and attitudes were found to be positively associated with NT adoption. Farmers who had been on their operation longer, expressed trust in the federal government, or hunted on their land for recreation were also more likely to adopt NT. Though some significant predictors of adoption in the Great Plains region may have an economic impact (climate, ownership and wheat cropping), no direct economic measures were found to be significant in predicting NT adoption in this analysis.

Barriers to NT adoption in the region may be lack of education on the benefits of NT on crop production and the prevalence of continuous wheat cropping in parts of the region. Because NT adoption rates were higher among farmers who had participated in a government program (CRP) or expressed trust in the federal government, outreach may especially need to be targeted to farmers with less involvement in federal government programs. Though reason for the influence of ownership on NT adoption was unclear, future research may focus on the role of farm size in tillage decisions.

ACKNOWLEDGEMENTS

I would like to express my gratitude to my committee for their guidance and support throughout my graduate career. I would like to thank my advisor, Keith Paustian, for encouraging me to purse my graduate degree since the very beginning of my career at CSU, and for his enthusiasm and insights through the whole process. I would like to thank my co-advisor, Stephen Ogle, for taking the time to teach me the research skills I needed to produce rigorous results from my thesis research and for his contributions to my academic development. I would like to thank Kathleen Sherman for happily guiding me through interpretation and analysis of the survey data, though I had no prior experience with this type of data, and for bringing a critical social science perspective to my thesis research. I would also like to thank my family, friends and colleagues for their support during the years I pursued my degree.

TABLE OF CONTENTS

INTRODUCTION

Background

In the 21st century, agriculture will face many challenges from climate change and will need to find ways to adapt, while meeting demands for food production as the global population is estimated to reach 9 billion people by the middle of the century (Godfray et al. 2010). The influence of climate change on agriculture is two-fold; agriculture is highly sensitive to changing climate conditions and agriculture is a net greenhouse gas (GHG) emission source. This means that agriculture will need to adapt management to address climate change and increase production, while reducing GHG emissions.

Global climate change estimates predict higher global mean temperatures of 1-3℃ by the end of the 21st century (IPCC 2007). In addition to temperature changes, models predict increased precipitation in the higher latitudes and decreased precipitation in the lower latitudes, as well as more frequent extreme weather events (IPCC 2007). Observational data over the last century has shown that climate change is upon us, with average temperatures rising in the U.S. by more than 1℃ in the last 50 years (Karl et al. 2009). Over this same time period, precipitation increased in the northern regions of the country and decreased in the southwestern and southeastern regions (Karl et al. 2009). Changes in precipitation are not predicted to be uniform throughout the year, but rather shift seasonally. Precipitation in winter and fall may increase in the northern regions of the U.S. and decrease in the southern regions, while summer precipitation is predicted to decrease throughout the U.S. (Karl et al. 2009). Higher mean temperatures, which will be further propagated through heat-waves and warmer nights, and more variable precipitation will surely impact agricultural production (Hatfield et al. 2011). Additionally, elevated concentrations of CO_2 may impact agricultural production. Experiments evaluating crop growth and yields under elevated CO_2 found modest improvements in yields in C3 crops and little change in C4 crop species (Long et al. 2006). However, it is not known how elevated CO2 will interact with changing climate conditions to impact yields. Furthermore, increased weed competition may be expected, as weed species also show substantial increases in growth, along with enhanced resistance to herbicides under elevated CO_2 (Hatfield et al. 2011).

While agriculture will likely confront many challenges from climate change, it is also contributing to climate change. Agriculture is a significant source of greenhouse gases (GHG), contributing 13.5% of total emissions globally between 1970 and 2004 (IPCC 2007). In the U.S., agriculture is responsible for approximately 6% of total emissions, emitting 462 Tg CO_2 eq in 2008 (USDA 2011). The primary agricultural sources of GHG were N_2O from soils (46.3%), enteric CH_4 from livestock (30.5%), CO_2 from energy use (15.6%) and CH_4 from livestock waste (9.7%) (USDA 2011). However, agricultural soils were estimated to offset total agricultural emissions by sequestering roughly 40 Tg CO_2 eq atmospheric carbon (USDA 2011). Though agriculture is currently a net emitter of GHG, there are many mitigation options for agriculture to reduce its emissions and perhaps even become a net sink for GHG (Smith et al. 2008). In the U.S., 20% of the total land base is in cropland agriculture (EPA 2011), representing a large potential sink of carbon (Morgan et al. 2010). Soil carbon stocks represent the balance between carbon (C) that is added to the soil through plant residues and is lost from the soil through respiration (Paustian et al. 1997). Synthesis of experimental research has predicted increases in soil carbon stocks under agricultural management practices that reduce soil disturbance and/or increase organic matter inputs to the soil (Ogle et al. 2005). Practices that reduce soil disturbance include reduced tillage or conversion of annual cropland to permanent vegetative cover, such as grasslands. Various practices increase inputs, including planting of high residue crops, irrigation, addition of organic matter amendments, planting of cover crops, continuous cropping, and planting of perennial grasses which have higher belowground inputs (CAST 2004).

In particular, no-till (NT) has been demonstrated to frequently increase SOC storage, compared to full-inversion tillage (FT) practices (West and Post 2002). Under NT, crops are planted in narrow slots created by specialized seed drills, in the untilled seedbed of the previous crop (NRCS 2011). Tillage physically disturbs and mixes crop residues into the soil and alters soil temperature, aeration and water, which increases organic matter decompositions rates (Paustian et al. 1997). Reduced disturbance under NT favors formation of more stable soil aggregates that protect organic matter, resulting in lower rates of decomposition and higher organic matter stocks in the soil (Six et al. 2000). Similarly, conversion of annual croplands to permanent vegetative cover reduces soil disturbance and generally increases organic matter inputs to the soil, resulting in higher SOC stocks (Conant et al. 2001). Ogle et al. (2005) estimated annual increases in SOC stocks after switching from conventional till (CT) to NT of approximately 0.5% to 1.15%, depending on climate, while Conant et al. (2001) predicted SOC stocks to increase by about 3% per year after conversion of croplands to permanent grasslands. In addition to the potential to mitigate climate change, Delgado et al. (2011) proposed that increasing SOC stocks will enhance resiliency of soils to the effects of climate change.

Conservation Practices and N_2O Emissions

Though the effects of conservation practices on SOC are relatively well-established (Cole et al. 1997; Kern and Johnson 1993; Paustian et al. 1997), less is known about their impacts on soil N_2O emissions. Though N_2O represents a much smaller proportion of total anthropogenic climate forcing compared to CO_2 (IPCC 2007), N_2O is the most significant source of GHG emissions from agriculture in terms of global warming potential (GWP) (USDA 2011). Robertson et al. (2000) measured total GHG emissions from a long-term cropping experiment and found that all annual cropping systems were net sources of GHG and N_2O was the single largest source of emissions. Sources of N that stimulate emissions of N_2O from agricultural soils include: mineralization of soil organic matter, N from atmospheric deposition, fertilization from past years, mineralization of N from crop residues and manure, N_2O from subsurface aquifers, and N fertilization in the current year (Mosier et al. 1996a).

The biological processes of denitrification and nitrification generate N_2O. The process of nitrification oxidizes NH_4 to produce NO_3^-, though NO and N_2O are also lost through the process in varying amounts (Firestone and Davidson 1989). During denitrification, anaerobic bacteria reduce NO_3^- or NO_2 to produce N_2O , which may be further reduced in the process to produce N_2, especially under full anaerobic conditions (Firestone and Davidson 1989). Several factors influence the processes of nitrification and denitrification: mineralizable organic carbon, soil moisture and temperature, soil oxygen availability, concentrations of NO_3^- and NH_4 and soil pH (Bouwman 1996). Management practices such as NT and conversion of cropland to grassland affect these factors in various ways. As previously discussed, these management practices have been found to increase soil organic matter, resulting in larger quantities of organic C and organic N. Though climate is the main driver of soil moisture and temperature, differences in disturbance regimes among management practices can also affect the soil environment. Residue cover of the soil surface, as is common under NT and permanent grassland, increases the surface albedo leading to lower soil temperatures and reduced evaporation rates, compared to surfaces with less residue cover and lower albedos (Teasdale and Mohler 1993). Furthermore, soil aggregate formation in less disturbed soils influences soil moisture through improved water infiltration and retention (Arshad et al. 1999). In modern agricultural systems, the dominant sources of NO_3^- and NH_4 in soils are biological fixation of N by leguminous crops and N fertilizer additions (Bouwman et al. 2002).

A previous meta-analysis by Six et al. (2004) determined that emissions of N_2O would likely increase under NT relative to FT in both humid and dry climates, though emission differences were predicted to decrease over time, especially in humid climates. Evidence from Six et al. (2004) and many experimental studies, suggest that emissions responses to NT adoption would vary by climate. There has not been a comprehensive analysis of the effects of conversion of cropland to permanent grassland, but research evaluating croplands and grasslands suggests that emissions under grassland would be lower, largely due to lower N fertilizer additions to grasslands (Stehfest and Bouwman 2006).

In my first chapter, I expand on the Six et al. (2004) analysis and further explore the effects of NT adoption on N_2O emissions, as well as the impact of conversion of cropland to grassland on N_2O emissions. I compiled data from published field experiments that measured N_2O emissions from FT and NT systems in temperate ecosystems, with equal N fertilizer additions. Using a linear mixed-effect modeling method, I found that climate and soil texture were significant drivers of differences in N_2O emissions between FT and NT croplands. More specifically, emissions were predicted to increase in humid climates, while emissions were predicted to decrease or not change in dry climates, depending on soil texture. Due to an interaction between climate and soil texture, the model predicted a decrease of about 1 kg N_2O-N ha^{-1} yr^{-1} in dry climates and low clay soils under NT. No difference was predicted under NT in dry climates with moderate clay soils. Though emissions were predicted to be higher in humid climates for all soil textures, emissions from soils with moderate clay contents were estimated to be lower than from soils with low clay contents, but high uncertainty in these predictions limits the inferences that can be drawn from these results. In contrast to the Six et al. (2004) analysis, there was no effect of time since NT adoption on N_2O emissions. Even though I was able to double the size of the dataset from the Six et al. (2004) analysis, high uncertainty estimates indicate that more research is still needed, especially on the interaction of soil texture with climate. Given that very few studies measured N_2O emissions for more than 1 or 2 years and the high variability of N_2O emissions, more long-term measurements are needed to understand the effects of NT adoption on emissions over time.

I conducted a similar analysis for conversion of cropland to grassland, including studies that measured N_2O emissions from annual croplands and perennial grassland in temperate ecosystems. Because N fertilizer application rates are usually quite different between croplands and grasslands, I tested difference in fertilization rate as a predictor variable. Using the same linear mixed-effect modeling method, I found that change in N fertilization rate, climate and soil texture were drivers of N_2O emissions changes after conversion of annual croplands to grasslands. Change in N fertilizer was the most significant driver of N_2O emissions, which is not surprising, given the well understood relationship between N fertilizer and N_2O emissions (Bouwman et al. 2002). When N fertilization was increased after conversion to grassland, N_2O emissions increased across all climate and soil types. Similarly, when N fertilizer rates decreased after conversion to grassland, N_2O emissions also decreased. When there was no change in N fertilizer rate, emissions were higher in grasslands, especially on moderate clay soils, though there was high uncertainty in the predictions. In general, emissions were predicted to be higher in moderate clay soils than low clay soils, across all fertilizer rate changes.

Adoption of NT in the Great Plains

In my first chapter, I estimated NT to reduce or not change emissions of N_2O in dry climates and conversion of annual cropland to grassland was predicted to reduce emissions when N additions were also reduced. Both practices were also previously discussed as conservation practices that sequester SOC and therefore may mitigate agricultural GHG emissions, depending on climate and N additions. Furthermore, Delgado et al. (2011) supported conservation practices that improve SOC stocks as adaptation strategies under climate change. However, demands on food production will not permit widespread conversion of annual croplands to grasslands. Paustian et al. (1998) suggested that mitigation technologies must also supply additional benefits to farms and society at large. No-till, aside from being a potential mitigation technology, has also been associated with many environmental and crop production benefits, especially in drier climates, such as the Great Plains, U.S. Perhaps the greatest environmental benefit of NT is reduced soil erosion, with some field experiments showing NT to decrease erosion by upwards of 90% compared to FT (Ghidey and Alberts 1998; Langdale et al. 1979; Meyer et al. 1999; Mickelson et al. 2001; Rhoton et al. 2002; Williams and Wuest 2011). Increased soil moisture under NT due to increased residue cover, improved soil structure and higher organic matter contents (Blevins et al. 1971), has been demonstrated to improve water use efficiency and permit intensified crop rotation systems in regions where wheat-fallow rotations are conventional (Peterson et al. 1996). Field experiments throughout the Great Plains have found higher profits when intensified crop rotations were grown with NT, compared to FT wheat-fallow systems (Dhuyvetter et al. 1996). Additionally, previous research has found that NT generates savings associated with equipment, fuel and labor (Varner et al. 2011, West and Marland 2002). Though there are many benefits of NT, it is only used on about 17% of all annual croplands in the Great Plains region (CTIC 2004).

In my second chapter, I addressed the discrepancy between potential benefits of NT and low adoption rates, by evaluating NT use in the Great Plains at the regional and local levels. Using county-level statistics and a linear-mixed effect modeling method, I found several variables significantly affected NT use in the Great Plains region: mean annual temperature (MAT), mean annual precipitation: potential evapotranspiration ratio (MAP:PET), mean sand percent, mean slope percent, years the operator has been on an operation, proportion of wheat hectares in the county, and proportion of full-owner operations by area. Interactions were also found between MAT and MAP:PET ratio, and mean sand percent and mean slope percent. Climate variables, MAT and MAP:PET ratio, interacted to predict higher rates of adoption in cold, dry climates, while the lowest rates were predicted in warm, wet climates. This finding is consistent with previous research that estimates yields for winter wheat and spring wheat to increase or not change after NT adoption in cool, dry climates (Ogle et al. 2012). The interaction between mean sand percent and mean slope percent predicted highest adoption rates on soils with low mean sand contents and steeper slopes, indicating high adoption on soils susceptible to water erosion. Higher rates of adoption were also predicted on soils that had high sand contents on all slopes, which are likely more prone to erosion caused by wind. Prevalence of NT in counties with more erodible soils may imply that farmers are using NT for soil conservation. As the number of years an operator has been on an operation increased, likelihood of NT adoption also increased. Phillips et al. (1980) suggested that successful NT farmers may have greater management skill, which may be attributed in some part to experience. Proportion of wheat hectares and proportion of full-owner operations by area were both negatively correlated with adoption, indicating that counties with high proportions of wheat and high proportions of full-owner operations were more likely to have low NT rates. Proportion of wheat hectares was assessed as a 10-yr mean, indicating that counties with high proportions of wheat were likely growing continuous, monoculture wheat. Previous research has found NT to produce lower yields in monoculture systems, possibly due to increased incidence of pests and disease (Decker et al. 2009). Furthermore, continuous winter wheat cropping is prevalent in the southern part of the Great Plains, which may explain lower NT adoption rates in that region (Vitale et al. 2011). The reason for the negative relationship between ownership and NT adoption was unclear, though previous research has proposed that because NT equipment can be transferred across operations, the practice is more associated with the operator than the land owner (Lee and Stewart 1983). Over the entire region, the model predicted a lower mean adoption rate (13%) than estimated by the Conservation Technology Information Center (CTIC) (17%) (CTIC 2004), indicating there may be other dynamics driving NT adoption that were not captured by the model.

I also evaluated NT adoption at the local level using detailed household surveys that were conducted in farm households in 10 counties in Colorado, Montana and South Dakota. Binary logistic regression modeling was used to evaluate the survey results. Similar to the regional analysis, ownership was found to negatively affect NT adoption, indicating that operators who owned more of their operation were less likely to use NT. However, operators were more likely to use NT if they were enrolled in the Conservation Reserve Program (CRP), trusted the federal government, hunted on their land for recreation, or cited soil moisture conservation at a local conservation issue. The CRP enrolls lands that are highly erodible, therefore farmers with land in the CRP may be more aware of soil conservation issues on their farm. Farmers who placed trust in the federal government were more likely to use NT. This finding is consistent with research in Ohio that linked NT use with frequent participation in government programs (Camboni and Napier 1993). The relationship between hunting and NT is likely a practical one, as NT fields provide better fall and winter habitat for wildlife than tilled fields (Warburton and Klimstra 1984). Farmers who were concerned about soil moisture conservation were also more likely to use NT, which is consistent with the finding at the regional scale that counties with dry climates were more likely to use NT and previous research showing soil moisture benefits from NT (Blevins et al. 1971).

A follow-up survey was also conducted among the same households to ask more direct questions about influences on adoption. We were not able to survey all households, so the data was not used for modeling, but rather to qualitatively inform discussion of the results. The majority of operators ranked fuel prices, yields and soil type as having influence on their tillage choice, while responses for weather and erosion were mixed among operators. Though responses on the influence of erosion were mixed among all operators, five out of 9 NT operators ranked it as being a primary influence on their tillage choice. Conversely, operators who used other tillage cited yields as a primary influence on their tillage decisions while no NT operators ranked yields as having as much influence on their tillage choice.

Summary

Given the challenges posed by climate change on agriculture, it is important to understand the impacts of management practices on GHG emissions, as well as factors driving adoption of these practices. No-till and conversion of cropland to grassland are practices that reduce disturbance of the soil and enhance SOC stocks. Understanding the impact of these practices on N_2O emissions is also important, because N_2O is a major source of GHG emissions from agriculture. In my thesis, I found that the influence of NT adoption on N_2O varied by climate and soil type. In general, emissions would be expected to increase in humid climates, with small differences depending on clay contents. In dry climates, the opposite effect was found, with emissions predicted to be lower in soils with low clay contents or not different in soils with moderate clay contents, following a shift to NT. After conversion of cropland to grassland, changes in N_2O emissions were largely dependent on changes in N fertilizer application. If applications of N were increased after grassland conversion, emissions were predicted to be higher, and similarly, if applications of N decreased, emissions were predicted to be lower. When N fertilizer application was not changed after conversion to grassland, N_2O emission differences were estimated to be near zero. Soil texture also influenced emissions, with moderate clay soils having higher emissions relative to low clay soils. Differences due to climate were also observed, though there was high uncertainty in the estimates. Though there were some clear trends in emissions under both practices (higher emissions under NT in humid climates and the effect of N fertilizer change under grassland conversion), more research is needed to better understand the interacting effects of climate and soil texture on emission rates under both practices.

In addition to my finding that N_2O emissions are likely reduced under NT in dry climates, previous research has demonstrated many other ways that NT may be beneficial to the environment and crop production, especially in dry climates such as the Great Plains, U.S. However, NT adoption is relatively low in this region. I evaluated factors affecting NT adoption at the regional scale using county-level statistics and at the local scale, using household surveys. I found that many factors affected NT adoption, including environmental variables, farm structure and cropping system, and operator characteristics and attitudes. The influence of environmental variables was especially apparent over the region. Counties in dry, cool climates were predicted to have high rates of adoption, as were counties with higher proportions of soils that were more prone to soil erosion. Additionally, surveyed farmers were more likely to use NT if soil moisture conservation was a major concern. Farm structure and cropping systems also influenced adoption, through ownership, proportion of wheat cropping and CRP enrollment. Farmers who owned more of their land, both in the regional analysis and in the household surveys were less likely to adopt NT. No-till was also less common in regions growing high proportions of wheat. Conservation Reserve Program enrollment increased likelihood of NT adoption among surveyed households. Experience played a role in adoption at the regional level, as time on an operation was positively correlated with NT rates. Attitudes of farmers could not be tested at the regional level, but the local household survey results suggest that attitudes influence tillage choice. Farmers were more likely to use NT if they expressed trust in the federal government and hunted wildlife on their lands.

References

Arshad, M. 1999. Components of surface soil structure under conventional and no-tillage in northwestern Canada. Soil and Tillage Research. 53: 41-47.

Blevins, R.L., D. Cook, S.H. Phillips, and R.E. Phillips. 1971. Influence of no-tillage on soil moisture. Agronomy Journal 63: 593-596.

Bouwman, A.F. 1996. Direct emission of nitrous oxide from agricultural soils. Nutrient Cycling in Agroecosystems. 46: 53-70.

Bouwman, A.F. 2002. Emissions of N_2O and NO from fertilized fields: Summary of available measurement data. Global Biogeochemical Cycles 16: 6-1 – 6-13.

Camboni, S.M., and T.L. Napier. 1993. Factors affecting use of conservation farming practices in east central Ohio. Agriculture, Ecosystems & Environment 45: 79-94.

