DISSERTATION

MANURE MANAGEMENT DECISION-MAKING OF CATTLE-FEED GROWERS IN NORTHEASTERN COLORADO

Submitted by

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ABSTRACT

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Rural water supplies, including household wells and small-town water systems, located near livestock production and irrigated agriculture operations are often at risk for high nitrate-levels resulting from concentrated feedlot manure disposal as administered by livestock-feed farmers. Efficient manure management is one approach to minimizing nutrient pollution of rural groundwater and surface waters, and crop-farmers near the feedlots are *de facto* manure managers. This study observes how farmers value manure and whether they frame manure as a waste disposal issue, as an important fertilizer resource, or both. This distinction places manure management in the overlap between environmental sociology and natural resource sociology. The study identifies factors related to how farmers choose fields on which to apply manure, the monetary value of cattle manure as perceived from a farmer's perspective, and how densely farmers choose to apply manure. Using response data from a mail-survey of farmers operating near feedlots, I found that a farmer's manure source, perceptions about manure application, and practical knowledge, along with some personal and farm-operation characteristics, are related to how farmers perceive manure's value, and to how efficiently they apply it. Having one's own livestock and viewing manure as an inexpensive fertilizer are factors that appear to increase manure's perceived value. Factors that reduce manure's perceived value include years of experience in farming, cover-crop nutrient crediting, size of an operation, and concern for the hazard of water pollution.

Recognizing the nutrient value of applied manure to reduce the quantity of commercial fertilizer being applied could substantially increase a farm's profitability while protecting water resources from over-application of nutrients. Yet while farmers typically reduced the nitrogen application on a manured field, that reduction was usually small relative to the nutrients added. This concurs with the results of numerous other studies concluding that many farmers are deliberately over-fertilizing to seek the best possible yield and applying extra nitrogen to plan for the most favorable climatic conditions possible. While farmers might be expected to distribute manure more sparingly over a larger field, the opposite turned out to be true. This finding is consistent with the plausible hypothesis that larger fields are especially appealing as places to dispose of large amounts of manure.

In addition to exploring some of the practical aspects of a farmer's role as a manure manager, I have found it relevant to consider some of the structural background elements that make it inevitable for most farmers to over-apply nitrogen as a means of maximizing yield when growing cattle-feed crops. Farmers' economic success depends in large part on complying with the recommendations of agricultural conglomerate companies that supply their inputs. Note that nitrogen is typically over-applied to corn crops even in areas where no manure is used or available. Being expected to over-apply nitrogen, farmers are unlikely to hold back on applying manure, and are likely to see only benefits in adding organic matter to the land they are cropping. The primary research presented here provides some dimensions in which to work with farmers, aiming toward curbing the over-application of crop nutrients.

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PREFACE

This study came about as part of a research project regarding manure management issues conducted among farm operators where high groundwater nitrate levels had been detected near feedlots. Throughout the following chapters I have used the pronouns 'I' and 'we' based on whether a statement referred specifically to my own work or to ideas that were developed in conjunction with other members of the team conducting the research. Also, where the words "sustainable" and "sustainability" are used, they are intended to refer to environmental sustainability, as opposed to financial, cultural, or other types of sustainability.

Three chapters (IV, V, and VI) were originally written as journal articles. The first two of these have been adapted from their published form, as noted in the text. Chapter VI is intended to be submitted for publication, with some modification, shortly after the completion of this dissertation. (02/2023)

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CHAPTER I. INTRODUCTION

Farmers as Agents of Manure Disposal

This study explores how farmers in a beef-cattle production area of northeastern Colorado view and manage feedlot manure. The farmer is a key agent within an agricultural complex that includes concentrated animal feeding operations (CAFOs) producing highly localized accumulations of livestock manure that contribute to an environmental health hazard. While CAFOs produce the manure in the context studied here, farmers within the immediate vicinity are the primary agents of disposal for it. Crop producers in this locale fill a dual role in livestock production, producing a reliable supply of feed-stocks for the animals and providing disposal service for most of the animals' waste byproduct of manure, which makes the proximity of irrigated farmland a key factor in the locating of these CAFOs. Numerous cattle and other livestock operations are located in this study region along the South Platte River, in northeastern Colorado between Greeley and Julesberg (see maps in Figures I.1-I.4), using water from the shallow alluvial aquifer through which it flows. Because this aquifer is shallow, applied manure and fertilizers often result in dangerously high nitrate concentrations, depending on soil drainage and recharge water quantity (Bauder, Waskom and Wardle, 2017; Ceplecha et al., 2004; Dennehy et al., 1998). These effects are not only local but are carried by the river system, which is ultimately a tributary of the Missouri and Mississippi Rivers far downstream, even to the Gulf of Mexico (Burkart and Jha, 2007; Hilton et al., 2006; Isbell et al., 2013; Rabalais, Turner and Wiseman, 2002; Rabotyagov et al., 2014). Thus, as the farmer is a key agent within a problematic production system, understanding how farmers make manure management (MM) decisions has potential to inform policy for reducing the impact of manure on water quality.

Before discussing the details of the study, I will here describe briefly the production area we studied, and its socio-economic and environmental contexts. Figure I.1 shows the high-nitrate groundwater contamination vulnerability for the lower 48 States, with our study area outlined by a purple box. Following that are three maps depicting the South Platte River Basin. Figure I.2 shows land uses within the basin, with the agricultural areas in yellow. The farmers we studied had operations along the South Platte River between Greeley and Julesberg, indicated approximately by the purple rectangular boxes. Figure I.3 depicts the alluvial aquifer (in brown) underlying the same area. The intersection of the yellow areas of Figure I.2 with the brown areas of Figure I.3 convey a reasonable picture of the study area. Keeping this intersection in mind, Figure I.4 shows the large-scale feedlots of the area, notably the large blue and red circles near Greeley, Fort Morgan and to the northeast of that. While there has been some consolidation of feedlots over recent years, the total amounts of cattle housed in these feedlots, at the time of this writing, has not changed significantly. If anything, this consolidation has increased the concentration of cattle in limited spaces and intensified the amount of manure applied onto a smaller total land area.

Cattle Production in Northeastern Colorado – Feedlots and Farming Operations

The farms and farmers studied were located in the portion of the South Platte River Basin extending eastward from Greeley about 150 miles across the plains of Weld, Logan, Morgan and Sedgwick Counties, where agriculture is the primary land use relying heavily on water from the river and the underlying aquifer to irrigate crops that are mostly fed to livestock. The land slopes gently eastward from Colorado’s Front Range of the Rocky Mountains, and the South Platte River continues approximately another 80 miles into Nebraska before merging with the North

Platte to become the Platte River. (The Platte empties into the Missouri River just south of Omaha.) Cattle feeding is the largest agricultural industry in Colorado, and at the time of our study, from 1998-2001 there were typically a million cattle on feed in the state at any one time (CASS, 2002). This northeast portion of the state had, and still has, one of the largest and densest populations of cattle and feedlots in the U.S., including several of the largest feedlots in the world (CASS, 2018; CASS, 2004; Davis et al., 1997). The counties we studied produced 1,163,000 head of cattle in 2004 (CASS, 2004).

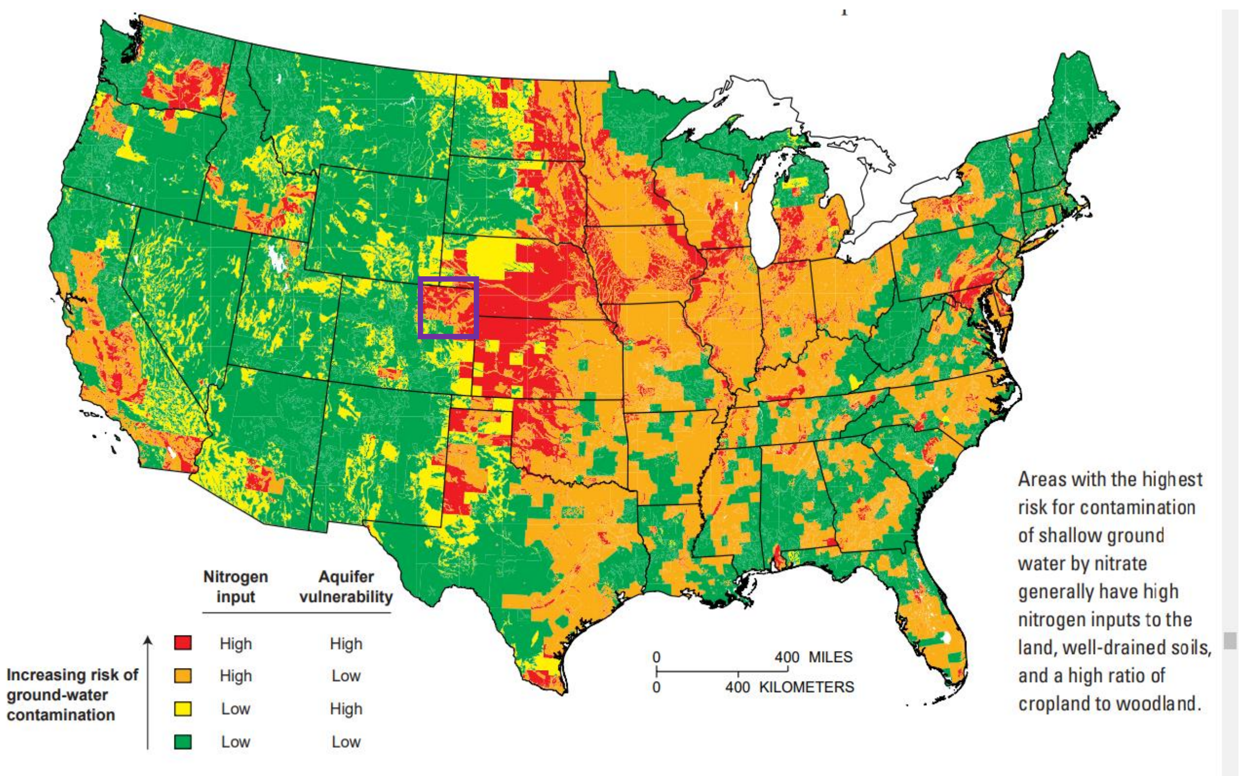


Figure I.1. Nitrate Groundwater Contamination Risk for 48 States.
(Source: USGS Circular 1225, p. 51 - Study area shown in purple box.)

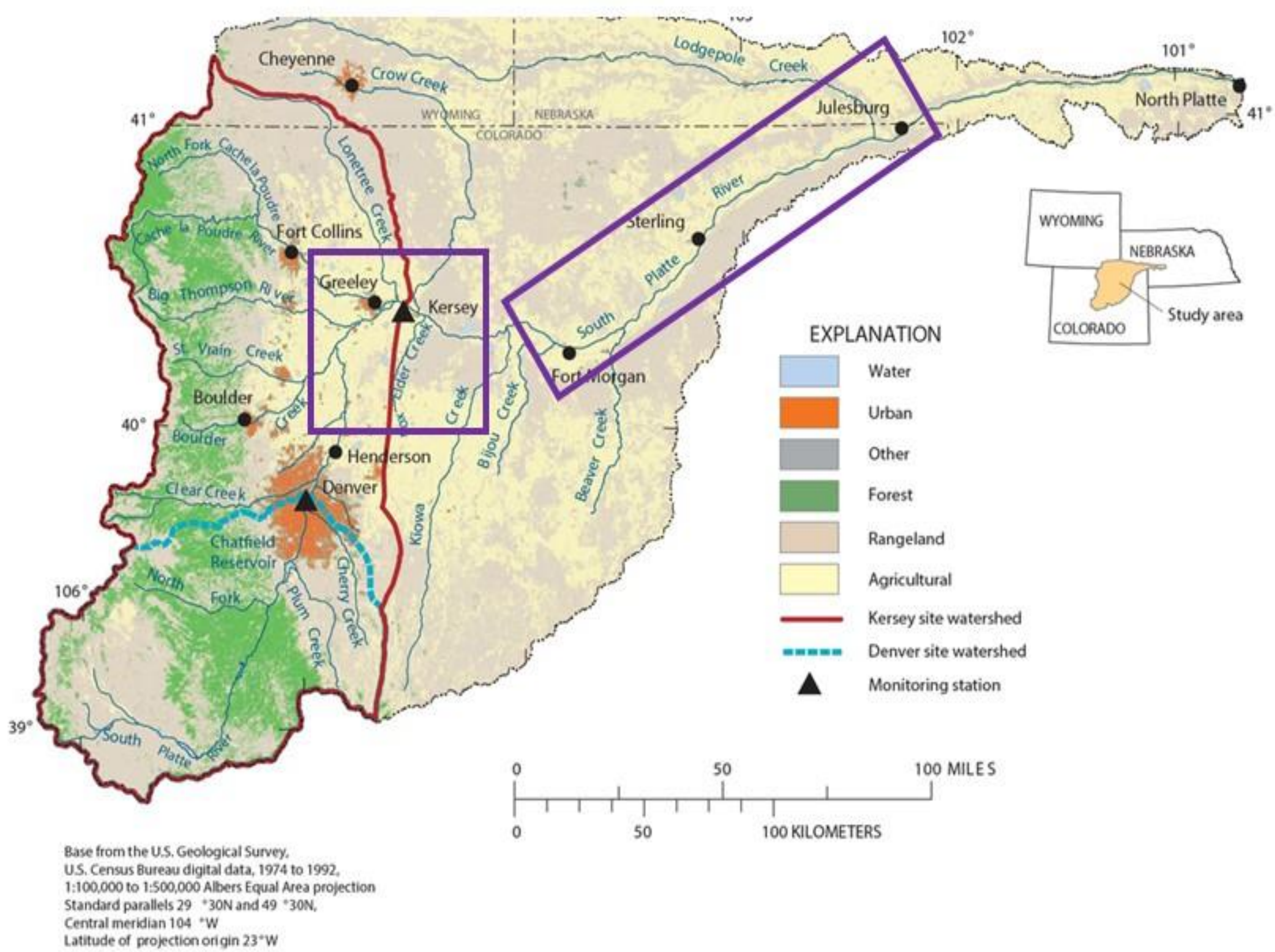
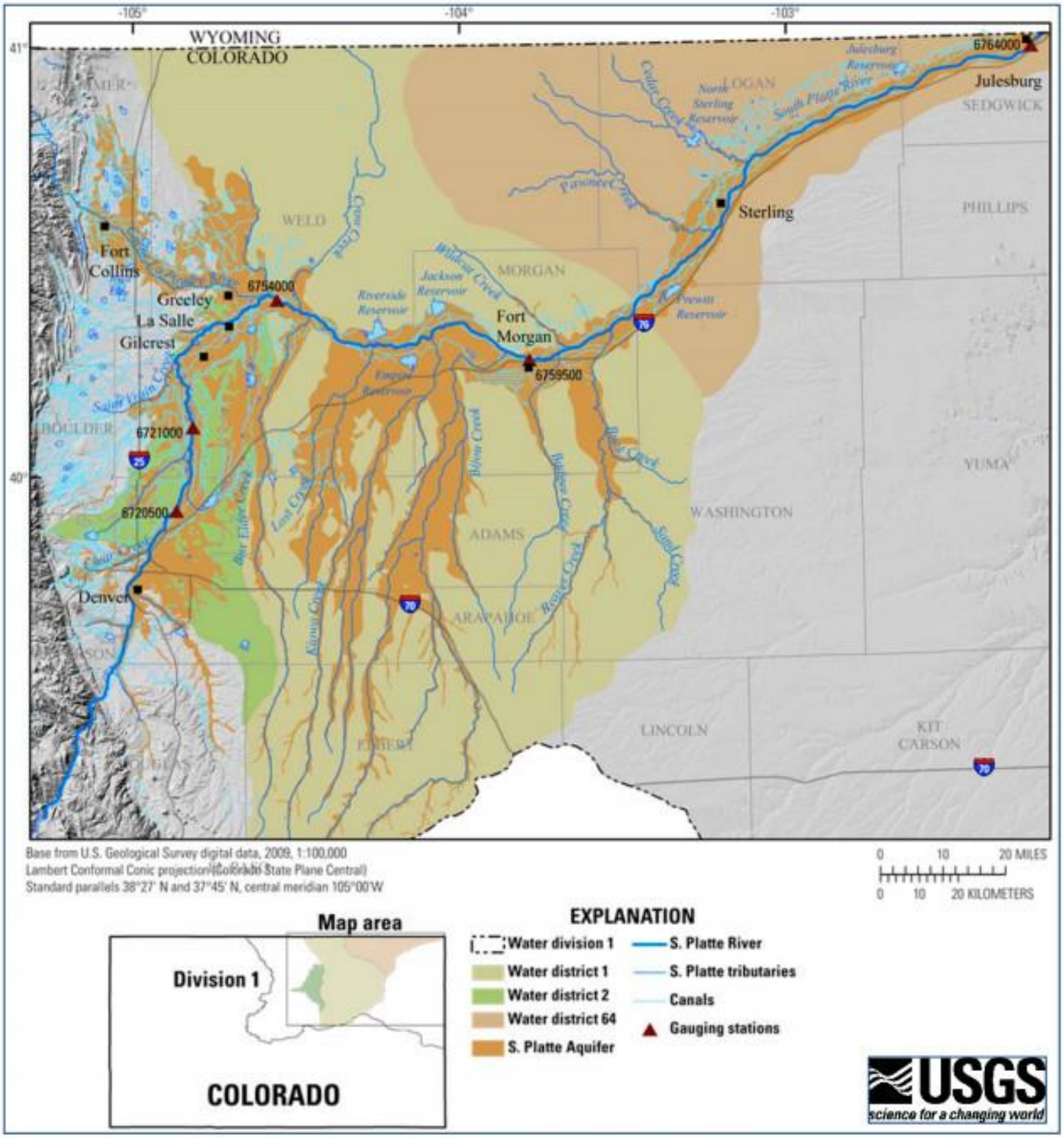


Figure I.2. **Land Use in the South Platte River Basin** ranges from forested areas in the mountains, to urban areas along the Front Range corridor, and to agricultural areas in the plains. This study focuses on the agricultural areas (shown in yellow) along the South Platte River between Greeley and Julesburg, approximately within the purple boxes. (Source: USGS - Public domain.)



Area of the HB1278 Investigation in the South Platte Alluvial Aquifer in Water Districts 2, 1, and 64, Extending Approximately From Denver to Greeley to Julesburg.

Figure I.3. **South Platte Alluvial Aquifer** (shown in orangish brown along river and tributaries) (Source: USGS, Colorado Water Conservation Board)

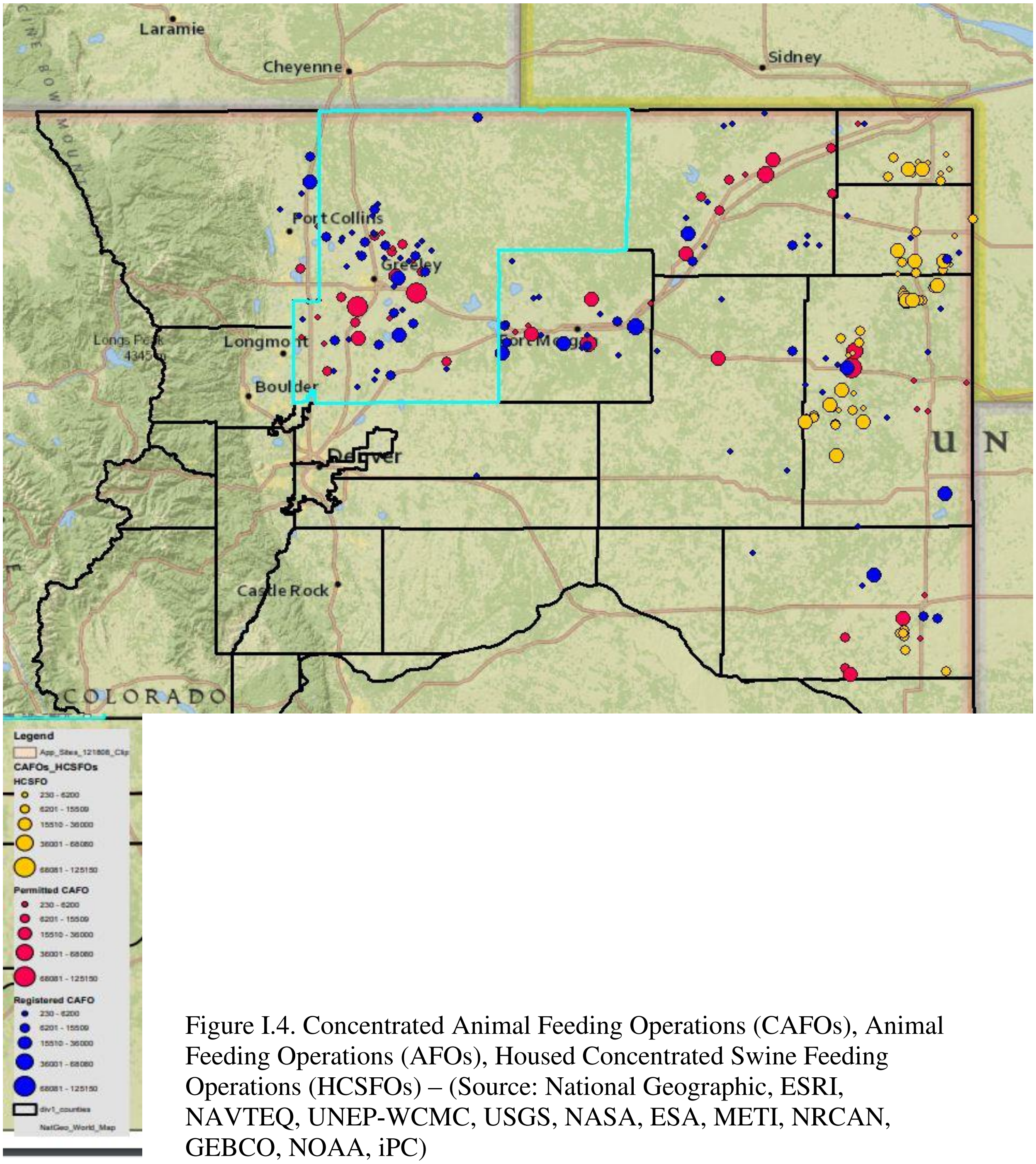


Figure I.4. Concentrated Animal Feeding Operations (CAFOs), Animal Feeding Operations (AFOs), Housed Concentrated Swine Feeding Operations (HCSFOs) – (Source: National Geographic, ESRI, NAVTEQ, UNEP-WCMC, USGS, NASA, ESA, METI, NRCAN, GEBCO, NOAA, iPC)

The corn used to feed much of the cattle in the areas we studied was produced on approximately 350,000 acres, irrigated, as mentioned above, with water from the alluvial aquifer of the South Platte River Basin, and amounting to around 40 million bushels of grain corn and two million tons of silage corn per year (CASS, 2004). The typical total acreage for a farm operation in this area ranges from about 600 to 1400 acres, increasing in size as one moves east (CASS, 2002). A majority of these fields produce corn in one form or another (including shell corn and silage corn). Other crops commonly grown in the area included, beets, soybeans, potatoes and onions. Corn fields have conventionally been seen as the most appropriate place to use cattle manure produced within this system.[1]

While the farmers we studied are in general the endpoint of manure management, spreading it on crop fields and pasture, the original phase of its management is in the feedlots. While that phase is not the focus of study here, it helps to know how manure comes to be transferred from the feedlots into the care of the farmers. Large feedlots, considered "point-sources", are required to manage manure such that it does not enter waterways, by using concrete structures, grass buffer strips and other containment techniques. These containment structures and procedures are managed according to each operation's specific "comprehensive nutrient management plan" (CNMP), a requirement for registration as a CAFO. Although they stockpile and manage it temporarily, large CAFOs are not typically substantial crop producers, and do not usually have land on which to disperse manure. At some point they must transfer manure off the feedlots. Therefore, by various means, they transfer it into the care of separately owned farming operations who can apply it to their crop fields. After making these transfers the feedlot operators are no longer responsible for manure's effects (Boesch, 2019; Livingston, 1998), and at this point farmers take over management of the manure.[2]

[1] There are some significant differences between manure management procedures for feedlots and for dairies (Hinrichs and Welsh, 2003), as I will describe later.
[2] Of course there are also smaller CAFOs operated by crop producers, and these typically use their own manure. The amount of manure these operations produce is small relative to the volumes of the CAFOs.

Farmers, Manure Management, Nutrients and Water

Thus, given that large feedlots do not themselves disperse the manure they create, farmers, typically those growing feed crops for the feedlots, are the primary agents of dispersal for the manure. Applying fertilizers and manure have long been common practices for these farms. Maximizing feed-crop yield is of primary economic importance for their operations, and field-application of manure is traditionally seen as beneficial for crop yield and long-term soil health.

Farmer situations vary as to how easy or difficult it may be to acquire and apply manure, and whether they want to apply it at all. Some farmers accept manure from feedlots for application even if they are not enthusiastic about it, because their customer feedlots make it a good deal for them, sometimes giving it to farmers for free or even paying them, by crediting their accounts, to take manure away from the feedlot. Many farmers who maintain little or no livestock purchase manure from the feedlots as inexpensive fertilizer and to supplement the organic matter of their soils. The choice for these farmers is affected by the cost of transportation, as manure is often very heavy and trucking it can become expensive, depending on the distance. Farmers who own some cattle have a ready and proximate source of manure, and a need to disperse it. Not only is there pressure to do something with the manure, but the transport cost is relatively low, assuming their crop-operations are near the cattle. Some farmers simply do not use any manure at all, either because they are too far away for it to be cost-effective, or in some cases because they find it unpleasant or inconvenient.

Certain times of the year are appropriate for hauling and spreading manure, particularly when the ground is somewhat dry and not frozen or covered with snow. During these periods one can observe numerous manure spreader trucks making trips back and forth from the feedlots, hauling loads of manure off to crop fields within a relatively short distance. A larger feedlot that has large manure storage piles may have ramps up to and down from a loading dock for the trucks being loaded with manure. For longer distances, a large semi-trailer may be used to haul the manure, which is dumped in a pile at the field and then distributed with a manure-spreader attached to a tractor, using the tractor's power takeoff (PTO) to operate a conveyor belt in the trailer's floor. Timing of manure spreading is especially affected by soil-moisture, because wet ground can be unnecessarily compacted by the heavy spreader trucks, so times when the ground has become relatively dry (during fall and spring) are busy times for manure haulers and farmers.

Whether or not farmers think about soil conditions and the underlying aquifer in making manure management decisions, such matters do affect whether their practices contribute to contamination, as the permeability of the soil and the often shallow location of the aquifer are key factors underlying the potential nutrient pollution issue in this region. Depending on the amounts of water and nutrients applied onto a crop, nitrogen (N) moves downward over time, transported by irrigation water and precipitation, eventually leaching below the root zone of the plants, which in the case of corn extends approximately one meter below the surface. Soil permeability is a key factor affecting how quickly the water moves downward taking N below the plant root zone. Farmers are generally aware of the soil types of their crop fields in relation to irrigation and fertilizer management. Our questionnaire included soil type as a factor in relation to their manure application choices for a field on which they had applied manure, particularly because of its effect on percolation of water toward the groundwater below.

Most farmers have a keen sense of what could be described as "water awareness", especially in regard to quantities of water available and quantities needed for producing their crops. They necessarily consider soil moisture as a function of precipitation, in combination with the irrigation water supplied to their fields through surface ditches or pumped through wells from an underground aquifer (Ternes, 2018). It is probably fair to say that most farmers are aware of the potential for water runoff from their operations to become polluted by the chemical fertilizers, herbicides and pesticides they use, and for this water to enter surface waters or the aquifer. One area of inquiry for our study was to what extent the farmer was or was not concerned about excess nutrients entering the aquifer as a result of their operations.

Irrigation method, amount, and timing comprise another set of factors affecting the transport of N into groundwater. Irrigation water in this area is conveyed through a system of ditches in combination with well water pumped from the aquifer. The water is applied to fields either using conventional flood irrigation, by siphoning it from the ditches with tubes, or pumping it through sprinkler systems such as circular or partial-circle pivot systems. The amount of water applied, including precipitation, is somewhat variable, affecting how fast the N moves down through the soil and below the plant root zones (Hall, 1996). Some irrigation systems are more likely than others to transport nutrients deeper into the soil, even beyond the root zones of the plants.

While the plants absorb some amount of the nutrients, a large portion is typically lost, depending especially on how heavily the nutrients were applied in the first place and how much water passes through. The depth to groundwater in most of the area studied here is less than 15 meters (Ceplecha et al., 2004). The shallow nature of the aquifer, in combination with the coarse soils and widely practiced irrigation, have long caused the South Platte River Basin to be vulnerable to contamination by agricultural inputs. Over many years these nutrients have accumulated in the relatively shallow aquifer of the basin. Some questions in our study were designed to explore whether farmers perceived this nutrient load as a hazard, and the level of their concern.

The USGS has estimated that 300,000 tons of N enter the South Platte River Basin each year, and that over 70% of it comes from fertilizer and manure applications on agricultural land

(USGS, 1998)[3]. The USDA-ARS reports that nitrate leaches into the South Platte's shallow alluvial aquifer from fertilizer and manure applications (Schuff, 1992). A survey conducted by the North Front Range Water Quality Planning Association from 1988 to 1991 determined that 70% of groundwater wells in this region had nitrate concentrations above the EPA safe drinking water standard (Davis et al., 1997; DuBois, 1994) and that the highest nitrate concentrations were found in groundwater of areas surrounding the feedlots. That survey also concluded that some farmers apply more nutrients than crops can utilize (Dubois, 1994). Another study determined that some farmers may have applied manure at excessive rates due to insufficient crediting of nutrients and because of the transportation costs for hauling manure over longer distances (GPAC, 1995). The same study concluded that less than 50% of farmers routinely test soil for nutrients, and that manure analysis was even less common (Davis et al., 1997; DuBois, 1994; GPAC, 1995). For these reasons, it concluded that manure and other fertilizer application practices may likely contribute to pollution of the South Platte River and the aquifer (GPAC, 1995).

Macro-Scale Context of this Project – Where it Fits into a Broader Picture

Rural activities, such as concentrated manure application that follow agricultural conventions but create imbalances of nutrients and chemicals, lead to environmental disruption at multiple levels. Merging river systems accumulate waterborne nutrients progressively from higher to lower elevation watersheds, such that the end-waters of many rivers include toxic levels of nutrients and other chemicals which can, at times, kill nearly all the native waterborne life forms

[3] Phosphorus (P) is another nutrient of concern which is contained in manure. P transported in surface water is a problem, but does not appear to be so in groundwater in the way that N does.

where they empty into the ocean, creating so-called "dead zones" (Burkart and Jha, 2007; Hilton et al., 2006; Isbell et al., 2013; Rabalais, Turner and Wiseman, 2002; Rabotyagov et al., 2014; Ribaudo et al., 2003; Ribaudo et al., 2015).