CAST. 2004. Climate Change and Greenhouse Gas Mitigation: Challenges and Opportunities for Agriculture. Task Force Report, No. 141, Council for Agricultural Science and Technology, Ames, Iowa, US.

Cole, C.V., J. Duxbury, J. Freney, O. Heinemeyer, K. Minami, A. Mosier, K. Paustian, N. Rosenberg, N. Sampson, D. Sauerbeck, and Q. Zhao. 1997. Global estimates of potential mitigation of greenhouse gas emissions by agriculture. Nutrient Cycling in Agroecosystems 49: 221-228.Conant, R.T., Paustian, K., Elliott, E.T., 2001. Grassland management and conversion into grassland: Effects on soil carbon. Ecological Applications. 11, 343-355.

CTIC. 2004. Crop Residue Management Survey, 2004. Conservation Tillage Information Center, West Lafayette, IN, US.

Decker, J.E., F.M. Epplin, D.L. Morley, and T.F. Peeper. 2009. Economics of five wheat production systems with no-till and conventional tillage. Agronomy Journal 101: 364-372.

Delgado, J.A., P.M. Groffman, M. Nearing, T. Goddard, D. Reicosky, R. Lal, N.R. Kitchen, C.W. Rice, D. Towery, and P. Salon. 2011. Conservation practices to mitigate and adapt to climate change. Journal of Soil and Water Conservation 66: 118A-129A.

Dhuyvetter, K., C. Thompson, C. Norwood, and A. Halvorson. 1996. Economics of dryland cropping systems in the Great Plains: a review. Journal of Production Agriculture 9: 216-222.

EPA. 2011. U.S. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2009. U.S. Environmental Protection Agency, Office of Atmospheric Programs, EPA 430-R-11-005, April 2011.

Firestone, M.K., and E.A. Davidson. 1989. Microbiological basis of NO and N_2O production and consumption in soils. In Exchanges of Trace Gases Between Terrestrial Ecosystems and the Atmosphere , ed. M.O. Andreae and D.S. Schimel. New York: John Wiley & Sons.

Ghidey, F., and E.E. Alberts. 1998. Runoff and soil losses as affected by corn and soybean tillage systems. Journal of Soil and Water Conservation 53: 64-70.

Godfray, H.C.J., J.R. Beddington, I.R. Crute, L. Haddad, D. Lawrence, J.F. Muir, J. Pretty, S. Robinson, S.M. Thomas, and C. Toulmin. 2010. Food security: the challenge of feeding 9 billion people. Science (New York, N.Y.). 327: 812-8.

Hatfield, J.L., K.J. Boote, B.A. Kimball, L.H. Ziska, R.C. Izaurralde, D. Ort, A.M. Thomson, and D. Wolfe. 2011. Climate impacts on agriculture: Implications for crop production. Agronomy Journal. 103: 351-370.

IPCC. 2007. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon S, Qin D, Manning M, Chen Z, Marqui M, Averyt KB, Tignor M, Miller HL (eds) Cambridge University Press, Cambridge United Kingdom and New York, NY, USA, pp 996.

Karl, T.R., J.M. Melillo, and T.C. Peterson. 2009. Global Climate Change Impacts in the United States. Cambridge University Press.

Kern, J.S., and M.G. Johnson. 1993. Conservation tillage impacts on national soil and atmospheric carbon levels. Soil Science Society of America Journal 57: 200-210.

Langdale, G., A. Barnett, R. Leonard, and W. Fleming. 1979. Reduction of soil erosion by the no-till system in the Southern Piedmont. Transactions of the ASAE 22: 82–86.

Lee, L.K., and W.H. Stewart. 1983. Landownership and the adoption of minimum tillage. American Journal of Agricultural Economics 65: 256–264.

Long, S.P., E.A. Ainsworth, A.D.B. Leakey, J. Nosberger, and D.R. Ort. 2006. Food for thought: Lower-than-expected crop yield stimulation with rising CO2 concentrations. Science 312: 1918-1921.

Meyer, L., S. Dabney, and C. Murphree. 1999. Crop production systems to control erosion and reduce runoff from upland silty soils. Transactions of the ASAE 42: 1645-1652.

Mickelson, S., P. Boyd, J. Baker, and S. Ahmed. 2001. Tillage and herbicide incorporation effects on residue cover, runoff, erosion, and herbicide loss. Soil and Tillage Research 60: 55-66.

Morgan, J. A., R.F. Follett, L.H. Allen, S. Del Grosso, J.D. Derner, F. Dijkstra, A. Franzluebbers, R. Fry, K. Paustian, and M.M. Schoeneberger. 2010. Carbon sequestration in agricultural lands of the United States. Journal of Soil and Water Conservation. 65: 6A-13A.

Mosier, A.R., J.M. Duxbury, J.R. Freney, O. Heinemeyer, and K. Minami. 1996 Nitrous oxide emissions from agricultural fields: Assessment, measurement and mitigation. Plant and Soil 181: 95-108.

NRCS. 2011. Conservation Practice Standard, Residue and Tillage Management No Till/Strip Till/Direct Seed. National Handbook of Conservation Practices, Natural Resources Conservation Service, United States Department of Agriculture, May 2011.

Ogle, S.M., F.J. Breidt and K. Paustian. 2005. Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. Biogeochemistry 72:87-121.

Ogle, S.M., A. Swan, and K. Paustian. 2012. No-till management impacts on crop productivity, carbon input and soil carbon sequestration. Agriculture, Ecosystems and Environment. In press.

Paustian, K., O. Andren, H.H. Janzen, R. Lal, P. Smith, G. Tian, H. Tiessen, M. Van Noordwijk, P.L. Woomer. 1997. Agricultural soils as a sink to mitigate CO2 emissions. Soil Use and Management 13: 230-244.

Paustian, K., C.V. Cole, D. Sauerbeck, and N. Sampson. 1998. CO2 mitigation by agriculture: an overview. Climatic Change 40: 135-162.

Peterson, G.A., A.J. Schlegel, D.L. Tanaka, and O.R. Jones. 1996. Precipitation use efficiency as affected by cropping and tillage systems. Journal of Production Agriculture 9: 180-186.

Phillips, R.E., R.L. Blevins, G.W. Thomas, W.W. Frye, and S.H. Phillips. 1980. No-tillage agriculture. Science 208: 1108-1113.

Rhoton, F.E., M.J. Shipitalo, and D.L. Lindbo. 2002. Runoff and soil loss from midwestern and southeastern US silt loam soils as affected by tillage practice and soil organic matter content. Soil and Tillage Research. 66: 1-11.

Robertson, G.P., E.A. Paul, and R.R. Harwood. 2000. Greenhouse gases in intensive agriculture: Contributions of individual gases to the radiative forcing of the atmosphere. Science 289: 1922-1925.

Six, J., E.T. Elliott, and K. Paustian. 2000. Soil macroaggregate turnover and microaggregate formation: a mechanism for C sequestration under no-tillage agriculture. Journal of Soil Science 32: 2099-2103.

Six, J., S.M. Ogle, F.J. Breidt, R.T. Conant, A.R. Mosier, and K. Paustian. 2004. The potential to mitigate global warming with no-tillage management is only realized when practised in the long term. Global Change Biology 10: 155-160.

Smith, P., D. Martino, Z. Cai, D. Gwary, H. Janzen, P. Kumar, B. McCarl, S. Ogle, F. O'Mara, C. Rice, B. Scholes, O. Sirotenko, M. Howden, T. McAllister, G. Pan, V. Romanenkov, U. Schneider, S. Towprayoon, M. Wattenbach, and J. Smith. 2008. Greenhouse gas mitigation in agriculture. Philosophical transactions of the Royal Society of London. Series B, Biological sciences 363: 789-813.

Stehfest, E., and L. Bouwman. 2006. N_2O and NO emission from agricultural fields and soils under natural vegetation: Summarizing available measurement data and modeling of global annual emissions. Nutrient Cycling in Agroecosystems 74: 207-228.

Teasdale, J.R., and C.L. Mohler. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agronomy Journal 85: 673-680.

USDA. 2011. U.S. Agriculture and Forestry Greenhouse Gas Inventory: 1990-2008. Climate Change Program Office, Office of the Chief Economist, U.S. Department of Agriculture. Technical Bulletin No. 1930. 159 pp.

Varner, B.T., F.M. Epplin, and G.L. Strickland. 2011. Economics of no-till versus tilled dryland cotton, grain sorghum, and wheat. Agronomy Journal 103: 1329-1338.

Vitale, J.D., C. Godsey, J. Edwards, and R. Taylor. 2011. The adoption of conservation tillage practices in Oklahoma: Findings from a producer survey. Journal of Soil and Water Conservation 66: 250-264.

Warburton, D., and W. Klimstra. 1984. Wildlife use of no-till and conventionally tilled corn fields. Journal of Soil and Water Conservation. Soil and Water Conservation Society 39: 327–330.

West, T.O., and G. Marland. 2002. Net carbon flux from agricultural ecosystems: Methodology for full carbon cycle analyses. Environmental Pollution 116: 437-442.

West, T.O., and W.M.Post. 2002. Soil Organic Carbon Sequestration Rates by Tillage and Crop Rotation: A Global Data Analysis. Soil Science Society of America Journal 66: 1930-1946.

Williams, J.D., and S.B. Wuest. 2011. Tillage and no-tillage conservation effectiveness in the intermediate precipitation zone of the inland Pacific Northwest, United States. Journal of Soil and Water Conservation 66: 242-249.

CHAPTER 1

INFLUENCE OF AGRICULTURAL CONSERVATION PRACTICES ON SOIL N_2O EMISSIONS

Chapter Summary

Research has shown that adoption of conservation practices to reduce soil disturbance has the potential to mitigate CO_2 emissions; however, impacts of these practices on soil N_2O emissions, a potent greenhouse gas, are less clear. Our objective was to evaluate changes in soil N_2O emissions after a shift from full-tillage (FT) to no-till (NT) on cropland and conversion of cultivated croplands to grasslands. We reviewed published literature evaluating impacts in temperate regions of the world, and analyzed those data using a linear mixed-effect model, with management practices, soil texture and climate variables as fixed effects. In cropland soils with transitions from FT to NT, the model predicted average increases in N_2O emissions in humid climates on low to moderate clay soils of 0.8 and 0.4 kg N_2O-N ha^{-1} yr^{-1} respectively; however, in drier climates, emissions were predicted to decrease by as much as 1 kg N_2O-N ha^{-1} yr^{-1} on similar soil types. In cropland to grassland conversions, N_2O emissions decreased as much as 4.5 kg N_2O-N ha^{-1} yr^{-1} in humid and dry climates on moderate to low clay soils if the amount of nitrogen (N) fertilizer application was also reduced. In the case of no change in N fertilizer, changes in N_2O emission changes were estimated to be near zero, while N_2O emissions were estimated to increase as much as 6.9 kg N_2O-N ha^{-1} yr^{-1} if fertilization rates were higher on the converted grassland. Results indicate that adoption of NT or conversion of cropland to grassland can change soil N_2O emissions, but the amount of change depends on climate, soil texture and N fertilizer management.

Introduction

Greenhouse gas emissions from anthropogenic sources have increased 70% in the last few decades (IPCC 2007a). While CO_2 is the most dominant greenhouse gas emitted by anthropogenic activity, quantities of more potent greenhouse gases, methane and nitrous oxide (N_2O), have also been rising due to anthropogenic activity. Nitrous oxide is roughly 300 times more potent as a greenhouse gas than CO_2 on an equal mass basis, and atmospheric concentrations of N_2O have been increasing linearly at a rate of about 0.26 percent yr^{-1} for the last few decades (Mosier et al. 1998; Bockman and Olfs 1998; IPCC 2007a). The IPCC (2007a) reported that in 2004, N_2O contributed about 7 percent of total global greenhouse gas emissions on a CO_2-eq. basis.

The agricultural sector is responsible for about 58 percent of total nitrous oxide emissions generated from anthropogenic activity (IPCC 2007b), and Robertson et al. (2000) found that soil N_2O was the greatest single source of global warming potential (GWP) in a full greenhouse gas assessment of annual cropping systems in a long-term field experiment in MI. Sources of N that influence soil N_2O from agriculture include: mineralization of soil organic matter, N from atmospheric deposition, fertilization from past years, mineralization of N from crop residues and manure, N_2O from subsurface aquifers, and N fertilization in the current year (Mosier et al. 1996a).

Research has shown that adoption of conservation practices to reduce soil disturbance, such as switching from full-inversion tillage (FT) to no-till (NT) or conversion of croplands to permanent grasslands, has the potential to sequester carbon in soils and mitigate greenhouse gas emissions (Cole et al. 1997; Kern and Johnson 1993; Paustian et al. 1997), although there is currently debate about the magnitude and generality of soil C increases in response to conservation tillage (Baker et al. 2007; Christopher et al. 2009; Syswerda et al. 2011; VandenBygaart et al. 2011). Regardless of the effect on soil carbon, the effect of these management changes on soil N_2O emissions is arguably less clear. In a meta-analysis, Six et al. (2004) found that N_2O emissions were higher in the first 10 years after adoption of NT in both humid and dry climates, but over time emissions from NT systems were lower in humid climates and similar in dry climates relative to FT systems. Field studies have shown mixed results, both supporting and contradicting the finding. Studies in drier climates of the Great Plains have shown a decrease in emissions even when NT had been used less than 10 years (Kessavalou et al. 1998; Mosier et al. 2006). Long-term NT studies in moist climates of Minnesota and Canada found both higher and lower emissions of N_2O under NT, with variation among individual plots and year of sampling (Drury et al. 2006; Venterea et al. 2005).

While no comprehensive analysis of the effects of grassland conversion on soil N_2O emissions has been done, Stehfest and Bouwman (2006) evaluated both annual croplands and grasslands globally and the results suggest that emissions would be lower under grassland management. Specifically, N_2O emission rates were lower on fertilized grasslands than fertilized croplands and natural grasslands had much lower emissions than both fertilized croplands and grasslands. In a long-term study monitoring emissions from both croplands and unmanaged grassland ecosystems, Robertson et al. (2000) found much lower rates of N_2O emissions on a per hectare basis from grassland ecosystems than annual cropping systems in Michigan. In both of these analyses, the unmanaged grassland systems did not receive N fertilizer whereas the cropland systems did. While this discrepancy in N inputs may explain some of the difference in N_2O emissions, other field studies where no N was added to either cropland or grassland treatments yielded mixed results, showing increases in emissions after conversion to grassland in some cases and decreases in others, even within the same site (Kessavalou et al. 1998; Mosier et al. 1997; Rochette et al. 2004).

Our objective was to analyze changes in soil N_2O emissions with a shift from FT to NT practices and conversion of cultivated annual croplands to perennial grasslands, including how a range of climate and soil characteristics influenced the effect of the management change on N_2O emissions. In addition, we evaluated the consistency of our findings from the meta-analysis with the mechanistic understanding of management impacts on soil N_2O emissions, and identified knowledge gaps requiring further study.

Methods

Literature Review

We conducted a literature review of studies that evaluated the impacts of tillage changes and conversion of cropland to grass cover on N_2O emissions. Studies were selected on the following criteria: 1) all data were gathered from studies that tested annual cropland or grassland treatments in replicated, factorial experiments, 2) all studies were located in temperate climates, and 3) the same amount of N fertilizer was added to both treatments for studies used in the tillage analysis. The N fertilizer criteria was not included for grassland conversion because changing fertilizer rates is a common practice when converting from cropland to grassland, and was part of the change in many of the experiments. A total of 19 studies were found for tillage including 88 individual treatments (Table 1.1). Our analysis builds on an earlier study by Six et al. (2004) but with about twice as many treatments allowing for more generalization than the earlier study. A total of 11 studies were found for conversion of cropland to grassland with 44 individual treatments (Table 1.1).

Table 1.1. Studies included in the analyses by management change, authors, location, soil clay contents, mean annual precipitation to potential evapotranspiration ratio (MAP:PET), and years since conversion (ND means “not determined” because the grassland reference condition was typically native grassland and not recently converted)

Reference	Location	Clay Contents (%)	MAP: PET	Years
	NT Adoption			
Almarez et al. 2009	Ste-Anne-de-Bellevue, QE, Canada	30	2.05	1
Arah et al. 1991	Penicuik, U.K.	15, 17	1.74	1
Burford et al. 1981	Oxfordshire, U.K.	35, 50	1.06	4-5
Chapuis-Lardy et al. 2009	Andranomanelatra, Madagascar	60	1.68	5
Chatskikh and Olesen 2007	Denmark	5	1.51	2
Choudhary et al. 2002	Turitea, New Zealand	20	1.78	1
Drury et al. 2006	Woodslee, ON, Canada	37	1.63	7-9
Dusenbury et al. 2008	Bozeman, MT, U.S.A.	8	1.12	4
Elmi et al. 2003	Ste-Anne-de-Bellevue, QE, Canada	10	2.05	8-9
Grandy et al. 2006	Hickory Corners, MI, U.S.A.	20	1.80	2-13
Jacinthe and Dick 1997	Piketon, OH, U.S.A.	20	1.85	2-3
Kaharabata et al. 2003	Woodslee, ON, Canada	37	1.63	1
Kessavalou et al. 2003	Sidney, NE, U.S.A.	28	0.89	1-3
Lemke et al. 1999	Breton, AB, Canada	12	1.51	15, 17
Lemke et al. 1999	Ellerslie, AB, Canada	39	1.19	15-16
Malhi et al. 2006	Star City, SK, Canada	30	1.17	2-3
Mosier et al. 2006	Fort Collins, CO , U.S.A.	33	0.74	3-5
Mutegi et al. 2010	Foulum, Denmark	9	1.46	6
Oorts et al. 2007	Boigneville, France	21	1.04	33
Parkin and Kaspar 2006	Boone, IA, U.S.A.	26	1.62	9
Perdomo et al. 2009	Paysandu, Uruguay	29	1.42	11
Regina and Alakukku 2010	Jokioinen, Finland	46, 62	1.65	5, 6
Regina and Alakukku 2010	Vihti, Finland	47	1.55	5
Ussiri et al. 2009	South Charleston, SC, U.S.A	20	1.78	43
Venterea et al. 2005	Rosemount, MN, U.S.A.	23	1.64	13
Vinten et al. 2002	Midlothian, U.K.	30	1.89	2
	Grassland Conversion			
Ambus and Christensen 1995	Copenhagen, Denmark	25	1.45	ND
Burke et al. 1995	Nunn, CO, U.S.A	15	0.84	ND
Dusenbury et al. 2008	Bozeman, MT, U.S.A.	8.5	1.12	ND
Goossens et al. 2001	Louvain-La-Neuve, Belgium	17	1.36	ND
Goossens et al. 2001	Watervliet, Belgium	16	1.32	ND
Kessavalou et al. 1998	Sidney, NE, U.S.A.	27	0.89	ND
Mosier et al. 1997	Nunn, CO, U.S.A	14, 15	0.91	ND
Perdomo et al. 2009	Paysandu, Uruguay	29	1.42	ND
Rochette et al. 2004	Quebec City, QE, Canada	19, 22, 77	3.90	ND
Sylvasalo et al. 2004	Jokioinen, Finland	10, 57	1.57	ND
Vermoesen et al. 2006	Gent, Belgium	25	1.32	ND
Wagner-Riddle et al. 1997	Elora, ON, Canada	16	1.90	ND
Xu-Ri et al. 2003	Xilin River Basin, Mongolia	22	1.00	ND

Tillage practices were classified into full tillage (FT) or no-till (NT) according to the descriptions of tillage operations provided in the studies. Tillage was classified as FT if one or more passes with the following tillage implements were used: moldboard plow, disk plow, disk chisel, twisted point chisel plow, heavy duty offset disk, subsoil chisel plow, bedder or disk ripper. Systems were also classified as FT if there were two or more passes with one of the following implements: chisel plow, single disk, tandem disk, offset disk-light duty, one-way disk, heavy duty cultivator, ridge till, or rototiller. Systems were classified as NT if managed only with seed drills and fertilizer or pesticide applicators.

Long-term climate data were obtained for all of the study sites. Mean annual precipitation and mean annual temperature for studies in the U.S. were derived from PRISM (Parameter-elevation Regressions on Independent Slopes Model) climate mapping system (Daly et al. 1994), while climate data for studies outside the U.S. were based on a high-resolution surface climate dataset created at the Climatic Research Unit and Tyndall Centre for Climate Change Research at the University of East Anglia, UK (New et al. 2002). In addition, potential evapotranspiration (PET) for all studies was based on the latter dataset, and was derived using the Thornwaite method (Thornwaite 1948).