This statement from the Environmental Protection Agency (EPA) website sums up the problem:

"The National Water Quality Assessment shows that agricultural nonpoint source (NPS) pollution is the leading source of water quality impacts on surveyed rivers and streams, the third largest source for lakes, the second largest source of impairments to wetlands, and a major contributor to contamination of surveyed estuaries and ground water… Impacts can be generated from activities such as poorly located or managed animal feeding operations and manure, overgrazing, plowing too often or at the wrong time and improper application fertilizer." (US EPA, 2019)

This dissertation addresses the problem just described by exploring the farmer's role in managing manure as related to nutrient losses which generate water pollution that can potentially harm both ecosystems and human health. While not the only source of excess nutrients, manure mismanagement is important enough to warrant concern, and reducing it will be a necessary step toward resolving the problem described above.

Research Question

The general research question addressed here is this: **How do farmers in a beef-cattle production system make manure management decisions that affect field-application rates?** Farmers are in a different position, relative to land-use, from most other contemporary occupations. Their role is to make a living by producing crops and animal products that can be sold in a marketplace. In this role, farmers orchestrate various natural phenomena with help from synthetic resources to produce crops that become food, inputs toward other processes, and other outputs such as fiber and oil. In addition to planting and watering crops, farmers manage various hazardous inputs that fertilize and protect the crops, in order to optimize their yields and attempt to shield their investments from potential failure conditions. As human populations grow and land-use expands into previously undeveloped terrain, environmental resources become ever more subject to some degree of degradation and pollution. Farmers, like it or not, are in a critical position to affect and manage a large share of these issues. The objective of this analysis is to identify some factors that affect farmers' decisions relating to manure management.

Sustainable Manure Management – Three Perspectives on How Farmers See Manure

The analysis presented here comprises three papers, based on survey data, and considers three aspects of how farmers think about manure application from.

1. The first paper, Chapter IV, examines manure-using farmers' decisions of which fields within their operations to manure, by comparing the physical and logistic differences between fields that received manure and those that did not. As such, it identifies what makes a field relatively more or less appropriate, in the farmer's mind, for manure application.
2. The second paper, Chapter V, explores how farmers perceive the monetary value of manure, which is important because we can presume that financial motivations underlie their behavior. Further, this paper examines the monetary value of manure in the minds of farmers of various categories and in various situations, depending on the nature of their access to manure and on whether they chose to acquire and use manure. This paper is based in the assumption that the higher the value they perceived for manure, the more likely farmers were to apply it efficiently by maximizing its effectiveness in fertilizing plants, and therefore to lose less of its nutrients.
3. The third paper, Chapter VI, explores the relationships of farm-specific, and farmer-specific, factors with manure application-rates. Some farmer characteristics are associated

with applying manure at rates that are distinctly higher than what is considered appropriate. It is potentially helpful to know what factors are associated with over-application of manure and what is more likely related with sustainably reduced application rates.

Each of these three chapters was written as a standalone article for journal submission, necessarily including an introduction to the over-arching issue of nutrient overloading in livestock agriculture and the inherent hazards. Each of these chapter introductions emphasizes a different aspect, and there is inevitably some overlap and repetition in describing the issue of nutrient overloading around feedlots. Therefore, I hereby apologize to the reader, and urge you to bear with me in the beginning of each of these three chapters. I have attempted to move directly into the new material specific to each of the three perspectives.

While I have already given the reader some geographical and social context for the area that was studied, before presenting the three papers in Chapters IV, V, and VI, I will lay out a brief literature review, in Chapter II, of the agricultural, sociological and environmental contexts for this project. Then follows a general description, in Chapter III, of the research questions and methods used to gather and analyze the data, exploring some theoretical aspects that interconnect the multiple levels contained within this issue. Following the three papers of Chapters IV, V, and VI, I will discuss how those papers work together to provide insight and some conclusions regarding farmers' approaches to feedlot manure management.

Because I was part of a team conducting a survey of farmers and their operations, there have been some parts of this study in which the first-person plural ('we') is appropriate in describing the thinking, questioning, and analysis of the survey data. This shows up especially in Chapters V and VI, which were co-authored. Throughout this dissertation, I have tried to use the pronouns

‘I’ and ‘we’ appropriately to reflect the actual processes, both my own and those where I participated in conjunction with others.

Significance of this Project

This project adds to a body of literature on manure management factors that has grown considerably over the last quarter century, exploring farmers’ decision-making on whether, how, and where to apply manure, and contributing to a better understanding of how manure can be sustainably managed (Centner, 2011; Centner, 2004; Hinrichs and Welsh, 2003; Morton, 2011; Osmond et al., 2012a; Osmond et al., 2012b; Ribaudo et al., 2003). For the purposes of this project, I am observing farmers as agents within an evolving food-production industry. Within that context, I am also considering whether, and to what extent, farmers consider environmental impacts, and what factors influence their manure management decisions.

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CHAPTER II. LITERATURE REVIEW - CONTEXTUAL BACKGROUND ISSUES

Livestock Production Agriculture in a Rural Setting

While the focus of this project is on farmers and their decision processes, some complexities of the background spatial context are necessary to understand why this focus is important. Below, I will review discourse around the physical aspects of this agricultural industry, and that around the interaction of these physical factors with conventional farming practices, information handling, and attitudinal factors that have been seen to produce and maintain the nutrient pollution issues and problems identified in the previous chapter.

Physical Factors

The livestock industry in eastern Colorado is geographically centered around vulnerable water resources -- in this case, as described in the previous chapter, the South Platte River and South Platte River Basin – and the river is directly fed by both surface water and groundwater, so that manure nutrients accumulate in the river as well as in local well-water (Ceplecha et al., 2004; Dennehy et al., 1998; Hall, 1996; Litke, 1996). Excess and exogenous nutrients adversely affect riparian ecosystems, as well as rural households that depend on wells for potable water, and communities and ecosystems downstream where the combined accumulations become severe. This issue is replicated in many agricultural areas around the country but goes largely unnoticed due to relative non-visibility at the local level (Carolan, 2006; Osmond et al., 2012a; Nowak et al., 1997). Farming, while distinctly separate from livestock production, is an intimately connected component of the meat production industry, and for most farmers providing feed to CAFOs, that is their primary, if not their only, source of income.

Farmers' Relationships with Feedlots

Farmers in the study area are typically in contractual or *de facto* relationships with the feedlots, by which they sell livestock feed to CAFOs. And in these arrangements the farmers are often expected and encouraged to take away feedlot manure in approximately the same quantity as the feed products they have provided, either receiving the manure for free or in some cases with compensation for the hauling costs. This general pattern was described to me by several interviewees (Extension Agent-2, 2015; Farmer-3, 2014; Spreader-Hauler-2, 2016), and has been noted in previous literature such as Trachtenberg and Ogg (1994). Because each CAFO purchases most of the feed produced by farmers in its vicinity, they are in a monopsonist relationship where the CAFO has a lot of control and the farmer has relatively little power.

Large feedlots are considered potential point-sources of pollution and are subject to nutrient-management regulations as administered through the National Pollutant Discharge Elimination System (NPDES) (Centner, 2011). But because of "right-to-farm" provisions in many states including Colorado, the farmers are exempt from these regulations, and so they may typically be pressured or incentivized to provide what effectively amounts to disposal service for the feedlots (Extension Agent-2, 2015; Spellman and Whiting, 2007; Spreader-Hauler-2, 2016). In many cases the farmers' crops stand to benefit considerably by applying the nutrients and organic matter contained in the manure received. In this sense, the service provided by the farmer is also of benefit to the farmer.

In addition to these benefits, farmers can usually reduce their input costs by substituting manure for some portion of their fertilizer needs, especially if they have a ready manure supply nearby in the feedlots they serve. However, this process often leads to applying more nutrients than the crop can actually take up. Maximizing yield is a primary goal for these farmers, and excess nutrients, in the combination of manure and commercial fertilizers, help insure the highest possible yield (Houser, 2018; Sheriff, 2005; Osmond et al., 2015). Taking advantage of cheap, available manure to assure a profitable yield for the current season is generally a higher priority for a farmer than reducing manure's long-term impact on groundwater. Also, because the nutrient content of manure is highly variable and not reliable, farmers do not usually reduce their fertilizer application as much as would be necessary to compensate for the nutrients present in the manure they apply (Amon-Armah et al. 2015; Sheriff, 2005; Osmond et al., 2012b).

Economic Rationality and Farmers' Decision-Making for Profitability

Economic rationality in farmers' decision-making focuses on the profitability of their individual operations, independent of environmental sustainability or environmental concerns. Perhaps the individual farmer's situation is similar to that of an individual truck driver in choosing a truck that gets low or high gas-mileage. If the driver chooses a low-emission vehicle, she or he may feel good about contributing less air-pollution; but if it comes with a possible reduced profitability through reduced load capacity or lowered highway speeds, then the individual driver may be unwilling to sacrifice income for the good of the whole population, especially when other drivers apparently are not making that same sacrifice. If the individual's caution will likely make very little difference, why would that person give up the benefits that their peers are gaining? The typical farmer apparently believes that applying extra nutrients can reduce the risk of a lower-than-expected yield or can increase the chance of achieving a relatively high yield (Sheriff, 2005).

The prevalent political-economic climate in the U.S. has been negative toward regulation, making it difficult for policy-approaches to protect environmentally sensitive natural resources. Given this social political climate, we explored other, not regulation-based, aspects of farmers' operational thinking that might be available to improve nutrient-application efficiency and thereby reduce the loss of N into groundwater. This approach fits well with recent analysis in which Osmond et al. identified three strategic approaches that may potentially address this persistent over-application of nutrients (2015). They found that nutrient management adoption rates improved when programs included measures to reduce management demands, to include working directly with small groups of farmers, and to provide significant funding for agency personnel and for sharing adoption costs with farmers (Osmond et al., 2015). The general implication here is that if the goal is to see farmers reduce their contributions to nutrient pollution, it will take more than just the threat of regulation. Farmers will also need guidance, a sense of community with others engaged in the process with them, as well as funding assistance and support of various types (Osmond et al., 2015).

Farmers make decisions under conditions of considerable ambiguity and uncertainty (McCown, 2005). McCown suggests that interested parties are more likely to influence farmers' decision-making successfully not by telling farmers what they *should* do but by listening to farmers, understanding what factors affect their decision-making regarding specific resources, and considering the variables particular to those decision situations. Many farmers pride themselves on being independent thinkers and are often distrustful of "expert" advice, preferring generally to rely on their personal experience, knowledge shared by other farmers around them, "common sense", and their intuition (Osmond et al., 2015; Stuart and Houser, 2018). Our study examines how farmers view manure management and some other aspects of their farming operations to better understand what influences their manure management decision-making.

Glenn Sheriff's article, "Efficient Waste? Why Farmers Over-Apply Nutrients and the Implications for Policy Design", mentioned above, explores farmer perceptions of agronomic advice and input sustainability (2005). Given the combination of risk-factors faced by farmers, Sheriff argues that farmers are economically rational when they over-apply nutrients for the purpose of seeking the best possible crop-yields. More simply stated, there is little or no cost to the farmer in over-application of free nutrients, but a clear risk of less-than-maximum yield from under-application. Given that nutrient contamination is a form of NPS pollution, Sheriff discusses 12 different approaches and types of policy measures designed to reduce over-application of nutrients exploring their costs and feasibility. Not all over-application of nutrients should be considered inefficient, according to Sheriff; and each of the policy responses he discusses, such as insurance, education, cost-shares, regulation, taxes, and land retirement, has a potential role to play, but each also has costs that would need to be considered (2005). One aspect of our study is a consideration of the interplay between providing crops with a plentiful supply of nutrients and practicing techniques that minimize a loss of nutrients into the local surface water and groundwater.

While sociology generally considers rational choice to be only one small component of how most human decisions are made, a rational-choice approach may turn out to be relatively useful in the context of farmer decision-making. Recent attention to rational choice modeling suggests that rational decision-making is contextual and is appropriately dependent on the specific experience-base of the individual farmer (Vlaev, 2018). As Sheriff suggests, farmers are not in a position to take chances on procedures or practices that are far outside their personal experience, given that their financial livelihoods in any year depend on a successful growing season (Sheriff, 2005). Rather they might be comfortable making slight adjustments on a trial basis within their local context (Vlaev, 2018).

Lois Morton discusses farmer decision-making aspects that affect water quality as generally an automatic behavior (2011). She aptly cites the cognitive science perspective of Marc deMey, who describes decision-making as follows: "… the mind uses past experiences and decision frames as rules of thumb to guide new decisions… If there is a problem, try to arrive at a solution by applying a familiar (and simple) method, even if it does not seem entirely appropriate. When difficulties arise, try to overcome them by adapting the procedure in such a way as to make the difficulties disappear." (deMey, 1982, p. 211). Given the complexities and riskiness of farming, the safety, risk-reduction and peace-of-mind achieved by relying on tried-and-true practices are likely very appealing. In addition to the benefits in reliability of conventional practices and heavy fertilization to maximize yield, there is little obvious pressure for farmers to change from the practices that have insured their past success. In the next sections, I discuss reasons for the apparent lack of resistance to excess use of nutrients in these rural areas, and the long-distance result of accumulated nutrients that result in "dead zones".

Rural Culture, Remoteness of Effects, and the Non-Obvious Nature of Nutrient Excess

Unlike urban waste-treatment facilities, very few people are present in rural areas to observe whether manure management is creating a problem -- a situation notably applicable in the wide-open spaces and low population of the South Platte study area. Further, field-applied manure looks about the same whether applied sparingly or at excessive rates. In a typically rural setting, most observers are employed within the agricultural industry or are residents within a local culture that is very comfortable with the convention of manure application. Excess nutrient application is relatively non-visible and considered to be NPS, so that its effects are rarely noticed except in the case of a catastrophic event, such as a fish-kill incident (Carolan, 2006);

and in many cases, the people impacted may be very far away. Such exceptional events are likely to catch attention within the sub-field of environmental sociology, but most typical agricultural activities are subsumed into the more functionalist tradition of natural resource sociology, which normalizes the complexities of managing natural resources and minimizes conflict (Buttel, 2002). Even in rural areas where water pollution is widely recognized, farmers are generally not convinced that their own activities contribute significantly to the nutrient pollution problem (Osmond et al., 2012a; Nowak et al., 1997). If there is awareness of these hazards, there is almost no local political constituency to address them, because relatively few people who are uninvolved in the agricultural industry populate these areas, and because non-human species are traditionally not represented within our legal system (Freudenburg and Keating, 1985). While there are citizen-activist groups that attempt to address these environmental issues (Sierra Club, National Resources Defense Council, etc.), these groups' resources are mostly used to focus on more location-based and time-focused issues where there is high public visibility, leaving the pervasive nature of this widely dispersed issue largely out of the public discourse. This relative non-visibility accounts partially for the relative lack of pressure on farmers to address nutrient pollution.

Along with the general unawareness of these water pollution issues, there is no unified strategy for addressing them. Voluntary mitigation techniques, typically disseminated by state cooperative extension services and by the Natural Resources Conservation Services (NRCS) as "best management practices" (BMPs), are not widely accepted by many farming communities, as I will discuss later. Also some of these BMPs conflict with others, so that farmers often find them more confusing than helpful. Additionally, each affected location has unique conditions that call for its own set or combination of measures (Sheriff, 2005; Osmond et al., 2015), and many farmers believe that some recommendations are unnecessary or inappropriate in their particular cases. For these and other reasons I will discuss below, little is done by many farmers to reduce the loss of nutrients into waterways or to groundwater. As nutrients build up throughout our longest river systems, they accumulate and become deposited where rivers empty into the ocean (Rabalais, 2014; Rabotyagov et al., 2014). Where this happens, “dead zones” often occur, at which points the problem becomes highly visible.

“Dead Zones” Resulting from Excess Fertilization, and Practices to Reduce them

One locale where the effects of these excess nutrients has become obvious and severe is the Mississippi Delta in the Gulf of Mexico, where a very large “dead zone” results from the cumulative nutrients that enter via sub-watersheds as far away as Montana, Minnesota, and New York (Rabotyagov et al., 2014; Ribaudo, 2015; Ribaudo et al., 2012). The Northern Colorado area of the current study was cited in the Proceedings of the National Academy of Sciences (PNAS) as one area where some level of conservation practices could be employed to beneficial effect both locally and remotely, so as to reduce biodiversity loss and to minimize the dead zone where the rivers meet the ocean (Rabotyagov et al., 2014). Ten research scientists studied various scenarios for reducing this hypoxic zone by modeling the hypothetical spending of public funds to promote the use of conservation practices and to reduce fertilizer application rates at various levels. According to their report, “A number of cropland conservation practices can limit the loss of N and P from cropland into waterways and include reduced tillage, terraces, and riparian buffers. Reduced fertilizer application rates, and altered timing and method of application, can also be used to control losses of N and P. … (These) findings suggest that the existing suite of ‘working land’ cropland conservation practices can be sufficiently effective to reach the national hypoxia reduction goals.” (Rabotyagov et al., 2014, pp. 18530-3). Soil permeability, fertility, and structural suitability for crop-production are all factors that can be affected by how and when farmers apply manure. In addition to the physical characteristics regarding irrigation and nutrient percolation described in Chapter I, there are physical soil-related factors that complicate manure management.

Complicating Factors – Soil Permeability and Manure’s Mixed Impact

Another aspect of manure management is manure’s potential as a soil amendment that will reduce nutrient movement through the soil column and thereby reduce pollution. Whether or not farmers think in these terms, their choice to use manure can have this beneficial effect as a source of organic matter, both reducing pollution and possibly improving their yields. In this context, it should be noted that soils in the areas studied are varied. Highly permeable soils allow manure nutrients to percolate quickly, reaching groundwater (Ceplecha et al., 2004). On the other hand, adding organic matter of manure to these very soils can sometimes improve their structure and allow them to support higher crop yields while filtering out more nutrients (Trachtenberg and Ogg, 1994; USDA, 1991). Complexity of the issue, and conflicting objectives such as protecting water-quality vs. preventing wind-erosion or reducing nitrogen volatilization into the atmosphere, can lead to a wide variety of manure-handling tactics (Osmond et al., 2012b). Farmer thought processes and decision-making processes are therefore important, as they can potentially contribute either to excess manure application or to environmentally sustainable manure management (MM) practices and, in some cases, both simultaneously (Sheriff, 2005).

While Colorado State University (CSU) Extension has provided BMPs for MM and irrigated crop production that would help limit over-application (Bauder, Waskom, and Andales, 2014), nationwide studies indicate that relatively few growers appear to follow such guidelines (Ribaudo, 2015; Ribaudo et al., 2012). Even a very few operations that overapply nutrients onto highly permeable soils can seriously overload groundwater with nitrate over time (Extension-Specialist-2, 2017). For policy planning purposes, it would be helpful to understand what factors influence the farmer's choice between conserving manure nutrients or not adopting the recommended conservation measures or BMPs.

Barriers to Adoption of Conservation Measures and Developing Effective Policies

In an effort to understand what factors affect a farmer's choices regarding manure management, we examined not only the situation of the farm, but also the farmer's preferences and attitudes, likes, and dislikes in connection with the benefits and problems of using manure. Adoption of effective manure management as a conservation practice may depend a lot on how the farmer perceives manure and working with it. There is a significant body of literature addressing barriers to the adoption of innovation (Rogers, 1995); and while taking an innovative approach in managing manure application may seem easy enough, there are apparent barriers that really need to be addressed.

McCann, Nunez and Nowak have identified many of these barriers to the adoption of BMPs and to sound manure management practices in general (2006). While research has identified numerous innovations and nutrient management practices that could help mitigate the excess nutrient problem, there are solid reasons that many of these opportunities have been widely ignored by farmers and agricultural systems in general. McCann et al. identified seven types of obstacles – essentially issues of cost, time availability, and timing or convenience factors that reduce the feasibility and the likelihood of a farmer's adopting improved MM measures (McCann, Nunez and Nowak, 2006). Some of these obstacles and barriers to adoption of conservation measures are concerns that we addressed in the study and analysis presented in the chapters below.

In addition to the types of obstacles mentioned above, McCann, Nunez and Nowak cited the lack of policies that would require farmers to protect water and soils as a key reason for the industry's failure to address the issue of manure nutrient management (2006). Because farmers in northern Colorado had expressed concern that increased regulations or enforcement would seriously disrupt their ability to operate effectively, we wanted to know to what extent farmers saw high groundwater nitrate levels as a problem, and how concerned they were regarding possible regulation of manure management in the future.

Because of the complexity and variability of farming conditions, McCann et al. theorized the need for a "systems methodology" that would adapt innovative strategies to the local needs and conditions of each farming situation (McCann, Nunez, and Nowak, 2006, p. 32A). Localized policies, they argued, would illuminate how the local situation is problematic and would tailor case-by-case remediation strategies to address those specific problems, rather than casting a set of one-size-fits-all solutions that create extra work for many operations in which little or no change is truly necessary (McCann, Nunez, and Nowak, 2006). Our study considers where farmers stand in regard to this aspect of policy development, that is, what level of government, if any, should regulate manure management.

NPS Pollution is a Matter of Scale

While many farmers are making choices that are economically rational at the individual level by over-applying nutrients to their crops (Sheriff, 2005), these choices are clearly not rational from an environmentally sensitive societal perspective. Awareness of water-borne nitrate as a problem is obscured by the differences in scale between its sources and its manifestations. As described earlier, each individual farmer is striving to be as productive as possible. From where the farmer stands, excess nitrogen does not appear to be a problem, but insufficient nitrogen does. Only from a high-altitude perspective does the nutrient-accumulation problem become apparent. One reason for the current study of farmer behavior is to help bridge the gap between local farm operators and downstream communities where the nutrient overloading displays its most extreme negative consequences.

By its nature, most farming occurs in low-population areas, so the over-application of nutrients goes largely unnoticed. Much farther downstream, where the small excesses of many farms have accumulated, this overloading of nutrients becomes a problem. It is virtually impossible to point a finger at any individual farmer as the source of the problem. It **is** possible, however, to identify the level of nutrients emitted by a watershed; and so the watershed becomes an appropriate unit-of-analysis (Osmond et al., 2012b; Osmond et al., 2015). Some nutrient-impaired river basin watersheds have been identified and the effectiveness of their nutrient management plans (NMPs) evaluated (Osmond et al., 2015). In general, there is a considerable gap between the recommendations necessitated by these NMPs and the actual adoption of such practices by the farmers who would need to make the necessary changes. The primary conclusion of the evaluation by Osmond et al. is this: “Without better dialogue with farmers and meaningful investment in strategies that reward farmers for taking what they perceive as risks relative to nutrient reduction, little progress in true adoption of nutrient management will be made" (2015). Even in watersheds where NMPs have been implemented, success has only been achieved where there was very deliberate outreach and education, trust cultivated within the immediate farming community, and significant ongoing financial incentives (Osmond et al., 2015). The social networks in farming communities are typically sparse enough and removed enough from outside influences that regulatory pressure will likely be needed, along with incentives and local consensus, if nutrient over-application is to be significantly reduced. If we wish to reverse the accumulated overloads, we will clearly need to understand better what factors affect the farmers' decisions and to negotiate with farmers in a way that brings them onboard.

"Non-point Source" as a Term, and Increasing the Effectiveness of Policy

Effluents emerging from smaller-scale operations are typically viewed as NPS pollution and are not controlled by enforceable regulations, for various reasons. The polluting source operations are considered too numerous to monitor directly, and the nutrients involved would be difficult to trace back to their sources, being cumulative and diffuse (Ribaudo, 2003). However, the fact that nutrient over-application is difficult or expensive to monitor does not mean it is appropriate to ignore it. Calling it "NPS" is one factor that makes it culturally acceptable for farmers to ignore the recommended, but voluntary, practices and BMPs needed. As many researchers have pointed out, effectively addressing these issues is complicated and multi-layered, and perceiving the source more realistically could be an important step toward gaining support in doing what is necessary. Therefore, in the discussion chapter later, I will make the argument that "non-point source" is a misnomer, because the term gives the illusion that there is no identifiable source. It would be more appropriate in actuality to label this "multi-source" or "widespread-source" pollution. Like many environmental pollution phenomena, the cumulative effects of over-applied N are manifest in locations far away from their sources, such as the hypoxia created by algal blooms that lead to fish kills, or such as the “dead zone” of the Mississippi Delta (Rabotyagov et al., 2014; Robertson and Vitousek, 2009). The change in discourse I am suggesting is mainly semantic. Literature I am citing here has already identified the problems of excess nutrients and ineffective regulation. My suggestion of renaming NPS pollution is a matter of reframing, given that its diffuse nature has supported a mindset that it simply cannot be controlled or reduced.

Manure mismanagement is an extreme case of NPS pollution, locally exacerbating a pervasive nutrient management issue. The American Fisheries Society, in a statement posted on their web-site (2015), describes NPS as follows:

> Nonpoint source pollution is probably the most pervasive and ubiquitous water quality problem in North America. Nonpoint source pollution results from nearly every type of human activity and land use. In the United States a comprehensive program to control nonpoint sources of water pollution is defined and regulated through the Clean Water Act Amendments of 1977 administered by the U.S. Environmental Protection Agency. Nonpoint sources of pollution are defined by the Act as "…sources of pollution which enter surface or groundwaters through widely diffused small increments," and include:
>
> - Urban and industrial stormwater runoff;
>
> - Agriculturally related nonpoint sources of pollution including runoff from manure disposal areas, and from land use for livestock and crop production;
>
> - Silviculturally-related nonpoint sources of pollution;
>
> - Mine-related sources of pollution including new, current, and abandoned surface and underground mine runoffs;
>
> - Construction-activity-related sources of pollution;
>
> - Sources of pollution from disposal on land, in wells, or in subsurface excavations that affect ground and surface water quality;
>
> - Saltwater intrusion into rivers, lakes, estuaries, and groundwater resulting from reduction of freshwater flow from any cause, including irrigation, obstruction, groundwater extraction, and diversion;

> - Sources of pollution related to hydrologic modifications, including those caused by changes in the movement, flow, or circulation of any navigable waters or groundwaters due to construction and operation of dams, levees, channels, or flow diversion facilities; and
>
> - Sources of pollution related to the disposal of municipal or industrial residual wastes and land disposal. Similar but less comprehensive legislation controlling nonpoint sources of pollution has been promulgated in Canada and Mexico.
> (American Fisheries Society, 2015)

Their statement goes on to say that fisheries and aquatic scientists should be involved in a broad array of research areas and policy development activities (American Fisheries Society, 2015).

Labeling all these water-flows as NPS pollution has perhaps been a necessary step in focusing public attention on point sources of pollution for many years, taking a “divide and conquer” approach. However, based on a large range of sources, I argue here that framing such widespread pollution as “non-point source” promotes the socially-constructed illusion that it is uncontrollable. For policy-making it has been effective to begin with the “low-hanging fruit” of easily detectable point sources, but NPS pollution can no longer be externalized indefinitely. Traceability is no longer the obstacle it has been in the past. Some researchers believe that regulation and enforcement will be necessary to gain control of NPS pollution (Centner and Mullen, 2002). While identifying pollution sources by examining the polluted water itself has been virtually impossible in the past, it is becoming a reality through modern chemical analysis techniques such as “stable isotope analysis” (Michener and Laitha, 2007).

Policy Addressing Societal and Individual Levels Simultaneously

Societal environmental considerations are more typically addressed through governmental regulation than through market forces, especially where a market-failure becomes an obvious hazard as seems clearly to be the case here. Regulatory agencies creating policy are in the precarious position of having to address both the individual and societal levels of this difficult and complex issue at the same time. Colorado's Regulation 85, briefly described below, exemplifies the difficulty of this, in that it has allowed a 10-year period for the farming community to develop or attempt to create a viable synthesis of these two goals, attaining acceptably high crop yields while minimizing the over-application of nutrients. (Extension-Specialist-3, 2019)

Nutrient Management Regulation in Colorado

Colorado's "nutrients management control regulation", known as Regulation 85, was adopted in 2012, by the Colorado Department of Public Health and Environment's (CDPHE) Water Quality Control Commission (WQCC). It provides a ten-year opportunity for agricultural operators to address their water-quality management issues voluntarily through BMPs. That regulation began the enforcement of limits to point-source pollution, such as from wastewater treatment plants and from CAFOs. It also specified that NPS nutrient pollution from agricultural operations would be evaluated in 2022, to determine whether BMPs adopted by local farm operators are sufficiently protecting public water quality. This regulation provides an opportunity/mandate for agriculture to self-regulate its NPS nutrient-pollution; if unsuccessful, it would potentially become regulated in the near future. This approach can be compared to the self-regulation efforts of the Golf-Course industry which relies partially on Ecological Modernization (EM) theory for its legitimation (Millington and Wilson, 2013). The EM theoretical approach credits large-scale industries and corporate entities with integrating environmental protection gradually into their operations, thereby precluding the need for additional regulations. The effectiveness of this approach is clearly debatable (Millington and

Wilson, 2013); and Colorado's WQCC will soon begin evaluating whether self-regulation has been effective in Colorado's farming sector (Extension-Specialist-3, 2019).

If the results of this evaluation show that regulatory strategies are necessary, a multi-measure approach will likely be appropriate, based on the meta-analyses of programs that have been implemented in other locations (Osmond et al., 2015).

What Farmers are Thinking and Whom Do They Trust?

Lois Morton applies the concept of "mental maps" and the idea that farmers are dealing with a broad range of site-specific issues, to the extent that their conceptual frame for addressing the agricultural and environmental situation is typically based in a different set of criteria than the decision factors previously identified (Morton 2011; Morton 2008). Farmers naturally take exception to the generalized recommendations of researchers suggested by extension specialists and natural resource professionals because their local situations involve unique challenges and uncertainties, and their economic lives as farmers are on the line. Farmers also tend to see themselves as self-reliant in their decision-making, considering all types of recommendations. But in the end, having to live with the results of their own choices, they rely on their own judgement based on experience (Morton, 2011). When farmers were asked to specify the key factor in making their manure application decisions, their most common response was "use (my) own judgment based on experience" (Morton, 2011).