Statistical Analyses

Changes in N_2O emissions after transitions from FT to NT or conversion from annual cropland to grassland were evaluated using a linear mixed-effect modeling method. The linear mixed-effect modeling method is similar to linear regression modeling, except that it allows for both fixed and random effects. The random effects account for dependence among observations

(Pinheiro and Bates 2000). The general structure of the model is given in the following equation:

$$Y = \beta_o + \beta_1 X_1 + ... + \beta_p X_p + \gamma_{site} + \gamma_{year*site} + \varepsilon \qquad (1)$$

where Y is the change in N_2O emissions; X 's are known covariates for the fixed effects determined from the studies; β's are unknown regression coefficients to be estimated from the data; and $\gamma_{site}, \gamma_{year*site}$ are random effects accounting for dependence among samples from the same site and time series data within sites. In the tillage analysis, fixed effects that were tested included management characteristics, such as years since tillage change, amount and type of N applied, crop type, irrigation, and residue management; and environmental variables, including soil texture and climate. Percent clay content was used as the soil texture variable. Sand and silt contents were not tested explicitly, because those variables are highly correlated with clay contents (i.e., correlated variables cannot be included in the same regression model due to multicollinearity). For climate, the specific variables were mean annual temperature (MAT), and the ratio of mean annual precipitation:potential evapotranspiration (MAP:PET). This ratio is commonly used as an index of dry to humid climatic conditions, where ratios less than or equal to 1 are considered to be dry climates and ratios greater than 1 are considered to be humid climates (Holdridge 1947). Similar variables were tested in the grassland conversion analysis, including grassland cover type, grazing intensity, N fertilizer change, MAT, MAP:PET ratio, and soil texture. In the grassland analysis, time since transition was not evaluated because it was not reported in many of the studies, especially in cases where cropland was compared to native grassland.

For both analyses, we tested first- and second-order interactions among fixed effects, and random effects were included in the models to account for spatial dependencies among samples from the same site and repeated samples from the same treatment plots. Variables were included in the statistical models that were significant at an alpha level of 0.1. Changes in N_2O emissions were predicted from the model given in Equation 1, and associated prediction variance was expressed as 1 standard deviation and derived from the error covariance structure of the fixed effects. Predictions were obtained from the model for clay contents of 15%, which will be referred to as low clay soils, and 30% which will be referred to as moderate clay soils. Predictions were not made for higher clay soils due to a limited number of studies. A study by Rochette et al. (2008) was deemed an outlier and not included in the model because there were no other studies in this highest range of clay contents and MAP:PET ratios (Table 2.1), and it had a large influence on predictions across the full range of clay contents and MAP:PET ratios. All statistical analyses were conducted in Splus 8.0 for Windows Enterprise Developer (Insightful Corp., Seattle, WA).

Results

Tillage

Most of the studies addressing the influence of no-till adoption estimated differences in N_2O emissions between no-till (NT) and full-inversion tillage (FT) ranging from -1 to +1 kg N_2O-N ha^{-1} yr^{-1}, while a relatively small number of studies had a larger decrease or increase in emissions (Figure 1.1a). The dataset included studies with clay contents ranging from 5 to 62 percent, and MAP:PET ratios ranging from 0.74 to 2.05. The time since adoption of no-till was from 1 to 33 years (Table 1.1).

Results of the meta-analysis show that climate and soil texture influenced the change in N_2O emissions with NT adoption (Table 1.2). With adoption of NT, N_2O emissions increased in humid climates and decreased or exhibited no change in drier climates (Figure 1.2).

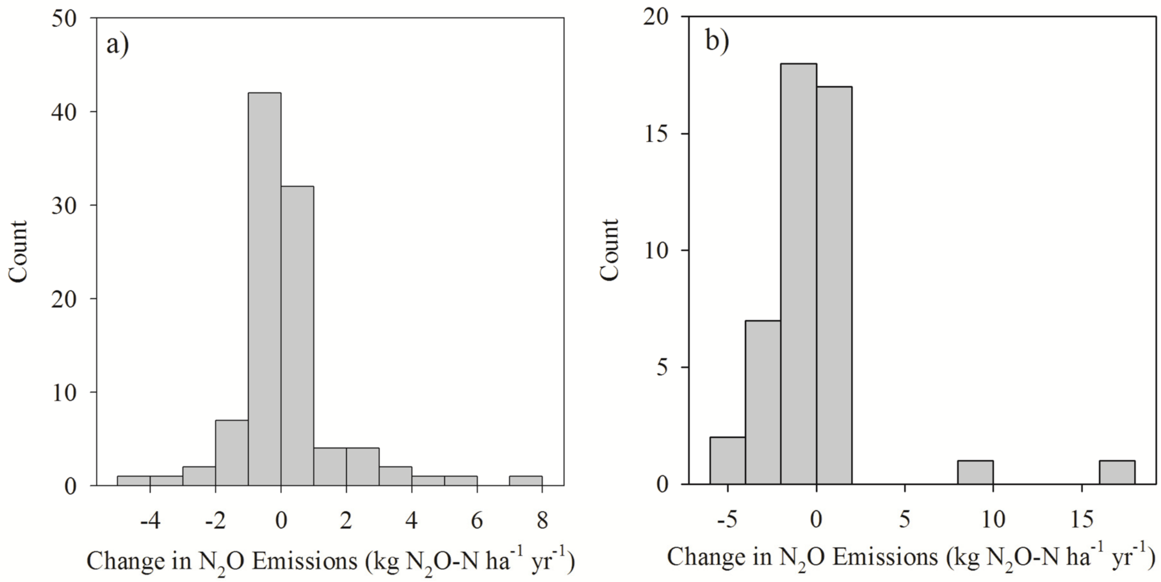

Figure 1.1. Histograms showing N_2O emissions changes after switching from full-inversion tillage (FT) to no-till (NT) (a) and conversion of cropland to grassland (b). Negative emission changes indicate an emissions reduction after adoption of conservation practice.

An interaction of climate and soil texture revealed a differential climate response that depended on the soil texture. In drier climates, low clay soils emitted less N_2O after adoption of NT, whereas there was little or no change in N_2O emissions on moderate clay soils following NT adoption. In contrast, in humid climates, both low and high clay soils showed an increase in N_2O with NT conversion.

Grassland Conversion

Conversion of croplands to grasslands resulted in a much wider range of differences in N_2O emissions, compared to the tillage analysis (Figure 1.1b). Most differences were within a range of -5 to +5 kg N_2O-N ha^{-1} yr^{-1}. The dataset included studies with clay contents ranging from 9 to 77 percent, and MAP:PET ratios ranging from 0.84 to 3.9. The change in fertilizer rates varied from -180 kg N ha^{-1} yr^{-1} to +339 kg N ha^{-1} yr^{-1}.

Table 1.2. Linear mixed-effect models for N_2O emissions change after adoption of no-till (NT) or conversion of croplands to grasslands

Parameter	**Parameter value**	**s.d.**	**p-value**
	Adoption of NT		
Intercept	-4.64	2.11	0.03
Clay %	0.12	0.06	0.06
MAP:PET†	2.86	1.27	0.03
Clay % x MAP:PET	-0.07	0.04	0.07
Random effect: site		0.0001	
Random effect: site by time		0.0002	
	Conversion to Grassland		
Intercept	-1.68	2.8	0.55
N fertilizer change	0.02	0.005	0.0001
Clay %	0.14	0.04	0.0008
MAP:PET	0.51	1.65	0.76
Clay % x MAP:PET	-0.04	0.01	0.0003
Random effect: site		4.2	
Random effect: site by time		0.0005	

† MAP:PET = Ratio of mean annual precipitation to potential evapotranspiration

The results of the statistical analysis show that N fertilizer rate had the most significant influence on N_2O emissions with cropland conversion to grassland (Table 1.2). It is well established that mineral fertilization increases N_2O emissions (Bouwman et al. 2002). When N fertilizer application was increased, emissions on all soil and climate types were higher, and similarly, decreasing N application reduced N_2O emissions (Figure 1.3). However, soil texture also has a significant influence on emissions changes, with moderate clay soils having a larger change in emissions than low clay soils. Responses of emissions to clay contents are relative to climate, with greater apparent differences as a function of soil texture in emissions in dry climates than humid climates.

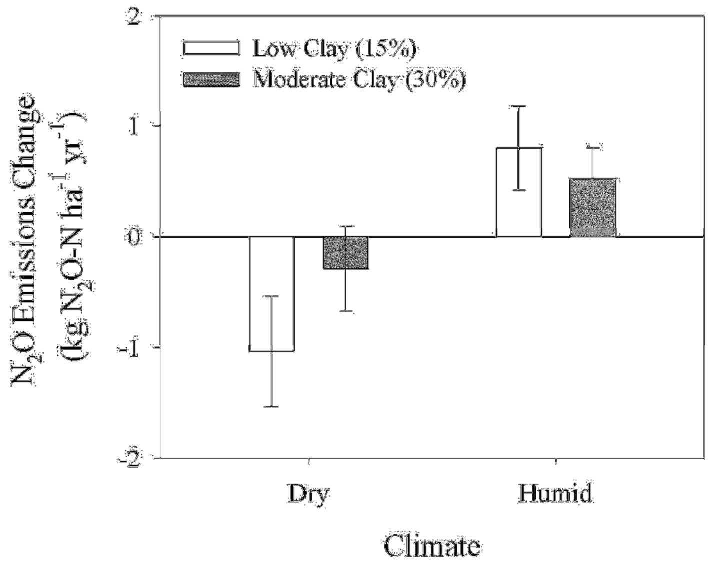

Figure 1.2. Predicted N_2O emission changes after switching from full-inversion tillage (FT) to no-till (NT) in dry (mean annual precipitation to potential evapotranspiration ratio (MAP:PET) = 1.0) and humid (MAP:PET = 2.0) climates with low clay, as represented by 15% clay content on the graph, and moderate clay, as represented by 30% clay contents on the graph. Note that there were insufficient data to make predictions for higher clay soils. *Error* bars represent ± 1 s.d. of the estimate

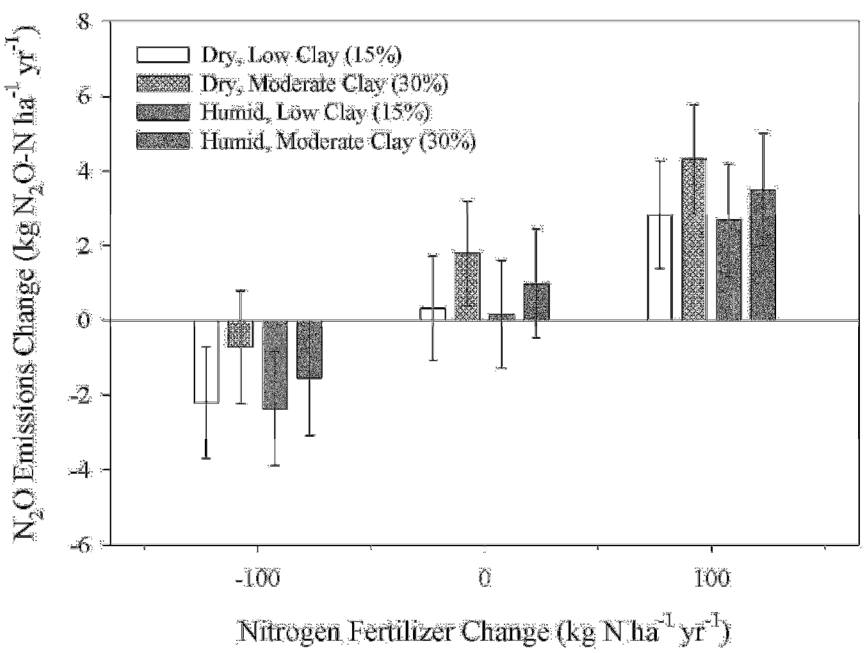

Figure 1.3. Predicted N_2O emission changes after conversion of cropland to grassland by N fertilizer change in dry (mean annual precipitation to potential evapotranspiration ratio (MAP:PET) = 1.0) and humid (MAP:PET = 2.0) climates with low clay, as represented by 15% clay content on the graph, and moderate clay, as represented by 30% clay content on the graph. Note that there were insufficient data to make predictions for higher clay soils. *Error* bars represent ± 1 s.d. of the estimate

Discussion

NT Adoption

A conceptual diagram was developed to guide the discussion on the influence of modeled drivers on N_2O emissions and to generally describe related mechanisms that more directly control denitrification and nitrification (Figure 1.4). Modeled drivers are ordered by level of influence on the response variable, N_2O, as defined by the meta-analysis and are described as distal drivers.

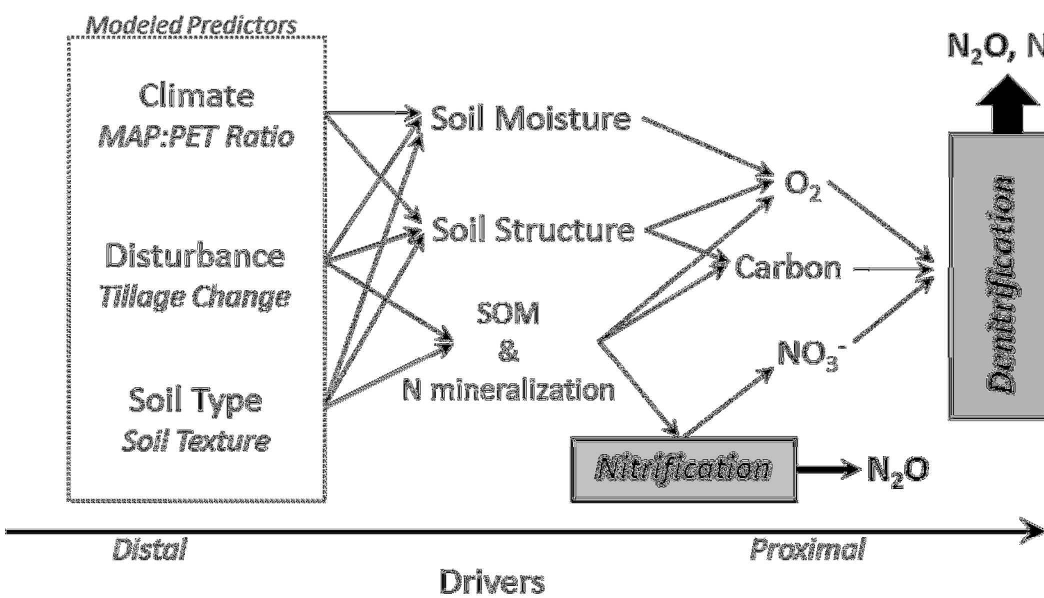

Figure 1.4. A conceptual diagram showing significant variables from the meta-analysis and proposed underlying mechanisms that affect N_2O emissions after adoption of NT (adapted from Robertson 1989).

Moving across the diagram to the right, drivers are ordered according to distal to proximal mechanistic influence on N_2O emissions, with O_2, carbon, and NO_3^- availability being the most proximal drivers. We found that climate was the most significant driver of the change in N_2O emissions with adoption of NT, with emissions increasing in humid climates and decreasing in dry climates (Figure 1.2). In a previous analysis, Six et al. (2004) also found increases in emission responses in both humid and dry climates, though emissions decreased over time. Soil moisture is generally higher in wetter climates and at higher water contents, diffusion of oxygen into the soil is reduced. This reduction in O_2 availability creates anaerobic conditions in the soil that lead to higher production of N_2O (and N_2) from denitrification. The practice of NT tends to enhance surface soil moisture by increasing surface albedo because soil residues are retained on the surface. Higher surface albedo leads to reduced soil warming relative to soils with lower surface albedo, which then reduces evaporation of water from the soil (Teasdale and Mohler 1993). Previous research has also determined that surface soil organic matter contents are generally higher under NT, which may also increase retention of water in the soil. Formation of soil aggregates under NT will influence soil moisture status by improving water infiltration and soil water retention (Arshad et al. 1999). Nitrous oxide emissions are driven by both nitrification and denitrification, but there are differences in the relative dominance of these processes. Davidson (1992) found that nitrification dominated when moisture content was below field capacity, which would be more common in a dry climate. However, when soil moisture content was increased above field capacity, there was a 2-5 fold increase in emissions, which were attributed to denitrification (Davidson 1992). In an analysis at a shortgrass steppe ecosystem, Parton et al. (1998) found that nitrification accounted for 60-80% of soil N_2O emissions at typical soil moisture conditions, but as soil moisture was increased experimentally, denitrification became the dominant source of N_2O. The use of irrigation in dry climates may also affect N_2O emissions, but there were only a few experiments with irrigation (Malhi et al. 2006, Mosier et al. 2006, Oorts 2007).

We also found that soil texture influences emissions of N_2O after NT adoption, through an interaction with climate (Figure 1.2). Soils with higher clay contents generally retain more soil moisture than soils with low clay contents, however a differential impact of clay contents was only observed in dry climates. Thus the results suggest that in dry climates, higher clay soils cause an increase in the volume and/or frequency of anaerobic conditions in the soil. In wet climates, soil texture may not be as influential because moisture levels tend to exceed the threshold for higher denitrification rates compared to dry climates irrespective of texture; or perhaps in soils with higher clay contents, fully anaerobic conditions lead to higher emissions of N_2 and less N_2O. Several studies have similarly shown that texture has a significant influence on the N_2O emission differences between FT and NT management. For example, Lemke et al. (1998) determined that clay content explained 92% of the variation in N_2O emissions between FT and NT management across multiple sites in Alberta. Similarly, Burford et al. (1981) found that emissions from NT were greater than FT on soils with higher clay contents at a study site in the UK.

While soil moisture appears to be a key driver influencing the change in nitrous oxide emissions with NT adoption, there may be other influences that further explain N_2O response to NT. Higher soil organic matter contents may increase N_2O emissions by providing substrate for denitrifying bacteria. Soil organic matter also supplies organic N, which can lead to higher N_2O emissions via nitrification, as well as supply nitrate for denitrification (Baggs 2003). However, soil organic matter tends to be higher in NT (West and Post 2002, Ogle et al. 2005) because soil disturbance is minimized and soil structure is further developed with more aggregate formation (Six et al. 2000). Previous research has shown that soil aggregates can provide ideal conditions for denitrification by providing anaerobic zones within soil aggregates, as well as organic matter for denitrifying bacteria (Parkin 1987). Minimized soil disturbance may have less of an impact in the coarser textured soils (low clay soils), as coarser soils tend to have less soil aggregation. Poor soil structure resulting from long-term tillage may result in reduced infiltration rates, as well as subsoil compaction that reduces drainage (Singer and Shainberg 2004; Verbist et al. 2007), causing precipitation to pool in large rainstorm events, as are common in the dry climate regions, leading to relatively greater emissions in the FT soil.

Grassland Conversion

A conceptual diagram similar to that for NT adoption was also developed to describe how modeled drivers of N_2O emissions change from grassland conversion interact with mechanistic processes (Figure 1.5).

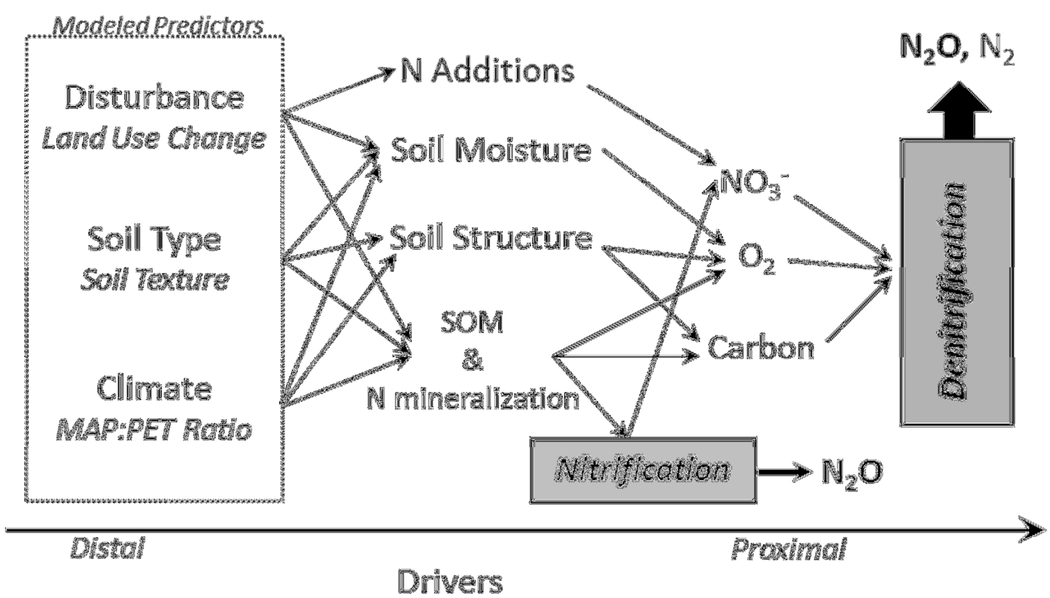

Figure 1.5. A conceptual diagram showing significant variables from the meta-analysis and proposed underlying mechanisms that affect N_2O emissions after conversion of annual croplands to grasslands (adapted from Robertson 1989).