A meta-analysis completed by Osmond et al. in 2015 found that farmers typically overapply nutrients partly because they do not trust university-extension recommended nutrient application rates, and because they view abundant nitrogen as "insurance". Houser (2018) found that even when farmers complete nutrient management plans (NMPs), they usually apply more nitrogen than specified by the plans in order to protect against the risk of a lower-than-maximum yield. In many cases, farmers follow fertilizer application recommendations made by fertilizer dealers, whose representatives are typically called “crop consultants” (Osmond et al., 2015). These fertilizer recommendations are prescribed by the hybrid seed companies, often with nutrient recommendations inflated to assure a maximum yield (Stuart and Houser, 2018). “Crop consultants” have been recognized as one of the information sources that farmers regularly use and trust (Eanes et al., 2017). “Consultants”, in this case, are a distinctly different from “experts”.

R.L. McCown points out that the traditional knowledge transfer process, of ‘experts’ such as scientific researchers or university extension agents disseminating knowledge, is a serious barrier and point of resistance for farmers (2005). Scientific researchers often assume they understand the relevant factors in farmers’ choices. McCown argues that these researchers could be much more effective if they asked farmers what they think and explored how experience, knowledge and personal relationships contribute to farmers’ mental decision models (McCown, 2005; Morton, 2011). According to a comprehensive meta-analysis of farmers in the U.S., BMPs oriented toward resource-conservation are among farmers’ “most disliked practices” (Osmond, et al. 2012b), compared with conventional practices.

Monitoring Program Effectiveness – Meta-Analyses and Complexity at Many Levels

The studies on which I report here provide ground-level insights into why the results of many conservation programs have not been very successful at protecting the water quality in agricultural areas, by looking closely at farmers’ attitudes and behaviors regarding manure management. Several research projects have examined the effectiveness of conservation programs designed to protect water quality in agricultural watersheds, and much of the resulting information has been disseminated in a series of reports produced by USDA, through the National Institute of Food and Agriculture (NIFA) and the Natural Resources Conservation Service (NRCS) (Osmond et al., 2012b). Like the analysis of McCann, Nunez and Nowak mentioned above, these meta-analyses have cited financial concern on the part of farmers as a major barrier to adoption; but they have also indicated that other issues such as time management, family dynamics, and neighbor-related concerns act as barriers to adopting and maintaining effective conservation practices. Disappointingly, as mentioned above, they have found that some of the most often recommended BMPs for nutrient-management are among farmers' most disliked practices (Osmond, et al. 2012b, p. 124A).

Part of the problem in farmers' experience with BMPs may be that such recommendations emphasize broad-brush generalized solutions purported to apply throughout a region or in all situations while overlooking the wide variations of both physical conditions and farm-management cultures within a watershed (Osmond et al., 2012b; Ribaudo, 2015) as well as the local and personal knowledge of the farmers who are intimately familiar with the ground they farm (McCown, 2005). Physical solutions for one farming challenge may add to the environmental problems, as in the case of tile-drains – well-drained soils may be very productive, but the drainage system becomes a rapid conduit for soluble nitrate into groundwater (Ribaudo, 2015).

Factors that Lead to Better Nutrient Management Adoption-Rates

Osmond et al. (2015) found that nutrient management adoption rates improved when programs included measures to ease management demands, to work directly with small groups of farmers, and to provide significant funding for agency personnel along with cost-share funding for farmers. Each of these measures involves a significant commitment of resources and local attention, so a deeper understanding of how farmers view and manage nutrients, as developed in this study, is clearly an important piece of the puzzle at hand.

Farmers typically operate somewhat in isolation from society at large and their time is largely consumed by managing their farms; so it is natural that they are likely to focus on productivity in their own realm without much attention to downstream impacts. Besides their concern for financial solvency, farmers tend to struggle with time management, family dynamics, and neighbor concerns, such that BMP recommendations are often seen as a burden to be avoided unless they clearly improve the individual farm's financial outlook (Osmond et al., 2015). Apparently more socially connected farmers are more amenable to working with agency personnel and to addressing societal environmental standards than those who are less connected. Based on this understanding, it may be appropriate to find new ways of conveying the effects of excess nutrients downstream, such as online maps showing instream nutrient measurements, or photographic presentation of dead zones downstream, and to have town-hall meetings where local community members have opportunities to propose and discuss local solutions. Toward this end, our inquiry into farmers' views and decisions regarding manure management explored the types and sources of knowledge they would trust and apply in running their operations. In addition to knowledge sources around management practices, we should look at how farmers think generally about water and other environmental resources they work with.

"Groundwater Citizenship" and Land-Use

How farmers manage manure and fertilizers in general can have effects that reach well beyond their own farms. In that groundwater becomes altered and unhealthy for drinking from rural wells, and in that polluted groundwater changes the riparian ecology of the river basins wherever it surfaces, there are clearly some environmental issues to consider. Groundwater has traditionally been viewed as a common property resource; and when it becomes toxic, humans and other species that depend on it are harmed (Sampat, 2000).

This raises the issue of "groundwater citizenship" discussed by Brock Ternes (2018). A large percentage of farmers own wells or use well-water in growing their crops. Ternes asserts that well owners, typically in rural areas, are usually more aware of groundwater supply and water quality issues than others who use publicly managed water supplies, because their land-use activities and water usage can affect both the quality and quantity of their water source (2018). While Ternes does not discuss surface water *per se* in his article, the use of irrigation-water shares (typically controlled through ditch-systems and owned by irrigation-water companies) would probably be another point of distinction appropriate for research into what affects a person's attention to "water-citizenship". One might expect concerns about water quality to influence manure management choices in that manure application, like commercial fertilizer application, has the potential to affect well-water quality directly. Later in this analysis I consider whether this concern affects the typical farmer's manure management decisions.

Environmental Sustainability vs. Profitability – "Conservationism" and "Productivism"

Lois Wright Morton discusses the need for farmers to practice "Conservation Agriculture" which is "not just a decision to adopt one new farming technique, but a reconstruction of beliefs and values about the agroecosystem and the (farmer's) role as manager of a new crop production system" (2011, p. 213). Whether specific farmers choose to adopt sustainable MM practices may also depend on the levels of "conservationism" or "productivism" in their thinking (Ribaudo 2015; McGuire, Morton, and Cast, 2013). "Conservationist" farmers are inclined to use environmentally sustainable practices on principle to protect the natural ecosystems they manage. "Productivist" farmers, on the other hand, may also be likely to implement practices that protect water quality **if** these practices also provide benefits such as improved yields or lower costs (Reimer, Thompson, and Prokapy, 2012). Productivist thinking may be especially hazardous if the field soils are highly permeable, or where a tile-drainage system expedites the transfer of nutrients into groundwater (Ribaudo, 2015).

Where on the productivist/conservationist continuum farmers are located may be less relevant than the extent to which they attempt to achieve nitrogen use efficiency (NUE), as this approach would lead directly to capturing nitrogen within a crop and avoiding the waste of letting it migrate into any water supply (Tully and Ryals, 2017). Efficiency as a goal is complicated by what measure farmers use in perceiving their level of farming success. If farmers strive to maximize crop yield, then applying excess nitrogen may help reach this goal even though their cost per bushel will be higher. If, however, they seek to maximize return on their investment, a slightly lower yield would produce a considerably higher financial return due to the cost-savings of reduced input (Amon-Armah et al., 2015).

This "maximum economic rate of nitrogen" (MERN) fertilization approach has repeatedly proven to improve bottom-line revenues (Amon-Armah et al., 2015). However various economic, cultural, and psychological factors, such as vertical integration of the beef-industry (Hinrichs and Welsh, 2003), attention to gross-sales figures, and bragging rights, have prevented this MERN approach from overriding the desire to maximize crop yield. Additionally, farmers tend to be fearful of applying too little nitrogen, in case the current season turns out to be a very productive year with high potential yields (Sheriff, 2005; Woods et al., 2014). Also, as mentioned above, pressure to over-apply N comes in part from seed-companies who supply new hybrid varieties every other year, virtually forcing farmers to rely on those companies' often inflated fertilizer recommendations (Stuart and Houser, 2018). It may be possible, in viewing our farmers' responses, to gain some insight into whether they were striving to maximize yield quantities or to achieve the highest possible return on their investments. For those farmers who used manure on some fields, we calculate whether they reduced the commercial N applied in order to account for the N they likely added by using manure. Farmers' relationships with NUE, MERN, and other N-efficiency tactics will be topics for discussion in later chapters of this document.

Before moving on, it seems important to mention that this discussion occurs within the general context of environmental sociology and the sociology of livestock agriculture.

Environmental Sociology and Farming in the Context of Livestock Production

Environmental sociology includes a broad spectrum of topics, ranging from human activities that have created environmental problems to the politically modulated adaptations and mitigations developed in response to such issues, and to the resilience of the populations affected. The groundwater pollution issue that led to this study represents an instance where a specific food-sector, livestock management and processing, has amassed and concentrated into an industrial form that affects both local populations and a broad range of eco-systems. The human appetite for meat, along with a rapid increase of urban populations, has led to high levels of profitability for the livestock industry. This in turn has attracted major capital investment and resulted in widespread industry concentration and consolidation. Like many industries that grow financially powerful through economies of scale and cost-reduction, the livestock industry externalizes byproducts that do not contribute to their bottom-line, in this case livestock manure. It does this through the channel of farmers applying manure to crop-fields, which is explored throughout this paper. Using terms from a world-systems perspective, one might observe that the advancement of capitalism is constantly re-shaping the food production system and this in turn affects the ecology and natural environment of which humanity is a part (Moore, 2011). Expanding on that analysis is a different project from the current one, and would be worthy of continued research at a macro-theoretical level. In the current project, I focus on the farmer's role specifically, as one segment within the ecological/economic cycle.

The economically based structure of contemporary agricultural policy supports the centralization and consolidation of animal production, which in turn generates large localized volumes of manure that the livestock industry attempts to externalize by passing them on to crop-farmers. Farmers, as recipients of these manure accumulations, are clearly in a key position to control whether excess nutrient application results in hazard to the environment. The nutrients contained in manure would allow them to reduce greatly, or in some cases eliminate, their commercial fertilizer applications, greatly increasing profitability with only a slight drop in crop yields (Amon-Armah et al., 2015). One question that I would pose to farmers in future research, considering the MERN strategy (Amon-Armah et al., 2015) is this: "If you could make more money by reducing fertilizer input costs significantly and crop yield only slightly, would you do so?"

Sociological propositions arising from the current project can likely be theoretically located within a middle range (Merton, 1949), applying to specific local agricultural and typically rural situations. Such propositions may be somewhat generalizable to certain environments, industries, or populations, but less widely applicable to an overarching view of the world in general. This is in keeping with the necessity of evaluating rural problem issues locally, given that each rural area is geographically unique and involves its own set of physical, historical, cultural, social, political and economic characteristics. And, given that each local farming environment may need to be examined and addressed uniquely, it seems appropriate that a middle-range theoretical approach should apply. This project contributes also to the sub-fields of environmental and natural resource sociology, while being embedded in the general sub-fields of rural sociology and sociology of agriculture.

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CHAPTER III. RESEARCH QUESTIONS and METHODS

Questions Addressed in this Analysis

Three research studies follow, each of which analyzes a separate aspect of how farmers' think and behave regarding manure management. All of them draw on data gathered as part of a survey described in "Manure Management and Crop Production in Northeastern Colorado", a research and education project funded in part by the USDA under Sustainable Agriculture Research and Education (SARE) Grant #SW96-007 (Davis, 1999). These three analytical studies, Chapters IV, V, and VI of this document, are intended to work together to better understand the nature of farmers' choices in managing feedlot manure. The data used within each of the three studies are described separately in each chapter. Some summary information is provided in Appendix B of this document. The discussion in Chapter VII brings together the insights of the three studies to determine what we might conclude and where additional future research attention may be appropriate.

Chapter IV - What factors affect farmers' manure management decisions regarding the types of fields they choose for manure application? Understanding how farmers choose which fields they deem appropriate for manure application can provide some insight into what affects the farmer's choice of whether or not to apply manure on a field. Understanding what makes a field less appropriate for manure application in the farmer's mind could also provide insight into why some farmers may choose not to use manure at all, even if it is available.

Chapter V - How do farmers perceive the value of manure in monetary and utilitarian terms? Understanding how farmers perceive the value of manure should be an indicator of how concertedly the farmer may attempt to maximize its fertilizer function and not to waste its nutrients. The more effectively a farmer targets a crop with nutrients, the less money needs to be expended on inputs and the smaller is the residual amount of nutrients that ends up in the local water table.

Assuming a utilitarian perspective, the perceived value of manure represents the farmer's inclination to use manure efficiently. Here we use the concept that managing manure as a valuable resource is a potential element of sustainable manure management. By contrast, over-applying manure as a waste byproduct can be interpreted as undervaluing manure's nutrient properties (Hall, 1996). Sustainable manure management techniques are more likely to be practiced by those who place the highest value on manure, and the least sustainable manure management activities are likely practiced by those who assign the lowest value to it. I sought to find whether farmers who placed a higher value on manure were likely to apply manure at a substantially lower rate than those who perceived its value as being lower.

Chapter VI - How are manure application-rate decisions affected by non-monetary factors such as preference, location, personal situation, convenience, knowledge, or social pressures? The more sparingly and carefully a farmer applies manure and nutrients in general, the less likely it is that excess nutrients will migrate below the root-zone into the groundwater below. This study identifies which factors have a substantial effect on manure application rate, by identifying what contributes to manure over-application.

Chapter VII brings together the three analyses of farmers and their manure management decisions, to create a more comprehensive picture of farmers and their relationships with manure application in this crop-production setting.

Supporting questions involve details such as the following: Is the farmer's focus typically on crop-yield expectations, crop nutrient needs, input costs and/or long-term sustainability of soil and water conditions? Do farmers typically consider non yield-related issues like water quality impacts, regulations, or the concerns of their neighbors? And do farmers willingly or intentionally take on the intermediary function and responsibility of waste management for the industrial-scale feedlots? We chose to study farmers' preferences relative to some of these elements in order to better understand their preferences for and against various aspects of manure and its application in their operations. We wanted to understand how these elements shaped their thinking and influenced their manure management decisions, approximating a mental model of factors affecting their decision processes. Here I turn to describing the methods used in these studies for data acquisition and analysis.

Methods – Data Acquired and Used in this Study

As a graduate research assistant, I helped develop and conduct a mail-survey that explored farmers' manure management choices from several angles. The survey was conducted in two livestock production areas located along the South Platte River of northeastern Colorado, and through it we acquired data related to the issues listed above (Davis, 1999). I have also conducted approximately two dozen interviews with farmers, ranchers, and manure haulers operating in these areas, to seek personal insights into how they approach these decisions. The questionnaire used for the mail-survey is contained in Appendix C. Resulting data from survey responses are presented throughout Chapters IV, V and VI of this document, and additional summary information is shown in Appendix B.

The following section briefly describes the development of our questionnaire as a survey instrument intended to acquire data we deemed relevant in answering the research questions that I have described above.

Types of Farmer Decisions that Might Affect Nutrient Management

In preparing to create the survey instrument, I interviewed a cross-section of people involved in the farming of feed-crops, ranging from farmers and feedlot operators to manure haulers, crop consultants, fertilizer dealers and extension agents. This provided a reasonable background sense of what questions might be appropriate to ask of crop-producers relating to manure management. In retrospect, the team developing the questionnaire has realized there were several items that we did not think to ask which could have provided valuable insights and enhanced the knowledge obtained. These missed opportunities will be identified to some extent in the discussion chapter near the end of this document.

A key element of variability among the farm operators responding to our survey was the scale of operation as represented by size. Size of operations, in terms of livestock numbers and crop-acres, along with amounts of manure and N fertilizer applied were some of the data we requested. We also asked respondents about some of their preferences and behavioral choices as farm operators. One section of our questionnaire sought to understand the farmer's preferences for and against various aspects of manure application, using a 5-level Likert scale. We wanted to understand how these elements shaped their thinking and influenced their manure management decisions, approaching an understanding of factors affecting these decision processes. Among other issues, our survey questionnaire asked farmers about their levels of concern regarding regulation, neighbors, water pollution and excess groundwater nitrate levels.

With the issue of knowledge access and acceptance of research information in mind, we included questions regarding experience, information sources, and relationships, to see whether and how these elements affected the farmer's manure management choices. We also explored to what extent farmers practiced BMPs, and their attitudes toward these practices relating to the need for and the possibility of regulation. In the following section I briefly describe the specific kinds of independent variables we chose to consider as potentially influencing a farmer's decisions regarding manure application and manure management in the vicinity of livestock operations.

Factors Affecting Manure Management Decisions

In this section, I identify some of the key variables we thought might prove useful in understanding the considerations a farmer would face regarding whether to apply manure to a field, how much of it to apply, and other aspects of manure management. Analysis of their relevance will be discussed in the following chapters.

- Distance, in miles, from a (potential) source of manure - Transportation cost is a key factor.
- Field size, in acres - A farmer might attempt to match the amount of manure available with a field that would accommodate that amount, avoiding overapplication and/or the need to supplement with other fertilizer. Among operations that reported both a manured and a non-manured field, the sizes of the manured fields ranged from 5 to 290 acres.
- Potential or expected yield of the field, based on previous yields - Manure might be a factor for increasing yield, especially if manure is perceived as a supplementary fertilizer.
- Reduction of commercial nitrogen fertilizer applied - Because manure is cheaper than commercial fertilizer, applying it could reduce fertilizer input cost.
- Soil type (sandy, loam, or clay) - Added manure might improve soil's nutrient composition, texture, and water-retention characteristics.
- Crop grown on the field - Some crops benefit from manure's nutrients more than others.

- Type of irrigation (furrow, sprinkler, or drip) - Some irrigation systems are more likely to transport nutrients deeper into the soil, even beyond the root zones of the plants.
- Ownership status of a field - Presumably, long-term improvement of a rented field would be a waste of resources because the farmer renting the field might not end up using the field for a long period. On the other hand, negative factors like weed-seeds or salts might be seen as of less concern than for a field the farmer owns.
- Soil testing - Where it is used, soil testing can indicate the level of nutrients already present as well as the need for organic matter and other nutrients.

Additionally, we asked farmers to rank the importance of the following perceived benefits and drawbacks of using manure:

Presumed Benefits

- "Inexpensive fertilizer" – Manure as a substitute for commercial chemical fertilizers
- "Source of organic matter" – Manure used to enhance field-soils, especially through moisture-retention and improved soil texture
- "Improves soil properties" – a more general description representing the two previous items
- "Increases yield" – Manure provides a greater output volume of the crop
- "A way to reduce wind erosion" – Manure can be surface-applied to hold down topsoil.
- "A way to dispose livestock waste" – Field application of manure is an accepted removal practice.

Presumed Drawbacks (or Problems)

- "Causes more weeds" – Weed seeds are often a component of fresh manure.
- "Damage to plants from salts" – Manure can contain salts.
- "Soil compaction" – Spreader trucks are heavy and compact the soils.
- "Unpredictable nutrient content" – Manure's nutrient contents are highly variable.
- "Doesn't get spread evenly" – Manure can be "clumpy", and is often spread unevenly.
- "Lower crop yields" – Manure alone usually does not provide as much of a yield boost as commercial fertilizer.
- "Inconvenient to apply" – Manure is typically very heavy and requires special spreading equipment.
- "Additional tillage required" – Manure is more effective if incorporated into the soil
- "Relationship with neighbors" – Some neighbors are likely to complain about manure's odor, and possibly the increased presence of flies.
- "Possible water pollution" – Excess nutrients can be a problem, especially where the water table is high or where runoff flows into a natural waterway. Are farmers concerned about this?
- "Regulatory concerns" – Regulations concerning manure management can be a point of stress for livestock producers.

We also asked which of a number of farming or conservation-oriented practices the farmers had used or engaged in. (A checked box indicated "yes", and an unchecked box indicated "no"):

Best Management Practices Used

- "Crop yield goal"– Striving for a high yield seems like it would correlate with trying to maximize the soil's fertility for the crop being grown.

- “Past experience”– This reflects the farmer’s knowledge and experience with using manure and commercial fertilizer.
- “Plant tissue analysis”– This might represent the operator’s level of reliance on technical methods.
- “Irrigation water analysis”– Did they account for nutrients in their irrigation water?
- “Manure credit”– Did they rely on manure nutrients to cover part (or all) of the crop’s nutrient needs?
- “Legume credit”– Did they use a cover crop to provide some crop nutrients?
- “Consultant” – Did they use a consultant to help determine their nutrient application combination?
- “Field scouting for insects, diseases, etc.” – We thought this approach might possibly indicate how they approach specific field situations.
- “Irrigation management”– Does water conservation correlate with higher manure valuation?
- “Conservation tillage” – Is this practice seen as working well with efficient manure usage?
- “Water-flow control practices” – Does this match with irrigation management, or does it represent a different thought process and relationship with manure usage?

As for operation parameters and personal information, we collected some data on the size of each operation in acres, the acreage planted in different crops, the number and types of livestock they maintained. Also we collected some personal data, including the respondent’s number of years in farming or ranching, their approximate level of education, whether they worked outside the farm, and the approximate gross sales of their operation.

The mail survey was conducted in two areas along the South Platte River in Colorado where there is a prevalence of large feedlots, supported by numerous farming operations. The first survey round was conducted in Weld County, and the second was conducted in Logan, Morgan, Sedgwick, and Phillips Counties. We asked farmers to consider a typical manured field and a typical non-manured field from their previous growing season and to answer a set of questions relating to the above-mentioned factors for each of the two fields. This methodology provided appropriate data for matched-pair comparisons of the field characteristics that might distinguish manured fields and non-manured fields in our sample areas. Having pairs of fields matched by the operator-respondent means that each pair comparison controls for all other operation-related characteristics; only the field-specific data for the manured field and the non-manured field are different in each case. A dozen follow-up phone interviews were conducted with a few farmers, manure hauler-spreaders, and crop consultants to gain insights into some of the mail-survey results.

In the first survey round, we addressed the questionnaires to approximately 1,100 farmers in the feedlot area of Weld County, using a list obtained from the Farm Service Agency. We sent a follow-up postcard 3 weeks later and a second copy of the questionnaire 3 weeks after that. On the basis of questionnaires returned with notes from some farmers or their families, we determined that approximately 200 of these farmers were no longer active. Given the return of 273 valid questionnaires, the return rate was approximately 30%. Two years later, we sent approximately 600 questionnaires to the farmers of a similar livestock area farther east, also near the South Platte River. This area included four counties (Morgan, Logan, Sedgwick, and

Phillips), and those lists were provided by the Colorado State Cooperative Extension Service and the U.S. Department of Agriculture's Natural Resource Conservation Service. These mailings yielded a similar return rate of around 32%. Because of the differences in time and locale of the two survey rounds, a location variable identifying each case as part of the eastern or western sample was designated. Farms in the eastern, more rural, sample were typically about twice as large in field size and total acreage. Later, the phone interviews were conducted with informants of various roles within the livestock industry to gather personal opinions that might explain some of the survey results.

Some of the variables have proven to be helpful in understanding the MM choices that farmers make, while others, even ones that would appear to an outsider as relevant, are less consistent in their effects. These results are presented and discussed in the next four chapters. Farmer situations vary in ways that often prevent any simple cause and effect relationship from emerging statistically. Nevertheless, we have found that a deeper understanding of different farmer situations and characteristics is likely to provide insights and a basis for communicating with farmer groups that may help turn the tide in limiting the amount of excess nutrients allowed to go unused into groundwater or to remain in the soil after a crop has been harvested.

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CHAPTER IV. COMPARING MANURED VS. NON-MANURED FIELDS

A Farmer's Choice: Which Field to Put That Manure On?[4]

Introduction

This chapter discusses the choice of fields for manure application by livestock feed growers in northeastern Colorado. The study involved a mail survey of farmers supporting livestock production along the South Platte River in five northern Colorado counties (Sustainable Agriculture Research and Education [SARE], 1999). The farmer's choice of where to apply manure is important because placement is one factor affecting how manure contributes to the excess levels of nutrients in the rivers and water tables of industrial-scale livestock production areas. In many parts of these rural study areas, approximately 70% of the household wells were found to draw water with nitrate levels above 10 mg/L, the level designated as acceptable by the Environmental Protection Agency (EPA); and this problem is attributed to the high amount of manure applied in combination with commercial nitrogen fertilizer (Hall, 1996; SARE, 1999). Heavy manure application densities could be reduced by applying manure to more fields, thus distributing it over larger areas at lower densities.

Farmers are *de facto* stewards of the land and water. Therefore, it behooves us, as a society, to be aware of factors that affect farmers' resource management choices and the long-term ecological implications of those choices. In addition to having an impact on water quality, manure application decisions are relevant to air quality and to protection of mountain ecosystems. Natural resource managers and researchers have become aware of pollution and

[4] Adapted from: "A Farmer's Choice: Which Field to Put That Manure On?" *Journal of Extension*. February 2016. Research in Brief. 54(1): 1RIB5.

biodiversity loss resulting from airborne nutrients released through manure redistribution (Baron et al., 2000; Beem, 2008; Gebhart et al., 2011; Rueth & Baron, 2002). Farmers make many decisions under conditions of ambiguity and uncertainty (McCown, 2005). McCown suggests that interested parties are more likely to influence farmers' decision-making successfully not by telling farmers what they should do but by understanding what factors affect their decision-making regarding specific resources and considering the variables particular to those decision situations. As a small step toward that end, I explored some factors related to farmers' choices of field(s) on which to apply manure.

Research Questions

This article discusses factors that make one field more appropriate, as chosen by the farmer, for manure application than another field. This discussion is based on a section of the mail-survey questionnaire that addressed differences in field characteristics between a "typical manured field" and a "typical nonmanured field," for farmers who used manure on some fields. The research questions were based on the expectation that the choice of whether to apply manure on a specific field would relate to certain factors, for the reasons described below.

- Distance, in miles, from a (potential) source of manure. Fuel cost for transportation is a key factor, and wet manure is quite heavy. Previous research shows that the distance is typically no more than 3–5 miles (Hall, 1996; Hoag, Lacy, & Davis, 2004; SARE, 1999).
- Field size, in acres. The farmer might attempt to match the amount of manure available with a field that would accommodate that amount, avoiding overapplication and/or the need to supplement with other fertilizer. Among operations that reported both a manured and a non-manured field, the sizes of the manured fields ranged from 5 to 290 acres, as follows: 5–19

acres, 19%; 20–29 acres, 23%; 30–49 acres, 24%; 50–99 acres, 15%; and 100–290 acres, 19%.

- Potential or expected yield of the field, as estimated on the basis of the previous year's yield. Adding manure might be seen as a factor for increasing yield, especially if manure is perceived as a nutrient supplement.
- Reduced commercial nitrogen fertilizer applied (measured in pounds per acre). Because manure is cheaper than commercial fertilizer, applying it reduces fertilizer input cost. The opportunity to reduce fertilizer expense by substituting manure might have benefits for the use of some fields.
- Soil type (sandy, loam, or clay). Added manure might improve soil's nutrient composition, texture, and water-retention characteristics. Farmers rated approximately 24% of their field soils as sandy, 68% as loam or sandy loam, and 8% as clay or loamy clay. These figures were approximately the same for both manured and nonmanured fields.
- Crop grown on the field (typically corn, beets, or soybeans in the study area). Some crops benefit from manure's nutrients more than others, and some crops are not appropriate for manure use at all. Approximately 73% of the manured fields were corn fields. Other crops grown on the manured fields included soybeans, beets, potatoes, wheat, hay, and assorted vegetables; and the proportion of fields planted with each of these crops was about 4%.
- Type of irrigation (furrow, sprinkler, or drip). Some irrigation systems are more likely to transport nutrients deeper into the soil, even beyond the root zones of the plants.

Manured fields—furrow, 65%; sprinkler, 26%; no irrigation, 9%

Nonmanured fields—furrow, 67%; sprinkler, 26%; no irrigation, 8%

- Ownership status of the field. Presumably, long-term improvement of a rented field would be a waste of resources because the farmer renting the field might not end up using the field for a long period. Although there were no major differences in manure application between owned and rented fields, the eastern (more rural) sample had about half the field-rental rate (17%) of the western sample (35%). (See the "Methods" section for more information about the two samples.)

Methods

Within farms where manure was used, we asked each operator to compare two typical fields within their operation, one where manure was used and one where it was not used. For each field, they provided information such as field-size, soil type, crop grown on the field, type of irrigation, whether the field was owned or rented, potential yield of the field, weed-severity in recent years, amount of commercial nitrogen applied, and distance from a potential source of manure, whether manure was used or not. Having matched-pair field data allowed for the possibility of relatively reliable associations regarding why a farmer might decide to apply manure on one field but not another. Other than the field-specific data, all information about the farm and farmer is identical for each case of this manured vs. non-manured field comparison.

The mail survey was conducted in two areas along the South Platte River in Colorado where there is a prevalence of large feedlots, supported by numerous farming operations. The first survey round was conducted in Weld County, and the second was conducted in Logan, Morgan, Sedgwick, and Phillips Counties. We asked farmers to consider a typical manured field and a typical non-manured field from their previous growing season and to answer a set of questions relating to the above-mentioned factors for each of the two fields. This methodology provided appropriate data for matched-pair comparisons of the field characteristics that might distinguish manured fields and non-manured fields in our sample areas. Having pairs of fields matched by the operator-respondent means that each pair comparison controls for all other operation-related characteristics; only the field-specific data for the manured field and the non-manured field are different in each case. A dozen follow-up phone interviews were conducted with a few farmers, manure hauler-spreaders, and crop consultants to gain insights into some of the mail-survey results.

In the first survey round, we addressed the questionnaires to approximately 1,100 farmers in the feedlot area of Weld County, using a list obtained from the Farm Service Agency. We sent a follow-up postcard 3 weeks later and a second copy of the questionnaire 3 weeks after that. On the basis of questionnaires returned with notes from some farmers or their families, we determined that approximately 200 of these farmers were no longer active. Given the return of 273 valid questionnaires, the return rate was approximately 30%. Two years later, we sent approximately 600 questionnaires to the farmers of a similar livestock area farther east along the South Platte River. This area included four counties (Morgan, Logan, Sedgwick, and Phillips), and those lists were provided by the Colorado State Cooperative Extension Service and the U.S. Department of Agriculture's Natural Resource Conservation Service. These mailings yielded a similar return rate of around 32%. Because of the differences in time and locale of the two survey rounds, a location variable identifying each case as part of the eastern or western sample was designated. Farms in the eastern, more rural, sample were roughly twice as large in field size and total acreage. Later, the phone interviews were conducted with informants in various roles within the livestock industry to gather personal opinions to explain some of the survey results.

Results and Discussion

Using results from the mail survey, matched pairs of manured and non-manured fields were analyzed. Among the field characteristics considered, distance from a manure source, expected yield, cost savings through nutrient substitution, and field size were the most significant factors affecting farmers' manure-application choices. Understanding such factors may provide extension agents with discussion points for influencing farmers to protect water quality and air quality while making their work lives easier and improving their crop yields.

This section presents the statistical results found by modeling the data using conditional logistic regression. The odds of a farmer's applying manure to a particular field appears to be related (inversely) to the distance of the field from a manure source and to the expected corn-yield potential of the field. The relationship between odds of manure application and field size is more complicated, as I describe below.

Distance from a Manure Source

As can be seen in Table IV.1, the coefficient for ‘distance to a manure source’ shows that distance from a manure supply is inversely related to probability of manure application, largely because transportation is a major cost factor: Longer distances result in higher transport costs (see Table IV.1). More than one interviewee stated that a standard practice is to haul manure from a feedlot to a field about the same distance as that from which the farmer had previously hauled corn or silage to the feedlot (or even to the same field). This practice apparently represents a "nutrient replenishment," or "nutrient recycling," approach. The fact that farmers actually follow this practice is corroborated by the relationship of the variable "Expected Yield" and the odds of a field being manured (see Table IV.1).

Table IV.1

Conditional Logistic Regression of Manured/Nonmanured Fields

	Model 1		Model 2		Model 3	
VARIABLES	b (SE)	OR	b (SE)	OR	b (SE)	OR
Distance (miles) to a manure source	-0.272** (0.113)	.761**	-0.254** (0.128)	0.775**	-0.283* (0.160)	0.753*
Field expected-yield (standardized)	1.099** (0.460)	3.001**	1.789*** (0.570)	5.983***	1.763*** (0.562)	5.830***
Commercial nitrogen applied (lbs/ac)			-.0235*** (0.0056)	.977***	-.0258*** (0.0064)	0.974***
Field size					-.0376* (0.0204)	0.963*
Interaction – field size*Eastern (more rural sample)					0.0303 (0.0219)	1.031
N - matched field pairs	111 pairs		105 pairs		101 pairs	
Pseudo R2	.106		.362		.408	

Dependent variable: Field was Manured (1) or Not Manured (0). OR = odds ratio.
Standard errors are shown in parentheses.
*** $p < 0.01$.
** $p < 0.05$.
* $p < 0.1$.

Expected Corn Yield

Expected corn yield is positively associated with using manure. This may be because applying manure to a high-yield field does not likely harm the yield, and might even boost it. A lower yield expectation might lead a farmer to stick with the more conventional (and possibly more reliable) approach of using strictly commercial fertilizers. This finding is consistent with a study indicating that farmers are less interested in monitoring the amount of nitrogen applied to a crop where they rely on manure to supply much of the nitrogen (Wortmann, Koelsch, Shapiro, Deloughery, & Tarkalson, 2005). Several interviewees mentioned that a field is often used to produce corn for several seasons in a row. So the reported yield of the previous year may have been boosted additionally by fertilizer and manure applied over a period of several years.

Reduction of Commercial Nitrogen Fertilizer Applied

Reducing the use of commercial nitrogen fertilizer by substituting manure creates reliable savings. Whether a farmer chose to lower operation cost for a field by applying manure or chose to apply manure to the field and was thereby able to reduce commercial nitrogen applied is not clear, as this analysis only indicates a relationship consistent with either decision type.

It is clear that even when the farmer reduced nitrogen applied because manure was used, the amount of the reduction was typically not as much as it could have been. A study using yield-cost optimization showed that maximum economic rates of nitrogen (MERN) would be considerably lower than what most farmers apply, and less even than is called for by nutrient management plans (Amon-Armeh et al., 2015). The yield reductions using a MERN approach were quite small, and the reductions in cost and pollution resulting from excess nutrients were relatively large. Farmers seem to strive for the highest possible yields, even if the marginal fertilizer expense is providing relatively little yield-increase. Settling for a slightly lower yield would normally provide a considerably higher economic return. However, many farmers do not maximize profit, responding instead to the risk of having less than maximum-possible yields (Osmond et al., 2015; Sheriff, 2005).

Field Size

Field size has a complicated relationship to likelihood of manure application. Because manure is available in finite amounts and farmers often prefer to handle an entire field uniformly, we might expect smaller fields to get manured, as a single truckload would typically be used to cover roughly one acre of cropland. However, as one farmer explained, larger fields are more suited for efficient manure spreading because less vehicle-turning is required. Commercial fertilizer, on the other hand, is lighter and easier to apply, and it can be applied in virtually any amount so that matching supply to fields is not an issue. Size of a field thus has countervailing implications, which may imply interactions with other factors. In Model 3 (Table V.1), the interaction of field-size with sample location ('eastern' counties sampled vs the 'western' county) is included. The eastern sample had notably larger fields, and its typical manured fields were larger than the non-manured ones. For future research, field size could be considered in conjunction with amount of manure available.

Location

Location was a relevant control factor. The effect of yield was somewhat different between the two areas studied. This may involve physical and cultural differences between these areas. One area receives about 40% more annual precipitation, and in one area, there is a higher diversity of crops. While this relationship was not as statistically significant, it was nevertheless substantive and would be worth exploring through further research comparing the manure management criteria of farmers in different counties or regions. In Model 3, I have included location in interaction with field size.

Field Ownership

Field ownership data showed that rented fields were more likely to be manured than owned fields, possibly as a less costly way to maximize yield than using commercial fertilizer. A typical farmer may see the extra cost of renting the field as a reason to keep other costs down for that field. Also, perhaps on a rented field the farmer does not care about the possible long-run problem issues of salt, weeds, or compaction. Because this relationship was not statistically significant, it was not included in the models.

Other Factors

Some other factors did show a tendency toward influencing manure-application decisions, and some of these were mentioned by interviewees. Soil testing, where it is used, can indicate the need for organic matter and other nutrients. One hauler-spreader said he recommends basing manure-application choice not on a need for nitrogen but rather on the idea of supplementing soil organic matter. For nitrogen, he recommends spreading commercial nitrogen. A large dairy operator who also grows most of his own feed expressed his disagreement with water-quality regulations that limit manure application on sandy soils, saying that these soils are exactly the ones needing augmentation through the addition of manure's organic matter and nutrients. Soil fertility, he indicated, is the key to healthy plants that can effectively use excess nutrients.

Conclusion

In this study of northern Colorado farmers, the most significant criteria in a farmer's choice of fields for manure application are characteristics that reduce the overall cost of fertilizing through substitution of manure while still obtaining a high expected yield. Although manure-management best management practices typically emphasize strategies such as containment of manure away from open water flows, use of grass filter strips, and agronomic application rates, farmers' decisions are also influenced by field-specific factors. Like many farming decisions, the choice of fields on which to apply manure appears, not surprisingly, to be driven largely by the bottom line. Any attempts to influence manure management practices, whether to protect water quality or air quality, are more likely to be effective if they reduce costs and/or provide increased likelihood of financial success for the operation.

Understanding and discussing pragmatic issues such as those described above may help extension agents encourage practices that protect water quality and air quality while making farmers' work lives easier and improving yields. For example, an agent might discuss the value of substituting manure for commercial fertilizer in relation to the expected yield for the field. Or an agent could help a farmer identify the benefits of applying manure on a field that might otherwise have been perceived as too small or too large to be appropriate. Avoiding manure application on windy days might be seen as beneficial in that more nitrogen might actually be incorporated into the soil and become available to crops. In some cases, special incentives, or at least some additional benefit to the farmer, might be required to achieve cooperation.

Extension agents and research specialists can be key players in assisting farmers to reduce overapplication of nutrients while achieving economic success, especially if they can convey a realistic understanding of the specific considerations entering into the farmers' immediate decision processes. Becoming knowledgeable and conversant regarding the above-discussed factors affecting manure application field-choices is one possible step toward establishing or increasing the trust of their farmer clients.

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CHAPTER V. PERCEIVED VALUE OF MANURE[5]

For another perspective on farmers' manure management attitudes within the context of animal and crop production, we asked our survey respondents to identify a monetary value for the manure they might use, whether they actually used it or not. This perceived value of manure represents a farmer's inclination to use manure efficiently, based in the principle that managing manure nutrients as a valuable resource corresponds to managing those nutrients sustainably. By contrast, undervaluation of manure's nutrient value can lead to the dumping of manure for waste disposal (Asai et al. 2014; Hall, 1996; Hogberg et al. 2005). The most desirable manure management strategies are likely to be practiced by those who assign the highest value to manure; and, conversely, the least desirable manure management strategies are likely to be practiced by those who assign the lowest value to it. This chapter is designed as a stand-alone journal article considering factors that affect farmer perceptions of manure's monetary value.

Introduction – Perceiving the Value of Manure as an Agricultural Input

Feedlot Manure, Farming, and Valuing Nutrients - Reviewing the Literature

Feedlots in rural areas are a known hazard to water quality. For over half a century, concentrated animal feeding operations (CAFOs) in the United States have been consolidating and creating ever-larger concentrations of manure that threaten both water and air quality. Farmers within close range of feedlots are in a position to disperse these mountains of manure,

[5] Adapted from: Stroheim, E. & D. Hoag. 2021. "Valuing Cattle Manure as an Agricultural Resource for Efficiency and Environmental Sustainability". *Sustainability* (Basel). 13(16):9375. https://doi.org/10.3390/su13169375

using it as fertilizer and to amend their soils. If they apply manure in such a way that most of the nutrients are removed by a crop, they are also reducing the loss of these nutrients into the local water sources. But if they over-apply manure, compared to crop needs, much of these nutrients can wind up in water-systems or in the atmosphere, where they become environmentally hazardous. How highly farmers value that manure helps determine whether they apply it sustainably or over-apply it (Fleming, Babcock, and Wang 1998; Hoag and Roka 1995). Some see manure primarily as a waste to be disposed of as cheaply as possible, while others view it also as a valuable resource that can supply nutrients and other benefits. We surveyed approximately 400 farming operations and conducted a dozen interviews in two major feedlot areas of northern Colorado.

Here we explore a range of factors associated with how these farmers value manure. Our research question is whether and to what extent the farmer's manure source, along with certain perceptions about manure application, experiential knowledge, and some personal or farm-operation characteristics, are associated with how farmers perceive manure's value. These findings will add to the agricultural and natural resource sociology literature by showing specifically how farmers value manure, thereby giving policy makers and advisors relevant information about how to increase farmers' nutrient-management efficiency and to reduce pollution from this important source. For example, we find that elements affecting how livestock producers manage manure are different from those for crop-producers that receive and apply manure but do not produce it within their own operations. Finding ways to bridge this gap by moving manure from where it is oversupplied to where it is needed would be highly beneficial.

Fertilizer Management –

Agriculture has been identified as a major contributor to numerous environmental problems, from water pollution to greenhouse gas generation and biodiversity loss (Dudley and Alexander 2017; Ribaudo 2006; Stuart and Houser 2018). The demonstrated potential for water pollution has led to policies and regulations that are somewhat effective in containing point-source manure nutrients at the typical feedlot, and in preventing most direct releases of manure into surface waters while minimizing groundwater infiltration (Almasri 2007; Asai, Langer, Frederiksen, and Jacobsen 2014; Livingston and Cory 1998). But manure disposal through crop-field application is another story. Once the manure has been transferred off the property of an originating feedlot, some of it becomes a non-point source (NPS) pollutant, which is relatively unregulated (Livingston and Cory 1998; Ribaudo 2015). Feedlot manure is typically wet and heavy, and transporting it is expensive, so over-application within a short radius of a feedlot is common. Understanding farmer decision-making and behavior patterns regarding fertilizer management will be a key knowledge area for maintaining biodiversity and an acceptable quality of natural resources in the future.

Nutrient use efficiency (NUE) involves tightening up and carefully monitoring nitrogen cycles at many levels. This big-picture analysis has been identified and described by Tully and Ryals in their recent overview, "Nutrient cycling in agroecosystems: Balancing food and environmental objectives" (2017). Effective manure management (MM) on the part of farmers is one essential element in preventing degradation of environmental resources. Ultimately, avoiding or minimizing pollution from manure mismanagement is strongly linked to farmers viewing manure as a valuable resource and not merely as a waste byproduct to be externalized (Asai et al. 2014; Hogberg et al. 2005).

Additional support for attention to manure's economic value was demonstrated in a recent analysis comparing yield and pollution resulting from different nutrient application schemes (Amon-Armah et al. 2015). That study concluded that maximum economic rates of nitrogen fertilization (MERN) for most crops, including grain-corn, are distinctly lower than the application rates defined by corresponding nutrient management plans (NMPs); and that the reduction in yields under a MERN scheme is relatively small, while the reductions in production cost and in pollution are large (Amon-Armah et al. 2015). In other words, if the farmer optimizes net income by minimizing fertilizer input cost (manure plus commercial fertilizer) and accepting a slightly lower yield per acre, both the financial and the environmental benefits are significant. A similar strategy, promoted by Scharf et al. (2005) and called "economically optimal nitrogen fertilizer rate (EONR)", emphasized addressing the variability of nitrogen needed among fields and even within fields. A mental barrier to these approaches may be a farmer's conventional desire to maximize yield rather than net income, even though the latter path is more economically rational. Burton and Wilson (2006) studied the identity psychology of farmers regarding conservation and concluded that: "… despite much talk of an increasing 'conservationist' component to farming -- farmers' self-concepts are still dominated by production-oriented identities." In a recent study of Montana wheat farmers regarding the importance of factors affecting nitrogen fertilizer application, the percentage saying that "maximizing yield" was important or very important was considerably higher (89%) than "minimizing cost" (73%) (Jackson-Smith, et al. 2018). The similar level of importance for "matching crop yield goal" was identified by 79% of the same sample. And these economically oriented preferences were all ranked higher among farmers than environmental goals like "reduced risk of nitrate leaching" (66%) or "accounting for soil organic matter" (55%). We mention this to emphasize the notion that reducing nitrogen over-application is more likely to be achieved through financial considerations than environmental ones, at least given current agricultural thought modes.

Research Focus and Methods of Analysis

Here we hypothesize that farmer characteristics, including attitudes toward manure and MM, are partial determinants of manure's perceived value, which in turn affects how efficiently and sustainably farmers choose to manage manure. Theoretically, the more highly they value manure, the more efficiently farmers tend to use it. Another way to interpret this valuation is to see economic value as the language through which farmers express preference, which in turn may or may not lead them to use manure efficiently.

Through a mailed questionnaire, we explored farmer attitudes toward MM and estimated how those attitudes affected adoption of manure use. A similar study, conducted with part of this study's data, previously found that "pressures" such as owning cattle, and "preferences", both positive and negative ones, toward manure application do affect a farmer's choice whether to adopt land application of manure (Hoag, Lacy, and Davis, 2004). Pressures to use manure can include both a high demand or need for crop-nutrients, as in the case of a feed-corn grower, and a large supply of manure, in the case of the cattle feedlot operator. Preferences include positives like the benefit of increased crop-yield, and negatives such as concern about neighbors' objections to the smell of manure. Here we consider factors affecting the monetary amounts indicating farmers' "willingness to accept" (WTA) or "willingness to pay" (WTP) for manure, which can in turn represent their inclination toward efficient use of manure, and thereby to manage manure's nutrients sustainably.

Additionally we have conducted approximately a dozen in-person interviews with farmers, livestock operators, crop consultants and manure haulers not known to have participated in the mail-survey. Using the mail-survey data, we have examined the circumstances and perceptions that contribute to how farmers value manure. Having a ready supply of manure, either in one's own operation or nearby at a neighboring feedlot for example, reduces the cost of acquiring manure, effectively raising its value. While sustainable farming may not be a farmer's primary intended goal, it may nevertheless be a beneficial result of effective MM. The efficient farmer is motivated to consider NUE and to apply manure so as to deliver a maximum amount of nutrients to the plants, while minimizing the excess nutrients going into groundwater or surface waters. On the other hand, having to dispose of a large amount of manure might lower the marginal value of additional tons for some farmers. Both the survey data and interviews with informants showed that farmers who applied manure to their fields usually reduced the amount of commercial fertilizer applied, but not by the amount that would be expected. Those who relied heavily on manure's nutrients were still likely to add significantly more commercial nitrogen than would seem appropriate, as a sort of "insurance", in order to obtain the highest possible crop-yield. Excess nitrogen does not typically hurt the crop it feeds; and most farmers would rather over-fertilize than under-fertilize.

For these and other reasons, we are trying here to understand what drives farmers' perceptions of manure's value. The research contribution of this chapter is to identify some of the factors that lead a farmer to perceive manure as having a higher or lower value. Perception of manure's resource value represents one type of sustainable management factor. Nevertheless, as Carlisle

(2016) points out in her article on farmer adoption of soil-health practices, factors that affect the adoption of conservation practices are highly varied and complex. Addressing this issue will likely involve multiple aspects of farm management.

Managing Manure from Feedlots in Northeastern Colorado

As feedlot sizes grow yearly, there are increasingly concentrated aggregations of manure for dispersal from each operation (Galyean, Ponce, and Schutz 2011; Gollehon et al. 2001; Ribaudo, Gollehon, and Agapoff 2003). Since land application is the commonly practiced method for disposing and recycling manure, these increasing concentrations need a broader land-base of surrounding farms for application of manure (Aillery et al. 2005; Ribaudo et al. 2003). Accommodating the larger manure volume makes it increasingly difficult for farmers to apply it at rates low enough that their crops can use all the nutrients and prevent the residual nutrients from infiltrating the surrounding waterways and groundwater (Amon-Armah et al. 2015). Increased adoption of sustainable MM by farmers could help reduce the potential pollution problem (Ribaudo et al. 2003; von Keyserlingk et al. 2012). However, the convention of heavy land-application is maintained, in part, by a loose regulatory structure as described below.

The Manure Ownership Loophole and the Value of Manure

NPS pollution is very difficult to regulate in the United States, especially in a "Right-to-farm state" (Colorado Revised Statutes, 2016), primarily because of the political climate. Although point sources, such as CAFOs, are regulated under the Clean Water Act (CWA), manure given away, such as to a farmer, is thereby externalized from the system and becomes invisible to regulation (Heinzen and Russ, 2014; Livingston, 1998; Livingston and Cory, 1998; Ribaudo, 2001). CAFOs commonly dispose of their manure by passing it back to farmers with whom they have a feed-purchase relationship; this is according to three farmers, a cattle owner, and a manure hauler I interviewed. Farmers may apply that manure on crop-fields lightly or heavily, and frequently or seldom. Manure's value, as perceived by farmers, presumably influences how they apply it, particularly because the competitive nature of livestock agriculture makes profitability essential to the sustainability of their operations (Horan, Ribaudo, and Abler, 2001; Ribaudo, 2015). Thus, the extent to which a farmer perceives manure as valuable can be expected to affect his or her likelihood of using it sparingly and thus sustainably. Previous studies have examined factors affecting sustainable manure management, such as the adoption of manure testing to measure its nutrient value as a fertilizer (Ali, McCann, and Allspach, 2012). Knowing the nutrient content of manure applied should allow farmers to avoid over-fertilizing while maintaining yield. Whether particular farmers choose to adopt sustainable MM practices or not may also depend on the levels of "conservationism" or "productivism" in their thinking (McGuire, Morton, and Cast, 2013; Ribaudo 2015). "Productivist" thinking farmers are less likely to consider conservation practices that provide public benefits like improved water quality unless these practices also give private benefits such as improved yields (Reimer, Thompson, and Prokopy, 2012). Such an approach is especially problematic if the field soils are highly permeable, or where the drainage system expedites the transfer of nutrients into groundwater (Ribaudo, 2015). Nutrient loss into the atmosphere is yet another way that nitrogen can be transferred into surface waters, such as when manure is applied while the wind is blowing toward the mountains and nitrogen is thereby conveyed into mountain ecosystems (Aillery et al., 2005; Baron et al., 2000; Wolfe, Van Gorp, and Baron, 2003). "Conservationist" practices are not always clear-cut, in that water-protection practices and wind-borne pollution avoidance techniques may conflict. Trade-offs among options make MM choices complex. Even so, maximization of nutrient uptake by a crop is possibly the most effective way to avoid the harm created by wasteful handling of manure nutrients.

Valuing Manure as an Agricultural Input

Farmers' profit margins can vary widely, being dependent on variables such as weather and market supply conditions that are somewhat unpredictable. Most farmers are highly cost-conscious, as their livelihoods depend on minimizing expenses and maximizing yield. Where manure is available, it usually presents an opportunity to reduce fertilizer expense, and many farmers believe it provides soil-enhancement benefits as well. For the farmer who sees it positively, manure is a resource to be spread "agronomically", or at a rate such that a crop can benefit from a large proportion of its nutrients (Bauder, Waskom, and Andales, 2014; Waskom and Davis, 1998). Previous WTP research by Norwood, Luter, and Massey, (2005) found that most farmers would substitute manure for commercial fertilizer even if the monetary cost were only slightly lower than the cost of commercial fertilizer. That study also found, on the other hand, that approximately 25% of the farmers in their sample perceived manure negatively and would only accept manure applied on their fields if they were paid to do so. Dumping of manure for waste disposal has been characterized as undervaluation of manure's nutrient value (Hall 1996; Larney, Hao, and Topp, 2011; Nunez and McCann, 2004).

We have based the current analysis in the assumption that placing a relatively higher monetary value on manure indicates a stronger inclination to use it efficiently and therefore sustainably. A lower or negative value, in this scheme, reflects a relatively less sustainable approach, because it would likely result in more wasteful application, letting more nutrients escape unused into the surrounding surface water and groundwater, or volatilize and be dissipated into the atmosphere. This analysis is unique because we look at where the value comes from, rather than directly at what affects BMP adoption as has been done in previous studies. This approach is useful because programs or policies could potentially be developed or adjusted to reward sustainable manure management patterns that are consistent with higher manure valuation. By treating the value of manure as a dependent variable we identified several factors, both operation-related and personal, associated with perceiving the value of manure as higher or lower.

Methods and Measures - What Determines Manure's Perceived Value?

To collect data, we used the instrument of a mailed questionnaire, part of a survey of farmers supporting livestock production along the South Platte River in five northeastern Colorado counties (Sustainable Agriculture Research and Education [SARE], 1999), where there is a prevalence of large feedlots and numerous feed-crop producing operations. Various sections of this questionnaire provided information on farmers and their operations, largely in regard to their practices and beliefs around manure management as fertilizer, irrigation, and other farming practices. The purpose was to gather insight into farm-related and farmer-related factors affecting their manure management choices. The questionnaire was sent to approximately 1700 farm operators listed with government-managed farm-support agencies, around 300 of whom turned out to be no longer active. The effective response rate was approximately 31%.

One section of the questionnaire provided three possible blocks of questions, based on the farmer's manure-source situation, wherein a subset of manure-valuation questions was configured to be relevant for the logistics of their situation (see Table V.1). The set of these questions asked in each block was designed to be appropriate for whichever of these three situations they identified:

I. "Did not apply manure"

II. "Used manure mostly from my own livestock"

III. "Purchased or received manure from an outside source"

Within each of these groupings, we asked our respondents to write in a per-ton monetary value for the manure they used or could have used. In each case the value they wrote indicated either a positive or a negative dollar value per ton. Farmers were asked to write their perception of manure's value in only one of the six boxes. The wordings of these six boxes are each depicted, in condensed form, in Table V.1 below. Note that a negative monetary value is implied if the farmer indicates needing to be paid to accept manure or to have manure hauled away. Data collected in other parts of the questionnaire were used to model what variables might be related to farmers' perceptions of manure's value.

Table V.1 Question Response-Space for Manure's Perceived Value, Based on Manure-Source Situation (Each respondent was to enter a value in only one of these six spaces.)

Manure-Source Situation of Respondents	Manure's Value Perceived as **Positive**	Manure's Value Perceived as **Negative**
Did Not Apply Manure (Block I)	I would pay up to $____ per ton to have manure delivered and spread if I could get it.	Someone would have to pay me at least $____ per ton to accept manure spread on my land.
Used Manure from Own Livestock (Block II)	I would sell manure to them for ______ $/ton.	I would pay up to _____$/ton to have manure taken away.
Purchased or Received Manure from Outside Source (Block III)	The most I would pay to have manure delivered and spread would be $______ / ton	The least I would accept to have manure delivered and spread would be $_____/ton.

The rest of this section describes some of the factors that may affect a farmer's perception of manure's value, and reasons we thought they might affect it. Later, in the "Results and Analysis" section below, we discuss the analytical tools and methods we used to quantify the relevance of these factors, and some limitations resulting from this multi-tracked questionnaire format.

Perceptions - Potential Benefits of Applying Manure

We asked farmers to rate potential benefits on a Likert scale

("1" -- "Does not matter to me" ←→ "5" -- "Real and significant to me"):

- "Inexpensive fertilizer" – Manure as a substitute for commercial chemical fertilizers
- "Source of organic matter" – Manure used to enhance field-soils, especially through moisture-retention and improved soil texture
- "Improves soil properties" – a more general description regarding the two previous items
- "Increases yield" – Manure provides a greater output volume of the crop
- "A way to reduce wind erosion" – Manure can be surface-applied to hold down topsoil
- "A way to dispose livestock waste" – Field application of manure is an accepted removal practice.

The first and fourth of these responses represent the benefit of manure for its yield-increasing properties in the short term. The second and third item, however, reflect a longer-term orientation toward the enhancement of soil properties, indicating some concern for using sustainable practices. Reducing wind erosion usually involves leaving manure on the surface, rather than tilling it into the soil; so, this benefit may likely provide a different environmental benefit from the other usages. And waste-disposal as an objective, while providing an important function, can easily lead to over-application of manure.

Perceptions - Potential Problems of Applying Manure

(Also using the Likert scale shown above):

Next, we asked each farmer to rate potential problems that might result from applying manure to their fields, including:

- "Causes more weeds" – Weed seeds are often a component of fresh manure.
- "Damage to plants from salts" – Manure can contain salts.
- "Soil compaction" – Spreader trucks are heavy and compact the soils.
- "Unpredictable nutrient content" – Manure's nutrient contents are highly variable.
- "Doesn't get spread evenly" – Manure can be extremely "clumpy".
- "Lower crop yields" – Manure alone usually does not provide as much of a yield boost as commercial fertilizer.
- "Inconvenient to apply" – Manure is typically very heavy and requires special spreading equipment.
- "Additional tillage required" – Manure is more effective if incorporated into the soil
- "Relationship with neighbors" – Some neighbors are likely to complain about manure's odor, and possibly the increased presence of flies.
- "Possible water pollution" – Excess nutrients can be a problem especially where the water table is high or where runoff flows into a natural waterway.
- "Regulatory concerns" – Regulations concerning manure management are a point of stress for livestock producers.

The first three of these potential problems could be seen as longer-term issues, while the next three would relate to the current year's productivity. Additional tillage might have a mixed significance for the farmer, since it would require some extra resources; but it might also be seen as advantageous in helping provide a higher yield. The last three of these possible problems reflect concern for the opinions of others, either aesthetically or regarding the potential for water pollution and the possibility of punishment.

Knowledge Represented in Practices Relating to Manure and its Application

We also considered whether knowledge about nitrogen fertilizer, horticultural principles, or experience with manure and fertilizer application would affect the perceived value of manure, asking whether the farmer used any of the following practices or strategies (indicated by checking a box next to one of the bullets below):

- "Crop yield goal"– Striving for a high yield seems like it would correlate with trying to maximize the soil's fertility for the crop being grown.
- "Past experience"– This reflects the farmer's knowledge and experience with using manure and commercial fertilizer.
- "Plant tissue analysis"– This might represent the operator's level of reliance on technical methods.
- "Irrigation water analysis"– Did they account for nutrients in their irrigation water?
- "Manure credit"– Did they rely on manure nutrients to cover part (or all) of the crop's nutrient needs?
- "Legume credit"– Did they use a cover crop to provide some crop nutrients?

- "Consultant" – Did they use a consultant to help determine their nutrient application combination?
- "Field scouting for insects, diseases, etc." – We thought this approach might possibly indicate how they approach specific field situations.
- "Irrigation management"– Does water conservation correlate with higher manure valuation?
- "Conservation tillage" – Is this practice seen as working well with efficient manure usage?
- "Water-flow control practices" – Does this match with irrigation management, or does it represent a different thought process and relationship with manure usage?

Most of these practices are considered "best management practices" (BMPs); and our intent was to see if using BMPs was also associated with managing manure sustainably.

Demographics – Location of Operation and Personal History

We identified which of the two general regions farmers were operating, eastern or western. The eastern sample was more rural, with larger acreages. Also, we asked about each individual farmer's personal history, as follows:

- "How many years farming or ranching?" (Number of years), and
- "Highest level of education completed?" (Highest level attended, of 5 categories)

Regarding the operation, we also asked for the approximate level of Gross Sales in the previous year. (<$50K, $50-99K, $100-249K, $250-499K, $500-1M, >$1M)

Data Analysis Methods, Including Adjustment for "Outliers"

In examining the data for factors influencing farmers' perceptions of manure's value, we found that, probably because of the hypothetical nature of the questions, there were some unrealistically extreme values, both positive and negative ones. Because of these unrealistic responses, the manure values and residuals were not normally distributed. Upon closer inspection of the data, we found that a significant portion of these values were outliers, but that the median values were well aligned with observed reality, and that it was appropriate to use a more robust form of multiple regression analysis than the typical ordinary least squares (OLS) method.[6] For this reason we have chosen to use simultaneous quantile regression, which is more robust to outliers and which determines regression slope coefficients for multiple quantile levels of the response variable. This was especially appropriate because of the choice to consider median values; the .50th quantile is the median level and is a widely accepted approach used for "median regression" analysis. As discussed below, this method revealed that multiple ranges in the perception of manure's value are affected differently by several factors. Before selecting factors for a model, we used Spearman correlation to identify appropriate possibilities among the ordinal variables collected on the Likert scaled items, and a Wilcoxon rank-sum test to consider some binary variables relating the use or non-use of certain farming practices and testing procedures, including some BMPs.

Results and Analysis

We found that the three manure-source groups were clearly different in how they reported manure's value. Close examination of the data revealed that a part of manure's perceived value

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[6] We attribute this problem of outliers to a combination of phrasing and structure within the questionnaire, which apparently led to some extreme responses, and I will address this wording issue later in the discussion section below.

for operators who used manure mainly from their own livestock was apparently inflated by the proximity of their manure source. That is to say that their transportation fuel cost was much lower than that of other groups, because the transport distance was typically much shorter, reducing the inherent expense of transport and effectively increasing manure's perceived value. It also became clear that the third manure-source group consisted of two different situations, those who purchased manure and those who accepted it free or for credit. Separation of these two sub-groups is described below. Summary statistics for the variables discussed, excluding the source-situation group-variable, can be viewed in Table V.5.