The largest influence on N_2O emissions when annual croplands were converted to permanent grasslands was a subsequent change in N fertilizer application. In most cases, N fertilizer applications are greatly reduced when annual cropland is converted to permanent grassland, however there are studies where N additions are higher than on croplands such as some European pasture systems (Goossens 2001, Sylvasalo 2004, Vermoesen 1996). A large change in N additions affects N supply in the soil for denitrifying and nitrifying bacteria that produce N_2O. However, the change in N_2O emissions with an equal increase or decrease in N fertilizer was not symmetrical (Figure 1.3). The magnitude of the relative change in N_2O emissions under increasing N fertilizer was larger than the magnitude of the relative change in N_2O under decreasing N fertilizer. This response may be similar to the response we found when N additions were unchanged between cropland and grassland. Where N inputs were unchanged, emissions were either higher or not different after conversion to grassland (Figure 1.3), suggesting that "background" emissions may be higher from grasslands. Grassland soils would likely have larger soil organic C stocks due to higher inputs of organic matter from plant biomass turnover and reduced decomposition, suggesting higher potential for N mineralization. It is also possible that the observed asymmetry in emissions due to N additions, is due to a non-linear response to N additions, that is sometimes exhibited under N rates high enough to exceed plant demand for N, which leaves more N for denitrifying and nitrifying bacteria in the soil (McSwiney and Robertson 2005). However, because we tested relative N rate increases, it is difficult to evaluate whether or not we observed this effect.

Where there were no changes in N additions after conversion to grassland, emissions increased in moderate clay soils and showed no change in low clay soils (Figure 1.3). Differences in responses between dry and humid climates were relatively small. As with adoption of NT, an alteration in the disturbance regime affects soil microclimate, organic matter dynamics and soil structure, all of which affect soil moisture (Burke et al. 1995, Kucharik et al.

2001). Because clay plays a key role in all of these, generally increasing soil moisture relative to low clay soils, it is not surprising that emission changes appear to be higher in moderate clay soils, regardless of change in N additions (Rochette et al. 2004).

The role of climate is uncertain. When comparing between climate zones, estimates for N_2O emission changes did not differ within the same soil texture class, given the high error associated with the estimates. However, the results do suggest a difference between the impact of clay contents in dry and humid climates. This is similar to the finding with NT adoption; clay contents had a larger impact on emissions in dry climates than humid climates.

While changes in N additions and soil moisture associated with clay contents can largely explain changes in N_2O emissions with grassland conversion, there may be other factors that are contributing. As with adoption of NT, undisturbed grassland soils have more developed soil structure and increased soil aggregation, as well as higher soil organic matter contents. These dynamics may influence N_2O emissions changes after conversion to grassland, in the same way they do in NT cropland systems. The key difference in grasslands is the permanent vegetative cover, and increased organic matter input, especially belowground input from roots. Alternatively, previous research has suggested compelling reasons why croplands may have higher emissions, such as increased N turnover rates due to frequent cropping and tillage, and higher soil N availability (Kessavalou et al. 1998, Wagner-Riddle et al. 1997). Further research is needed to evaluate these mechanisms in order to understand the consequences of converting annual cropland to grassland for soil N_2O emissions.

Conclusion

This synthesis of previous field research revealed generalities in how management changes interact with climate and soil to affect mechanistic processes that govern N_2O emission rates. While uncertainties in predictions of N_2O emissions associated with land use and management changes remain, key findings in this study show that N_2O emission changes depend largely on site-specific conditions. Specifically, with adoption of NT, higher N_2O emissions were predicted in more humid climates, whereas lower emissions were predicted in dry climates, especially for low clay soils. Some cropland management practices have yet to be studied adequately, such as the influence of irrigation in dry climates, and the earlier finding of Six et al. (2004) that emissions differences disappear over time was not confirmed with this larger dataset. With cropland conversion to grassland, it was not surprising that changing fertilization rates would influence soil N_2O emissions. However, the impact did vary with soil texture and to a lesser degree, climate. Our results, as well as the literature, demonstrate a lack of consensus on the impact of converting cropland to grassland if there is no change in fertilization rates. Further research is needed across a range of climate, soil and management conditions to refine our understanding of the effect of these conservation practices on soil N_2O emissions.

Acknowledgements

This research was supported by the National Research Initiative of the Cooperative State Research, Education and Extension Service, United States Department of Agriculture, Grant # 2005-35400-15294.

References

Almaraz, J.J., F. Mabood, X.M. Zhou, C. Madramootoo, P. Rochette, B.L. Ma, and D.L. Smith. 2009. Carbon dioxide and nitrous oxide fluxes in corn grown under two tillage systems in southwestern Quebec. Soil Science Society of America Journal 73: 113-119.

Ambus, P. and S. Christensen. 1995. Spatial and seasonal nitrous-oxide and methane fluxes in Danish forest-ecosystems, grassland-ecosystems, and agroecosystems. Journal of Environmental Quality 24: 993-1001.

Arah, J.R.M., K.A. Smith, I.J. Crichton, and H.S. Li. 1991. Nitrous-oxide production and denitrification in Scottish arable soils. Journal of Soil Science 42: 351-367.

Baggs, E.M., M. Stevenson, M. Pihlatie, A. Regar, H. Cook, and G. Cadisch. 2003. Nitrous oxide emissions following application of residues and fertiliser under zero and conventional tillage. Plant and Soil 254: 361-370.

Baker, J.M., T.E. Ochsner, R.T. Venterea, and T.J. Griffis. 2007. Tillage and soil carbon sequestration - what do we really know? Agriculture, Ecosystems and Environment 118: 1-5.

Bockman, O.C., and H.W. Olfs. 1998. Fertilizers, agronomy and N_2O. Nutrient Cycling in Agroecosystems 52: 165-170.

Bouwman, A.F. 1996. Direct emission of nitrous oxide from agricultural soils. Nutrient Cycling in Agroecosystems 46: 53-70.

Burford, J.R., R.J. Dowdell, and R. Crees. 1981. Emission of nitrous-oxide to the atmosphere from direct-drilled and ploughed clay soils. Journal of the Science of Food and Agriculture 32: 219-223.

Burke, I.C., W.K. Lauenroth, and D.P. Coffin. 1995. Soil organic-matter recovery in semiarid grasslands - implications for the Conservation Reserve Program. Ecological Applications 5: 793-801.

Chapuis-Lardy, L., A. Metay, M. Martinet, M. Rabenarivo, J. Toucet, J.M. Douzet, T. Razafimbelo, L. Rabeharisoa, and J. Rakotoarisoa. 2009. Nitrous oxide fluxes from Malagasy agricultural soils. Geoderma 148: 421-427.

Chatskikh, D., and J.E. Olesen. 2007. Soil tillage enhanced CO_2 and N_2O emissions from loamy sand soil under spring barley. Soil and Tillage Research 97: 5-18.

Christopher, S.F., R. Lal, and U. Mishra. 2009. Regional study of no-till effects on carbon sequestration in midwestern United States. Soil Science Society of America Journal 73: 207-216.

Choudhary, M.A., A. Akramkhanov, and S. Saggar. 2002. Nitrous oxide emissions from a New Zealand cropped soil: tillage effects, spatial and seasonal variability. Agriculture, Ecosystems and Environment 93: 33-43.

Cole, C.V., J. Duxbury, J. Freney, O. Heinemeyer, K. Minami, A. Mosier, K. Paustian, N. Rosenberg, N. Sampson, D. Sauerbeck, and Q. Zhao. 1997. Global estimates of potential mitigation of greenhouse gas emissions by agriculture. Nutrient Cycling in Agroecosystems 49: 221-228.

Daly, C., R.P. Neilson, and D.L. Phillips. 1994. A statistical topographic model for mapping climatological precipitation over mountainous terrain. Journal of Applied Meteorology 33: 140-158.

Davidson, E.A. 1992 Sources of nitric-oxide and nitrous-oxide following wetting of dry soil. Soil Science Society of America Journal 56: 95-102.

Drury, C.F., W.D. Reynolds, C.S. Tan, T.W. Welacky, W. Calder, and N.B. McLaughlin. 2006. Emissions of nitrous oxide and carbon dioxide: influence of tillage type and nitrogen placement depth. Soil Science Society of America Journal 70: 570-581.

Dusenbury, M.P., R.E. Engel, P.R. Miller, R.L. Lemke, and R. Wallander. 2008. Nitrous oxide emissions from a northern Great Plains soil as influenced by nitrogen management and cropping systems. Journal of Environmental Quality 37: 542-550.

Elmi, A.A., C. Madramootoo, C. Hamel, and A. Liu. 2003. Denitrification and nitrous oxide to nitrous oxide plus dinitrogen ratios in the soil profile under three tillage systems. Biology and Fertility of Soils 38: 340-348.

Goossens, A., A. De Visscher, P. Boeckx, O. Van Cleemput. 2001. Two-year field study on the emission of N_2O from coarse and middle-textured Belgian soils with different land use. Nutrient Cycling in Agroecosystems 60: 23-34.

Grandy, A.S., T.D. Loecke, S. Parr, and G.P. Robertson. 2006. Long-term trends in nitrous oxide emissions, soil nitrogen, and crop yields of till and no-till cropping systems. Journal of Environmental Quality 35: 1487-1495.

Holdridge, L.R. 1947. Determination of world plant formations from simple climatic data. Science 105: 367-368.

Insightful Corp. 2007. S-Plus 8.0 for Windows Enterprise Developer.

IPCC. 2007. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marqui, K.B. Averyt, M. Tignor, and H.L. Miller. (eds) Cambridge University Press, Cambridge United Kingdom and New York, NY, USA, pp 996.

IPCC. 2007. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Metz, B., O.R. Davidson, P.R. Bosch, R. Dave, and L.A. Meyer. (eds) Cambridge University Press, Cambridge United Kingdom and New York, NY, USA, pp 996.

Jacinthe, P.A., and W.A. Dick. 1997. Soil management and nitrous oxide emissions from cultivated fields in southern Ohio. Soil and Tillage Research 41: 221-235.

Kaharabata, S.K., C.F. Drury, E. Priesack, R.L. Desjardins, D.J. McKenney, C.S. Tan, and D. Reynolds. 2003. Comparing measured and expert-N predicted N_2O emissions from conventional till and no till corn treatments. Nutrient Cycling in Agroecosystems 66: 107-118.

Kern, J.S., and M.G. Johnson. 1993. Conservation tillage impacts on national soil and atmospheric carbon levels. Soil Science Society of America Journal 57: 200-210.

Kessavalou, A., A.R. Mosier, J.W. Doran, R.A. Drijber, D.J. Lyon, and O. Heinemeyer. 1998. Fluxes of carbon dioxide, nitrous oxide, and methane in grass sod and winter wheat-fallow tillage management. Journal of Environmental Quality 27: 1094-1104.

Kucharik, C.J., K.R. Brye, J.M. Norman, J.A. Foley, S.T. Gower, and L.G. Bundy. 2001. Measurement and modeling of carbon and nitrogen cycling in agroecosystems of southern Wisconsin: Potential for SOC sequestration during the next 50 years. Ecosystems 4: 237-258.

Lemke, R.L., R.C. Izaurralde, and M. Nyborg. 1998. Seasonal distribution of nitrous oxide emissions from soils in the Parkland region. Soil Science Society of America Journal 62: 1320-1326.

Lemke, R.L., R.C. Izaurralde, M. Nyborg, and E.D. Solberg. 1999. Tillage and N source influence soil-emitted nitrous oxide in the Alberta Parkland region. Canadian Journal of Soil Science 79: 15-24.

Linn, D.M., and J.W. Doran. 1984. Effect of water-filled pore-space on carbon-dioxide and nitrous-oxide production in tilled and nontilled soils. Soil Science Society of America Journal 48: 1267-1272.

Malhi, S.S., R. Lemke, Z.H. Wang, and B.S. Chhabra. 2006. Tillage, nitrogen and crop residue effects on crop yield, nutrient uptake, soil quality, and greenhouse gas emissions. Soil and Tillage Research 90: 171-183.

Mosier, A.R., J.M. Duxbury, J.R. Freney, O. Heinemeyer, and K. Minami. 1996 Nitrous oxide emissions from agricultural fields: Assessment, measurement and mitigation. Plant and Soil 181: 95-108.

Mosier, A.R., J.M. Duxbury, J.R. Freney, O. Heinemeyer, and K. Minami. 1998. Assessing and mitigating N_2O emissions from agricultural soils. Climate Change 40: 7-38.

Mosier, A.R., A.D. Halvorson, C.A. Reule, X.J. Liu. 2006. Net global warming potential and greenhouse gas intensity in irrigated cropping systems in northeastern Colorado. Journal of Environmental Quality 35: 1584-1598.

Mosier, A.R., W.J. Parton, D.W. Valentine, D.S. Ojima, D.S. Schimel, and J.A. Delgado. 1996. CH_4 and N_2O fluxes in the Colorado shortgrass steppe .1. Impact of landscape and nitrogen addition. Global Biogeochemical Cycles 10: 387-399.

Mosier, A.R., W.J. Parton, D.W. Valentine, D.S. Ojima, D.S. Schimel, and O. Heinemeyer. 1997. CH_4 and N_2O fluxes in the Colorado shortgrass steppe .2. Long-term impact of land use change. Global Biogeochemical Cycles 11: 29-42.

Mutegi, J.K., L.J. Munkholm, B.M. Petersen, E.M. Hansen, and S.O. Petersen. 2010. Nitrous oxide emissions and controls as influenced by tillage and crop residue management strategy. Soil Biology and Biochemistry 42: 1701-1711.

New, M., D. Lister, M. Hulme, and I. Makin. 2002. A high-resolution data set of surface climate over global land areas. Climate Research 21: 1-25.

Ogle, S.M., F.J. Breidt, M.D. Eve, and K. Paustian. 2003. Uncertainty in estimating land use and management impacts on soil organic carbon storage for us agricultural lands between 1982 and 1997. Global Change Biology 9: 1521-1542.

Oorts, .K, R. Merckx, E. Grehan, J. Labreuche, and B. Nicolardot. 2007. Determinants of annual fluxes of CO_2 and N_2O in long-term no-tillage and conventional tillage systems in northern France. Soil and Tillage Research 95: 133-148.

Parkin, T.B., and T.C. Kaspar. 2006. Nitrous oxide emissions from corn-soybean systems in the Midwest. Journal of Environmental Quality 35: 1496-1506.

Parton, W.J., A.R. Mosier, and D.S. Schimel. 1988. Rates and pathways of nitrous-oxide production in a shortgrass steppe. Biogeochemistry 6: 45-58.

Paustian, K., O. Andren, H.H. Janzen, R. Lal, P. Smith, G. Tian, H. Tiessen, M. Van Noordwijk, P.L. Woomer. 1997. Agricultural soils as a sink to mitigate CO_2 emissions. Soil Use and Management 13: 230-244.

Perdomo, C., P. Irisarri, and O. Ernst. 2009. Nitrous oxide emissions from an Uruguayan argiudoll under different tillage and rotation treatments. Nutrient Cycling in Agroecosystems 84: 119-128.

Pinheiro, J.C., and D.M. Bates. 2000. Mixed-effects models in s and s-plus. 528pp.

Regina, K., and L. Alakukku. 2010. Greenhouse gas fluxes in varying soil types under conventional and no-tillage practices. Soil and Till Research 109: 144-152.

Robertson, G.P., E.A. Paul, and R.R. Harwood. 2000. Greenhouse gases in intensive agriculture: Contributions of individual gases to the radiative forcing of the atmosphere. Science 289: 1922-1925.

Rochette, P., D.A. Angers, G. Belanger, M.H. Chantigny, D. Prevost, and G. Levesque. 2004. Emissions of N_2O from alfalfa and soybean crops in eastern Canada. Soil Science Society of America Journal 68: 493-506.

Rochette, P., D.A. Angers, M.H. Chantigny, and N. Bertrand. 2008. Nitrous oxide emissions respond differently to no-till in a loam and a heavy clay soil. Soil Science Society of America Journal 72: 1363-1369.

Singer, M.J., and I. Shainberg. 2004. Mineral soil surface crusts and wind and water erosion. Earth Surface Processes and Landforms 29: 1065-1074.

Six, J., S.M. Ogle, F.J. Breidt, R.T. Conant, A.R. Mosier, and K. Paustian. 2004. The potential to mitigate global warming with no-tillage management is only realized when practised in the long term. Global Change Biology 10: 155-160.

Stehfest, E., and L. Bouwman. 2006. N_2O and NO emission from agricultural fields and soils under natural vegetation: Summarizing available measurement data and modeling of global annual emissions. Nutrient Cycling in Agroecosystems 74: 207-228.

Syswerda, S.P., A.T. Corbin, D.L. Mokma, A.N. Kravchenko, and G.P. Robertson. 2011. Agricultural management and soil carbon storage in surface vs. deep layers. Soil Science Society of America Journal 75: 92-101.

Syvasalo, E., K. Regina, M. Pihlatie, and M. Esala. 2004. Emissions of nitrous oxide from boreal agricultural clay and loamy sand soils. Nutrient Cycling in Agroecosystems 69: 155-165.

Teasdale, J.R., and C.L. Mohler. 1993. Light transmittance, soil temperature, and soil moisture under residue of hairy vetch and rye. Agronomy Journal 85: 673-680.

Thornwaite, C.W. 1948. An approach towards a rational classification of climate. Geography Review 38: 55-94.

Ussiri, D.A.N., R. Lal, and M.K. Jarecki. 2009. Nitrous oxide and methane emissions from long-term tillage under a continuous corn cropping system in Ohio. Soil and Tillage Research 104: 247-255.

VandenBygaart, A.J., E. Bremer, B.G. McConkey, B.H. Ellert, H.H. Janzen, D.A. Angers, M.A. Carter, C.F. Drury, G.P. Lafond, and R.H. McKenzie. 2011. Impact of sampling depth on differences in soil carbon stocks in long-term agroecosystem experiments. Soil Science Society of America Journal 75: 226-234.

Venterea, R.T., M. Burger, K.A. Spokas. 2005. Nitrous oxide and methane emissions under varying tillage and fertilizer management. Journal of Environmental Quality 34: 1467-1477.

Verbist, K., W.M. Cornelis, W. Schiettecatte, G. Oltenfreiter, M. Van Meirvenne, D. Gabriels. 2007. The influence of a compacted plow sole on saturation excess runoff. Soil and Tillage Research 96: 292-302.

Vermoesen, A., O. VanCleemput, and G. Hofman. 1996. Long-term measurements of N_2O emissions. Energy Conversion and Management 37: 1279-1284.

Vinten, A.J.A., B.C. Ball, M.F. O'Sullivan, and J.K. Henshall. 2002. The effects of cultivation method, fertilizer input and previous sward-type on organic C and N storage and gaseous losses under spring and-winter barley following long-term leys. Journal of Agricultural Science 139: 231-243.

WagnerRiddle, C., G.W. Thurtell, G.K. Kidd, E.G. Beauchamp, and R. Sweetman. 1997. Estimates of nitrous oxide emissions from agricultural fields over 28 months. Canadian Journal of Soil Science 77: 135-144.

West, T.O., C.C. Brandt, B.S. Wilson, C.M. Hellwinckel, D.D. Tyler, G. Marland, D.G.D. Ugarte, L.A. Larson, and R.G. Nelson. 2008. Estimating regional changes in soil carbon with high spatial resolution. Soil Science Society of America Journal 72: 285-294.

Xu, R., Y.S. Wang, X.H. Zheng, B.M. Ji, and M.X. Wang. 2003. A comparison between measured and modeled N_2O emissions from Inner Mongolian semi-arid grassland. Plant and Soil 255: 513-528.