For the purposes of the current study, we consider manure's value as a function of four variable types:

1. Source-situation (as represented in different source-related groupings),
2. Perceptions of manure's benefits and problems,
3. Knowledge in practices relating to manure and its application, and
4. Demographics of location and operator personal history.

There may be other types of variables involved, but these are the main categories of factor variables we found potentially to have some effect, as I describe briefly in the following paragraphs.

Manure Source-Situation - Manure's Value as Perceived by Source Groups

The manure value questions in the questionnaire essentially separated farmers into three groups, based on the source of the manure they used or could have used. For each of these groups there were some operators who perceived a positive value to manure, and a smaller number of operators who assigned it a negative value. In another part of the questionnaire, we asked what source of manure they had used. Based on their manure source, we have differentiated between those who purchased manure and those who accepted it free or for credit, typically from a feedlot. In this way, we arrived at four source categories.

The perceived manure values for these four groupings are presented in Table V.2 below. Farmers who did not apply manure valued manure the least, as a group. Generally, farmers in this group did not have livestock, they were located farther from a manure source at a median distance of 3 miles, and they valued manure at a median value of $1.00/ton.

Those who used manure primarily from their own livestock all valued manure positively, and generally at a higher level than any of the other groups. The median distance from manure source to manured field, for this group, was only 1/3 of a mile, and they perceived it to have a median value of $3.75/ton. This might reflect the availability of manure and the absence of transfer costs such as transportation, negotiation and accounting; essentially this reflects the proverbial concept of "a bird in the hand”.

We focus here on the medians of perceived values and of the actual dollar amounts paid or received, because medians represent the most typically perceived dollar values, and provide a more realistic measure of the amount actually paid for manure than would the mean. This is verified by the actual values paid for manure as reported by those who purchased it, which ranged from ten cents to around $3.00 per ton. While the mean of perceived manure values entered was considerably higher, that was likely an effect of the speculative nature of these questions. In the discussion section of this paper I will address the limitations created by the question-format, and how we might have reduced the problem of outliers by presenting these questions differently. Some farmers entered exceptionally high numbers that have apparently distorted the means and skewed the distribution, while most (approximately 75%) of the reported values were more realistic and much nearer the center of the range, which is reasonably well represented by the median. This was another reason for choosing quantile regression instead of OLS regression, in that the .50th quantile regression is essentially median regression. Because it uses least absolute deviations, quantile regression is not subject to the constraints of least squares regression and is considered to be more "robust". Median values are appropriate in this context, because we are seeking to understand the most typical, most common, and most reality-based choices within each farm-operator situation.

Within the third group, we were able to separate those who purchased manure from those who accepted it free or for credit. Those who purchased manure from an outside source typically transported it 4 miles, and said they valued it at a median value of $2.25/ton. Those who accepted manure free or for credit, approximately 1/3 of those who used manure, typically transported it 3 miles, and said they valued it at a median of $1.50/ton. These results are depicted in the bottom two rows of Table V.2. Note that those farmers who "Accepted Manure Free or For Credit" actually received a median amount of $0.95/ton, which is a negative amount in that they were paid to accept the manure, but only around 1/4 of these respondents actually perceived manure's value as negative.

We might reasonably assume that the variation in distance from a manure source accounts for much of the difference in valuations between manure user-groups. In addition to these group differences, farmer response as to the value of manure was also related to individual perceptions, to the knowledge acquisition practices they used, and to certain demographic characteristics.

Table V.2 Value of Manure Perceived by Farmers – Four Manure Source Groupings

Manure Source (if used)	Median Distance from Manure source to field	Dollar Value Perceived (Median) per ton	Actual Dollar Amount Paid/(Received) per ton (Median)	Number of Farmers in this Category
DID NOT USE Manure	3 miles	$1.00	n/a	134
Used Manure from Own Livestock	0.33 miles	$3.75	n/a	69
Purchased Manure from Outside Source	4 miles	$2.25	$2.13	38
Accepted Manure Free or For Credit	3 miles	$1.50	($0.95)	52

The Value of Manure Application as Seen by Different Source-Situation Groups

In addition to the differences among the source-based groupings, within two of the groups there were major differences in the perception of manure's value. Whereas all farmers who applied manure from their own livestock viewed manure's monetary value positively, some farmers in each of the other groups perceived manure as having negative value, that is they would want to be paid to accept manure. Among those who did not use manure at all, there were many who assigned a positive dollar value to manure and a smaller number who assigned it a negative value.

Farmers perceived manure in terms of its beneficial aspects, and also in terms of various problems associated with using it. Some of these perceived characterizations can be described as follows:

- Inexpensive fertilizer, increasing crop yield while reducing commercial fertilizer expense;

- Soil amendment, enhancing soil properties by adding organic matter, aeration and water-retention capacity;
- Inconvenient waste material requiring disposal; or as
- A combination of these three and other possible perceptions.

Most farmers who acquired manure from an outside source were willing to pay considerably for it. However approximately 1/5 of the purchasers valued it negatively but bought it anyway, apparently seeing it as a much cheaper alternative to commercial fertilizer. This finding is consistent with a study from Norwood, Bailey, Luter, and Massey (2005), who found that most farmers would substitute manure for commercial fertilizer even if the manure's cost were only slightly lower than that of the equivalent commercial fertilizer. The 'outside source', in most cases, was a feedlot with whom the farmer had a regular arrangement to provide livestock feed, either in the form of corn silage or corn grain, according to several of our informants. The common arrangement, as farmers and manure-haulers described it, is to take manure away from the feedlots in approximately the same volume as the amount of livestock feed delivered, not at the same time of course. Sometimes farmers would receive the manure free; sometimes the feedlot would credit them a dollar or so per-ton; and sometimes the farmers would actually be purchasing the manure – depending on the supply and demand situation of manure for that year. Some farmers who received manure may have been pressured to accept it even though they may not really have wanted it. This is reflected in the relatively low manure value assigned by those who "accepted manure free or for credit" (see Table V.2, above).

Negative Factors Affecting the Perceived Value of Manure

The problems associated with manure-application indicated an awareness of potential risks in using manure, but not necessarily an unwillingness to do so. Higher ranking of the problems did not correspond to lower valuation of manure, but in fact to a slightly higher valuation of it. One possible interpretation is that being realistic about the challenges of using manure arises from experience or from discussion with other operators, and this can help a farmer use it more effectively. Of the manure benefits and potential problems, we found only three of them, along with two of the farm management practices, provide partial explanation for how farmers perceive the value of manure.

Modeling Value Factors

Considering the demographic factors, the demand-situation factors, perceived advantages and disadvantages, and knowledge factors around the issue of manure and crop management, we used quantile regression analysis, as mentioned previously, to explore the relationships between these factors and the farmer's perceived value of manure. We considered the expectations described above, and used the answers reported by the mail-survey respondents. Some of the expected factors were clearly more relevant than others. In several instances, there was considerable overlap in the implications of two or more variables, so it became appropriate to choose one as more representative of the factor in question. In considering regression models for a range of quantiles, some factors present a much different relevance at various perceived manure-value levels. Here we present a set of quantile regression models, in Table V.3 below, and discuss their implications. As mentioned previously, a set of summary statistics for all the variables described above is included at the end of this chapter in Table V.5.

As a procedure for model selection, we first considered several candidate factor variables, some ordinal ones using Spearman correlation, and then some binary variables using a Wilcoxon rank-sum test, to consider the use or non-use of certain farming practices and testing procedures. By way of interpreting the results, different perceived-value levels show distinctly different factors that influence manure's value perception. Unlike most factors we considered, the maintaining of livestock and hence having an immediate source of manure consistently adds value to the individual's perception of manure's value. The models, presented below at several quantile levels of the farmers' perceived value of manure, consider various farm and farmer characteristics, some of the practices they used, along with some preference factors, while controlling for the farmer group categories regarding whether or not they used manure and, if so, how they obtained it.

Table V.3. Simultaneous Quantile Regression Manure Value Factors Model

Manure's Perceived Value /ton	Coef.	Bootstrap Std. Err.	t	P>|t|	[95% Conf.	Interval]
q05 ~$-2.00						
inexfert	1.31299	.5724833	2.29	0.023	.186107	2.439873
winderod	-.2267637	.3056554	-0.74	0.459	-.8284194	.3748919
moretill	-.1385778	.4642756	-0.30	0.766	-1.052463	.7753079
pastexp	-1.591825	2.614164	-0.61	0.543	-6.737578	3.553927
legmcrdt	1.719765	1.293049	1.33	0.185	-.8254879	4.265018
yearfarm	-.0327548	.0348142	-0.94	0.348	-.1012835	.035774
eastern	-3.230683	2.800166	-1.15	0.250	-8.742563	2.281197
_IBlock_2	5.029955	1.63824	3.07	0.002	1.805225	8.254686
_IBlock_3	2.790593	1.8639	1.50	0.135	-.8783301	6.459517
_IBlock_4	3.526316	1.71586	2.06	0.041	.1487964	6.903835
cons	-7.163774	3.50317	-2.04	0.042	-14.05946	-.2680915
q10 ~$-1.20						
inexfert	.5422222	.5255529	1.03	0.303	-.4922824	1.576727
winderod	.1140741	.2330045	0.49	0.625	-.3445748	.572723
moretill	-.3614815	.3228157	-1.12	0.264	-.9969157	.2739527
pastexp	-.4688889	1.04838	-0.45	0.655	-2.532532	1.594754
legmcrdt	.94	.9670237	0.97	0.332	-.9635009	2.843501
yearfarm	.0096296	.0266823	0.36	0.718	-.042892	.0621513
eastern	-1.742222	1.600763	-1.09	0.277	-4.893182	1.408738
_IBlock_2	2.137037	1.002623	2.13	0.034	.1634621	4.110612
_IBlock_3	.7333333	1.128207	0.65	0.516	-1.487443	2.954109
_IBlock_4	.9518519	1.095594	0.87	0.386	-1.204728	3.108432
cons	-2.884445	2.920718	-0.99	0.324	-8.633621	2.864732

Manure's Perceived Value /ton	Coef.	Bootstrap Std. Err.	t	P>|t|	[95% Conf.	Interval]
q25 ~$0.25						
inexfert	.4156085	.1697828	2.45	0.015	.081406	.7498109
winderod	.116455	.1056655	1.10	0.271	-.0915382	.3244483
moretill	-.1732804	.1412331	-1.23	0.221	-.4512854	.1047246
pastexp	-.0935979	.4193852	-0.22	0.824	-.9191207	.731925
legmcrdt	.5298942	.3975304	1.33	0.184	-.2526093	1.312398
yearfarm	.0013757	.013007	0.11	0.916	-.0242274	.0269787
eastern	.487619	.3961932	1.23	0.219	-.2922523	1.26749
_IBlock_2	1.209312	.4598362	2.63	0.009	.3041652	2.114459
_IBlock_3	.5169841	.4952636	1.04	0.297	-.4578986	1.491867
_IBlock_4	.1520635	.4666432	0.33	0.745	-.7664825	1.07061
_cons	-1.666614	.8305163	-2.01	0.046	-3.301412	-.0318156
q50 ~$1.50						
inexfert	.3143526	.1304596	2.41	0.017	.0575543	.5711509
winderod	.1560062	.10061	1.55	0.122	-.0420357	.3540482
moretill	.1053042	.132524	0.79	0.428	-.1555577	.3661661
pastexp	-.1903276	.4291445	-0.44	0.658	-1.035061	.6544056
legmcrdt	-.3330733	.3567122	-0.93	0.351	-1.03523	.3690832
yearfarm	-.0156006	.013156	-1.19	0.237	-.0414971	.0102959
eastern	.574103	.3636817	1.58	0.116	-.1417724	1.289978
_IBlock_2	2.446958	.8533406	2.87	0.004	.767232	4.126684
_IBlock_3	.7539781	.396422	1.90	0.058	-.0263436	1.5343
_IBlock_4	.0421217	.5869195	0.07	0.943	-1.113178	1.197421
_cons	-.5288611	.540961	-0.98	0.329	-1.593695	.535973
q75 ~$3.75						
inexfert	.6000466	.3246506	1.85	0.066	-.0389996	1.239093
winderod	.3579413	.3251563	1.10	0.272	-.2821002	.9979828
moretill	.589497	.3449338	1.71	0.089	-.0894749	1.268469
pastexp	-1.704797	1.593664	-1.07	0.286	-4.841785	1.432191
legmcrdt	-1.913973	1.015526	-1.88	0.060	-3.912946	.0849996
yearfarm	-.0536563	.0369391	-1.45	0.147	-.1263677	.0190552
eastern	1.873079	1.283519	1.46	0.146	-.6534163	4.399574
_IBlock_2	5.66367	1.662341	3.41	0.001	2.391499	8.935842
_IBlock_3	1.24157	1.635175	0.76	0.448	-1.977129	4.460268
_IBlock_4	-.2635305	1.502128	-0.18	0.861	-3.220337	2.693276
_cons	.735142	1.785531	0.41	0.681	-2.779518	4.249802
q90 ~$12.00						
inexfert	2.227711	.7950365	2.80	0.005	.6627521	3.792671
winderod	.8199005	.8377878	0.98	0.329	-.829211	2.469012
moretill	3.503383	1.12911	3.10	0.002	1.28083	5.725936
pastexp	-4.683134	3.472044	-1.35	0.178	-11.51755	2.151279
legmcrdt	-7.942736	2.494415	-3.18	0.002	-12.85277	-3.032699
yearfarm	-.1959701	.0666925	-2.94	0.004	-.3272485	-.0646917
eastern	3.567413	3.497763	1.02	0.309	-3.317625	10.45245
_IBlock_2	9.783881	4.261035	2.30	0.022	1.396408	18.17135
_IBlock_3	3.810448	3.170234	1.20	0.230	-2.429879	10.05077
_IBlock_4	-.3714428	4.284594	-0.09	0.931	-8.805289	8.062403
_cons	-.2280597	5.000162	-0.05	0.964	-10.07044	9.614319
q95 ~$20.00						
inexfert	1.694575	.983704	1.72	0.086	-.2417593	3.63091
winderod	.446934	1.01508	0.44	0.660	-1.551162	2.44503
moretill	5.471108	1.112675	4.92	0.000	3.280906	7.661311
pastexp	-5.511793	4.216857	-1.31	0.192	-13.8123	2.788718
legmcrdt	-8.254717	3.12387	-2.64	0.009	-14.40378	-2.105653
yearfarm	-.1933962	.0825152	-2.34	0.020	-.3558202	-.0309722
eastern	7.102594	4.419875	1.61	0.109	-1.59754	15.80273
_IBlock_2	13.73703	7.092477	1.94	0.054	-.2238878	27.69794
_IBlock_3	2.025943	3.276736	0.62	0.537	-4.424023	8.47591
_IBlock_4	1.241156	4.100933	0.30	0.762	-6.83117	9.313481
_cons	2.283609	5.544984	0.41	0.681	-8.631205	13.19842

Simultaneous quantile regression Number of obs = 293
bootstrap(10000) SEs

{Stata command: xi: sqreg m_value inexfert winderod moretill pastexp legmcrdt yearfarm eastern i.Block, quantile(5 10 25 50 75 90 95) reps(10000) }

It is worth noting that several of the non-included variables were conceptually similar to some of the included ones, and that those included were the ones more consistently identified by the respondents. This may reflect variations in the vocabulary of the questionnaire and its familiarity to the population surveyed, as well as the diverse range of priorities among farmers. One example is the preference of “Inexpensive fertilizer”, which expresses much the same concept as “Increases yield”. Farmers who valued manure higher consistently expressed the importance of the manure as inexpensive fertilizer more than the fact that it increases yield. Perhaps this reflects an acceptance of the MERN approach (Amon-Armah et al. 2015), or of EONR (Scharf et al. 2005), wherein a focus on the bottom-line allows for a slightly lower yield but a distinctly higher return on investment. Similarly, the terms “Source of organic matter” and “Improves soil properties” seem like good reasons to perceive manure’s value at a higher level, but neither of these were as clearly or consistently related to higher valuation of manure. The benefit “a way to dispose of livestock waste” is probably quite relevant to those who have livestock, but, possibly because livestock ownership is 'controlled for' by the demand-source groupings, it did not demonstrate a real effect in any of the model levels.

The two positive preference items related to higher manure valuation were:

- “Inexpensive Fertilizer” – Thinking of manure as a substitute for commercial fertilizer was one of the only consistent factors at all or nearly all the quantiles evaluated. This effect was strong at every level and positively valued at all levels of manure valuations, including the median.
- “A way to Reduce Wind Erosion” – Farmers valued manure as a top-dressing to help hold topsoil in place during high wind events. However, even though this effect was high in the

middle ranges, from the 25^{th} quantile to the 75^{th} quantile, it was a little weaker at the median 50^{th} quantile, much weaker at the extremes (10^{th}, 90^{th} quantiles), and even negatively associated with manure's perceived value at the 5^{th} and 95^{th} quantiles. This wind-erosion prevention factor appears to become shadowed at the more extreme value levels by other factors. At the negative end of the manure-value scale, past experience seems to override it, while at the high perceived-value level, several other factors appear to be much more important in a complicated way that we will discuss below.

One negative preference item was related, but not necessarily as we expected:

● "Additional Tillage Required" – Even though manure application requires extra tilling, this aspect was associated with higher manure value at the median, and increasingly so toward the highest values. At the low manure-value quantiles, extra tillage was associated with somewhat lowered values, but starting around the median, the extra tillage links with a relatively steep increase in value. Tillage, necessary to incorporate manure into the soil, may likely be seen as providing extra benefits - it loosens and aerates the soil. The need for extra tillage, for those who value manure highly, seems to be perceived as providing multiple benefits. Apparently using manure and plowing it into the soil are seen as complementary practices, such that a strong preference for tillage may accompany a propensity to incorporate manure into one's farming practice, or vice-versa. For some farmers, this may also be associated with the benefit of wind-erosion control because, according to a hauler-spreader we interviewed, manure used to control erosion is often allowed to sit on the field surface until shortly before planting, at which time it is tilled into the soil. Used in this sequence, the manure provides a double benefit, but as mentioned above, the protection against wind-erosion is not strongly or consistently valued.

Most other negative preference factors, such as concern about weeds, salts, soil-compaction, neighbor issues and fear of regulation did show some downward effect on value, but these effects were inconsistent and not strong enough to be included in our model. To the extent that farmers often share, among themselves, technical information and beliefs about farming practices that work effectively for them in their operations, some of the terminology we used in our questionnaire may have been outside their familiarity, reducing the questionnaire's ability to collect the desired information. There may have been other vocabulary or phrasings that would have better connected with their thinking processes. In future research, we would probably place additional emphasis on identifying farmer's contemporary vocabulary in generating the questionnaire's wording.

- "Past Experience" - The primary knowledge factor that surfaced as a practice related to manure's value was using "past experience for determining nitrogen fertilizer or manure application rates" – relying on past experience for fertilizer decisions was related to a somewhat lowered manure valuation, and this effect became large and consistent toward the high end of the manure-value continuum. The large effect was mostly canceled out for two of the demand-groups, those who used manure from their own livestock and those who purchased manure. Just as with the preference factors, several knowledge-oriented practices were apparently unrelated to the perceived value of manure. Here again our choice of phrasing, or the practices themselves, may not have been within the mainstream farmer's normal word-usage. In retrospect it may have been better to ask about the use of these practices in determining application rates for nitrogen fertilizer and separately for manure.

● “Legume Crediting” – For farmers at the median and higher manure-value quantiles, there was a negative relationship to using legume-crediting which suggests that a farmer might see these two techniques as interchangeable, and might be using either a legume cover-crop or manure, but not both. Either practice would enhance a field's soil properties and provide some crop nutrients, so using either of these practices would make the other less important. Below the median of manure values however, manure's value was slightly increased for those who used legume crediting, although not as consistently as it was reduced in the higher manure value quantiles. This suggests that for those who perceive manure’s value at a lower level, the two soil-enhancement approaches may be seen more as complementary to one another.

Demographics

● “Years in Farming” - The number of years in farming was related to a slight reduction in the perceived value of manure up to the median, and this effect increased considerably toward the highest manure-value quantiles. A possible explanation for this might be that as a farmer ages, even though believing manure has a high value, the physical difficulty of applying manure may become a little more daunting each year. The alternative to manure, commercial fertilizer, is especially easy to use, since it is light and easily spreadable and field-application is typically included as a part of the service. "Years in farming" may also reflect a preference to reduce the workload or to keep their operations as simple as possible, which could result from years of dealing with farming's risks, uncertainties and unanticipated conditions.

● "Rurality" – The smaller sample was located in a considerably more rural area, and for all but the two lowest manure value quantiles, this more rural group perceived manure to have higher value than the metro-area group. This could easily reflect a continuum of cultural bias to the extent that "country living" often includes the smell of livestock present, which diminishes as one moves closer to an urban area.

- The “Block” variable links each response with one of four categories:
    1. Did Not Use Manure
    2. Used Manure from Own Livestock
    3. Purchased Manure from Outside Source
    4. Accepted Manure Free or For Credit.

These four categories are represented in the regression tables by the dummy variables Block 2 through Block 4; Block 1 is left out because it represents the base condition where none of these other three is indicated. At all quantile levels of manure valuation, those who had manure from their own livestock (Block 2) placed considerably higher value on manure than all the other groups. Those who purchased manure (Block 3) and valued it positively indicated a perception of manure’s value consistently higher than those who accepted it free or for credit. However, the few respondents who valued it negatively (the .05th and .10th quantiles) but purchased manure anyway actually saw its value as lower than those who accepted it free or for credit (Block 4). Not surprisingly, the latter group was consistently represented in the lowest (.05th quantile), and, at that level, valued manure more than those who purchased it, apparently feeling fortunate to get a good deal.

Figure V.1 below depicts graphically the regression coefficients for each variable at the quantile levels modeled. Following that, in Table V.4 below, we show a simplified presentation of the effects of factors modeled on manure’s perceived value, indicating the direction, positive, neutral, or negative, on perceived value. This interprets Table V.3 into a more useable form which could reasonably be applied in working with farmers and understanding their attitudes about the value of manure application in regard to their crop-input management.

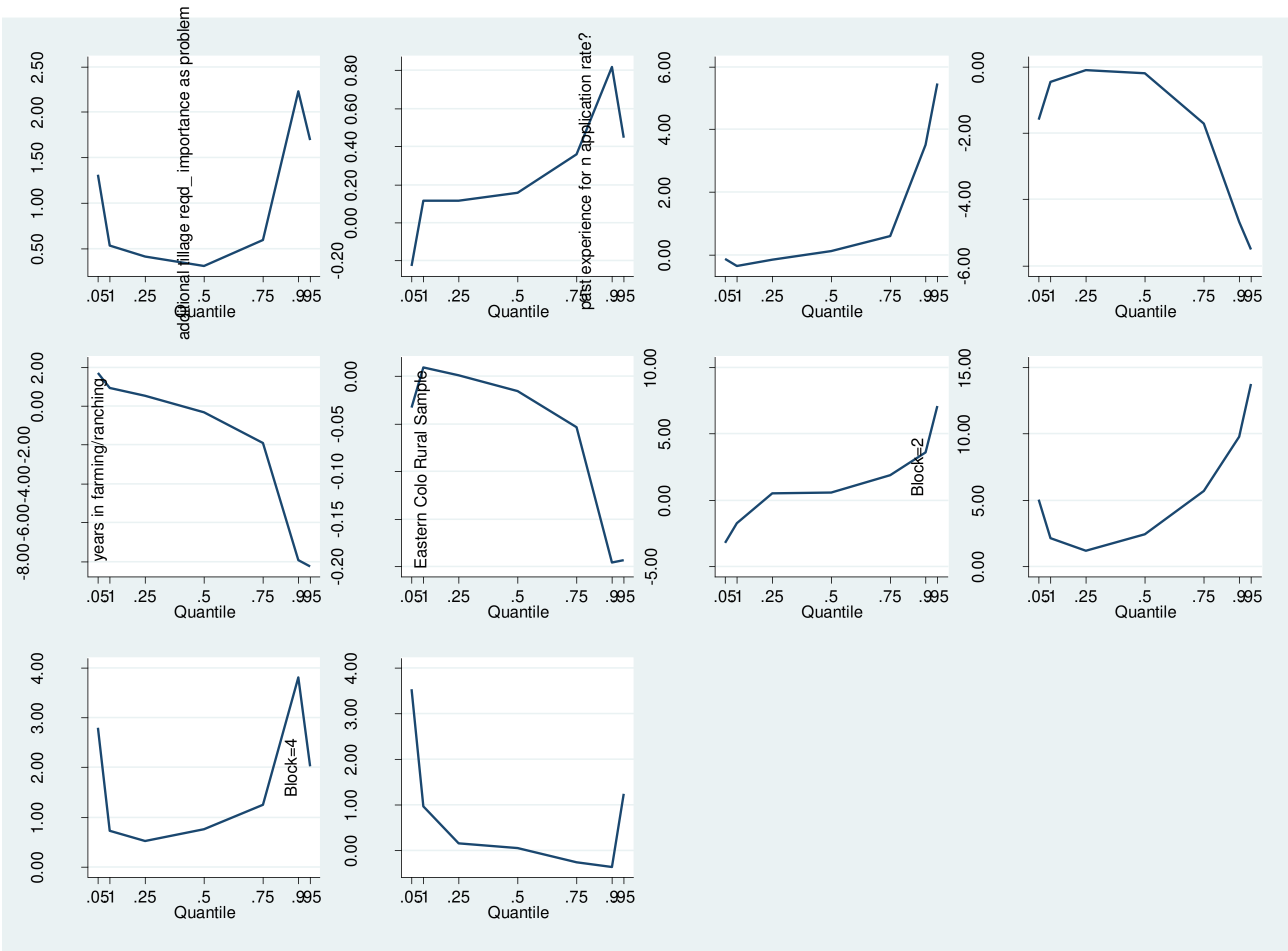

Figure V.1. Graphs of Coefficients for each Variable Modeled at Different Quantile Levels

Table V.4. Manure Perceived-Value Levels and Factor Effect Directions

Manure Perceived-Value Level (per Ton)	Inexpensive fertilizer	Reduces Wind Erosion	More Tillage Needed	Past Experience	Legume Nutrient Credit	Years in Farming	More Rural Area	Did Not Use Manure	Used Manure Mostly from Own Livestock	Purchased Manure	Accepted Manure Free or for Credit
Very Low (*Negative* up to ~ -$1.20/ton)	+	- 0	-	-	+	-	- 0	0	++	+	+
Low (~ $0.25/ton)	+	+	-	-	+	0	+	0	+	+	0
Median (~ $1.50/ton)	+	+	+	-	-	-	+	0	+	+	0
High (~ $3.75/ton)	+	+	+	-	-	-	+	0	++	+	0
Very High (~ $12.00/ton and above)	+	+	++	-	-	--	+	0	+	+	0

++ Strong Positive Effect	+ Positive Effect	0 Negligible Effect	- Negative Effect	-- Strong Negative Effect

Among the variables not included in this model were:

- "Concern Regarding Water Pollution", which distinctly reduced the perceived value of manure in the lowest two quantiles, 5% and 10%, where values ranged from -$30 to -$1.00, and also at the highest quantiles 90% and 95%, where values ranged from $3.75 to $50.00. However, any effects in the median and mid-ranges from 25% to 75% were inconsistent.
- "Consultant" which showed some upward influence on manure's perceived value in the low quantiles up to the median level, but very little and very inconsistent pressure in the higher levels.
- "Field scouting" – Using the practice of field scouting for insects, diseases and the like was also related to a somewhat lower manure valuation throughout most of the quantile

ranges, except at the extreme lowest and highest levels where it was related to increased valuation of manure; and none of these connections were reliable based on the data. This may indicate that even while some farmers prefer to avoid possible contamination of their fields and see manure as potentially bringing in unwanted weed-seeds or pests, it nevertheless appears that field scouting is not a key factor in regard to the perceived value of manure.

Conclusions

Interpreting this information for more sustainable manure management involves understanding several aspects of farmers' perception and views regarding manure application in crop production. Perceiving manure as cheap fertilizer, and as a means to control wind erosion, were both related with higher manure valuation. However, the need for extra tilling, which we anticipated might be inconvenient and a negative value factor, was also related to a higher perceived value of manure, likely because these two practices work well in combination.

These perceptions were also moderated by the demographic group or situation of the operation. More rural operators, for the most part, perceived manure's value to be higher. Additional years in farming were linked with a somewhat lowered value of manure. Perhaps this is related to aging and becoming less willing to take on the additional work of applying manure. Alternatively, it could mean that experience reduces the perceived value of manure.

Knowledge factors also appear related to the perceived value of manure. Farmers who said they relied on "past experience" and on "legume crediting" for deciding about fertilizer application-rates, saw manure's value to be substantially lower than others who did not indicate using those practices, except at the lowest value level where legume crediting related positively with lowering manure's perceived value. These factors may reflect the variability and relative inconsistency of manure's contents, in that manure application can introduce unexpected or undesired side-effects, requiring additional attention and new layers of decision-making. Farming is complex, and simplifying or standardizing the overall process of daily farm-operation might likely become especially desirable as a farmer ages and strives to streamline his or her work-life.

An important goal of this project is to suggest ways of shaping policy so that farmers are more likely to manage manure sustainably, thereby reducing nutrient impacts on the environment of which they are stewards. Policies that support and reward the efficient use of manure as a valuable, low-cost fertilizer will almost certainly generate more success than simply recommending or advocating environmental sustainability measures. In other words, "conservationist" goals are more likely to be achieved if recommended practices also happen to support "productivist" objectives.

Recognizing the fertilizer value of applied manure to reduce selectively the quantity of commercial fertilizer applied on already highly fertile parts of a field could increase profitability while protecting resources from over-application of nutrients. Advances in "precision agriculture" provide an opportunity for adjusting nutrient levels to accommodate the variabilities inherent in soils of specific fields (Delgado, Khosla, and Mueller 2011; Khosla et al. 2002). Rather than uniformly applying nutrients over an entire field, fertilizer application-rates can be programmed to adjust as a tractor progresses through each row, using real-time data that shows nutrient needs specific to each location within a field. This approach can tailor the application rate of commercial fertilizer, avoiding the excesses of blanket fertilizing where manure's nutrients have already provided a solid fertility base (Scharf et al. 2005). Far from being a simple solution, precision agriculture opens up a more complex set of decisions for the farmer; but it could eventually provide more economically efficient and more sustainable use of crop nutrients, including manure.