CHAPTER 2

NO-TILL ADOPTION IN THE GREAT PLAINS: REGIONAL PATTERNS AND LOCAL PERSPECTIVES

Chapter Summary

Since the Dust Bowl of the 1930s, much progress was made toward development and deployment of agricultural conservation practices in the U.S. Great Plains. Over the past 30+ years, the conservation practice of no-till (NT) has been a major technological advancement and has been shown to provide many environmental benefits, including reduced soil erosion, reduced run-off, increased soil organic matter, and improved soil structure. Furthermore, NT has been shown to increase soil moisture retention, which may improve crop production in the dry regions of the Great Plains. Though many benefits have been associated with NT management, it was only used on 17% of all croplands in 2004. The objective of this study was to evaluate the factors that influence NT adoption in the Great Plains, using county-level statistics, and at the local level within this region, using household surveys. Environmental variables, climate, slope and soil texture, influenced NT adoption at the regional level. Cold and dry climates had the highest adoption rates, which was consistent with findings in the household surveys, in which NT farmers were more likely to cite soil moisture conservation as an issue. Soils more prone to erosion (i.e., steep slopes (water) or high sand (wind)) also had higher rates of adoption, indicating that farmers were likely to adopt NT to conserve soil. Components of farm structure were also important, with ownership, cropping system, and Conservation Reserve Program (CRP) enrollment influencing NT adoption. Ownership was negatively correlated with NT adoption, at both the regional and local levels. Proportion of wheat cropping was also negatively

related to NT adoption across the region. However, farmers who had land enrolled in the CRP were more likely to use NT, according to the local household surveys. Some operator characteristics and attitudes were also found to be positively associated with NT adoption. Farmers who had been on their operation for a longer period of time, were more likely to use NT across the region. Household surveys revealed information on attitudes and suggested that farmers who favored hunting on their land were more likely to use NT, as were farmers who expressed trust in the federal government. No direct measures of economic indicators were found to be significant at either the regional or household level.

Introduction

The Dust Bowl of the 1930s, perhaps the greatest environmental, economic and social disaster to strike the Great Plains region of the U.S., resulted from years of drought combined with inappropriate soil management. This soil erosion crisis exposed severe consequences of heavy plowing and low residue cover to sustained agricultural productivity and the environment, spurring a new era of conservation agriculture awareness and research (Rice 1983). Since the 1980's significant technological advances in herbicidal weed control have permitted the development of a conservation agriculture movement known as no-till (NT). The defining characteristics of NT agriculture are the absence of tillage implements, which results in minimal soil disturbance and retention of crop residues on the soil surface, and the use of a specialized seed drill that prepares a narrow seedbed through the surface residues (Hayes 1982). Herbicides are used to control weeds, and fertility amendments are typically applied to the surface of the soil (Phillips et al. 1980). Research comparing full-inversion tillage (FT) and NT management shows marked reductions in soil erosion, sometimes on the order of 90-100% (Ghidey and

Alberts 1998; Langdale et al. 1979; Meyer et al. 1999; Mickelson et al. 2001; Rhoton et al. 2002; Williams and Wuest 2011). NT management is associated with other environmental benefits including reduced run-off, improved soil structure and fertility, high soil organism biodiversity and increased soil moisture status (Fawcett et al. 1994; Karlen et al. 1994; Kladivko 2001). The benefits to the soil imparted from NT may also serve to enhance resiliency of agricultural productions systems to the effects of climate change (Delgado et al. 2011). Furthermore, NT has been proposed as an agricultural management technique to increase soil carbon storage, mitigating greenhouse gas emissions to the atmosphere (Paustian et al. 1997; Ogle et al. 2005). Though the environmental benefits of NT are not disputed, the practice is not widely adopted in the Great Plains. In 2004, NT was only practiced on about 17% of all croplands in the Great Plains, indicating that there are significant barriers to NT adoption (CTIC 2004).

Though NT is a conservation practice, farmers may choose NT for entirely different reasons. Direct costs associated with labor and fuel are reduced compared to more tillage-intensive management. Varner et al. (2011) reported labor hours associated with operating machinery on NT systems were nearly half of that required for tilled systems. According to fuel consumption estimates by West and Marland (2002), practicing NT can reduce fuel use by 80% in machine operation. Though switching to NT requires an up-front investment in equipment, machinery costs are likely reduced in the long-term (Archer et al. 2008).

Crop production advantages associated with NT have also been demonstrated and include: increased land available for crop production because more erodible lands can be used, improved timing of planting and harvesting events, and increased water use efficiency of crops (Phillips et al. 1980). Residue cover that is retained on the surface and improved soil structure in NT systems serves to conserve soil moisture, which may be a great benefit to yields in more arid climates, which occur in the Great Plains (Blevins et al. 1971; Dao et al. 1993; Tanaka and Anderson 1997). Field studies have shown that improved water use efficiency under NT allows for more intensified cropping systems in dry regions where wheat-fallow rotations are common (Peterson et al. 1996). Peterson and Westfall (2004) found that under NT management in eastern Colorado, it was possible to shift from a wheat-fallow system to diversified and intensified crop rotations, increasing average annual yields and overall profitability. Other experiments in the Great Plains have discovered similar results, showing that NT combined with intensified rotations was generally more profitable than tilled systems, with high fallow frequency (Dhuyvetter et al. 1996). Though gains in soil moisture are often discussed as a benefit to rainfed systems, irrigated croplands in this region may also benefit through reduced irrigation needs (Archer et al. 2008).

Though there are numerous benefits of NT, there are also some challenges associated with a shift to NT crop production. NT soils are slower to warm in the spring than tilled soils due to mulch cover, resulting in delayed germination and effectively shortening the growing season, and resulting in lower yields than full-inversion tillage practices in some climates (Johnson & Lowery, 1985). In a meta-analysis, Ogle et al. (2012) found that yields of corn and winter wheat were reduced in the cool, moist climates of the Upper Midwest and the eastern portion of the Great Plains. Under NT, incidence of disease or insect infestation may be higher (Phillips et al. 1980). In an Oklahoma study, NT was found to be less profitable compared to CT in a continuous winter wheat-forage system (Decker et al. 2009). The reasons for lower NT yields in this study were unclear, but investigators suggested there might be a higher incidence of disease due to monoculture cropping (Decker et al. 2009). While experimental studies have generally found increases in profits under NT (Dhuyvetter et al. 1996), these increases largely depend on several other management factors besides tillage type, such as crop rotations, pest and disease pressure, and N fertilization rates.

Previous research has indicated that factors affecting adoption of NT may vary widely, and include not only the environmental and economic factors related to crop production, but also economic capacity to adopt new technologies as well as personal characteristics, perceptions and attitudes of farmers (Ervin and Ervin 1982; Knowler and Bradshaw 2007). Economic capacity of operators may influence adoption of new technology, though the literature remains inconclusive on the direction and extent of this influence (Knowler and Bradshaw 2007). Though there is disagreement in the literature regarding the influence of wealth on conservation adoption, multiple studies have shown that wealthier households were more likely to adopt conservation practices (Carlson et al. 1990; Gould et al. 1989; Lynne et al. 1988). Though machinery maintenance and fuel costs are generally lower for NT and profits have often been found to be higher (Archer et al. 2008; Dhuyvetter et al. 1996; Varner et al. 2011), the up-front investment in NT equipment has been cited as a barrier to adoption for some farmers (Vitale et al. 2011). Changes in tillage practices may also be influenced by a farmer’s perception and acceptance of risk (Bultena and Hoiberg 1983). An economic study from Oklahoma found that NT systems were marginally more profitable than tilled systems, though yields were more variable and therefore may be less appealing to risk-averse farmers (Varner et al. 2011). Personal characteristics of farmers such as age, education level, and experience, or attitudes towards the environment and conservation may also influence the decision-making process (Knowler and Bradshaw 2007). Exogenous factors, in addition to the environmental variables previously discussed, such as crop prices, fuel prices, interest rates, etc., may additionally confound understanding of the decision-making process (FAO 2001).

The objectives of this study were to evaluate factors that influence broad, regional patterns of NT adoption in the Great Plains, using county-level statistics, and at the local level, using household surveys conducted in Colorado, Montana and South Dakota.

Methods

Regional Analysis

The regional analysis included the following USDA Land Resource Regions (LRR): Northern Great Plains Spring Wheat Region, Western Great Plains Range and Irrigated Region, and Central Great Plains Winter Wheat and Range Region (Figure 2.1) (USDA 2006).

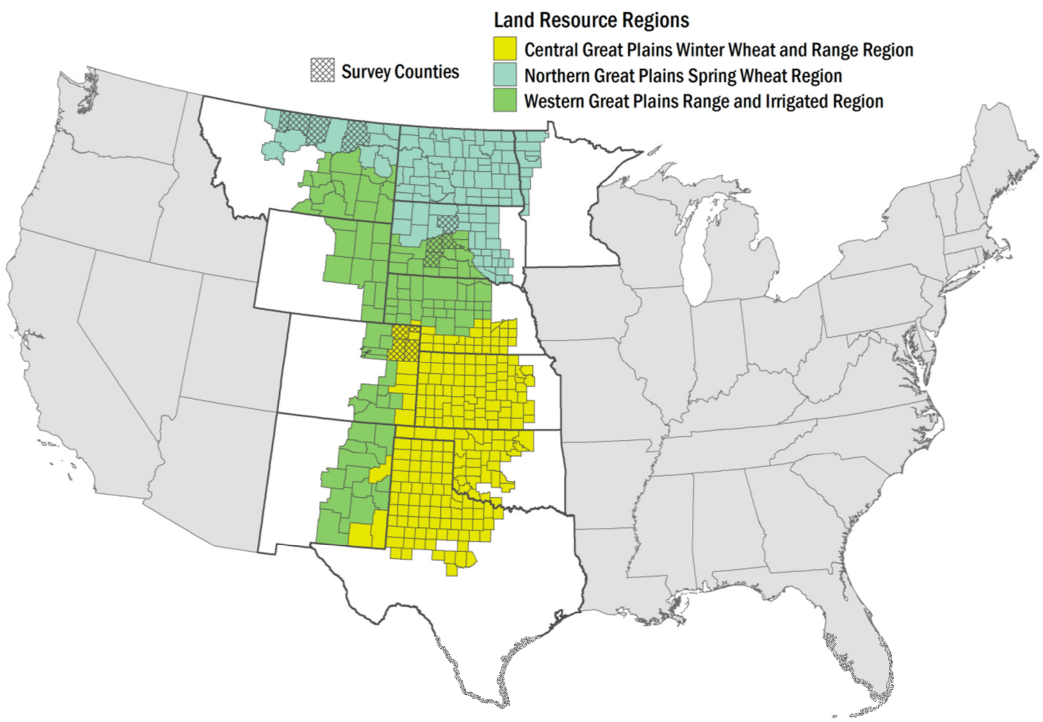

Figure 2.1. The Great Plains region, as defined by Land Resource Regions (USDA 2006) and counties where surveys were conducted.

NT adoption rates were analyzed with county-scale data from the Crop Residue Management Survey for 2004 (CTIC 2004). Several potential predictor variables were gathered from various sources for the analysis (Table 2.1).

Table 1.1. Predictor variables tested in the regional and household analyses and corresponding units, organized by variable type.

Variables	Regional Units	Household Survey Units
Environment		
Mean Annual Precipitation	cm	cm
Mean Annual Temperature	degrees C	degrees C
MAP:PET ratio	ratio	ratio
Soil Texture	% mean sand	Categorical (texture class); % mean sand (at household location)
Drainage Class*	categorical	categorical
Erodibility Index*	index	index
Slope	% mean	% mean (at household location)
Farm Structure and Crop Management		
Crop type	% area of wheat (all types)	% area of wheat (all types)
Cropland area	% of county area	% operation area
CRP enrollment	% of county area	yes/no
Fallow cropping	% area with fallow; hectares	% area with fallow
Irrigation	% irrigated	% irrigated
Livestock	# head per county	N/A
Ownership	% full-owners; % owned acres	% owned
Ownership type	% family farms	categorical (family, partnership or incorporated)
Economic		
Operation area	hectares	hectares
Asset value	$/acre	N/A
Govt payments	$/operation	yes/no
Gross Farm Income	$/operation; $/county	$; % of total household gross
Household Gross Income	N/A	$
Net Farm Income	$/county; $/acre	$
Off-farm work	days	# workers
Rent payments	$ income; $ expense	N/A
Fuel expenses	$/county	N/A
Operator Characteristics and Attitudes		
Age of principle operator	years	years
Children	N/A	#
Education	N/A	years; categorical
Operations with HS internet	#	N/A
Operations with internet	#	yes/no
Years on operation	years	years owned/leased
Community	N/A	multiple questions
Environmental attitudes	N/A	multiple questions
Environmental stewardship	N/A	multiple questions
Government Programs/Policies	N/A	multiple questions
Hunting on operation	N/A	yes/no
Information sources	N/A	open-ended; categorical
Local conservation issues	N/A	open-ended
Risk aversion	N/A	ranked

* Drainage class and erodibility index were highly correlated with soil texture, so soil texture was used in testing.

Data on crop management, farm structure and farmer social and demographic attributes were compiled from AgCensus and NASS. Most of these data came from the 2002 AgCensus

(USDA-NASS 2002), while annual cropping data were averaged from 1994-2004 from NASS to account for crops in rotations (USDA-NASS 2010). Enrollment in the Conservation Reserve program was acquired for 2004 from the Farm Service Agency (USDA-FSA 2004). Mean climate and soil properties for counties were calculated only for cropland areas in the county, by using the 2001 National Land Cover Dataset to select areas of cropland (Homer et al. 2004). Soil properties were derived from CONUS and STATSGO datasets (Miller and White 1998; USDA-NRCS 2006). Annual precipitation (MAP) and mean annual temperature (MAT) data were based on 30-yr climate normals from PRISM (Daly et al. 2008) and potential evapotranspiration (PET) data was downloaded from EOS-Webster U.S. Hydrologic Data (EOS-Webster 2008; Vorosmarty et al. 1998).

Adoption of NT was evaluated using a linear mixed-effect modeling method. The linear mixed-effect modeling method is very similar to linear regression modeling, except that it allows for both fixed and random effects (Pinheiro and Bates 2000). The general structure of the linear mixed-effect regression model is given the following equation:

$$Y = \beta_o + \beta_1 X_1 + ... + \beta_p X_p + \gamma_{state} + \gamma_{district*state} + \varepsilon \qquad (1)$$

where Y is the proportion of NT in the county; X 's are known covariates for the fixed effects; β 's are unknown regression coefficients to be estimated from the data; and $\gamma_{state}, \gamma_{district*state}$ are random effects accounting for dependence among counties within the same state and United States Department of Agriculture (USDA) districts within states. Inclusion of these random effects assumes correlation among counties within the same states and USDA districts, because government programs and services are administered to farmers through USDA district offices and states. We tested for first-order interactions among fixed effects, and random effects were evaluated to account for spatial dependencies between counties in the same district and state.

The distribution of the response variable, proportion of NT, was non-normal with a right-skewed distribution, and was therefore transformed using a fourth root transformation. A stepwise model fitting procedure was used and all variables were evaluated at an alpha level of 0.05. Models were compared with Akaike Information Criterion (AIC) by selecting the model with the lowest AIC when all variables met the alpha level requirement (Akiake 1973). All analyses were conducted in TIBCO Spotfire S+ 8.1 (TIBCO Software Inc. 2008).

Household Survey Analysis

Household surveys were conducted in 2005 in Colorado (Logan, Sedgwick, Washington and Yuma counties), Montana (Hill and Valley counties), and South Dakota (Dewey, Haakon, Jackson, and Stanley counties) (Figure 1.1). Counties were chosen by qualitative methods that prioritized neighboring or nearby counties that were representative of the region and also had variability in adoption rates among them. Potential participants were chosen at random from local telephone directories and asked preliminary questions to determine if they were eligible to participate in the survey. The main requirement was that they were the principle operator of a farm that produced crops, though they may have a mixed livestock-cropland operation. Most of the surveys were conducted in the operators' homes, although surveys were also conducted in nearby towns if necessary. Locations for the farm households were recorded either by GPS point or by rural addresses.

Participants were asked to give several basic characteristics of their operation, such as size, ownership, and proportion of dry land vs. irrigated, as well as detailed cropland management by cropping system, including tillage practices (see Appendix 1). Demographic data was collected from each operator, and several questions were asked that targeted socioeconomic and attitudinal characteristics. Question types also varied, with some being short responses, yes/no, ranked, close-ended and open-ended. NT adoption was coded as a binary 0/1 response, in which a 1 response indicated that the operator was using NT on at least some portion of the operation and a 0 response indicated that NT was not used. There were a total of 60 household surveys for CO, MT and SD combined, however, only 41 households were used in the analysis, due to data gaps. Of those 41 households, 18 were using NT on at least some portion of their farm at the time of the survey.

Binary logistic regression was chosen to evaluate NT adoption in the household survey data because it can assess a binary response variable, and independent variables that may be continuous and/or categorical. The response variable in a binary logistic regression can be expressed as a probability (π) where $Y_i = 1$ indicates an operator is using NT and $Y_i = 0$ indicates that they are not using NT:

$$\Pr ob(\mathrm{Y}_i = 1) = \pi_i \qquad (2)$$

$$\Pr ob(\mathrm{Y}_i = 0) = 1 - \pi_i$$

The general multiple logistic regression model is given in the equation below, where π is the probability of NT adoption, X represents explanatory variables and β represents the regression coefficients:

$$\pi_i = \frac{e^{(\beta_0 + \beta_1 \mathrm{X}_{1i} + \beta_2 \mathrm{X}_{2i} + \ldots + \beta_k \mathrm{X}_{ki})}}{1 + e^{(\beta_0 + \beta_1 \mathrm{X}_{1i} + \beta_2 \mathrm{X}_{2i} + \ldots + \beta_k \mathrm{X}_{ki})}} \qquad (3)$$

A stepwise model fitting procedure was used in which variables were selected with an alpha level of 0.1. Models were compared using maximum log-likelihood estimation. The binary logistic regression analysis was conducted with MINITAB software (MINITAB 2000).

A short follow-up telephone survey was conducted in 2010-2011 for the same households, but with the purpose of asking direct questions about influences on tillage choice (see Appendix 2). The questions were mostly ranked-response questions with opportunity for operators to describe how a particular factor affected their tillage choices. For questions about how particular factors influence tillage decisions, responses were ranked as follows: not at all, very little, some, a great deal, or the primary influence. We only completed follow-up surveys for 25 households from the original survey set, so we did not use these data in modeling, but rather reported trends in the responses and used the responses to qualitatively inform discussion of model results.

Results and Discussion

Model Results

Distribution of NT was highly variable over the Great Plains region, with higher adoption rates in the northern and central portions of the region, and much lower rates in the northeastern and southern regions (Figure 2.2). Statistical analyses indicate that several factors influenced adoption of NT in the Great Plains (Table 2.2). Significant fixed effects in the model were mean annual temperature (MAT), MAP:PET ratio, mean sand percent, mean slope percent, years on operation, proportion of wheat acres in county, and proportion full-owner operations by area. Interaction terms in the model were MAT * MAP:PET ratio and mean sand * mean slope. The MAP:PET ratio is commonly used as an index of dry to humid conditions, where ratios less than 1 designate dry climates and ratios greater than 1 designate humid climates (Holdridge 1947). To interprate the interaction terms, we graphed a regional prediction of the model, using regional means for non-interaction terms, and using the 1^{st} and 3^{rd} quantiles to represent low and high values for interaction terms (Figures 2.3 and 2.4).

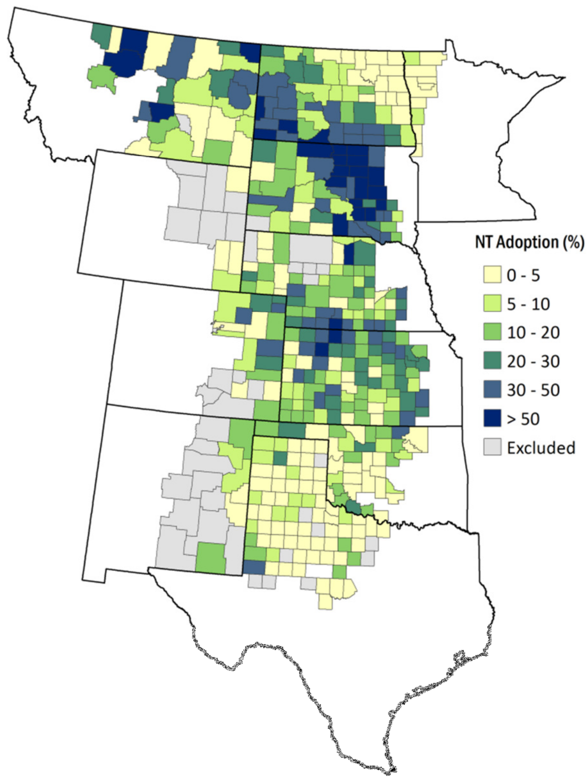

Figure 2.2. NT adoption rates as percent of total cropland area per county, estimated by CTIC (CTIC 2004).

Table 2.2. Linear mixed-effect model for adoption of NT in counties of the Great Plains.

Predictor	**β**	**SE β**	***p***
Intercept	0.65	0.23	0.005
Mean Temperature	-0.04	0.017	0.020
MAP:PET[1] Ratio	-0.75	0.27	0.005
Mean Sand Percent	0.005	0.0016	0.003
Mean Slope Percent	0.159	0.04	0.001
Years on operation	0.015	0.004	0.0004
Proportion total wheat acres	-0.154	0.056	0.007
Proportion full-owner operation area	-0.188	0.095	0.049
Mean Temperature * MAP:PET[1]	0.048	0.023	0.037
Mean Sand * Mean Slope	-0.003	0.001	0.006
Random effect: state		0.049	
Random effect: district in state		0.103	

1. MAP:PET = mean annual precipitation to potential evapotranspiration ratio

While MAT and MAP:PET were both negatively associated with NT adoption, their interaction term was positive. The results suggest that cold, dry climates would have the highest rates of adoption, and warm, wet climates the lowest (Figure 2.3).

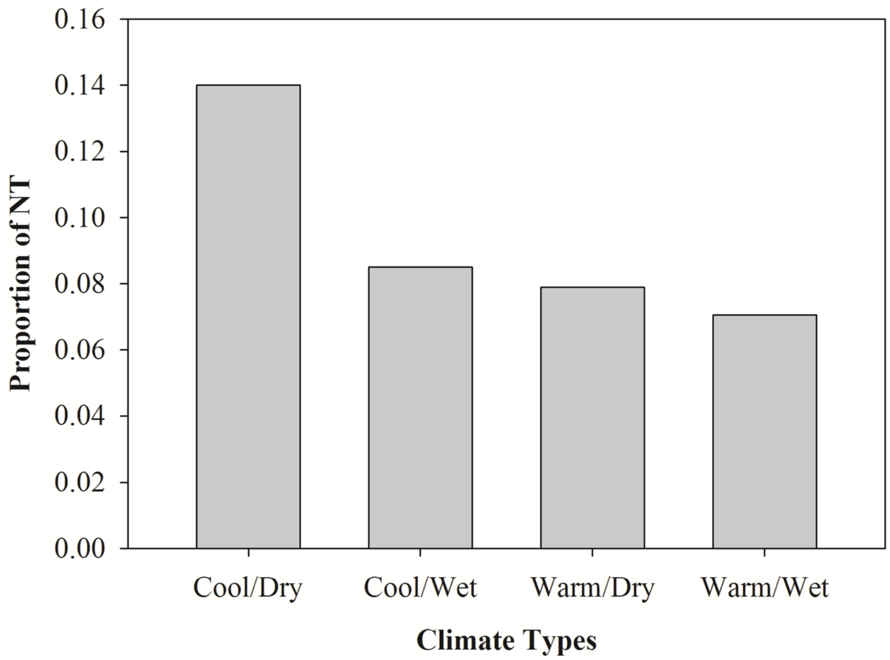

Figure 2.3. Regional predictions showing influence of interaction terms mean temperature (MAT) and MAP:PET ratio. Predictions were estimated using mean regional values for non-interaction terms and 1st and 3rd quantiles for interaction terms. Cool (MAT = 7 C, Warm (MAT = 14 C), Dry (MAP:PET ratio = 0.5), Wet (MAP:PET ratio = 0.7). Standard deviations were calculated, but were too small to show on the graph.

Mean sand content and mean slope percent had positive relationships with NT adoption, however, the interaction term for mean sand content and mean slope percent was negative. Predictions at the regional level suggested that NT adoption was higher in counties with low mean sand contents and steeper mean slopes or high sand contents, while low sand and low slope counties had lower rates (Figure 2.4).

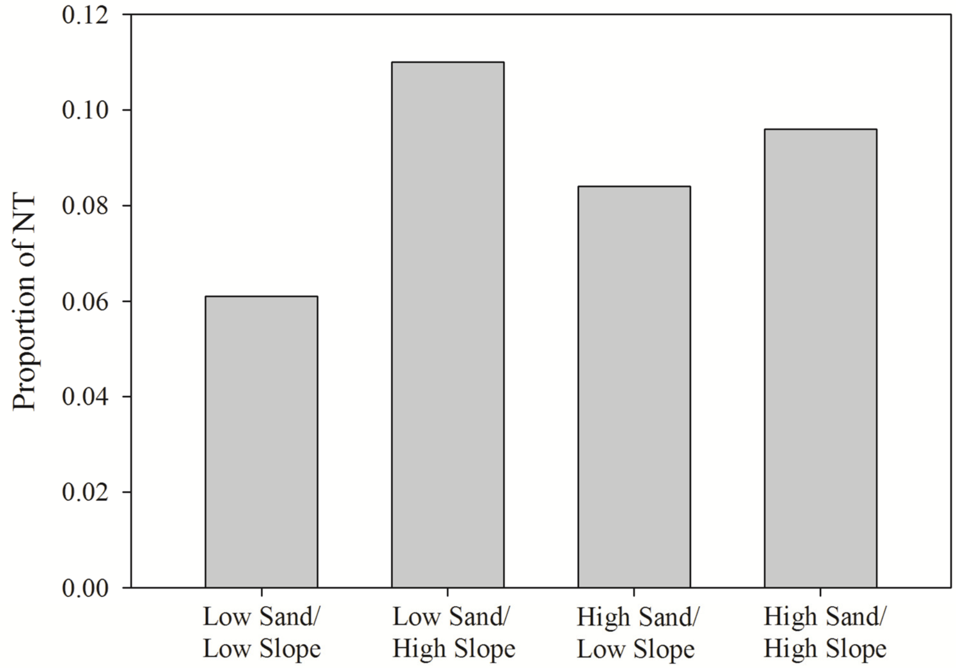

Figure 2.4. Regional predictions showing influence of interaction terms, soil sand content and percent slope. Predictions were estimated using mean regional values for non-interaction terms and 1st and 3rd quantiles for interaction terms. Low sand = 24% sand, High Sand = 44% sand, Low Slope = 0.8%, High Slope = 1.8%. Standard deviations were calculated, but were too small to show on the graph.

The number of years of operation was positively associated with NT adoption, indicating that farmers that had been farming longer were more likely to adopt NT. Conversely, proportion of full-owner operation area and proportion of wheat acres in the county were negatively associated with NT use in the county. The model results suggest that counties with high operation ownership and high proportion of wheat acres in the county, would have less NT.

NT adoption, along with 95% confidence intervals, was predicted for counties in the Great Plains region using county values for each of the predictor variables (Figure 2.5). The model predicted similar patterns of adoption as the CTIC data, with higher rates in the central and northern parts of the region and lower rates in the northeastern and southern portions of the region (Figure 2.2, Figure 2.5). The model predicted high rates of adoption (> 50%) in north-central SD, but failed to predict high rates of adoption found in other parts of the region, which were reported in the CTIC data. Overall, the model under-predicted NT adoption for the region with a mean rate of 13.8%, whereas CTIC reported a mean of 17%. Under-prediction may indicate that other dynamics were driving higher rates of NT adoption in some parts of the region, that were not captured in this analysis.

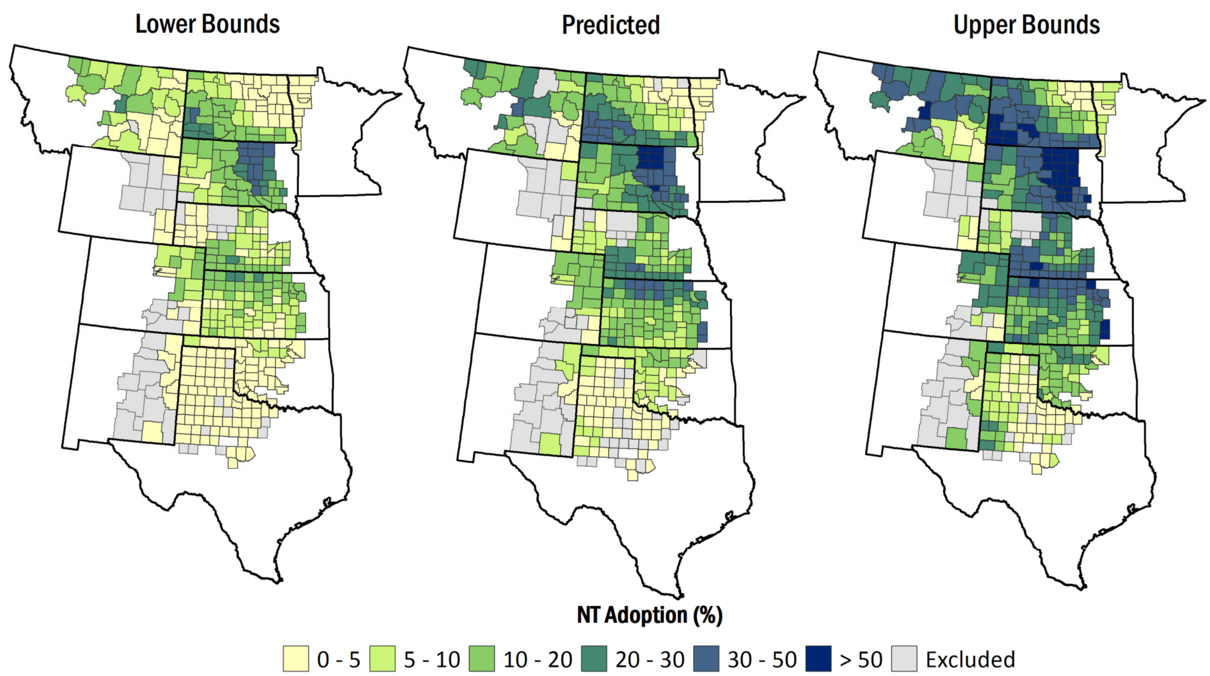

Figure 2.5. NT adoption rates predicted by the model for counties in the Great Plains with 95% confidence intervals.

Results of the binary logistic regression analysis indicated that multiple variables affected NT adoption at the household level (Table 2.3). Proportion of owned land was negatively associated with NT adoption, suggesting that operators who owned more of their land were less likely to use NT. Conversely, operators were more likely to use NT if they were enrolled in CRP, trusted the federal government, hunted on their land for recreation, or cited soil moisture conservation as a local conservation issue.

Table 2.3. Binary logistic model for adoption of NT among households in the Great Plains.

Predictor	**β**	**SE β**	***p***	**Odds Ratio**
Constant	-3.98	2.46	0.105	
Proportion Owned Land	-7.46	3.09	0.016	0
Enrolled in CRP	4.42	1.68	0.008	82.76
Trusts Federal Government	1.22	0.75	0.104	3.39
Hunts on Land	2.77	1.47	0.059	15.96
Moisture Conservation	2.46	1.22	0.045	11.67
Overall Model Evaluation	X^2	***p***		
Log-Likelihood Ratio	-12.44	0		
Goodness-of-Fit Test				
Hosmer-Lemeshow	7.13	0.52		

To compare the model predictions with actual responses from the surveys, we calculated predicted probability of NT adoption for unique combinations of the categorical responses and mean ownership rates (Table 2.4). The model predicted the more common combinations of responses quite well, while predictions for combinations with only one response were far less accurate.

When asked how certain factors influence tillage choices in the follow-up survey, the majority of farmers responded that fuel prices, yields and soil type factored into their tillage choice, while drainage and slope had little influence (Table 2.5). The influence of erosion and weather was mixed among operators. Though responses regarding erosion were mixed in the whole group, five out of nine NT operators said that erosion was a primary influence on tillage choice, while no operators using other tillage practices than NT cited erosion as a primary influence (Table 2.5). Responses on the influence of soil type were very similar between NT and non-NT operators. Six out of ten operators who use other tillage cited that yields have a great deal of influence or are the primary influence, while only three (of 9) NT operators responded that yields had a great deal of influence and none claimed it was the primary influence.

Table 2.4. Household survey responses for predictor variables and NT adoption, and predicted probability of NT adoption from the binary logistic regression analysis.

Number of Farms	Average Proportion of Owned Land	Enrolled in CRP[1]	Trusts Federal Government[2]	Hunts on Land[1]	Moisture Conservation[1]	Actual NT Adoption[1]	Predicted Probability of NT Adoption
1	0.43	1	1	0	0	0	0.17
1	0.71	1	1	1	1	0	0.83
1	0.67	1	2	0	0	0	0.11
1	1.00	1	2	1	0	0	0.14
1	1.00	1	3	1	1	0	0.86
1	0.70	0	3	1	1	1	0.43
1	0.58	1	1	0	1	1	0.45
1	0.53	1	1	1	0	1	0.62
1	0.90	1	2	1	0	1	0.25
1	0.67	1	3	1	0	1	0.87
2	0.84	0	1	0	1	0	0.00
2	0.61	0	1	1	1	0	0.11
2	0.80	0	2	1	0	0	0.01
2	0.84	0	3	1	1	0	0.21
2	0.81	1	1	0	1	0	0.13
2	0.18	0	2	1	1	1	0.91
2	0.62	1	2	1	1	1	0.97
4	0.79	0	1	1	0	0	0.00
4	0.87	1	1	1	0	0	0.11
4	0.63	1	3	1	1	1	0.99
5	0.60	1	1	1	1	1	0.92
Totals							
41	0.70	26	1.66	34	25	18	0.45
				Proportion of sample using NT		0.44	

1. A value of 1= yes response and value of 0=no response.
2. Values representing trust in federal government were ranked as follows: 1=Disagree, 2=Neutral, 3=Agree

Table 2.5. Responses to a short survey asking farmers about influences on their tillage decisions. Numbers represent counts of responses in each category.

	Drainage		**Slopes**		**Erosion**		**Weather**		**Soil Type**		**Yields**		**Fuel Prices**	
Response	*NT*	*Other*	*NT*	*Other*	*NT*	*Other*	*NT*	*Other*	*NT*	*Other*	*NT*	*Other*	*NT*	*Other*
Not at all	5	8	3	5	0	4	1	3	2	2	1	1	2	2
Very little	0	1	4	4	1	1	4	0	1	1	3	0	0	3
Some	5	2	3	0	3	1	1	6	3	2	2	3	2	2
A great deal	1	1	1	2	0	4	4	2	3	4	3	5	7	4
Primary influence	0	0	1	1	5	0	2	1	4	2	0	1	1	2
Total Responses	11	12	12	12	9	10	12	12	13	11	9	10	12	13

Environmental Variables

Analysis of NT use in the Great Plains region revealed that the key determinants for adoption included a combination of environmental variables, farm structure and cropping systems, and operator characteristics and attitudes. Environmental factors associated with variation in NT adoption rates in the Great Plains were climate, soil texture and slope. There may be several ways in which these environmental variables are affecting farm management decisions. Previous research has suggested that crop yields may change after a change in tillage practice, depending on climate region. In a meta-analysis by Ogle et al. (2012), crop yields for winter wheat and spring wheat were predicted to increase or not change in cool, dry climates after a change from conventional tillage to NT. The results of the present analysis found that NT rates were highest in cool and dry climates, which is consistent with the experimental research showing NT benefits to soil moisture in dry climates and the findings on yields from Ogle et al. (2012). Farmers in the household analysis who cited soil moisture conservation as a local conservation issue were more likely to adopt NT than those who cited other concerns, even soil erosion. Soil moisture conservation is an issue for farmers throughout the Great Plains. However, given that the question about local conservation issues was posed as an open-ended question, it may have been a primary concern to those farmers relative to other issues. Given that increased soil moisture conservation is a benefit of NT adoption (Blevins et al. 1971), it may also imply that farmers understand the effect that NT has on soil moisture and that played a role in their decision to adopt the practice. Though there may be many reasons for higher adoption rates in cool, dry climates than in warm, dry climates, there may be an additional soil moisture effect from greater and more uniform snow capture due to more surface residues under NT (Qui et al. 2011). At the regional level, cool, wet climates of the Great Plains had the second highest rates of adoption. Ogle et al. (2012) estimated that yields for corn and wheat would likely decrease in those regions, suggesting either that climate is not the only factor driving yield changes in conjunction with tillage changes, or yield is not the only consideration in tillage decisions. In the follow-up surveys, no NT farmers cited yields as being a primary influence in their tillage decisions. Furthermore, the Ogle et al. (2012) analysis only captures single crop yield changes relative to tillage changes, but not other cropping system changes that may be taking place in conjunction with adoption of NT.

In addition to climate, we found that soil texture and slope interacted to influence NT adoption. Specifically, counties with soils that had low sand and steeper slopes were predicted to have the highest rates of adoption, and counties with soils that had low sand and gentler sloping landscapes tended to have the lowest adoption rates. Soils with high sand contents, regardless of slope, also had higher rates of adoption. Soils with low sand content and steep slopes are at higher risk of water erosion, while soils with high sand contents on all slopes are more susceptible to wind erosion (Plaster 1997). Higher rates of adoption on these landscapes may suggest that farmers are using NT to conserve soil, since NT practices maintain high residue cover and improve soil structure, leading to significant reductions in erosion compared to intensive tillage practices (Shelton et al. 1992; Lyon and Smith 1992). Low adoption predictions in counties with soils that had low sand contents and gentle slopes may be due to physical constraints, such as poor drainage conditions, or a lack of impetus for erosion control through improved tillage practices. Soil texture and slopes were not predictors of adoption among surveyed households, perhaps due to the small sample size or limitations in characterizing soil texture across an entire farm. However, in the follow-up surveys, many farmers ranked soil type as being important, regardless of tillage practice. Anecdotes from the surveys did suggest that soil texture was important, but the way soil texture influenced their decisions seemed to vary widely. Responses from the follow-up survey ranked slopes as having little influence on tillage choice, though 5 out of 9 NT adopters cited erosion as a primary influence while no farmers using other tillage practices ranked it as high.

Farm structure and cropping systems

In both the regional and household analyses, ownership was found to be negatively associated with NT adoption. Some previous studies have shown ownership to be positively associated with adoption of conservation practices, such as terracing or installation of grassed waterways, which require a long-term investment in the land (Ervin 1982; Featherstone and Goodwin 2010). In contrast, tillage equipment can be easily transferred across operations. A previous analysis of minimum tillage also found that adoption was lowest among full-owner operators and proposed that a practice such as minimum tillage was more associated with the operator than the landowner (Lee and Stewart 1983). In addition, Ervin (1982) found no difference between conservation tillage adoption rates among Missouri farmers who owned or rented their cropland. The overall picture of farm tenure in the Great Plains during 2002 showed the majority of farms in cropland being operated by full-owners (52%), however the average size of full-owner farms was much smaller than farms operated by part-owners (406 ha [1004 ac] and 1214 ha [3001 ac] respectively) (USDA-NASS 2002). The surveys showed similar patterns, with NT adopters owning 58% of their operation, while non-adopters owned 79% of their operation. While there might be many factors that relate tenure to NT adoption, the difference in operation size might suggest that part-owners operate on a larger-scale and find the efficiency of NT beneficial or realize greater profits when marginal financial benefits of NT are aggregated over large operations. However, it should be noted that operation size was not significant in the regional or household analyses.

We also found that cropping system was important in predicting NT adoption at the regional level. Counties with higher proportions of wheat (all types combined) compared to other crops, had lower rates of NT adoption. Wheat is a predominant crop in the Great Plains region and over the whole region comprised 55% of total crop area on average between 1994 and 2004 (USDA-NASS 2004). We averaged total area of wheat over ten years to account for crop rotations, therefore counties with a high proportion of wheat were likely growing wheat extensively and frequently. This could indicate that continuous wheat cropping systems were common in those counties. Monoculture cropping can be problematic in NT systems, sometimes leading to lower yields than conventional tillage systems or to prohibitively higher pesticide costs (Decker et al. 2009; Dick and van Doren 1985; Epplin et al. 1993). Reduced yields in monoculture NT systems might be due to soil type or drainage conditions, increased pest problems that cannot be controlled with pesticide alone, disease, or delayed emergence due to lower soil temperatures (Dick and van Doren 1985; Decker et al. 2009). Though yield reductions under monoculture NT cropping are often unexplained, it has been shown that crops in rotation under NT often do not have lower yields when grown under the same conditions (Dick and van Doren 1985). Monoculture winter wheat cropping is pervasive in the southern portion of the Great Plains region, which may explain why NT adoption is especially low (Vitale et al. 2011). Popularity of continuous winter wheat in this region is driven by climate, lack of markets for alternative crops, and the need for winter livestock forage (Vitale et al. 2011). While cropping system was not significant at the local level, conversations with farmers provided some insights on the ties between cropping systems and tillage choice for further investigation. For example, one farmer in SD switched from conventionally tilled spring wheat to NT winter wheat to avoid timing issues with planting during wet springs.