Other important considerations, not covered here but worthy of future research in regard to field-application of manure, include: Variation in the permeability of soils, and variations in nutrient content of manure (Shepard 2000); timeliness of manure application relative to wind-conditions where volatilized nutrients are likely to be transported to vulnerable areas; and complexity of managing various, sometimes conflicting, goals where the decisions required of farmers are already highly complex and uncertain. Disciplinary pressures exerted by a small number of large agricultural-supply corporations may be a systemic underlying factor in the farmer's over-application of nitrogen (Stuart and Houser 2018). Additionally, from a cultural perspective, the knowledge base of stakeholder decision-making groups is highly relevant. The concept of "groundwater citizenship" raised by Ternes (2018) is also worthy of exploration in regard to water quality concern levels of different groups, especially among the farming populations around feedlots.

In working with farmers to encourage moderation in nutrient application, especially where inexpensive manure is readily available from local feedlots, it may be useful to identify their perceived valuation of manure as a precursor to discussing or attempting to influence their manure management practices, because variations in manure's perceived value apparently predispose farmers to view manure management differently at various perceived value levels.

Table V.5.

Summary Statistics for Variables Modeled

Variable	Mean	SD	Median	Min	Max
Manure's Perceived Value (Per Ton)	4.38	9.53	2.00	-30.00	50.00
Perceptions					
-- **Benefits of Using Manure** ("Importance as a Benefit" on a Scale of 1-5) –					
Inexpensive fertilizer	3.88	1.27	4.00		
Source of organic matter	4.22	1.06	5.00		
Improves soil properties	4.32	1.01	5.00		
Increases yield	4.06	1.15	4.00		
Reduces wind erosion	3.45	1.40	4.00		
Dispose livestock waste	3.60	1.46	4.00		
-- **Problems of Using Manure** ("Importance as a Problem" on a Scale of 1–5) –					
Causes weeds	3.55	1.25	4.00		
Salt damage	2.75	1.22	3.00		
Soil compaction	3.25	1.36	3.00		
Unpredictable nutrients	2.94	1.20	3.00		
Uneven spreading	2.90	1.21	3.00		
Lower crop yield	2.07	1.32	2.00		
Inconvenient to apply	3.13	1.24	3.00		
More tillage required	2.81	1.34	3.00		
Relationship with neighbors	2.28	1.37	2.00		
Water pollution	2.49	1.37	2.00		
Regulatory concerns	2.78	1.50	3.00		
Knowledge -- Practices Used -	(Proportion Checked)				
Crop yield goal	0.70	0.46	1.00		
Past experience	0.77	0.42	1.00		
Plant Tissue analysis	0.09	0.29	0.00		
Irrigation water analysis	0.16	0.37	0.00		
Manure credit	0.21	0.41	0.00		
Legume credit	0.16	0.36	0.00		
Consultant	0.17	0.37	0.00		
Field scouting	0.83	0.37	1.00		
Irrigation management	0.61	0.49	1.00		
Conservation tillage	0.46	0.50	0.00		
Water-flow control practices	0.15	0.35	0.00		
Demographics -- Farm/Farmer Attributes					
Percent of acres rented (computed) (percent)	46.8	89.2	33.3	0	55
Years in farming (years)	27.9	13.1	26.0	1	60
Education level (1 – 5)*	2.5	1.4	3	0	5

*** 1= High School; 2= Technical/vocational degree; 3= Some College; 4= Bachelor's Degree; 5= Graduate or Professional Degree**

Source Situation **(Number of Responses Depending on Whether Manure Was Used, or Source if Used)**

Did Not Use Manure	136
Used Manure from Own Livestock	72
Purchased Manure from an Outside Source	58
Accepted Manure Free or For Credit	27

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CHAPTER VI. OPTIMIZING MANURE APPLICATION-RATES FOR SUSTAINABILITY: What Factors Affect Manure-Use Rates of Crop Producers?

Introduction and Literature Review

Agricultural water-pollutants including nutrients and pathogens are widely recognized as problems for human and environmental health. Much of the nutrient excess in livestock production areas results from feedlot manure mismanagement in combination with the use of conventional fertilizers (Hall, 1996; Nowak and Cabot, 2008; Ribaudo et al., 2003; Ribaudo, 2015; Stuart and Houser, 2018). According to Ribaudo, Gollehon and Agapoff, "Application rate is the single most important manure management factor affecting the potential for contamination of water resources by nitrogen from manure" (2003, p. 31). This chapter is critical in addressing this excess by studying crop producers' decisions to use manure or not, and how densely they apply it. It expands on an analysis of a previous report on manure management (MM) decision-making (Hoag, Lacy, and Davis, 2004), which modeled factors affecting whether or not a farmer in northeastern Colorado would be likely to apply any manure, based on "pressures" and "preferences". Here we extend that model by considering factors that may affect *how densely* farmers applied manure, and what conditions might be associated with applying manure at more or less sustainable rates. The key contribution of the current study, then, is to identify factors that affect manure application rate or, in other words, the density of manure application onto crop fields, not only whether it is applied at all. This knowledge may potentially help in shaping or re-shaping agricultural environmental policy and practices regarding livestock waste and fertilizer management. Before delving into how farmers approach MM, we provide a brief overview of the beef-cattle feedlot business as the context in which these farmers operate, and which inevitably shapes some aspects of what they do.

Excess Nutrients in Livestock Production

Industrialization of agriculture contributes to increasingly crowded feedlots and to a standard business practice of externalizing manure management from the accounting of livestock production costs (Kellog, 2000; Hart and Mayda, 1998; Livingston, 1998). Confining livestock in feedlots generates localized concentrations of manure. Some of the manure's contents are carried away by precipitation and irrigation into surface waters, and runoff from the largest feedlots is minimized through a regulatory permitting system that requires large feedlots to contain and mitigate these animal wastes. While there are some alternatives for processing manure, into compost for example, much of it is applied directly onto nearby crop fields. In many cases, manure is applied densely and frequently enough to pollute local water supplies over time, especially if some of the local soils are sandy or porous (Hall, 1996; Ribaudo, 2015). In addition, large quantities of commercial fertilizer are typically used in producing livestock feed-crops, creating a baseline overload of nitrogen and phosphorous that are already problematic for water-quality (Osmond et al., 2015; Stuart and Houser, 2018). Manure from large feedlots dispersed onto surrounding croplands, along with runoff from smaller, less regulated feedlots, are combined with these high baseline nutrient-levels, compounding the pollution problem by intensifying the nutrient overload and creating nutrient "hot-spots" (Hall, 1996). In this context, the decisions of crop producers on whose fields the manure is applied are relevant. For that reason, this chapter focuses on manure application-rates reported by crop producers while particularly recognizing that application rates reflect two decisions, firstly whether to apply manure at all (per Hoag, Lacy, and Davis, 2004), and secondly, if any manure is applied, how much of it to apply.

Externalization of Manure Management from Livestock Production into Farming Operations

In contemporary U. S. livestock operations, feed producers are often contracted by livestock feeding operations, and many feedlot operators do not maintain enough crop land to absorb the manure generated by their animals (Ribaudo, 2003b). For reasons we describe below, handling of manure by farmers is much less regulated than is its handling by feedlot operators. Livestock producers predominantly avoid regulatory scrutiny by using farmers as their agents of manure disposal.

Remedying the excess nutrient problem without reducing feedlot animal density would require that farmers apply manure to larger-size areas of land, effectively reducing the per-acre amount of manure applied and thereby reducing the overall density of application. Because wet manure is heavy, the fuel cost of transporting it is high, so that spreading it over a wider radius, without first drying it, is economically impractical (Ribaudo, 2003b). Confining manure application to a relatively small-size land area leads to over-application, especially when many local growers choose not to apply it, with the result that those who do apply manure are therefore pressured to use even larger amounts.

Nutrients in Abundance - Farmers Add Commercial Fertilizer Even Where Manure is Applied

Over-application of manure happens within a context where commercial fertilizers are typically applied by crop producers throughout the area, so that even without manure application some nutrients often remain unused by the crops. Many crop producers apply manure to their fields in addition to commercial fertilizer, thus providing an over-abundance of nutrients, especially nitrogen, much of which inevitably winds up in groundwater and surface waters. As a consequence of manure application, groundwater nitrate and phosphorus levels in these areas of high-volume livestock production commonly exceed the maximum acceptable levels of nutrients specified under the U.S. Environmental Protection Agency's (EPA) Clean Water Act (CWA) (Kümmerer, Held and Pimentel, 2010; Osmond et al., 2015; Ribaudo et al., 2003b; USDA-ARS, 2008). There is a complex set of reasons for this over-application scenario, which we discuss below.

Reducing Manure Application Rates to Achieve Sustainability

The current study has focused on crop producers who, within our study area, were commonly in a position to apply manure from the livestock operations they served, in some cases their own. The study was initiated because we believed that extension agents promoting "best management practices" (BMPs) for sustainable manure management (SMM) would be better equipped if they could determine which client operators would be likely to adopt recommended SMM practices and which operators were less likely to adopt such practices regardless of how those measures were presented. One type of practice or BMP used to achieve SMM is using a relatively light, "agronomic-rate" application of manure. Not using any manure at all effectively pressures other farmers to over-apply manure, while heavy manure application leads to the excess nutrient problem described above. Each of these situations can be considered detrimental and unsustainable in the long run. This project identifies farm and farmer characteristics that affect or are related to differences in manure application-rates for their operations.

Government agencies may use various policy tools in attempting to improve farmers' MM practices, one goal being to distribute manure sparingly so that its nutrients are less of a groundwater hazard. In order to understand how farmers think about MM issues, we next consider the existing policy environment in which they operate, and how different farmers perceive the policies, practices and other variables that affect how they choose to manage manure.

Despite Policy Efforts to Promote Conservation, Some Farmers Over-Apply Nutrients.

Policy strategies appear to be necessary to address the nutrient oversupply issue; but farmer perceptions of policies range from seeing them as important to seeing them as unnecessary hindrances to their operations. In the article "What We Don't Know Can Hurt Us", McCann, Nunez, and Nowak (2006) discuss the institutions, both formal and informal, promoting adoption of conservation practices regarding MM. While they argue that strict regulation is necessary to induce significant environmental protection innovations, they also observe a range of issues that can influence whether farmers choose to adopt a conservation measure such as applying manure at an "agronomic" rate. Formal regulatory measures enacted by EPA in 2003 require large confined animal feeding operations (CAFOs) to meet nutrient application standards (Ribaudo et al., 2003). Smaller livestock operations are encouraged, but not required, to practice voluntary measures that can limit manure-related pollution, through extension of BMPs and recommended conservation practices (Bauder, Waskom, and Wardle, 2017). Manure application on crop-fields in almost any amount is protected in many states, including Colorado, under "Right-To-Farm" statutes, which generally protect conventional farming activities from "nuisance legislation" or complaint (Colo. Rev. Stat. §§ 35-3.5-101 to 35-3.5-103). These "Right-To-Farm" statutes came about in the 1980s, largely in response to urbanites moving to the countryside and subsequently attempting to displace existing agricultural operations because of displeasure with the smells they generated and the flies they attracted (Morris, 2017).

Partly because crop producers are not subject to EPA's MM regulations unless the manure comes from their own feedlots, they are often pressured to accept manure from the livestock operations they supply with feed. Farmers are encouraged by extension and conservation agents to apply manure at 'agronomic rates', limiting the density of manure application to an amount that plants can absorb (Ribaudo et al., 2003). Unfortunately, for reasons described in a number of recent analyses, some farmers do not realistically limit nutrient application to these rates, especially when manure application is combined with the regular addition of commercial N fertilizer (Osmond et al., 2015; Stuart and Houser, 2018). This study focuses on what affects the way different farmers do, or do not, practice SMM by minimizing nutrient application.

Some research concludes that more stringent environmental regulations could be effective in local rural areas where most farmers' levels of concern over environmental quality do not reflect that of the local society as a whole (Kara, Ribaudo, and Johansson, 2008). "Demand for environmental quality at the rural-urban fringe, expressed through citizen complaints over farming practices and local ordinances to reduce rural-urban conflicts, might spur the adoption of BMPs as a means of reducing potential conflicts with nonfarm residents" (Kara, Ribaudo, and Johansson, 2008). Numerous studies have also discovered that even farmers who understand the BMPs and the rationale for them choose to over-apply nutrients anyway, because of the perceived need to maximize yield (Luloff et al., 2012). In the words of one respondent reported by Luloff et al., "… Farmers want to brag about yields and not return on investments" (2012).

A review and synthesis of "Factors Influencing Farmers' Adoption of Best Management Practices…" (Liu, Bruins, and Heberling, 2018) concluded that BMPs are typically not adopted by farmers for a variety of reasons from personal to operation-specific; that a wide range of research topics and strategies will be essential to address the NPS pollution resulting from agriculture; and that mitigation approaches will need to be tailored by location and will be different on a number of geographical, cultural, and other dimensions. Our research included looking into a number of the factors identified by Liu et al. (2018), and some of these are discussed below. One of these factors is that most farmers view maximizing yield as essential, and a plentiful supply of nutrients helps insure the highest possible yield (Sheriff, 2005; Osmond et al., 2015). Additional pressure to over-apply nitrogen comes from seed-companies which supply new varieties of hybrid corn-seeds every other year (Stuart and Houser, 2018). Not having prior experience with the new seeds, many farmers rely on fertilizer application-rate recommendations from the seed companies, and these recommended fertilizer quantities are generally higher than necessary because the seed companies are intent on maximizing yields for their own marketing purposes (Stuart and Houser, 2018). Aside from reasons to over-apply nutrients, there are additional factors that incline some farmers not to adopt conservation measures or SMM practices, which we discuss in the next section.

Barriers to Adoption of Conservation Measures

Constraints that limit adoption of better farming practices such as improved manure management and application fall into several main categories, including the economic, technological, psychological, and political (McCann, Nunez, and Nowak, 2006). Manure is often perceived as an unreliable nutrient source, inconvenient, low-tech, unsanitary, and difficult to standardize. One aspect we identify here is how some of these perceptions affect farmers' choices of how heavily to apply manure.

Field application of manure by farmers usually involves believing that manure provides some increased profitability for their crops by improving soil properties, adding organic matter, or being a potential substitute for conventional/commercial fertilizers (Baumgart-Getz et al., 2012). Even farmers who see little value in using manure may feel pressure to help dispose of it. They may also believe that "… manure can't hurt, and it might even do some good" for their crops. On the other hand, application cost, time requirements, timing issues, and uncertainty factors all can become barriers to using manure (McCann, Nunez, and Nowak, 2006; Nunez and McCann, 2008; Ribaudo et al., 2003.)

Impacts of these factors are complicated by uncertain, confusing, and even conflicting recommendations coming from different agencies, such as by the guidelines addressing different issues of water quality vs. air pollution (McCann, Nunez, and Nowak, 2006). One example of this involves tilling of manure into the soil to prevent N runoff into surface waters, as opposed to leaving manure on the surface to prevent wind-erosion, while dispersing the manure's N content, and protecting groundwater (Aillery et al., 2005, p. iii).

While considerable research has been directed toward what inclines farmers to adopt conservation measures and BMPs, and toward 'barriers to adoption' of such measures, there has been relatively little attention given to factors that relate specifically to applying manure at agronomic vs. excessive rates. We have identified some indicator variables that we believe can help address this gap. In their meta-analysis of BMP adoption literature, Baumgart-Getz, Prokopy and Floress (2012) recognized that attitudes toward BMPs in general are unreliable in accounting for adoption, however awareness of **specific** practices, and farmer attitudes toward them, do provide relevant insights into what factors lead to their adoption. While we did acquire from our respondents some data on which BMPs they used, we also found the relationships between those and their MM choices to be murky and inconsistent, as opposed to the data relating directly to their attitudes regarding MM and manure application-rates. Baumgart-Getz et al. also found that, in many studies, farm-size showed a positive relationship with BMP adoption in general (2012). While controlling for this, we looked more deeply into other factors affecting manure application-rate and the issue of who over-applies manure. The BMP Adoption literature has not effectively addressed this, nor has the literature on Barriers to Adoption; hence we are here addressing this gap in the literature of MM research.

This gap in the literature is also evident at the macro level. Ribaudo, Gollehon and Agapoff (2003) identified the problem of large livestock production operations using insufficient land-areas for manure-application; but they did not discuss what actually affects how farmers distribute the manure at different rates. Therefore it is appropriate that we address the question of who over-applies manure.

Let us now turn to discussing hypotheses and proposed models explored within this study. Are there beliefs, concepts, knowledge or other factors in farmers' minds, or aspects of their situations that influence or relate to their decisions regarding manure application-rate? This study attempts to determine what farmer or operation characteristics, such as operation-size, typical field-size, or practice-preferences, might distinguish between operations that apply manure at sustainable, non-polluting rates and ones that over-apply it, as reflected in the respondents' reporting of tons/acre of manure applied and how often.

Research Questions

In order to address this application-density aspect of MM by crop-producers, we are here considering the following general research question and sub-questions:

What factors affect corn-growers' decisions of whether or not to use manure, and for those applying it, how densely to distribute that manure? Our primary concern here is to separate reasonable rates of manure-application from clearly unsustainable rates.

In this analysis, we consider several plausible factors that might affect manure application rates, as indicated by crop-growers' decisions of whether to and how heavily to distribute manure. To this end we consider factors such as those discussed above leading to over-application of manure (Liu et al., 2018); Osmond et al., 2015), and factors that act as barriers to adoption of conservation practices (McCann, Nunez, and Nowak, 2006; Nunez and McCann, 2008; Ribaudo et al., 2003), within the growers' profiles or operation logistics, related to their choice of whether to apply manure and, if so, at what application-rate. Understanding such factors could better inform efforts to encourage appropriate MM strategies and reduce the use of inappropriate ones. Are some producers inclined to apply manure sustainably, while others avoid using manure at all, and still others discard it carelessly or hazardously, thus over-applying it? If so, are there specific factors consistently associated with these different patterns? In the following section we discuss a number of factors that may affect these manure-application choices and how some of them have been studied in previous research.

Manure Application Predictors – Whether to Apply Manure, and at What Rate

Economic pressures and personal preferences are two types of factors known to contribute to an agricultural operator's decision whether to apply manure (Hoag, Lacy and Davis, 2004) and these could potentially affect rate of manure-application as well. Two pressure situations, 1) having a large number of cattle which produce manure requiring disposal, and 2) having many acres of corn crops near a feedlot which provide a conventionally accepted target for disposal of manure, both create incentives toward applying manure onto corn fields. Preference factors can be either positive or negative as described by Hoag et al. (2004). A belief that manure can increase corn yields and that it improves soil fertility are typical positive preference factors. In terms used by Baumgart-Getz et al. to analyze the existing BMP adoption literature, these preference factors are considered to represent an attitude based on the *profitability* of the practice

(2012). Concerns about weed seeds, salts contained in manure, and concern about soil-compaction by manure-spreading trucks are examples of negative preference factors that would be considered *risk* factors (Baumgart-Getz et al., 2012). Concerns around water pollution, neighbors' objections, and possible government regulation are other examples of negative preferences, which align with environmental awareness variables that Baumgart-Getz et al. label as *consequences* (2012). Here we consider whether these or other factors affect the rate of manure application in addition to the choice of whether or not to apply manure.

Are Application-Rates Partially Related to Rurality, and/or to Non-Visibility?

One reason for over-application of manure, as described above, is that large-scale livestock producers have economic incentives to externalize the costs of manure disposal from the livestock production process (Livingston, 1998). Any expenditure adds to the cost of beef production; and disposing manure within the least possible distance reduces this cost. This means that livestock producers have an incentive to pressure farmers in the nearest (and least visible) areas to dispose of their manure in large quantities. Given such incentive, we might expect excess application to be more common in rural areas where it is less obvious and perhaps more conventionally accepted. Manure over-application is visually (and olfactorily) not much different from that of ordinary manure-application at acceptable rates, so farmers can typically assume that manure over-application will likely go unnoticed.

Relative non-visibility of manure externalization, according to this argument, may be linked with low rural population densities and might be one reason for a common preference of having groundwater protection managed locally rather than by state or federal officials (Carolan, 2006).

Methods of Data Collection and Analysis

Our data was collected in two rounds of a mail survey that was conducted first in 1999 in Weld County and secondly in 2001 in four counties at the northeast corner of Colorado, east of and adjacent to Weld County, distinctly farther from any metropolitan area and more rural than Weld County. These areas are of special interest because they are highly vulnerable to nitrate contamination of groundwater (Ceplecha et al., 2004), and they are also dense with cattle feedlot operations. All the areas included in the survey are located along the South Platte River. The sample area was drawn so that it would likely provide enough agricultural land for a safe level of manure-application for the feedlots there, assuming most of the appropriate farming operations would accept manure applied to their fields.

Extending the Dataset from a Previous Survey to Include Application-Rate

Using the Weld County portion of the dataset (described in Chapter IV under "*Methods*"), Hoag, Lacy and Davis (2004) developed a model of the likelihood that a producer would apply or not apply manure to any field, based on 'pressures' such as number of cattle maintained and acres of corn grown; and on 'preferences', as in perceiving certain benefits and/or problems of using manure. Understanding factors that lead farmers to apply manure is of interest especially because if more producers would spread the existing volume of manure, it would be dispersed over a larger physical area and be used to support more cropland, reducing the density of manure applied and of the nutrients that would eventually contaminate local groundwater. In other words, sustainable MM could be more easily achieved if more farmers applied manure to their crop-fields and thus the total volume of feedlot manure was distributed over more crop-acres.

That analysis determined that operations having larger amounts of cattle and larger acreages of corn crops were more likely to apply manure, and also that perceiving greater benefits for using manure increased the likelihood of using manure, much more than perceiving manure's problems reduced the likelihood of using it (Hoag et al., 2004). Incidentally, it also showed that a farmer's age, level of education, and experience demonstrated no consistent relationship with the likelihood of applying manure. The lack of connection among those variables is consistent with findings of a recent meta-analysis (Burton, 2014). While the Hoag et al. model addressed the probability that an operator might apply manure at all, based on economic "pressures" and "preferences", it did not consider the per-acre rate of manure application by each operator.

The current study identifies factors that affect the density of manure application onto crop fields, not just whether it is applied at all. Manure application-rate is non-zero for those farmers who actually chose to apply manure, a subset which included about half the responding farmers. From the perspective of reducing pollution and optimizing the use of manure as a resource, rate of manure-application is critical. Applying manure excessively to a field is likely to leave much of the manure's nutrients unused by the plant crop, and those excess nutrients are destined to percolate gradually downward into groundwater. A less dense application of manure may be more completely consumed by the crop, leaving much less residual nutrient material to enter groundwater. The dependent variable of the Hoag et al. model, whether the farmer used any manure, did not distinguish between operations that used manure sparingly as a fertilizer from those that over-applied manure primarily to dispose of it, thus motivating the focus here on manure application-rates.

In addition to the data used by Hoag et al. (2004), we administered a second round of the same mail-survey which provided an additional 141 farm operator responses. This survey round targeted farmers in four smaller counties to the east and northeast of the first round, a more rural area with similar feedlots and crop production operations along the South Platte River.

In the expanded dataset of 414 cases, 372 operations had crop or pasture acreage providing an opportunity for applying manure as fertilizer, and for these operations we considered the rates of manure application as stated. In the questions regarding a “typical” manured field, our questionnaire asked the rate of manure application per acre. Where this data exists, it reasonably represents the density of manure-application. We also asked how often – every year, every two years, three years, etc. – the farmer would choose to apply manure on a field. This is clearly another factor in how densely manure is applied over time. This study attempts to determine what farmer or operation characteristics might distinguish between operations that apply manure at sustainable, non-polluting rates and ones that over-apply it, as reflected in the respondents’ reporting of tons/acre of manure applied and the frequency of application. Some of the factors considered relate to the physical situation of the operation, while others represent perceptions, cultural impressions or thought processes of the individual respondents.

This issue calls for a two-part model wherein the first part considers the choice whether to apply manure and the second part, for those who do apply manure, looks at their rates of application. The choice of manure application-rate may be affected by a different but overlapping set of factors from the choice whether to use manure or not. Data regarding the dependent variable, application-rate, is “censored” for those who did not apply manure, meaning that there is no data regarding the amount of manure that non-appliers would have applied had they done so; and this is why the two-part model is needed (Breen, 1996; Heckman, 1996). If our model did not consider factors of the decision of whether to apply manure, the results would be distorted by ignoring the selection criteria relating to why farmers choose manure-application in the first place. The choice to apply or not apply manure is binary, whereas rate of manure application (measured in tons/acre) has a continuous range of values. To be more specific, the first part of a two-part model considers whether a farmer applied manure, i.e., whether the manure application-rate was zero or non-zero; and the second part of the model considers the non-zero application-densities in tons per acre, as the dependent variable of a regression model. Further, for the non-zero application-rates, we are interested primarily in associations between farm or farmer characteristics and whether their manure application-rate choice was moderate and sustainable or excessive and therefore unsustainable.

In developing a two-part model for the manure application-rate question, we have concluded that the two questions affect sustainability of MM in interrelated but different ways. Not applying manure, in an area where it would be relatively cheap and beneficial to apply it, is a missed opportunity to reduce the over-supply of manure. Removing manure from a feedlot area where it has become concentrated is expensive beyond its intrinsic value, and it begs externalization from the industrialized livestock operations that produce it, as we have described above. However, addressing the over-supply issue by applying manure in large amounts that crops cannot fully use ensures that excess nutrients will eventually migrate downward into the groundwater below the root zone of the crops. The two parts of this manure issue, over-supply and over-application, are interrelated but occur through different decision-processes. We therefore find it appropriate to consider modeling the issue in terms of a three-valued response variable, indicating whether the cumulative amount of manure applied over time was: 1) Zero; 2) At a reasonably "Agronomic" rate; or 3) Clearly above that "Agronomic" level and therefore Unsustainable. In the following section, we look more closely at contributing factors, and explain why treating the application rate in categorical form is preferable.

Conceptual Descriptions of Variables Measured

Specific factors we have considered for both parts of the model are listed here, along with possible reasons for identifying them as relevant:

- The size of an operation, in terms of farmed acres or number of cattle, was determined to affect the likelihood of using manure (Hoag, Lacy and Davis, 2004). A larger operation has more space and possibly more fields on which to consider applying manure. Also previous studies have found farm-size, in acres, to be associated positively with conservation-BMP adoption, according to a meta-analysis by Baumgart-Getz, Prokopy, and Floress (2012). Large operations tend to be more visible, more connected to government agriculture-support agencies, and to have the economic resources necessary to implement BMPs. Size and resource-related attributes are aspects of "Capacity" as described in two meta-analyses of many BMP-adoption studies conducted by Prokopy et al. (2008) and Baumgart-Getz et al. (2012). Farm-size may also be related to the **rate** of manure-application, as large-scale feed-growing operations are under pressure from feedlot operator clients to dispose of large manure quantities (Hoag, Lacy and Davis, 2004).
- Characteristics of a typical field where manure was applied, such as distance to a manure source, soil type, size of the field, and expected yield might be considerations for the farmer in making MM choices, especially in deciding on manure application-rate (Nunez and McCann, 2008; Stroheim, 2016). These are field-parameters that farmer respondents were asked to enter in the questionnaire. Expecting a high yield might ease concerns about whether to rely on manure's nutrients for particular fields, knowing that these fields have already demonstrated reliable yields. Using manure on a high-performing field might allow that field to become even more productive. Even variations in the manured field size might be associated with the manure application-rate (MacDonald, Korb, and Hoppe, 2013), in that a

larger field could provide an easy opportunity for manure disposal. Field-size could influence application-rate either negatively or positively. A farmer might be expected to lower the application-rate to stretch the nutrient benefit over a greater area; however, large-acreage fields could also become targets for disposal or “dumping” of large manure amounts, increasing the per-acre application-rate (Osmond et al., 2015; Stroheim, 2016).

- Perceptions of benefits and problems relating to the application of manure are likely to predispose farmers in their MM choice of whether to apply manure, both positively and negatively (Hoag, Lacy and Davis, 2004; Nunez and McCann, 2004; Liu, Bruins, and Heberling, 2018). Indicators of how farmers perceived the benefits of using manure, as inexpensive fertilizer to provide nutrients and increase yield, a belief that manure improves soil properties or that manure provides a good source of organic matter can reasonably be expected to relate to the farmer’s chosen manure application-rate.

- Adoption of conservation practices, or BMPs, used by operators may indicate their openness to adoption of SMM practices and to conservation practices in general (Bauder, Waskom and Wardle, 2017; CDPHE, 2012; Liu et al., 2018; McCann et al., 2006; Weber and McCann, 2015). Participation in the use of some BMPs might indicate an openness to adjusting manure application-rates. However, the meta-analysis of Baumgart-Getz, Prokopy, and Floress (2012) points out that farmer attitudes toward BMPs in general are usually inconclusive unless they address a specific BMP individually.

- Concern about groundwater pollution resulting from excess nutrients might reflect a farmer’s general level of environmental concern or belief in resource-stewardship, at least in a local sense, which could potentially affect the chosen rate of application (Burton, 2014; Carolan, 2006).

Some of these factors relate to the physical situation of the operation, while others represent perceptions, culturally based impressions or thought processes of the individual operator-respondents. Some of these variables were measured effectively by our questionnaire, and some may not have been. In cases where data showed no relationship or a mixed relationship between IVs and DV, we chose to leave those IVs out of the model or, if appropriate, to control for them.

Using the mail-survey data from the 372 farming operations, we explored possible relationships between some of the concepts discussed above and manure-application behavior, using survey variables described below.

Dependent Variable (DV):

Manure Application Rate is derived by combining the farmer's estimate of the last season's manure application-rate in tons/acre applied to a "typical manured field", combined with the approximate frequency of manure application in years, so as to generate a long-term application-rate. We divided the tons/acre value by the interval (in years) between manure-applications – for example, 30 tons/acre every two years would be 30/2 or 15 tons/acre/year.

Given the lack of precision inherent in these estimates, we have chosen to separate them into simple binary categories of 'Agronomic' (acceptable) and 'Over-Application' (unacceptable), with the threshold set high enough that the unacceptable level is clearly outside the range of acceptability. While this approach has the disadvantage of losing some detailed information, it also avoids assuming an inappropriate level of precision in the manure application-rate estimates provided by farmers. The highly approximate nature of these estimates is related to variations in the weight/density of manure-loads based on water-content, inconsistency of manure-spreading rates and in the generally imprecise nature of manure-spreading equipment.