In the household analysis, enrollment in the Conservation Reserve Program was associated with higher rates of NT adoption. Enrollment in CRP and use of NT may indicate that farmers were motivated by a conservation ethic. Farmers enrolled in the CRP may also be more aware of conservation issues on their farms, such as soil erosion, and previous research has found that farmers who adopt conservation practices with conservation as the motivation must first need to perceive a problem (Camboni and Napier 1993; Ervin and Ervin 1982).

Operator Characteristics and Attitudes

At the regional level, we found that as the number of years farmers have been on their operations increased, the adoption of NT also increased. Similarly, success of NT farming has also been attributed to greater management skills of the practitioners (Phillips et al. 1980), and skill is often gained through experience. A study in Illinois also found that farmers with more experience were more likely to adopt practices for environmental benefit (Ervin and Ervin 1982). Other variables that might indicate experience, like age and education level, have previously been described as important in predicting conservation behavior (Knowler and Bradsahw 2007), but were not significant in this analysis. The lack of influence of education on NT adoption may be because gaps in education have narrowed across the farming community in the last few decades (Carlson et al. 1990), which is consistent with the households surveys, in which most participants had a high school education or higher.

Variables relating to attitudes or values were not available for testing at the regional level, but the household surveys revealed some influence of attitudes on NT adoption. Farmers who hunted on their land were more likely to adopt NT than those who did not. There is a practical relationship between NT and hunting, as no-till fields offer better fall and winter habitat for wildlife compared to conventionally managed fields (Warburton and Klimstra 1984).

Trust in federal government was also a driver for NT adoption in the household surveys. Though similar questions were asked about other levels of government, only the federal level was found to be significant. Camboni and Napier (1993) surveyed farmers in Ohio and discovered that NT adopters were more frequent participants in government programs. This is likely because many farm programs sponsored by the federal government are administered through local USDA-NRCS extension offices. Aside from administering farm programs, local USDA offices offer educational resources and advice on conservation practices, and often develop strong ties with the local agricultural community. Farmers who place more trust in the federal government may have stronger relationships with their local extension office and have access to more information and advice on NT.

Economic Variables

Research in other regions of the U.S. has tied economic variables to adoption of conservation practices (Carlson et al. 1990; Knowler and Bradshaw 2007). Though some of the variables that were found to be significant in this analysis may indicate an economic impact of NT in crop production systems (climate, ownership, and wheat cropping), more direct economic measures were not found to be significant, including income, government payments, expenses and assets.

Summary and Conclusions

Environmental conditions contributed greatly to tillage management decisions through soil texture, slope, and climate. Given that NT adoption was highest in counties with greater proportions of soils susceptible to erosion, the results suggest that farmers using NT in these counties are likely motivated to some degree by soil conservation. NT adoption was predicted to be highest in cold, dry counties, which was consistent with responses in the household surveys that cited soil moisture conservation as a major concern. Decisions to adopt NT on erodible soils and in dry climates were consistent with known interactions of NT with the environment. Furthermore, farmers who were on the same operation longer were more likely to adopt NT, which likely indicates a deeper understanding of the influence of these environmental factors on production and enough experience to apply the new practice effectively.

Characteristics of farms influenced NT adoption through cropping systems, land tenure and CRP enrollment. Regions of the Great Plains where wheat was grown extensively and frequently, perhaps indicating monoculture cropping, had some of the lowest rates of adoption. Similarly, where farms were operated primarily by full-owners, NT rates were lower. Results of the household survey analysis were consistent with this finding. The household surveys indicated that NT adopters may have prior experience with conservation, through the Conservation Reserve Program.

Attitudinal characteristics could not be assessed at the regional level, but attitudes did seem to affect NT adoption according to the household surveys. NT farmers tended to hunt on their lands, which indicates a practical link with the importance of wildlife habitat provided by NT, but perhaps also a positive attitude toward conservation. In addition, NT farmers also expressed more trust in the federal government than farmers using other forms of tillage, which may suggest stronger ties to local federal government offices or participation in farm programs. The results of this study suggest that farmers use NT because they value the effects of this practice for reducing soil erosion, as well as enhancing crop production. Therefore, farmers who use NT in this region likely understand its benefits and its challenges, demonstrating the importance of knowledge in adoption of new practices.

Increasing the adoption of NT may involve education on the benefits of NT, as well as information specific to local cropping systems and environmental conditions. In addition, farmers may be influenced to some degree by positive attitudes toward conservation and wildlife. Results also suggest that a change in tillage practice does not happen in isolation from other management practices on the farm. While our analysis showed NT adoption was limited in a particular cropping system, successful NT farmers may be changing their cropping systems in conjunction with a shift to NT, which would be consistent with field studies of crop rotations and tillage interactions. The underlying reasons for the negative relationship between land tenure and NT adoption were unclear, though they could relate to efficiency associated with NT or other economic factors that were not detected with the variables that were tested. In any case, the relationship is compelling and may further demonstrate that NT is viewed as a beneficial practice to farmers who do not necessarily have long-term ties to the land.

Acknowledgements

We would like to thank the students who traveled to CO, MT, and SD and spent hours on the phones to interview farmers: David Bartecchi, Heather Novak, Amy Samuelson, Andrea Akers, Chris Anderson, Michael Brydge, Michael Conway and Ben Jewell. We would also like to thank Dr. Gary Peterson for advice on survey design and for reviewing this manuscript, and Ram Gurung for statistical support.

References

Aase, J.K., and G.M. Schaefer. 1996. Economics of tillage practices and spring wheat and barley crop sequence in the Northern Great Plains. Journal of Soil and Water Conservation. 51: 167-170.

Akiake, H., 1973. Information theory and an extension of the maximum likelihood principle, Second International Symposium on Information Theory, Tsahkadsor, Armenian SSR, Hungary, pp. 267-281.Blevins, R.L., D. Cook, S.H. Phillips, and R.E. Phillips. 1971. Influence of no-tillage on soil moisture. Agronomy Journal 63: 593-596.

Bultena, G.L., and E.O. Hoiberg. 1983. Factors affecting farmers' adoption of conservation tillage. Journal of Soil and Water Conservation. 38(3): 281-284.

Camboni, S.M., and T.L. Napier. 1993. Factors affecting use of conservation farming practices in east central Ohio. Agriculture, Ecosystems & Environment 45: 79-94.

Carlson, J.E., B. Schnabel, C.E. Beus, and D.A. Dillman. 1990. Conservation attitudes and behaviors of farmers in the Palouse and Camas prairies: 1976-1990. Journal of Soil and Water Conservation 49: 493-500.

CTIC. 2004. Crop Residue Management Survey, 2004. Conservation Tillage Information Center, West Lafayette, IN, US.

Daly, C., M. Halbleib, J.I. Smith, W.P. Gibson, M.K. Doggett, G.H. Taylor, J. Curtis, P.P. Pasteris. 2008. Physiographically sensitive mapping of climatological temperature and precipitation across the conterminous United States. International Journal of Climatology 28: 2031-2064.

Dao, T.H. 1993. Tillage and winter wheat residue management effects on water infiltration and storage. Soil Science Society of America Journal 57: 1586-1595.

Decker, J.E., F.M. Epplin, D.L. Morley, and T.F. Peeper. 2009. Economics of five wheat production systems with no-till and conventional tillage. Agronomy Journal 101: 364-372.

Delgado, J. A., P.M. Groffman, M.A. Nearing, T. Goddard, D. Reicosky, R. Lal, N.R. Kitchen, C.W. Rice, D. Towery, and P. Salon. 2011. Conservation practices to mitigate and adapt to climate change. Journal of Soil and Water Conservation 66: 118A-129A.

Dhuyvetter, K., C. Thompson, C. Norwood, and A. Halvorson. 1996. Economics of dryland cropping systems in the Great Plains: a review. Journal of Production Agriculture (USA) 9: 216-222.

Dick, W.A., and D.M.V. Doren. 1985. Continuous tillage and rotation combinations effects on corn, soybean, and oat yields. Agronomy Journal 77: 459-465.

EOS-Webster, Earth Science Information Partner, University of New Hampshire, U.S. Hydrologic Data (GHAAS). http://eos-webster.sr.unh.edu/data_guides/ghaas_usa_dg.jsp Created 1998.

Epplin, F., D. Beck, E. Krenzer Jr, and W. Heer. 1993. Effects of planting dates and tillage systems on the economics of hard red winter wheat production. Journal of Production Agriculture 6: 57–62.

Ervin, C. A., and D.E. Ervin. 1982. Factors affecting the use of soil conservation practices: hypotheses, evidence, and policy implications. Land Economics 58: 277-292.

Ervin, D.E. 1982. Soil erosion control on owner-operated and rented cropland. Journal of Soil and Water Conservation 37: 285-288.

FAO. 2001. The Economics of Conservation Agriculture. Food and Agriculture Organization, United Nations, Rome, Italy. http://www.fao.org/DOCREP/004/Y2781E/y2781e00.htm#toc

Fawcett, R., B. Christensen, and D. Tierney. 1994. The impact of conservation tillage on pesticide runoff into surface water: a review and analysis. Journal of Soil and Water Conservation 49: 126-135.

Featherstone, A.M., and B.K. Goodwin. 1993. Factors influencing in a farmer's decision to invest in long-term conservation improvements. Land Economics 69: 67-81.

Ghidey, F., and E.E. Alberts. 1998. Runoff and soil losses as affected by corn and soybean tillage systems. Journal of Soil and Water Conservation 53: 64-70.

Gould, B.W., W.E. Saupe, and R.M. Klemme. 1989. Conservation tillage: the role of farm and operator characteristics and the perception of soil erosion. Land Economics 65: 167-182.

Hayes, W.A. 1982. Minimum-Tillage Farming. No-Till Farmer, Inc., Brookfield, Wisconsin, USA. pp

Holdridge, L.R. 1947. Determination of world plant formations from simple climatic data. Science 105: 367-368.

Homer, C. C. Huang, L. Yang, B. Wylie and M. Coan. *Development of a 2001 National Landcover Database for the United States.* Photogrammetric Engineering and Remote Sensing, Vol. 70, No. 7, July 2004, pp. 829-840. 2004.

Johnson, M.D., and B. Lowery. 1985. Effect of three conservation tillage practices on soil temperature and thermal properties. Soil Science Society of America Journal 49: 1547-1552.

Karlen, D., N. Wollenhaupt, D. Erbach, E. Berry, J. Swan, N. Eash, and J. Jordahl. 1994. Long-term tillage effects on soil quality. Soil and Tillage Research 32: 313-327.

Kladivko, E.J. 2001. Tillage systems and soil ecology. Soil and Tillage Research 61: 61–76.

Knowler, D., and B. Bradshaw. 2007. Farmers' adoption of conservation agriculture: a review and synthesis of recent research. Food Policy 32: 25-48.

Langdale, G., A. Barnett, R. Leonard, and W. Fleming. 1979. Reduction of soil erosion by the no-till system in the Southern Piedmont. Transactions of the ASAE 22: 82–86.

Lee, L.K., and W.H. Stewart. 1983. Landownership and the adoption of minimum tillage. American Journal of Agricultural Economics 65: 256–264.

Lynne, G.D., J.S. Shonkwiler, and L.R. Rola. 1988. Attitudes and farmer conservation behavior. American Journal of Agricultural Economics 70: 12-19.

Lyon, D.J., and J.A. Smith. 1992. Wind Erosion Control. *In* Conservation tillage systems and management: crop residue management with no-till, ridge-till, mulch-till. Ames, IA: MidWest Plan Service, Agricultural and Biosystems Engineering Dept., Iowa State University. p. 12-14.

Meyer, L., S. Dabney, and C. Murphree. 1999. Crop production systems to control erosion and reduce runoff from upland silty soils. Transactions of the ASAE 42: 1645-1652.

Mickelson, S.., P. Boyd, J. Baker, and S. Ahmed. 2001. Tillage and herbicide incorporation effects on residue cover, runoff, erosion, and herbicide loss. Soil and Tillage Research 60: 55-66.

Miller, D.A., and R.A. White. 1998. A conterminous United States multilayer soil characteristics dataset for regional climate and hydrology modeling. Earth Interactions 2: 1-26.

MINITAB. 2000. MINITAB Inc., Release 13.

Ogle, S.M., F.J. Breidt and K. Paustian. 2005. Agricultural management impacts on soil organic carbon storage under moist and dry climatic conditions of temperate and tropical regions. Biogeochemistry 72:87-121.

Ogle, S.M., A. Swan, and K. Paustian. 2012. No-till management impacts on crop productivity, carbon input and soil carbon sequestration. Agriculture, Ecosystems and Environment. In press.

Paustian, K., O. Andren, H. Janzen, R. Lal, P. Smith, G. Tian, H. Tiessen, M. Noordwijk, and P. Woomer. 1997. Agricultural soils as a sink to mitigate CO2 emissions. Soil Use and Management 13: 230–244.

Peterson, G.A., A.J. Schlegel, D.L. Tanaka, and O.R. Jones. 1996. Precipitation use efficiency as affected by cropping and tillage systems. Journal of Production Agriculture 9: 180-186.

Peterson, G.A., and D.G. Westfall. 2004. Managing precipitation use in sustainable agroecosystems. Annals of Applied Biology 144: 127-138.

Phillips, R.E., R.L. Blevins, G.W. Thomas, W.W. Frye, and S.H. Phillips. 1980. No-tillage agriculture. Science 208: 1108-1113.

Pinheiro, J.C., and D.M. Bates. 2000. Mixed-effects models in s and s-plus. 528pp

Plaster, E.J. 1997. Soil Science and Management, Third Edition. Delmar Publishers, Albany, NY, USA. p. 314-336.

Qiu, H., D.R. Huggins, J.Q. Wu, M.E. Barber, D.K. McCool, and S. Dun. 2011. Residue management impacts on field-scale snow distribution and soil water storage. Transactions of the ASABE 54: 1639-1647.

Rhoton, F.E., M.J. Shipitalo, and D.L. Lindbo. 2002. Runoff and soil loss from midwestern and southeastern US silt loam soils as affected by tillage practice and soil organic matter content. Soil and Tillage Research. 66: 1-11.

Rice, R.W. 1983. Fundamentals of No-Till Farming. The American Association for Vocational Instructional Materials, Athens, GA, USA.

Shelton, D.P., E.C. Dickey, P.J. Jasa, M.C. Hirschi, and L.C. Brown. 1992. Water Erosion. *In* Conservation tillage systems and management: crop residue management with no-till, ridge-till, mulch-till. Ames, IA: MidWest Plan Service, Agricultural and Biosystems Engineering Dept., Iowa State University. p. 8-11.

Tanaka, D.L., and R.L. Anderson. 1997. Soil water storage and precipitation storage efficiency of conservation tillage systems. Journal of Soil and Water Conservation 52: 363-367.

TIBCO Software Inc. 2008.

USDA. 2006. Land Resource Regions and Major Land Resource Areas of the United States, the Caribbean, and the Pacific Basin. U.S. Department of Agriculture Handbook 296.

USDA-FSA. 2004. CRP Enrollment and Rental Payments by County, 2004. US Department of Agriculture, Farm Service Agency, Washington, D.C.

USDA-NASS, 2011. County Data - Crops, 1994-2004. US Department of Agriculture, National Agriculture Statistics Service, Washington, D.C.

USDA-NASS, 2002. The Census of Agriculture, 2002. US Department of Agriculture, National Agriculture Statistics Service, Washington, D.C.

USDA-NRCS. 2006. U.S. General Soil Map (STATSGO2). Natural Resources Conservation Service, United States Department of Agriculture.. Available online at http://soildatamart.nrcs.usda.gov.

Varner, B.T., F.M. Epplin, and G.L. Strickland. 2011. Economics of no-till versus tilled dryland cotton, grain sorghum, and wheat. Agronomy Journal 103: 1329-1338.

Vitale, J.D., C. Godsey, J. Edwards, and R. Taylor. 2011. The adoption of conservation tillage practices in Oklahoma: Findings from a producer survey. Journal of Soil and Water Conservation 66: 250-264.

Vorosmarty, C.J., Federer, C.A., Schloss, A., 1998. Potential evaporation functions compared on US watersheds: implications for global-scale water balance and terrestrial ecosystem modelling. Journal of Hydrology 207: 147–169.

West, T.O., and G. Marland. 2002. Net carbon flux from agricultural ecosystems: Methodology for full carbon cycle analyses. Environmental Pollution 116:437-442.

Williams, J.D., and S.B. Wuest. 2011. Tillage and no-tillage conservation effectiveness in the intermediate precipitation zone of the inland Pacific Northwest, United States. Journal of Soil and Water Conservation 66: 242-249.

Young, Jr., H.M. 1982. No-Tillage Farming. No-Till Farmer, Inc. Brookfield, WI.

APPENDIX I

Participant #________
Are you a farmer? Y / N

Do you run primarily a dry land farm operation or an irrigated farm operation? (must be at least 75% dry land)

Do you have land enrolled in CRP? Y / N

Have you in the past had land enrolled in CRP? Y / N

What are your primary implements for tillage and planting?

Have you tried any different implements in the past?

Who owns this farm? (1-Participant/household member, 2-lease from non-family member, 3-lease from family member, 4-other/explain)

If owned, how long have you owned the operation?

If leased, how long have you been on this land?

(If they have only been there for a short time then ask if longer term farmer could be present for the interview – farmer who ran the farm previously and would know history of the operation starting in 1980)

How many acres do you currently own outright?

How many acres do you currently lease?

Which of the following best describes this operation?
______(1) Family or individual operation (exclude partnership and corporation)
______(2) Partnership operation (include family partnerships)
______(3) Incorporated under state law (number of shareholders)

Participant #________ Date: _____________ Interviewer: _______________

Location:

Directions:

GIS Coordinates:

Demographic Information

	You	Spouse
Date of Birth (Age at last birthday)		
Sex (M – 1, F – 2)		
Marital status (1-married, 2-divorced, 3-widowed, 4-never married)		
Years of current marriage		
Number of times married		
Years of last marriage		
Education (1-GED, 2-HS, 3-some college, 4-AA, 5-BA/BS, 6-grad school)		
If college, what emphasis		
Any formal agricultural training (Y / N)		
Ethnicity		
Is this land on an Indian Reservation? (Y / N)		
Religious Affiliation		
Political affiliation (1-Dem, 2-Rep, 3-Ind, 4-Other/explain)		

Children:

Sex	DOB	Marital status	Education	Education Goals	Present residence	Occupation	Participation in farm

Do any of your children help with the farm? Y / N

If applicable, explain at what age and why children migrated off the farm.

Does anyone else live in your household? Y / N Relationship: ______________________

Is it important to you that your children continue farming? Y / N

How does this affect your management decisions?

Open-ended Questions

What issues are farmers in this area most concerned with?

What conservation issues do farmers in this area talk about (if any)?

Do farmers in this area talk about soil/land conservation and/or erosion reduction? Y / N

If so, what specific solutions/practices are discussed?

If not, why do you think soil/land conservation issues are not discussed?

If not, what would have to change for soil/land conservation issues to be a priority?

What are the major trends in this community regarding farm size, land use practices, and types of operator?

What forms of farm subsidies are available to farmers in this area? Do you participate in any of these programs?

How important are these subsidy programs to the profitability of farming in this area?
Very Important   Important   Neutral   Not Very Important   Not Important at All

Land Use

Do you have a farm management/production plan for your operation, or any other resources that help explain your operation? Is it written? Could we have a copy?

Do you have any land that is <u>not</u> being used for production?

Go to table (1) Breakdown of Operation
Draw map of operation, if feasible – location of different fields
Go to table (2) Tillage Systems
Go to table (3) CRP Enrollment

If they have <u>only</u> used full/heavy tillage, or if they have <u>not</u> enrolled land in CRP, ask the following:

Why have you decided to use the tillage implements that you have chosen?

Why have you not enrolled any land in CRP?

Ask everybody:

What would influence you to use more reduced till or no till practices?

Which statement would best describe the conditions under which you would adopt conservation practices on your farm. (Cirlce One)

1. I would adopt conservation practices only if the conservation practices increase the profitability of my farm operations.
2. I would adopt conservation practices if the conservation practices kept the profitability of my farm operations at about the same level they are now (essentially break even).
3. I would adopt conservation practices even if the conservation practices reduced the profitability of my farm operations somewhat. A ____ percent or $_______decrease in profitability would be acceptable.

Please explain your answer:

____

____

On a scale of 1 to 5, how willing are you to take risks when it comes to changing your farm operations.

1	2	3	4	5
No Risks	A Little Risk	Moderate Risk	Aggressive Risk	Extreme Risk

Factors that Influence Operation

Are there any other factors important to you in making land use decisions that we haven't discussed?

How did you learn to farm?

What are your goals regarding your farm?

What practices/management approaches have been most beneficial for your operation?

What practices/management approaches were most beneficial when you first began this operation?

Under what conditions in the past have you been most likely to increase risks in your operation?

What is the <u>most</u> important factor that influenced your operations in the past 5 years?

Second?

Third?

Income

What is your total annual household income from all sources? $________
Percent from farm activities?

What amount of your household income comes from off-farm employment? $__________

How many household members have off-farm employment?
Why do they work off the farm?
When did they begin to work off the farm?
How far away do they travel to work?
How many hours do they work per week?

Do you currently __________ or have you in the past ___________ used operating loans?
What is the loan amount? Interest rate?
What is your average debt to asset ratio?
Current debts: $____________ Current assets: $___________

Expenses

What were your total agricultural production expenses last year? $_______

Lease cost $__________ Mortgage $__________

How many paid farm laborers do you employ?
What is the wage rate? $__________

Do you have any unpaid farm laborers? Y / N How many?

Environment

Environmental Stewardship

1. I do not pay much attention to the health of my land and the quality of my soils.	SA	A	N	D	SD
2. I believe that we should try to leave as much land aside as possible for other animals, birds, and insects to use.	SA	A	N	D	SD
3. I use chemical fertilizers and herbicides sparingly to protect the environment.	SA	A	N	D	SD
4. I am concerned with the affect that plowing has on my land.	SA	A	N	D	SD
5. It is wasteful to have land that is not being used for agriculture.	SA	A	N	D	SD
6. I have done things in the past to protect the environment that have cost me more money.	SA	A	N	D	SD

7. I do not believe humans are altering the global climate. SA A N D SD
8. Farming and ranching is not harmful to the environment. SA A N D SD
9. Explain:

In your opinion, who should be responsible for taking care of the environment in general?

On your farm?

Off the farm, such as waterways?

Do you think your operations have an effect on the environment? Y / N
On water quality? Y / N
On soil quality? Y / N
On air quality? Y / N

Do you think that there are any environmental problems on your farm/ranch? How serious are these problems? Do they cause a loss in yields/profits?

Do you know about carbon emerging as a commodity in the U.S.? Y / N

If yes, how would you get paid for this commodity?

Does anyone in your household hunt? How many people? How often?

Does hunting tie in to your ideas regarding the environment? Y / N

Hunting and Recreation

1. I like to hunt on my lands. SA A N D SD
2. I don't allow other people to hunt on my lands. SA A N D SD
3. I charge people to hunt on my lands. SA A N D SD
4. I have taken steps to improve the quality of hunting on my land. SA A N D SD
5. I use my land for other recreational purposes. SA A N D SD

Environment

1. Humans have the right to use nature and natural resources in any way they want. SA A N D SD
2. There are enough natural resources in this county for everyone to use. SA A N D SD
3. Humans are abusing natural resources in this county. SA A N D SD
4. Nature is strong enough to cope with whatever humans do. SA A N D SD
5. Land erosion is a serious problem in this county. SA A N D SD

6. Plants and animals have as much right to exist as humans.	SA	A	N	D	SD
7. Natural areas are important places where I go to relax.	SA	A	N	D	SD
8. It is important to have lots of wild animals in this county for people to hunt.	SA	A	N	D	SD
9. It is important to have wild animals in this county – even those that are not useful.	SA	A	N	D	SD
10. It is important to have wild animals in this county – even those that may be harmful to humans such as mountain lions.	SA	A	N	D	SD
11. Agricultural crops are more important than plants that are native to this area.	SA	A	N	D	SD
12. It is important to have useful wild plants on the farm.	SA	A	N	D	SD
13. It is important to have wild plants on the farm – even those that are not useful.	SA	A	N	D	SD

Government programs/policies

What programs are available to help farmers increase conservation practices in their operations? Do you participate in any? Which ones?

Are the offices that run these programs helpful and easy to work with? Y / N

Are there any conservation programs that you would like to take advantage of but do not? Which ones? Why?

What kind of programs might be proposed that would help you increase conservation practices?

How do you deal with government restrictions related to environmental policies (e.g. wetland protection, water quality, soil erosion, pesticides)?

Do you raise any certified organically produced products? What? Why?

Rugged Individualism

1. I do not trust policies and programs of the Tribal Government (if applicable)	SA	A	N	D	SD
2. I do not trust policies and programs from the local government.	SA	A	N	D	SD
3. I trust policies and programs from the state government	SA	A	N	D	SD
4. I trust policies and programs from the federal government.	SA	A	N	D	SD

5. I feel that the government should stay out of people's affairs SA A N D SD
6. I often take advice from others on how to run my farm SA A N D SD
7. I believe it is important to be self-sufficient SA A N D SD
8. I believe that the end times are coming SA A N D SD

Information Sources

What are your most important sources of information for decisions you make about your farm?	What type of information do you get here?	How often do you get information from this source?	Location

Where do you get information about the following topics (if not mentioned above)? (Include location and frequency of use)

Government programs:

Commodity prices:

New technologies:

Environmental impacts:

Alternative land practices:

	Do you know about these sources? (Y/N)	Do you use them? (Y/N) How often?	Why or why not?	How could the program be improved?
Field Days				
ARS				

Stations				
NRCS				
University Extension Agents				
Gov't internet sites (specify)				
Other gov't agents (specify)				

Who do you trust the most to provide you with accurate/useful agricultural information?

How far are you from the county seat? The closest town? How often do you visit these places?

Where are the markets that you deal with located?

Who are the middlemen involved in market transactions?

Community

In your opinion, when was this county most prosperous, now or when in the past?

Who is the most influential person/group in your county, in general? About what?

Who is the most influential person/group in your county in regard to farm operation decisions?

How often have you attended local meetings in the last 12 months? What topics were discussed?

Have you voted in a State election in the past 5 years? Y / N
Have you voted in a City election in the past 5 years? Y / N
Have you voted in a Tribal election in the past 5 years? (if applicable) Y / N
Have you voted in a national election in the past 5 years? Y / N

How dependent are people in your county on agribusiness (corporate agriculture)?

What groups are you affiliated with? (e.g. 4-H, Elks)

Name	Type	Why involved?	Frequency of participation

Which of the above groups influences your life the most?

Which of the above groups have an influence on farming?

Community Ties and the Farming Tradition

1. This community has prospered in the last 5 years	SA	A	N	D	SD
2. This community will prosper in the next 5 years	SA	A	N	D	SD
3. I would like my children to continue to farm this land	SA	A	N	D	SD
4. I do not believe farming is a good future for our children	SA	A	N	D	SD
5. My family has a long history of farming in this community	SA	A	N	D	SD
6. I believe it is important to preserve the tradition of farming in rural communities in America	SA	A	N	D	SD
7. I attend the county fairs	SA	A	N	D	SD
8. My children participate(d) in 4H and other Agricultural related programs	SA	A	N	D	SD
9. I would move from this community if I was offered a higher paying job	SA	A	N	D	SD
10. This community celebrates the farming tradition.	SA	A	N	D	SD
11. The population of this community is increasing	SA	A	N	D	SD
12. Agribusiness is good for this community (E.g. ADM, Cargill, Monsanto)	SA	A	N	D	SD
13. My family will be farming in this community for the next 20 years	SA	A	N	D	SD

Do people in your community voluntarily help each other? Y / N

In the past 12 months, how many times did someone in the community help you with farming?

How many times did you help someone else with farming?

Who is most likely to voluntarily help you with farming? (relationship)

Who has been the most likely to voluntarily help you with farming in the past? (relationship)

In the past, did people voluntarily help each other with farming less than today, the same as today, or more than today?

Who do you rely on the most, in relation to farm operations?

Do you think that in your family people generally trust one another in matters of lending and borrowing?
[ ] Do trust
[ ] Do not trust
[ ] Don't know/not sure
[ ] No Answer

Do you think that in this geographic community people generally trust one another in matters of lending and borrowing?
[ ] Do trust
[ ] Do not trust
[ ] Don't know/not sure
[ ] No Answer

Do you think over the last few years this level of trust has gotten better, gotten worse, or stayed about the same?
[ ] Better
[ ] The same
[ ] Worse
[ ] Don't know/not sure
[ ] No Answer

Compared with other communities how much do people of this geographic community trust each other in matters of lending and borrowing?
[ ] Less than other communities
[ ] The same as other communities
[ ] More than other communities
[ ] Don't know/not sure
[ ] No Answer

Income

Question	Yes/No 2002	Dollar amount 2002	Yes/No 2006	Dollar amount in 2006	Have ever? Prior to 2002
What was the value of **grains, oilseeds, dry beans, and dry peas** from this operation including the value of the landlord's share before any expenses?					
What was the value of **tobacco** from this operation including the value of the landlord's share before any expenses?					
What was the value of **cotton and cottonseed** from this operation including the value of the landlord's share before any expenses?					
What was the value of **vegetables, melons, potatoes, and sweet potatoes** (beets, cabbage, cantaloupes, pumpkins, sweet corn, tomatoes, watermelons, vegetable seeds, etc…) from this operation including the value of the landlord's share before any expenses?					
What was the value of **fruits, tree nuts, and berries** (almonds, apples, blueberries, cherries, grapes, hazelnuts, kiwifruit, oranges, pears, pecans, strawberries, walnuts, etc…) from this operation including the value of the landlord's share before any expenses?					
What was the value of **nursery, greenhouse, floriculture, and sod** (bedding plants, bulbs, cut flowers, flower seeds, foliage plants, mushrooms, nursery, potted plants, shrubbery, sod, etc…) from this operation including the value of the landlord's share before any expenses?					
What was the value of cut **Christmas trees and short rotation woody crops** from this operation including the value of the landlord's share before any expenses?					

What was the value of **other crops and hay** (grass seed, hay and grass silage, hops, maple syrup, mint, peanuts, sugarcane, sugar beets, etc…) from this operation including the value of the landlord's share before any expenses?					
What was the value of **hogs and pigs** from this operation including the value of the landlord's share before any expenses?					
What was the value of **milk and other dairy products** from cows from this operation including the value of the landlord's share before any expenses?					
What was the value of **cattle and calves** (beef and dairy cattle for breeding stock, fed cattle, beef and dairy cull animals, stockers and feeders, veal calves, etc.) from this operation including the value of the landlord's share before any expenses?					
What was the value of **sheep, goats, and their products** (wool, mohair, milk, and cheese) from this operation including the value of the landlord's share before any expenses?					
What was the value of **horses, ponies, mules, burros, and donkeys** from this operation including the value of the landlord's share before any expenses?					
What was the value of **poultry and eggs** (broilers, chickens, turkeys, ducks, eggs, geese, hatchlings, pheasants, poultry products, etc…) from this operation including the value of the landlord's share before any expenses?					
What was the value of **aquaculture** (catfish, trout, ornamental and other fish, mollusks, crustaceans, etc…) from this operation including the value of the landlord's share before any expenses?					

What was the value of **other animals and other animal products** (bees, honey, rabbits, fur-bearing animals, semen, manure, other animal specialties, etc…) from this operation including the value of the landlord's share before any expenses?					
Did you receive any **Government CCC loans** for all crops (Include barley, canola and other rapeseed, corn, cotton, flaxseed, oats, mustard seed, rice, safflower, soybeans, sorghum, sunflower seed, and wheat)?					
Did you receive payments for participation in **Federal Farm Programs** (exclude CCC loans)?					
Did you receive any **state farm program payments**					
Did you receive payments for participation in **Conservation Reserve Program and Wetlands Reserve Program** (CRP and WRP)?					
Did you receive any payments for participation in **other Federal farm programs** (include loan deficiency payments)?					
Did you receive payments for **custom work and other agricultural services provided for farmers and others-** plowing, planting, spraying, harvesting, preparation of products for market, etc (exclude if custom work is an entirely separate business from you agricultural operation)?					
Did you receive **gross cash rent or share payments from renting out farmland or payments received from lease or sale of allotments** (Include payments for livestock pastured on a per-head basis, per-month basis, AUM basis, etc.)?					
Did your receive payments for sales of **forest products** (Include pulpwood, timber, firewood, etc. Exclude sales of Christmas tress and maple products)?					

Did you receive payments for **recreational services**, such as hunting, fishing, etc…?					
Did you receive payments for **patronage dividends and refunds from cooperatives**?					
Is there any **other income** which is closely related to the agricultural operation (Include animal boarding, tobacco settlements, state fuel tax, and refunds)? – specify					
Did you grow or raise any crops, livestock, poultry, or their products that were sold directly to individual consumers for human consumption **(roadside stands, farmers markets, etc**)?					
What was the **total value of sales** from this operation including the value of the landlord's share before any expenses?					

Expenses

Question	Yes/No 2002	Dollar amount 2002	Yes/No 2006	Dollar amount in 2006
Production expenses for **fertilizer, lime, and soil conditioners** (include cost of custom application and organic materials)				
Production expenses for **chemicals purchased- insecticides, herbicides, fungicides, other pesticides**, etc…				
Production expenses for **seeds, plants, vines, trees**, etc. purchased (includes technology or other fees, seed treatments, and seed cleaning cost. Exclude items purchased for resale without additional growth)				
Production expenses for **livestock and poultry** purchased (breeding livestock- regardless of age including dairy cattle and all other livestock and poultry – include stocker and feeder cattle, calves, sheep, lambs, feeder pigs, chicks, poults, started pullets, horses, fish, goats, etc… include livestock leasing expense)				

Production expenses for **feed** purchased for livestock and poultry (include grain, hay, silage, mixed feeds, concentrates, supplements, and premixes, etc…)				
Production expenses for **gasoline, fuels, and oils** purchased for the farm business (include diesel, natural gas, LP gas, motor oil, and grease, etc…)				
Production expenses for **utilities** purchased for the farm business (include electricity, farm share of telephone, water purchased, etc…)				
Production expenses for **supplies, repairs, and maintenance** costs for the farm business				
Production expenses for **labor- hired farm and ranch labor** (include employer's cost for social security, workman's compensation, insurance premiums, pension plans, etc…) and **contract labor** (include expenses for labor, such as harvesting of fruit, vegetables, berries, etc… performed on a contract basis by a contractor, crew leader, etc…)				
Production expenses for **customwork and custom hauling** (example, custom planting, harvesting etc… and custom hauling of grain, livestock, milk, manure, etc…)				
Production expenses for **rent** (cash rent paid- include **rent for land, buildings, and grazing fees**) and (rent and lease expenses for **machinery, equipment** and farm share of vehicles (exclude custom hire)				
Production expenses for **interest paid** on debts secured by real estate and not secured by real estate				
Production expenses for **property taxes** (include farm real estate, machinery, livestock etc… for the farm business. Exclude taxes paid by landlords)				
All **other production expenses** (include animal health costs, storage and warehousing, marketing and ginning expenses, miscellaneous farm supplies,				

insurance, etc… Exclude health and payroll taxes.)				
Expenses paid by landlords (of all the production expenses what was the amount paid by landlords)				
Depreciation (depreciation expenses claimed by this operation for all capital assets)				

1. Breakdown of operation Total Acres in Agriculture:_____

Time frame	In general, how is your land broken down in terms of rotation systems, grazing land and hayland?	Soil type, slope/grade	Yield (crops) or Weight (animals)	Price/ Profitability	Implements (include depth, # of passes)	Own or lease?	Why were changes made
2001-2005	*A*						
	B						
	C						
	D						
	E						
1996-2000	*A*						
	B						
	C						
	D						
	E						
1991-1995	*A*						
	B						
	C						
	D						
	E						
1986-1990	*A*						
	B						
	C						
	D						
	E						
1981-1985	*A*						
	B						
	C						
	D						
	E						

2. Tillage - refer to implement chart first; fill out one row in the chart for each filed or set of fields managed in the same way in which conservation tillage was adopted; start with any conservation tillage practice adopted in 1981-1985, then 1986-1990, etc.; for each column, include: rotation, implement(s), yields, profit, fertilizer use and herbicide use (include years before the new tillage system was adopted)

	1981-1985	1986-1990	1991-1995	1996-2000	2001-2005	Why were changes made?
Field ID:_____ Size:_____ Soil Type:_____ Slope:______ Own or Rent?____						
Field ID:_____ Size:_____ Soil Type:_____ Slope:______ Own or Rent?____						
Field ID:_____ Size:_____ Soil Type:_____ Slope:______ Own or Rent?____						
Field ID:_____ Size:_____ Soil Type:_____ Slope:______ Own or Rent?____						

3. CRP enrollment – fill out one row for each field or set of fields that has enrolled in CRP at the same time; start with any field(s) enrolled in 1981-1985, then 1986-1990, etc.; for each column, include: rotation, implement(s), yields, profit, fertilizer use and herbicide use (include years before CRP enrollment and after CRP contract has expired)

	1981-1985	1986-1990	1991-1995	1996-2000	2001-2005	Why were changes made?
Field ID:_____ Size:_____ Soil Type:_____ Slope:______ Own or Rent?____						
Field ID:_____ Size:_____ Soil Type:_____ Slope:______ Own or Rent?____						
Field ID:_____ Size:_____ Soil Type:_____ Slope:______ Own or Rent?____						
Field ID:_____ Size:_____ Soil Type:_____ Slope:______ Own or Rent?____						

APPENDIX II

Investigator/co-investigator
signature____

1. Do you use no-till on your farm? Y/N

2. IF NO, what tillage are you using?

3. How long have you used no-till?

4. Why did you choose no-till? (state all the reasons influencing your decision)

5. What do your local Associations say about no-till? (see list from original survey).

6. What do your neighbors say about no-till?

7. Do your neighbors use no-till?

8. What have you learned from their experiences with no-till?

9. What do government extension offices say about no-till?
   What government extension offices do you get information from?

10. What other information have you heard about no-till? (List sources of information)

11. Given all this information, what are your conclusions about no-till in this area?

12. What are the soils like on your fields?

13. Are they sandy soils?
    What is the relative proportion of sandy vs. non-sandy soils on your fields?

    1 All sandy 2 Mostly sandy 3 Balance sandy/non-sandy 4 Mostly non-sandy
    5 All non-sandy

14. Do the soils on your fields influence your tillage decision? (on a scale of 1-5)

    1 Not at all 2 Very little 3 Some 4 A Great Deal 5 Primary Influence

    HOW (including variation)?

15. What are the slopes like in your fields?

16. What portion of your fields are hilly versus flat?

1 All hilly   2 Mostly Hilly 3 Balance hilly/flat   4 Mostly Flat 5 All Flat

17. Does the slope on you farm influence your tillage decision? (on a scale of 1-5)

    1 Not at all   2 Very little   3 Some   4 A Great Deal   5 Primary Influence

    HOW (include variation)?

18. What are the soil drainage conditions in your fields?

19. Do the drainage conditions on your fields influence your tillage decision? (on a scale of 1-5)

    1 Not at all   2 Very little   3 Some   4 A Great Deal   5 Primary Influence

    HOW (include variation)?

20. Do you irrigate?
    NO   Yes, Pivot   Yes, Furrow

21. Do you have erosion problems on your fields?

22. Is it predominantly wind or water erosion?
    1 All wind 2 Mostly Wind   3 Balance Wind/Water 4 Mostly water 5 All Water

23. Do the erosion problems on your fields influence your tillage decision? (on a scale of 1-5)

    1 Not at all   2 Very little   3 Some   4 A Great Deal   5 Primary Influence

    HOW (include variation)? (Ask about difference between erodible vs non-erodible)

24. What is the weather like in this area? (annual rainfall; hail, etc.)

25. Does the weather influence the crop rotations you use? (on a scale of 1-5)

    1 Not at all   2 Very little   3 Some   4 A Great Deal   5 Primary Influence

    HOW?

26. Does weather influence your tillage decisions? (on a scale of 1-5)

    1 Not at all   2 Very little   3 Some   4 A Great Deal   5 Primary Influence

    HOW?

27. Are your yields affected by your tillage decisions? (on a scale of 1-5)

1 Not at all 2 Very little 3 Some 4 A Great Deal 5 Primary Influence

HOW?

28. Do fuel prices affect your tillage decisions? (on a scale of 1-5)

1 Not at all 2 Very little 3 Some 4 A Great Deal 5 Primary Influence

HOW?

29. What other characteristics about your farm influence your tillage decisions?

30. [FILL GAPS in GROSS INCOME ANSWERS from original survey]

31. Policy makers use the Debt to Asset ratio to think about farm decisions. How does your debt load and the assets you own affect your management decisions?

32. How would you characterize your debt to asset ratio?

1	2	3	4	5
No Debt	Little Debt compared to Assets	Even Debt to Assets	More Debt than assets	No Assets