Independent Variables (IVs):

We asked farm operator respondents about certain characteristics and practices that we believed might affect their choice of manure application-rate. We looked for differences among feed-crop producers, differences between farmers who have livestock and those who do not, as well as differences related to the use of certain farming and conservation practices. We looked for factors relating to higher or lower manure application rates. We also considered farmer perceptions about manure as factors affecting farmer decisions regarding manure usage. Some of the IVs we considered as possibly explanatory for one or both parts of the model are described here.

Economic Variables -

- Pressures to dispose manure, and preferences of feed-growers, as modeled in a previous analysis of a subset of this study's data (Hoag et al., 2004) showed that the number of cattle, acres of corn, perceived benefits, and problems of using manure all contribute to the choice to use or not use manure. We considered whether these variables related also to the manure application-rate.
- Distance from a manure source (in miles) – manure is heavy, and fuel cost makes it expensive to transport more than a short distance.
- Operation size – represented by total acres; acres of corn grown; and number of cattle. Larger operations may have more pressure to dispose manure, but may also choose to avoid the complexity of applying manure to some fields, as its use cannot be standardized like the application of commercial fertilizers or other inputs.

- Size of target field – Larger fields might easily accommodate higher volumes of manure at a lower density of application. Also, large fields might be easier to access and require less turning of spreader vehicles.
- Valuation of manure in $/ton as a resource – Another measure of the farmer's perception of manure's benefit as an input

Knowledge-Related Variables -

- Farming Practices - Operators who use conservation practices that protect water or soil may be willing to adopt BMPs, including those intended for sustainable MM. Examples include soil testing, irrigation water analysis, and past experience for determining manure or nitrogen fertilizer application rates.

Demographic/Logistic Variables -

- Field Characteristics (size of the manured field, soil type, crop type, etc.) – may affect the appropriateness of using manure.
- Source of manure acquired (owned, purchased, or accepted free or for credit) – cost.
- Number of years in farming or ranching (which may indicate age and/or experience);
- Distance from a Metropolitan Area - 2 distinct groups – Using manure may be less visible in more rural areas. Also, local ratio of feed-crops to fed-cattle may differ.

Control Variable -

- Distance from a Metropolitan Area, as described, can also be seen as a control variable.

It is important to note that some of these variables, such as the Distance from a Metropolitan Area, may fit into more than one category. These categories are not mutually exclusive, and are intended as a theoretical tool, not to limit or direct the analysis.

Analytical Models

As described above, this study uses a two-part model, the first part of which addresses factors related to applying or not applying manure as previously modeled by Hoag, Lacy and Davis (2004), and the second part of which addresses factors associated with the rate of manure-application among those operations where manure was actually applied. "Appliers" only are represented in the second part of the model, because only these had non-zero application-rates.

Various methods have been developed to model two-part decision scenarios, including Tobit, Heckman, and Belotti's two-part method. Two-part models are necessary because estimating only the non-zero outcomes would provide distorted results.[7] Heckman and others have shown that analyzing only the nonzero outcomes of continuous variables generates invalid estimates of predictor variable effects. The analytical approach taken here, a two-part Heckman model, fits with substantive features of the behavior of interest: Density of manure-application implicitly involves a sequence of two decisions – 1) Whether to apply manure; and 2) for appliers, How much manure to apply. The model needs to incorporate the fact that many farmers within range of manure supplies are non-appliers of manure, whose manure application-rate was 0 tons/acre. We have therefore used a two-part model which takes into account both of these decisions.

The most common version of the second-part of Heckman's two-part model approach would utilize the continuous response variable, the application rate. While this application rate is continuous, ranging from just above zero to 50 tons/acre, many of the reported values are likely to be imprecise. Our goal is more simply to understand what distinguished those farmers who applied manure at "Agronomic" (sustainable) rates from those who applied manure at "Over-Application" (excessive) rates. For this we have adopted a Heckman Probit model (using Stata's

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[7] For a detailed discussion of why this is the case, please see: Belotti, F., P. Deb, W. G. Manning, & E. C. Norton, 2015. "twopm: Two-part models". The Stata Journal, 15(1), 3–20. https://doi.org/10.1177/1536867X1501500102

"heckprobit" command) and separated the manure-application rate data, which was continuous, into two rate-categories, "Agronomic" and "Over-Application" as described below. Essentially this represents a three-valued response variable indicating whether the cumulative amount of manure applied over time was: 1) Zero, 2) At or below a reasonably "agronomic" rate, or 3) Above that "agronomic" level and therefore unsustainable. While it is normally considered inappropriate and a waste of potentially useful information to reduce a continuous variable into discrete categories, this is a case where the categorization is appropriate because it achieves a clear and simple understanding, and because we have carefully chosen cutoff points to address the specified issue (Fedorov, Mannino, and Zhang, 2009; Ragland, 1992).

The categorization process involved separating the long-term application rate at a chosen level by specifying an arbitrary cutoff point, below which the amount of manure applied was considered to be "Agronomic" (agriculturally and economically appropriate), and above which it was considered to be "Over-Application" (unsustainable). The quantities we used for this re-classification are explained next.

The "Agronomic" manure-application rate that has typically been considered sustainable and acceptable for cattle in northern Colorado has been 20 tons/acre once every three years (averaging 6 1/3 tons/acre/year), according to the typical BMP literature as mentioned previously. In order to avoid including reasonable applications as unsustainable, we have conservatively, and somewhat arbitrarily, set the lower limit for "Over-Application" at a high level equivalent to 45 tons/acre over 3 years (15 tons/acre/year for 3 years), which is clearly an excessive amount in any case.

In summary, the model uses pressure and preference factors identified by Hoag, Lacy and Davis (2004) to account for the binary choice of whether or not a farmer chooses to apply manure, constituting the "selection" part of the two-part Heckman Probit model. The second part of the model evaluates how those factors, along with one other variable, affected the manure application-rate used by the farmers who did apply manure.

Results

The two-part Heckman Probit model in Table VI.1 shows how each of the explanatory variables included relates to the likelihood of applying any manure (the selection stage), and for those operations that did apply manure, of over-applying it. The "selection" first part of the model (shown in the left side data-portion of the table) lists the coefficient for each variable's contribution to the propensity to apply at least *some* manure ("Used Some M" = 1). The second part of the model (right side of the table) shows the coefficient for each variable's contribution to the propensity for over-applying manure ("Over-Applied M" = 1). Table VI.1 was created using the Stata command "heckprobit".

Note that each part of the model includes one variable that does not appear in the other part. The 'Square Root of Cattle' quantity (in hundreds) is relevant for the decision to apply manure, but not for the manure Application-Rate.[8] 'Size of Manured Field' does not exist for an operation that applied no manure.

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[8] Cattle numbers have a complicated relationship with the choice of whether to apply manure and virtually no statistically demonstrable relationship with manure application-**rates**. (Inclusion of the cattle numbers term in the second step of the model provided no additional explanatory power.) We believe this can be explained as follows: Cattle operations that grow corn are likely to apply some manure, because they need to dispose it and have crop-fields available to receive it. Having cattle leads to applying manure in the **selection part** of the model. However, most corn-producing operations are not feedlots, and most large feedlots buy their corn from outside farms rather than growing their own corn. Thus, most feedlot operators have little or no cropland on which to apply manure, and offload their manure to outside farm operations that provide their feed-corn. In other words, the largest amounts of manure applied to crop-fields come from feedlots that have no crop-fields and therefore were not included in the sample. Their manure was applied by operations having little or no cattle. Thus, the cattle numbers in our sample, while associated with applying **some** manure, are not correlated to the amount of manure applied in the corn-production operations represented, because the majority of applied manure came from feedlots not in the sample.

Table VI.1 Heckman Probit Analysis

Heckman Probit model with sample selection	Number of obs	=	377
	Censored obs	=	204
	Uncensored obs	=	173
	Wald chi2(5)	=	25.69
	Log likelihood	=	-312.293
	Prob > chi2	=	0.0001

("**M**" is used to abbreviate "Manure")

Variables	**Selection - HeckProbit – 1st Step – Used Manure (1) OR Did Not (0)**				**M Application Rate - HeckProbit - 2nd Step "Agronomic" (0), OR "Over-Applied" (1)**		
	Coef.	Std Err	*z*		Coef.	Std Err	*z*
Op. Size (Corn Acres in 100s)	-.120***	.046	-2.59		-.060	.074	-0.81
" " (SqRt. of Corn Acre100s)	.615***	.157	3.93		.422*	.268	1.58
Sq. Root of Cattle100s	.400***	.098	4.07				
Benefits (Perceived) of Applying M (Likert scale)	.268***	.076	3.52		.317**	.148	2.14
Eastern Colo (Rural Sample)	-.586***	.155	-3.79		-.736***	.264	-2.79
Size Manured Field (*100ac)					.565**	.242	2.33
Constant (_cons)	-1.469***	.316	-4.65		-2.829***	.727	-3.89
/athrho	.658	.637					
rho	.577	.425					

* $p \le 0.1$ ** $p \le 0.05$ *** $p \le 0.01$ LR test of indep. eqns. (rho = 0): chi2(1) = 1.32 Prob > chi2 = 0.251

{Stata command: heckprobit HowMuch corn100 corn_sqrt benscal sizem100s eastern, select(UsedSomeM = corn100 corn_sqrt cat_sqrt benscal eastern) }

Rho is an estimator of correlation between the errors of the selection and outcome equations for the two parts of the model. If *rho* were 0, it would indicate that the selection and outcome models could be treated separately with no problem of bias. However, the *rho* value of .577 indicates that the selection process is relevant, and that the outcome (manure application-rate) portion cannot accurately be modeled separately from the selection process (Certo et al., 2016).

Given that the probit regression model involves a complex and nonlinear relationship of predictors to the probability of the outcomes, directly interpreting the coefficients in Table VI.1 is difficult. To understand the effects of each variable, it helps to look at their marginal contributions to the probability of overapplying manure predicted by the model, as represented by the partial slope (i.e., derivative) while the other independent variables are held at particular levels, such as their means or at high and low representative values. We display such examples in Tables VI.2 and VI.3.

Next we use the model to explore some representative value levels of these variables, to see whether certain combinations contribute more or less than others toward the probability of manure over-application. Tables VI.2 and VI.3 compare marginal effect values of the explanatory variables at different combined levels for each variable, derived from the coefficients presented in Table VI.1. Cells on the right-hand side of Tables VI.2 and VI.3 contain the estimated marginal effect contributions (and standard errors) toward the probability of over-applying manure with respect to each explanatory variable, at each given combination point, for the variables included. Table VI.2 shows these marginal effects for the Western sample, and Table VI.3 shows them for the Eastern sample.

In order to better understand the tables, we first describe their structure, and then we observe and compare the levels of a few particular entries, as a way to help step the reader through them. After that, we offer a more summary discussion of the patterns revealed by these results.

Each marginal effect is the response, at a point, of a one-unit increase for that variable, on the likelihood of over-applying manure for that operational situation. A one-unit change for the Benefits-Scale represents one integer step in the Likert scale (ranging from 1-5). One unit of change for Operation-Size is 100 acres. A unit of change for Manured Field-Size is 10 acres.

Table VI.2. Marginal Effects of Explanatory Variables on the Probability of Over-Applying Manure, Displayed at Various Representative Values (w/ Std Error) -- Western Sample

Representative Variable Values | **Marginal Effects**[9]

Perceived Benefits Scale	**Operation Size**	**Manured-Field Size**		**Benefits Scale**	**Operation Size**	**Manured Field Size**	**Eastern**
Low Perceived Benefits	Small	Small		**.052** (.018)	.028 (.015)	**.009** (.006)	**-.121** (.067)
		Mid-Size		.066 (.022)	.035 (.017)	.012 (.008)	-.154 (.087)
		Large		.081 (.028)	.043 (.021)	.014 (.010)	-.187 (.106)
	Mid-Size	Small		**.062** (.022)	.017 (.009)	**.011** (.006)	**-.144** (.075)
		Mid-Size		.077 (.027)	.022 (.011)	.014 (.008)	-.179 (.094)
		Large		.091 (.033)	.026 (.012)	.016 (.010)	-.211 (.110)
	Large	Small		.070 (.026)	**.012** (.008)	.012 (.006)	-.162 (.082)
		Mid-Size		.085 (.031)	**.014** (.009)	.015 (.009)	-.197 (.099)
		Large		.098 (.037)	.016 (.010)	.018 (.010)	-.229 (.113)
Mean Perceived Benefits	Small	Small		.068 (.030)	.036 (.018)	.012 (.006)	-.159 (.074)
		Mid-Size		.083 (.036)	.044 (.021)	.015 (.009)	-.193 (.084)
		Large		.097 (.041)	.051 (.024)	.017 (.010)	-.226 (.108)
	Mid-Size	Small		.079 (.036)	.022 (.011)	.014 (.007)	-.183 (.082)
		Mid-Size		.095 (.043)	.027 (.013)	.017 (.009)	-.220 (.099)
		Large		.106 (.046)	.030 (.014)	.019 (.010)	-.247 (.111)
	Large	Small		.087 (.040)	**.014** (.010)	.015 (.007)	-.201 (.089)
		Mid-Size		.101 (.045)	.017 (.011)	.018 (.009)	-.234 (.103)
		Large		.112 (.050)	.019 (.012)	.020 (.010)	-.261 (.113)
High Perceived Benefits	Small	Small		.084 (.044)	.045 (.023)	.015 (.007)	-.196 (.084)
		Mid-Size		.099 (.049)	**.052** (.025)	.018 (.009)	-.230 (.099)
		Large		.111 (.053)	**.059** (.028)	.020 (.010)	-.257 (.110)
	Mid-Size	Small		.095 (.050)	.027 (.014)	.017 (.007)	-.220 (.091)
		Mid-Size		.108 (.053)	.030 (.015)	.019 (.009)	-.251 (.103)
		Large		**.118** (.056)	.033 (.016)	**.021** (.010)	**-.274** (.111)
	Large	Small		.102 (.053)	.017 (.011)	.018 (.008)	-.236 (.097)
		Mid-Size		.114 (.056)	.019 (.012)	.020 (.009)	-.264 (.107)
		Large		**.122** (.058)	.020 (.013)	**.022** (.010)	**-.283** (.111)

[9] Cells in this section of the table contain the estimated slope (and its standard error) of the probability of over-applying manure with respect to each explanatory variable, at each given combination of the four explanatory variables. (Highest and lowest column values are in **bold**.)

Table VI.3. Marginal Effects of Explanatory Variables on the Probability of Over-Applying Manure, Displayed at Various Representative Values (w/ Std Error) -- Eastern Sample

Representative Variable Values | Marginal Effects[9]

Perceived Benefits Scale	Operation Size	Manured-Field Size		Benefits Scale	Operation Size	Manured Field Size	Eastern
Low Perceived Benefits	Small	Small		**.015** (.009)	.008 (.006)	**.003** (.002)	
		Mid-Size		.022 (.012)	.012 (.007)	**.004** (.003)	
		Large		.031 (.016)	.016 (.010)	.005 (.005)	
	Mid-Size	Small		**.020** (.012)	**.006** (.004)	**.003** (.002)	
		Mid-Size		.028 (.014)	.008 (.005)	.005 (.004)	
		Large		.038 (.018)	.011 (.006)	.007 (.005)	
	Large	Small		.024 (.014)	**.004** (.003)	**.004** (.003)	
		Mid-Size		.033 (.017)	**.006** (.004)	.006 (.004)	
		Large		.045 (.020)	.007 (.005)	.008 (.005)	
Mean Perceived Benefits	Small	Small		.023 (.015)	.012 (.008)	**.004** (.002)	
		Mid-Size		.033 (.019)	.017 (.010)	.006 (.004)	
		Large		.043 (.024)	.023 (.012)	.008 (.005)	
	Mid-Size	Small		.029 (.019)	.008 (.005)	.005 (.006)	
		Mid-Size		.040 (.023)	.012 (.007)	.007 (.004)	
		Large		.053 (.028)	.015 (.008)	.009 (.006)	
	Large	Small		.035 (.023)	**.006** (.005)	.006 (.003)	
		Mid-Size		.047 (.027)	.008 (.005)	.008 (.005)	
		Large		.060 (.031)	.015 (.008)	**.011** (.006)	
High Perceived Benefits	Small	Small		.033 (.025)	.018 (.012)	.006 (.003)	
		Mid-Size		.045 (.030)	**.024** (.014)	.008 (.005)	
		Large		.058 (.035)	**.031** (.016)	.010 (.006)	
	Mid-Size	Small		.041 (.030)	.012 (.008)	.007 (.003)	
		Mid-Size		.054 (.035)	.015 (.009)	.010 (.005)	
		Large		**.068** (.040)	.019 (.010)	**.012** (.007)	
	Large	Small		.048 (.035)	.008 (.006)	.009 (.004)	
		Mid-Size		.062 (.039)	.010 (.007)	.011 (.005)	
		Large		**.076** (.044)	.013 (.008)	**.014** (.007)	

Each marginal effect applies at only one instantaneous point on the curve. For each column we have **bolded** the two lowest and two highest values, to show its range by indicating the strongest and weakest marginal effects.

At this point, let us note the overall row-sequence of the two tables. The first nine rows in each table represent a "Low Perceived Benefits (of using M)" value, followed by nine rows representing "Medium Perceived Benefits", and the bottom nine rows of each table reflecting "High Perceived Benefits". Within each such block of nine rows, the first 3 rows represent a "Small Operation Size", the middle 3 rows represent a "Mid-Size Operation", and the last 3 rows (within that block of 9 rows) refer to a "Large Operation Size". Lastly, each single row (within each set of 3 rows) reflects a "Small field", "Mid-Size field", and a "Large field" consecutively. The data columns on the right side show the marginal effect for each variable, given the specific combination of variable levels for that row. As mentioned above, for each column we have bolded the two highest and lowest marginal effect values for that variable, within that table.

The "representative values" for the key explanatory variables are as follows:

- Perceived Benefits (of Applied Manure) on a Likert scale of 1 to 5 are represented as follows: The "Low" value is 3.3, "Mean" is 4, and "High" is 4.67.
- Operation Size values shown are: "Small" operation size of 86 acres; "Mean" operation size of 201 acres, and "Large" operation size of 350 acres.
- Manured Field Sizes range from a "Small" field of 20 acres to a "Mean" size of 55 acres, and a "Large" field of 88 acres. For numerical-unit simplicity, we have considered Operation-Size in hundreds of acres and Field-Size in tens of acres.

As an example, the first row of Table VI.2 represents a Small-sized operation of 86 acres where the respondent perceived the benefits of applying manure as "Low" and where manure was applied to a Small field of 20 acres. The Manured Field Size marginal effect (2nd column from the right) for that row situation was .009, indicating that an additional 10 acres (to a size of 30 acres) would increase the likelihood of manure over-application by .009. Looking at the third section of Table VI.2 (18 rows below) labeled "High Perceived Benefit", we can compare the first case to a similar case with the difference of perceiving M's benefits as high-valued, and there we see that the marginal effect of the same field-size increase would be .015, more than a 50% higher marginal effect.

As a second example, also viewing Table VI.2, let us focus on the 3rd section of nine rows in which all the effects model the "High Perceived Benefit" level. For a "small operation" of 86 acres, an increase in field-size from small to large increases the marginal effect of operation-size from .045 to .059; but for a large operation of 350 acres, the same increase in field-size only increases the marginal effect of operation-size from .017 to .020, representing a much smaller effect of operation-size at this larger operation level. Even so, the positive effect of field-size, between small (20 acres) and large (88 acres) field-sizes, increases (from .015 and .020 for small operations, to .018 and .022 for large operations) as operation-size increases from small to large. Thus, the relative effect of operation-size diminishes, even as that of field-size increases, albeit a smaller increase at the larger operation-sizes.

As a third example of how to read these data, we can note that the "Perceived Benefit" effects change positively and consistently as each variable level increases. Comparing a cell in any Perceived Benefits block of data with the equivalent cell in any other block, a higher perceived level of M's benefits corresponds with a higher marginal effect toward manure over-application. This applies to both Tables VI.2 and VI.3.

Comparing Marginal Effects at Specific Variable-Level Combinations

In general, all three of the key variables were positively associated with increasing the probability of manure over-application; however, the marginal effect for each of them reflected varying levels and was moderated at different levels of the other two variables.

The first and last columns, Benefits Scale and Manured Field Size, show increasing positive marginal effects as Operation Size increases, and as each of their own levels increases. Benefits Scale effects, relative to the probability of manure over-application, rise with increases in both Operation Size and Manured Field Size. Manured Field Size also has an increasing positive marginal effect relative to the probability of manure over-application as each of the other two variables increases.

The marginal effect of Operation Size is different from that of the other two variables, in that its effect diminishes as the operation size level increases. Its positive effect is over twice as strong at the "Small Operation" size level compared to what it is at the "Large Operation" size, which can be seen in Tables VI.2 and VI.3 by comparing the "Small" values in the "Operation Size" column with the "Large" ones. (The middle values of that column, "Mid-Size" operations, are in between those of the high and low levels). To state this differently, an increase of Operation-Size for a smaller operation is associated with an increase in the probability of manure over-application; and this effect diminishes somewhat for larger-sized operations.

Preference for the benefits of applying manure shows a strong marginal effect at all sizes of operations and all sizes of fields. The differences between marginal effect for benefit-scale low ratings and high ratings are clear at each level. Low-, mid-, and high-level perceived values of manure have consistent contributions toward the probability of manure over-application, elevating slightly at increasing operation-size levels.

Marginal effects of manured-field size increase slightly with the Operation-size level, and even more strongly with increases on the Benefits scale. The increased marginal effects associated with higher perceived benefits of manure are consistently in the range of 50% higher for operations with high perceived benefits than for those with lower perceived benefit levels, as one can see by comparing the Benefits values for the top 9 rows with those of the bottom 9 rows in each table.

Overall, the Perceived Benefits of using manure have a consistently linked marginal effect for increasing the probability of manure over-application. Looking at the range of values in the first data column, and visually scanning each set of nine cells vertically, where the first nine rows represent "Low Perceived Benefits" and the bottom nine rows refer to "High Perceived Benefits", one can see that each set of values displays an increased range relative to the Benefits value set just before it. Higher Perception of M's Benefits appears to increase the marginal application rate for each of the other variables.

Size of the Manured Field is also linked with the increased probability of over-applying manure at all levels of Operation-size and of Benefits scale; and that marginal effect is notably strongest for the largest manured fields. Within the "Manured Field Size" column, each group of three values shows an increase of marginal effect from Small to Large fields; and those field-size increases are accompanied by increases of marginal effect for the Benefits Scale and for Operation Size as well.

The right-most column of data, "Eastern", distinguishes between the two locationally different samples. The eastern marginal effects in Table VI.2 are all negative, indicating a lower probability of over-applying manure for the eastern counties beyond the differences reflected in the other variables, and, by comparison, reflecting the higher probabilities for over-application within the western sample. These lesser eastern marginal effects are inversely proportional, more reduced for each of the other key variables, that is to say reduced more for large operations than for smaller ones and for higher perceived benefit respondents than for lower ones, and so also for larger field-sizes than for smaller ones.

Looking at Table VI.3, which replicates the structure of Table VI.2 for the eastern sample, we can see the same relationships among marginal effects as we saw in Table VI.2, with one major difference. All the Table VI.3 marginal effects are attenuated in the eastern sample relative to the other sample, displaying only 1/3 to 1/2 the marginal effects shown in the western sample. Thus, controlling for location, we see the model is stable, as indicated by the consistency of internal relationships among the variables.

Discussion

In this section we consider the implications of the results presented above, particularly observing that each variable represents a very different aspect of the operations and their operators. Perception of M's benefits is a preference factor, while size and location of an operation, and even the size of a particular field being manured are physical factors that reflect a more structural or logistic set of elements.

Perceived Benefits Scale

Higher perceived benefits of applying manure clearly lead consistently to higher manure application rates, likely because potential manure users are inclined to apply manure according to how much they value its benefits. This factor is clearly at play in both stages of the two-part model, reflecting the farmer's inclination whether to apply manure at all, and influencing application-rate or quantity of manure applied. There is no surprise here, as enthusiasm for applying manure is a preference factor in both choices. Believing manure to be beneficial is associated with using it, and also with using more of it, even to the point of over-application. The perception of manure as a benefit appears uniformly to amplify the effect of all the other variables. The consistency of this effect suggests that the model is quite stable. This variable probably summarizes how the farm operator feels about using manure, including also whether the "barriers to adoption" create resistance toward using it.

Total Operation Size

Over-application of manure becomes more likely as the size of operation increases, possibly because these growers experience pressure from their feedlot customers needing to dispose of large amounts of manure. However, this marginal effect, of increasing operation-size, is notably stronger at smaller scale operation-levels than for those in the larger size-ranges, diminishing at the mid-level and higher-level operation-sizes. This can be seen by comparing the Operation-Size effect occurring in sets of 3 rows each, sequenced in 3 blocks, within each 9-row Perceived-Benefit level. Note that within each block of 9 Perceived Benefit level rows, the range of each succeeding marginal-effect triplet is slightly lower than the three rows just above it.

Increasing Operation-Size from Small to Large shows a reduced slope of total acreage contribution to manure over-application (looking at each set of 3 rows and moving down from small to large operation-size), but the opposite effect for field-size, where the contribution of an additional 10 acres to manure over-application in field-size increases with each larger field-size increment.

An explanation for this probably has several components. 1.) The larger operations are more visible, such that the biggest growers are a little more cautious. 2.) Having more fields on which to apply manure allows an operation to spread it around more widely. 3.) Large operations tend to rely on economies of scale and may be likely to strive for a more standardized application-rate throughout their operations. Smaller scale operators, despite their size, are also expected, by the feedlot customers they supply, to take away large amounts of manure, and may be more likely to depend on the inexpensive nutrients aspect of manure-application. And, with less overall space available for manure application, the effects of preference and of field-size might easily lead to higher manure application-rates and a greater likelihood of over-application.

Field Size

Most surprisingly, field-size has a strong positive connection with likelihood of over-application. We found that an increase of field-size is consistently linked to an increase in the probability of manure over-application, at all levels of operation-size and all preference levels. The marginal effect of a slight increase in field size is half again (50%) stronger for larger fields than for small fields in the case of farmers with lower manure-use preference, and 20% to 25% stronger even for those with a high manure-use preference level. Given that increased "pressures" and "preferences" lead to a higher likelihood of manure over-application, the additional effect of field-size may reflect a relative shortage of disposal-spaces for manure within easy access distance of feedlots producing large amounts of manure.

Large fields provide easy targets for this much-needed disposal ground. Large crop-fields, while surrounded by county roads, are relatively isolated land-areas with very little foot traffic. People drive by quickly, and few humans are in a position to observe, complain about, or even to notice the excessive manure application-rates. “Out of sight and out of mind”, the manure applied on these larger fields has relatively little obvious impact on the human physical senses. This is consistent with the hypothetical discussion above regarding non-visibility and the externalization of manure-management in low population rural areas.

In viewing these marginal slope effects, it becomes clear that: The larger the field receiving manure, the higher the increase in probability of manure over-application. This is not to say that other elements are unrelated or do not contribute to increasing probability of manure over-application. Benefits scale and farm operation-size are both related to it also. But the consistently apparent connection between manured field-size and the probability of manure over-application was unexpected and substantial.

Location

The lower marginal effects evident in the eastern sample appear to reflect some locational differences not accounted for by any of the other three variables. There are some physical and cultural differences between these areas, such as a lower density of feedlots, higher annual precipitation, and lower cattle population densities, which may explain the lower incidence of over-application. More crop-production fields are available, within easy transport distance, per feedlot animal population, allowing lowered manure application-rates without causing as much over-supply. In other words, the locational difference in manure over-application rate might naturally occur because the ratio of cattle per cropland-acre is distinctly lower in the eastern counties, creating less pressure toward manure over-application in those 4 counties than in the more western county.

Conclusions

Manure-Application rate, like the choice of whether to apply manure, displays a consistent relationship with both of the key variables included in the model, the “pressure” of operation-size (represented here by corn-production acreage of the operation), and “preference” or the perceived-benefits of manure-application. While cattle-quantity is linked with the choice to apply manure, that did not relate consistently with manure application-rates.[10]

Most surprisingly, Field-Size of a typical manured field was consistently related to the probability of manure over-application across groups, not only among the largest operations. Field-size appears to reflect the systemic need for mass disposal of excess manure produced by animals clustered in feedlots. And further, larger fields appear to be more often targeted for high manure-disposal rates. The positive relationship between field-size and probability of over-application was surprising in that we expected that a typical farmer would logically try to stretch manure’s nutrients over a larger field, so as to maximize the benefits for a larger crop-volume. Instead, it appears that a larger field presents an easy target for getting rid of manure in larger quantities, essentially providing a waste-disposal economy-of-scale for industrial-sized feedlots. Any effort to monitor manure application-rates should take into account the higher probability for over-application of manure on larger fields than on smaller ones.

Policy and Nutrient Application Rates under Widely Varying Local Conditions

In policy development, limitation of manure application-rates is usually deemed an appropriate tool for reducing manure’s negative environmental impact, such that the nutrients are

[10] Level of rurality was also included as a control variable. The more rural eastern sample was somewhat less likely to apply manure and less likely to over-apply it. This can probably be attributed to a lower ratio of feedlot-cattle to crop-acreage in these more rural counties, hence a lower level there of “pressure” toward manure over-application.

mostly consumed by a plant crop instead of being externalized from the production process (Nunez and McCann, 2008; Osmond et al., 2015). In some cases, this approach may require providing financial incentives to farmers, while in other situations the cost-advantage and soil-improvement properties make manure seem a valuable substitute for commercial fertilizer, worthy of purchase for many farmers.

Possible Recommendations for Extension Agents, and Some other Considerations

Following are some possible ways of using the information included here to work with farmers toward more sustainable MM:

- When working with farm operators, agents might ask the farmers' perceptions regarding manure's benefits for application as fertilizer and for soil-amendment purposes, as well as their awareness of the potential hazards of excess nutrient application and the importance of considering M's contribution to a total nutrient picture.
- Consider the size of an operation as a factor that may indicate likeliness to apply manure and the probability of over-applying manure.
- Consider the size of an intended field for application in regard to the probability of manure application at agronomic or at possibly unsustainable rates. This could also provide an opportunity to familiarize operators with the issues and parameters in applying manure responsibly using SMM, as well as to develop relationships with extension agents and with other farmers who strive to manage manure sustainably.

Policy as A Work in Progress

Between the collection of the survey data used and the present, the study's relevance has apparently persisted and, if anything, increased. In 2012, Colorado's Department of Public Health and Environment (CDPHE) created Regulation 85 addressing water-quality management issues, including those created agriculturally (2012). It solidified rules applying directly to feedlots and specified a ten-year deferment period for crop-farmers to address pollution issues such as that of nitrogen runoff voluntarily, after which time the situation would be re-evaluated (CDPHE, 2012). While farmers in the region of our study would generally prefer to remain unregulated or to continue self-regulating, their situation may be changed in the near future, if they are determined to be insufficiently protecting public water quality. If that is the case, then regulations addressing nutrients and chemical applications will be developed and implemented.

While many farmers are sincerely attempting to curb their fertilizer application rates, it may very possibly be determined necessary to confront this issue through regulatory policy, because the downstream impacts of over-application are not obvious to many Colorado farmers, and their nutrient management practices may not have changed sufficiently to meet the Regulation 85 requirements.

We think the most important findings of this study are that the size of a farm operation applying manure and the size of specific fields where manure is applied are consistently positive indicators of a potential toward manure Over-Application. Knowledge of field-acreages might well be used by regulators as a factor in choosing how to monitor specific farming operations for potential manure over-application.

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CHAPTER VII. DISCUSSION AND CONCLUSIONS

In this study, we have focused on farmer thinking, decision-making, and behavior regarding manure management, as critical points of attention for remedying a serious environmental challenge. We begin with a brief review of this study's key findings, which have been presented in Chapters IV through VI, regarding farmers' relationships to the application of manure and synthesize those results into a more comprehensive picture. Following that we step back and look at a contextual view of the systemic excess-nutrient problem that results from heavily applying feedlot manure and commercial fertilizer, and how this picture connects with the policy environment. We conclude by discussing how these findings could be applied in working with farmers, some future research directions, and how technological advances along with policy developments might reasonably be expected to help address the nutrient pollution issue in the future.

Key Findings -- Three Perspectives on How Farmers Manage Manure (Chapters IV – VI)

In the next few pages, I revisit this study's results regarding farmers' manure management choices, the findings discussed in Chapters IV, V, and VI. This involves three perspectives: 1.) Fields appropriate for manure-application (Chapter IV); 2.) Farmers' perceptions of manure's value (Chapter V); and 3.) Farm factors affecting rates of manure-application (Chapter VI).

Choosing Fields for Manure-Application

In **Chapter IV** I looked at factors that differed between fields where farmers chose to apply manure and ones where they chose not to apply it. (This comparison was possible in cases where farmers had at least one manured and one non-manured field, roughly a third of our survey respondents. Most respondents who *had* applied manure to a field had also grown crops on a non-manured field.) Differences between fields where a farmer chose to apply manure and not to apply manure might also provide insights about the decision of some farmers not to use manure at all, because some farmers may only manage the sorts of fields that were typically not manured.

From this field-specific perspective, a high **expected yield** was a strong indicator for applying manure to a field. We might interpret this to mean that past performance of a field gave the farmer confidence in its productivity, so that using manure was not risky, and that a good yield for the current year was likely in any case. Where they used manure, farmers typically reduced their application of commercial fertilizer slightly, but not enough to offset the added nitrogen contained in the manure. "Nutrient-crediting", to account for nitrogen in the manure applied, was practiced to some extent, but in most cases not sufficiently to reduce the over-application of nutrients.[11]

This is not surprising, given the variability of nutrients present in any typical load of manure. Farmers may also wish to increase the range of nutrients in a field which is intended to produce a high yield. Addition of commercial fertilizer is typically seen as a form of "insurance" for a manured field, just in case the manure nutrients are insufficient. Typically no harm is done to the crop unless the excess nutrient amount is extreme. And when a farmer believes it necessary to

[11] We can interpret reduced use of commercial fertilizer between the compared fields (manured vs. non-manured) to reflect the perception of manure as a fertilizer substitute. While we asked farmers to report what crop they used the manure on, and how much commercial N they applied to their manured and non-manured fields, many skipped these questions. Among those who did answer them, 79% reduced the amount of N applied to a manured corn field vs. the non-manured one. Grass hay crops accounted for 11% of the reduced N reported; beets, alfalfa, cabbage, onions, and wheat altogether represented the other 10% of crops where manure was clearly identified as a fertilizer substitute. It is also worth noting that the reduction of commercial N applied was usually much less than the amount of N that was likely provided by the manure applied, and therefore that using manure was typically increasing the total quantity of N applied by a significant amount.

produce the greatest possible yield, it is widely considered economically rational to over-apply nutrients (Luloff et al., 2010; Osmond et al., 2015; Sheriff, 2005; Houser, 2018).

Another factor as to whether a field receives manure is the **distance from a manure source**. Proximity of a manure source effectively reduces the transportation cost in fuel and time. Clearly a farmer is incentivized to use manure on a field that is nearer rather than farther from the manure source.

Smaller fields were more likely to have manure applied, but while this effect was prevalent in the more metropolitan area, it virtually disappeared in the more rural sample where typical field-sizes were roughly double those of the metro area. Paradoxically, while larger fields were less likely to have manure applied, they were typically manured at higher rates.

Perception of Manure's Value - Do Farmers See Manure as a Resource to Use Efficiently?

In **Chapter V**, we considered how farmers perceived the value of manure in monetary terms, as a potential indicator of how likely farmers are to direct manure's application efficiently, thereby minimizing the amount of nutrients lost into the environment at large.

Manure's perceived value, as depicted in our sample, appears to be a function of four sets of variables which we have characterized as follows: 1.) **Source-situation**, representing how the manure was acquired: Whether from their own livestock, purchased from outside, or received free from a feedlot; 2.) **Perceptions** about the benefits and disadvantages of manure application; 3.) **Knowledge factors**, such as research-based farming practices; and 4.) **Demographics**, including some personal and farm-operation characteristics. These were the main categories that showed some consistent relationship with farmers' perceptions of manure's value and how efficiently those farmers applied manure as fertilizer. In the following paragraphs, we describe some possible interpretations of the results for each of these variable categories.

Source-situation: Farmers who own cattle have a ready and proximate source of manure. Much of the variation in perceived value of manure is explained by the farming location's proximity to a manure source. This source-situation affects the farmer's perception of manure's value partly as a function of how easy or difficult the manure is to acquire and apply. Pressure to remove the manure, and the transport cost, for a farmer who has cattle on the farm, is relatively low. Given the inherently low cost of their supply and transportation, cattle-holding operators value manure the highest. Farmers who own livestock and perceive manure as inexpensive fertilizer tend to value manure more highly than all the other groups.

Perceptions about manure application: While controlling for the source-situational groupings described above, we found that the benefits of manure as inexpensive fertilizer and as a method for reducing wind-erosion increased its perceived value, while concern about water pollution decreased its perceived value. Some farmers purchased manure as inexpensive fertilizer, and to supplement the organic matter of their soils. However, their valuation of manure appears to have been reduced by the cost of transportation. In other words, the value they specified appears to have been adjusted downward to compensate for transfer costs. Other farmers accepted manure for field-application, even though they perceived it less enthusiastically, when their client feedlots made it a good deal for them by giving it to them free or even sometimes paid them to take it away, crediting their accounts. Some farmers simply did not use any manure at all, either because they were too far away for transport to be cost-effective or simply because they found it unpleasant or inconvenient. Contrary to our hypothesis regarding the extra tillage required in using manure, which we had framed as a problem of using it, the additional tillage was instead perceived as a collateral benefit, increasing its value. No-till farming is generally considered an environmentally sound practice; but in the case of MM, tillage incorporates the manure into the soil, providing a benefit and reducing the potential for nutrient runoff.

Knowledge factors: Factors that accompany a reduction in manure's perceived value included: Past experience in years of farming, cover-crop nutrient crediting, size of the operation, and concern for the hazard of water pollution. Past experience lowered M's perceived value, as did the number of years in farming. This corresponds with the findings of Nunez and McCann (2008) that younger farmers were more likely to apply manure than older ones. Farmers may have found manure-application to be less valuable than they had originally expected; or some farmers may have found manure objectionable, inconvenient and management-intensive. Perhaps using manure becomes a more difficult physical chore as the farmer ages, leading to a desire to simplify the work by letting go of the complications of applying manure and by opting for the predictability of commercial nutrient application.

Another knowledge factor, "nutrient crediting" was often practiced by farmers who used cover-crops as a likely alternative to applying manure. Both approaches accomplish the same general objectives. It seems unsurprising that those who spent resources on growing cover-crops would prefer using them, and would place a somewhat lower value on manure-application as a resource.

Demographic factors: Size of operation, represented by gross sales, was related to a lower perceived manure-application value. We interpret this to be a result of increased standardization in larger-sized operations, as a means to contain costs through economies of scale. manure-application cannot easily or effectively be standardized for large-scale farming operations because of sourcing and timing issues, and because conventional manure-spreading is uneven at best. This also supports the concept that industrialization, indicated by growing sales volume, leads to externalization of environmental negatives from an operation's process, as an economic streamlining measure (Franzluebbers et al., 2011; Lemaire et al., 2013). Past experience is another demographic factor that overlaps with knowledge factors, apparently reducing the perceived value of manure-application as described above.

Using quantile regression (QR) analysis, it became clear that the relationship of some factors with perceived manure value were not linear and had significantly different influence at different value levels. These variations are relatively easy to see in the graphs of Chapter V, Figure V.1. At different perceived manure value-levels, farmers displayed concern about varying related factors and these variations can provide useful insights. For those who perceived manure as having a low value, receiving it free or for credit seemed to increase its value. For those who valued manure highly, this was mostly not the case. "Crediting" nutrients from a cover crop was related to increasing manure-application valuation at low value levels, but to decreasing manure-application valuation at higher value levels. This appears to indicate that farmers who planted cover crops saw manure as a useful cover-crop input, but preferred to limit cover-crop expenditures, finding manure helpful as long as it was cheap. High manure-application valuers may tend to see the manure itself as a primary crop input, with lower incidence of using a cover-crop. More years of experience in farming were also associated with lowered valuation of manure-application at all levels. This association could reflect aging and a preference for operational simplicity, as described above. The increased need for tillage when applying manure related to reduced manure-value at the low value levels; however, for those who valued manure highly, the extra tillage appeared to be associated with perceiving manure-application as being of higher value.

What Affects Manure Application-Rates?

In **Chapter VI** we looked at factors that affected manure-application rates, arriving at a two-part model that considers first the choice of whether to apply manure, and secondly factors linked to manure over-application. By controlling for frequency of application we found that farmers did tend to apply somewhat less manure per acre if they applied manure every year than if they only applied manure once every two, three or four years. The more often farmers applied manure, the lower was the per-acre amount of manure they indicated using; however, the reduction of manure applied was generally not proportional to the increased frequency of application. Applying manure more frequently increases the total N applied over time. We considered the combination of manure application-rate and frequency to indicate the cumulative application-rate. We then used a conservatively high threshold value of this rate to identify which operations had clearly over-applied manure.

Total farm operation-size and highly valuing the perceived benefits of manure-application are strong factors, both for choosing to apply manure and for increasing the amount of manure applied. The truly surprising finding was that larger manured fields were consistently likely to have manure applied at notably higher rates. We found it surprising that for larger fields the likelihood of manure over-application was higher, because we thought a larger field theoretically "should" provide more space over which to spread out the manure. This phenomenon was especially true for smaller-scale operations.

Apparently, this positive effect of field-size on manure application-rate reflects an economy of scale for manure disposal, as opposed to seeking greater efficiency in the use of nutrients. It appears to reflect a "dumping" strategy, whereby large-scale feedlots dispose of large manure volumes and minimize their costs by having farmers use the largest possible fields within the shortest reasonable distance and with the smallest number of spatial locations. In economic terms, this may simply demonstrate an economy-of-scale for optimization of manure-disposal. Concentrating feedlots into a relatively small area results in a considerable amount of manure to be disposed nearby, while high transport costs prevent most of the manure from being delivered very far from its source. When some producers need to get rid of a lot of manure, they apparently target the largest appropriate fields within a reasonable distance and dump as much there as possible. This may not be a complete explanation, but it is consistent with the finding that the more distant manured fields tend to be larger and to have notably higher application-rates.

Economies of Scale, Operation Size and Manure Externalization

In contrast to the relationship with field-size, when the overall size of an operation grows beyond a certain level, it may tend to standardize its process by relying solely on commercial fertilizers and become more likely to externalize manure-application from its scope of work. In evaluating the western (less rural) sample, Hoag et al. (2004) reported that corn farmers growing under 400 acres of corn were more likely to apply manure the more corn they grew. But above 400 acres, their likelihood of applying manure dropped off. In other words, operations above a certain size were decreasingly likely to apply manure and were therefore less likely to contribute to the redistribution and reduction of manure application density for the area. An operation that could apply manure but chooses not to do that is indirectly contributing to a heavier concentration of manure requiring disposal, and therefore to an increased potential for over-application of it by other operations in the surrounding area.

Similarly, livestock producers managing up to 580 head of cattle were increasingly likely to apply manure the more cattle they held; but over 580 head that likelihood went down (Hoag et al., 2004). In the case of cattle, this probably reflects the separation of feedlots from farm operation, as the larger feedlots tend not to grow their own feed, but rather have it provided by farmers nearby.

Contextual Issues – Stepping Back to Revisit the Big Picture

Overview: Feedlot Manure Disposal, Farming, and True Cost Externalization

As described in Chapters I and II, concentrated manure from feedlots distributed onto crop-fields in rural areas creates a known hazard to water quality, potentially affecting human health and ecosystems in these areas and downstream. Crop farmers growing grain for the feedlots are under pressure to dispose of manure from the livestock. Field-application of the manure provides various benefits in the forms of plant nutrients and soil-enhancement. However, this manure is typically added to fields that are also receiving high levels of commercially produced fertilizers (Osmond et al., 2015; Stuart and Houser, 2018). The combined nutrients often become pollutive to groundwater.

This manure-related water-quality degradation occurs partly because manure disposal is transferred from the feedlots to farmers, externalizing the environmental cost and responsibility from the industrialized feedlots to the farms. Economies of scale, government de-regulation or non-regulation, conventional agricultural practices, and non-visibility of the pollution are some of the systemic elements that allow, contribute to, and maintain this externalization, preventing or inhibiting attempts to control and reduce water-quality degradation.

This project has shown that both the size of manured fields and the total size of a farming operation are positively related to manure application-rates. Larger fields where manure is applied tend to receive considerably heavier application-rates than smaller ones. And while the total size of a farming operation that uses manure is positively associated with higher application rates, above a certain level it is also related to a lower likelihood of applying manure, leaving increased amounts of manure to be disposed of elsewhere in that local area. These size-related tendencies reflect the externalization of environmental consequences from feedlot-based agriculture, and from the monocultural production processes of the contemporary agri-business world in general. As discussed, MM choices made by the farming community we have studied are clearly affected by their embeddedness within a broader systemic structure wherein livestock production has become oligopolistic, and which includes farmers as the disposal agents for its toxic byproduct of manure.

Farmer Decision-Making Regarding Manure Nutrient Management

It is important to note here that farmers' crop-input decisions are structurally constrained and are not made in a truly free market situation. Since the 1950s, the U.S. economic climate has essentially forced farmers to grow larger or leave the industry ("get big or get out") because economies of scale have reduced prices and made smaller scale farming unprofitable (Feng et al., 2018; Hinrichs and Welsh, 2003).

Large-scale livestock producers expect to acquire maximum-yield feed-crops from farms that supply them. The typical farm operator is under pressure to provide the highest possible yield in order to maintain a contract with the feedlot, even if that means a lower profit margin for the farm (Amon-Armah et al., 2015; Hinrichs and Welsh, 2003; Tully and Ryals, 2017). This expectation is effectively a barrier to the adoption of resource conservation measures by which many farmers could potentially gain higher financial returns over the long-term, even while protecting local ecosystems. But because the returns on those investments might not be immediately realize, existing incentives (favoring short-term returns) are structured in a way that perpetuates the status quo. The following section explains in more depth some of the background forces affecting farmers that appear to be maintaining a pattern of nutrient over-application.

Crop Yield, Risk, and Profitability

Most farmers strive for the highest achievable yield, even if the return on their additional investment is considerably lowered because of the marginal cost. (Note: This observation was described to us by local extension agents within the study area.) Several factors appear to be involved, including the traditionally competitive nature of rural agriculture. As growing operations become larger and fewer, the bragging rights of maximizing yields per acre may give an individual farmer some edge over their competitors (Osmond et al., 2012a; Amon-Armah et al. 2015). High crop yields are traditionally seen as the “currency of the realm”. New concepts such as maximizing economic return on nutrient investment may be slow to gain acceptance, even if they are economically more “rational”. For a more complete description of this “MERN” (Most Economic Rate of Nitrogen) approach, the reader is encouraged to revisit Chapters II and IV. As part of the current livestock production system, crop farmers are rewarded for maximizing yield. Their clients, the feedlot operators, do not typically care about a farmer’s input costs as long as they are confident the farmer can be relied on to provide feed for their livestock.

From the typical farmer's perspective, it may in fact be economically rational to apply fertilizers above the "agronomically recommended" rates (Sheriff, 2005). This occurs because farming is subject to a range of uncertainties, such that over-application of fertilizers reduces the risk of insufficiently low crop-yields (Sheriff, 2005). As Glenn Sheriff states, "… (his) article examines why farmer perceptions of agronomic advice, input substitutability, hidden opportunity costs, uncertainty, and risk aversion can make it economically rational to 'waste' fertilizer by applying it above agronomically recommended rates" (2005).

From a simple efficiency standpoint, reducing the amount of commercial nitrogen fertilizer applied provides the farmer a distinct cost saving (Amon-Armah et al. 2015). Substituting manure for commercial fertilizer as a nutrient source does offer this cost saving. However, substituting manure for commercial fertilizer is somewhat risky because the nutrient content of manure is inconsistent. Nitrogen content of manure is uneven and varies dramatically within any given manure load. Therefore, farmers typically do not trust its nutrient content and are likely to reduce their perceived risk by adding commercial fertilizer, in addition to manure, as a form of "insurance" (Houser, 2018; Osmond et al., 2015). If a high crop-yield is the primary goal, then too much fertilizer is less risky than too little (Sheriff, 2005). When both manure and commercial fertilizer are applied, the total amount of nitrogen introduced is typically higher than if just one or the other were used. This deliberate over-application of nutrients helps explain why the cumulative nitrogen load is higher near feedlots than in areas farther away where crops are grown using mainly commercial fertilizers (Hall, 1996; Sheriff, 2005).

As we saw in Chapter VI, when farmers perceive manure application as providing strong benefits, they are inclined to use it in larger amounts, even to the point of over-application. And they typically do not reduce the use of commercial fertilizer enough to compensate for what is contained in the manure.

Environmental Stewardship and "Right-to-Farm" Statutes

Many farmers see themselves in a land-stewardship role; but a comprehensive approach to environmental protection is typically left to the realm of government through various policy instruments. Over-application of manure is rarely detected because manure application rates on crop-fields are typically not monitored or controlled. Manure application on crop-fields in almost any amount is protected in many states, including Colorado, under "Right-To-Farm" statutes, which generally protect conventional farming activities from "nuisance legislation" or complaint (Colo. Rev. Stat. §§ 35-3.5-101 to 35-3.5-103; Spellman and Whiting, 2007). These "Right-To-Farm" statutes came about in the 1980s, largely in response to urbanites moving to the countryside and subsequently attempting to displace existing agricultural operations because of displeasure with the smells they generated and the flies they attracted.

From an environmental resource perspective, it seems appropriate to consider whether these statutes are overly broad in protecting agricultural activities from enforcement of regulation, allowing uncontrolled nutrient-pollution of water resources. One question within our survey considered at what level, and by whom, farmers think groundwater pollution issues should be addressed: By local agencies, by livestock producers, by states or federal government, or by the farmers themselves. Environmental policy in agricultural areas is highly contested, and the next section provides a brief description of how policy has evolved around the feedlot industry.

Policy Approaches - Regulation vs. Voluntary Conservation Measures (or BMPs)

There are policies in place that address livestock waste pollution when it comes directly from feedlots or animal feeding operations (AFOs). Policy efforts to promote recommended manure-management practices consist of two basic types: Regulation directed at point sources such as feedlots; and Voluntary measures - practices recommended for farm-level manure management that are not legally required:

- <u>Regulation</u> of point-source polluters can be effective in controlling large operations, but is generally considered too expensive and intrusive for addressing the issue of smaller family farms (Shortle and Abler, 2001). The EPA defines large point-source livestock operations as Concentrated Animal Feeding Operations (CAFOs). These producers are required to file Comprehensive Nutrient Management Plans (CNMPs), whereby they agree to implement the manure management practices specified in their plans. (Ribaudo et al., 2003a)
- <u>Voluntary conservation measures</u> include guidelines and recommendations for smaller operations, considered "non-point source" (NPS) pollution: These measures include "best management practices" (BMPs), education, and agency extension efforts.[12] One example of a relatively effective BMP is the "buffer strip". Buffer strips of vegetation can reduce nutrient runoff, absorb excess nutrients, and provide an effective tool for helping curb the hazard of nutrient excess, especially when used in combination with other approaches (Bauder, Waskom and Wardle, 2017; Osmond et al., 2015; Ribaudo et al, 2001; Waskom and Davis, 1999).

Even though enforceable regulations are generally more effective in achieving results, U.S. rural culture is largely unaccepting of widespread regulation, especially where the pollution-

[12] Extensive EPA-recommended information on managing NPS pollution is available at this web-site: http://water.epa.gov/polwaste/nps/whatis.cfm, updated Aug. 27, 2012.

source is seen as NPS (Buttel, 2003; Livingston, 1999). And, because BMPs are voluntary, they can typically be ignored without peril by smaller farming-operations, which only need to avoid being caught in the act of creating blatant environmental hazards. In 2014, a workshop organized by US federal agencies on the role played by agriculture in global N pollution concluded that more research is still needed into grower adoption of BMPs (USEPA–USDA–USGS, 2015). Its executive summary pointed out that "… the appropriate technologies and basic knowledge for effectively mitigating reactive agricultural N loss already exist, but excess loadings of reactive N to the atmosphere and water continue, due mostly to the lack of adoption of BMPs and appropriate technologies" (USEPA–USDA–USGS, 2015).

This study expands the understanding of farmers' thinking and behavior regarding MM, in part to help overcome some barriers to adoption of relevant BMPs. State extension agents and policy developers promoting BMPs and sustainable nutrient management (SNM) practices could be well-served by understanding the characteristics of farm operators who are likely or unlikely to adopt these conservation practices.

Insights for Addressing Concentrated Livestock Production's MM Issue

The possibility of applying this research to address the problem of livestock manure-nutrient pollution depends on knowing how crop-farming fits into the agricultural industry and the landscape of the American economy. The economic rationality of farmers' decisions is focused on farm profitability, which is typically seen as independent of environmental sustainability and unrelated to ecological hazard (Sheriff, 2005). Reasons for this economic focus extend well beyond the mindset of individual farmers (Hinrichs and Welsh, 2003; Houser, 2018; Stuart and Houser, 2018). Agricultural operations, including livestock producers and their supporting feed-crop farmers, are partially shaped by their embeddedness within an industrialized organizational structure (Granovetter, 1985; Hinrichs and Welsh, 2003; Houser, 2018). The Safe Drinking Water Act of 1974, along with amendments created in 1996, regulates public drinking water sources. Yet because water used in farming is considered not to be a point-source, farming is exempt from being monitored through "right-to-farm" laws in many states, including Colorado (https://www.epa.gov/laws-regulations/summary-safe-drinking-water-act ; Spellman and Whiting, 2007). A revision of the Clean Water Act enacted in 2003 requires each concentrated animal feeding operation (CAFO) to follow a nutrient management plan that minimizes the hazard of pollution to water quality. This only affects large-scale livestock operations, and farming is generally exempt (Boesch, 2019; Livingston, 1998). This structure benefits industrial agriculture as much as it does farmers, and it seems likely that "right-to-farm" laws are supported by the deep pockets and political lobbying of major food-production conglomerates. These laws enable both the externalization of feedlot manure management and the over-application of fertilizers, making it easy for farms to provide cheap feed-stocks to the feedlots they support (Ashwood, Diamond, and Walker, 2019; Spellman and Whiting, 2007).

Farms are largely protected from regulation and are typically seen as too numerous to monitor. Pollutive farm runoff is treated as a NPS issue, and, in most cases, there is an assumption that it cannot be traced to its origins, as in the case of automobile emissions. Given this situation, it makes sense to explore the farmer-population that administers the manure disposal process directly.

As mentioned above, farmers spreading manure onto their fields are largely unregulated. Competition in their industry makes it seem counter-productive to incur the additional cost of curtailing nutrient pollution, because maximizing yield is essential and a plentiful supply of nutrients helps insure the highest possible yield (Sheriff, 2005; Osmond et al., 2015a). Additional pressure to over-apply nitrogen comes from the seed-companies who supply new varieties of hybrid corn-seeds every other year (Stuart and Houser, 2018). Not having prior experience with the new seeds each cycle, farmers rely on fertilizer amount recommendations from the seed companies, which are generally high. These seed companies depend on high yields for marketing purposes, and therefore specify high nutrient levels to assure that the latest seeds are demonstrating their highest possible productivity.

Being extremely busy with the immediate reality of their daily farm operations where their focus is typically quite localized, most farmers have virtually no indication that the excess nutrients they apply will have negative consequences (Carolan, 2006; Nowak et al., 1997; Osmond, 2012). Within their local communities, farmers rarely see any direct effect of nutrient over-application. Even where such effects are readily apparent, their own contributions are typically indirect and only a relatively minor portion of the total, so that changing their process would not likely produce any obvious benefit, at least in the short term. Overall, farmers have multiple reasons to over-apply nitrogen and very little pressure to avoid doing so (Sheriff, 2005; Stuart and Houser, 2018).

As Hinrichs and Welsh have pointed out, vertical integration of the food-manufacturing industry reduces the extent to which individual growers can make choices in the methods they use, including choices for using sustainable production practices (2003). More specifically, they have shown that while cow-calf operations and dairy operations have relatively high potential for practicing sustainable agriculture, beef-cattle feedlot operations have much lower potential for this, given the vertical integration and the industrialized nature of the feedlot model (Hinrichs and Welsh, 2003). Cultural perceptions of NPS pollution as a non-issue are becoming untenable for various reasons, as discussed below.

The Need to Address "Non-Point Source" Pollution

Considerable research and public awareness has been directed at fertilizer and nutrient sources including: Agriculture in general, ordinary residential lawn-care, golf courses, and even pet wastes. The cultural context involves various levels of the economy, including food production conglomerates that dominate the agriculture industry and promote high levels of fertilizer application (Stuart and Houser, 2018), leading ultimately to the end-consumers of red meat. Thus, the issue of feedlot manure management is embedded within a larger picture.

As mentioned above, excess nutrient application in agriculture is relatively invisible, but the cumulative results are not. We see algal blooms, "fish-kills", and "dead zones" downstream from where the nutrients were introduced. Even if there were no concentrated animal feeding operations (CAFOs), we would still need to consider the environmental effect of excess fertilizer nutrients accumulating in water that passes through the watersheds draining from higher to lower elevations. I will describe below how CAFOs greatly exacerbate this issue, especially in their local regions, and why their concentrated byproduct of manure is a critical factor.

Agricultural "non-point source" (NPS) pollution is widely recognized as a significant source of water quality impairment in the United States (Osmond et al., 2012b, 2015a; Ribaudo et al., 2015; US EPA, 2012). Although increased use of nitrogen fertilizers has contributed to major gains in crop yields and agriculture's ability to feed the world, the loss of nitrogen and phosphorus to the environment present a serious problem (Burkart and Jha, 2007; Jackson-Smith et al., 2018), which has been identified in this region by several previous studies (Ceplecha, 2004; Dennehy et al., 1998; DuBois, 1994; GPAC, 1995; Hall, 1996). Hazards associated with excess nutrients include toxicity to humans and animals, algal blooms leading to fish kills, loss of biodiversity, and hypoxic dead zones (Burkart and Jha, 2007; Hilton et al., 2006; Isbell et al., 2013; Rabalais et al., 2002; Ribaudo et al., 2003a). There is no question that these hazards are related to crop inputs including fertilizers and livestock manure (Hall, 1996; Ribaudo, Livingston, and Williamson, 2012). Excess fertilizer applications are estimated to be very high, with over 60% of total applied nutrients being lost to the environment (Mosier, Syers, and Freney, 2013).

Dumping – Field-size and Application-Rates

One of the most striking findings of this study is that, while larger fields could be expected to have manure distributed at a lower density than smaller fields, the opposite was in fact true. In other words, although manure's value could be optimized by spreading it more lightly over a larger area to maximize its benefit, the reality is consistent with targeting larger fields for dumping of manure in large quantities. Even as over-application of commercial N fertilizer is problematic throughout the Midwest (Stuart and Houser, 2018), manure over-application compounds this problem locally by appearing to be a separate unrelated process. On fields where manure is applied, some reduction of commercial fertilizer application is usually implemented; however, the net result is typically a substantial increase of nutrient over-application. This is even more often the case for larger fields, according to the data of our survey.

The same phenomenon is true for frequency of manure application. For operations that tend to apply manure densely, i.e., at high rates in tons/acre, we find that they also tend to apply manure more often, every year or every 2 years, than those who apply at lower, more sustainable densities. While they reduce their manure application-densities slightly if applying more frequently, those using high application-densities typically reduce the frequency of manure application less than those using lower application-densities.

It is no surprise that a few high-rate and high-frequency manure-appliers probably contribute the lion's share of the excess nutrients. These operations are likely linked more closely to the largest feedlot operations, due to the need for high volumes of feed-materials and the pressure to accept equivalent volumes of manure. Addressing the link between feedlots and feed crop producers would be a reasonable policy approach to close the loophole that has long allowed excess dumping of manure. Reviewing the semantics of calling nutrient pollution "non-point source" is likely going to become a key factor in unraveling this issue.

The Concept of "Non-Point Source" as an Issue in Itself

While tracing each source of application would be difficult, it would be more accurate to label it "multi-source", "multi-point", or "widespread" pollution. Framing nutrient pollution as "non-point source" (NPS) pollution is conspicuously deficient, to the extent that it allows nutrient overload sources to be systematically ignored.

One reason that NPS pollution has been categorically ignored is the difficulty of tracing it to its sources. Recent scientific advances in detection capabilities through chemistry, image analysis such as LiDAR, and geographic information systems may eventually change this equation. Detection and tracing of water pollution may become manageable and be deemed relevant in addressing accumulations of pollutants with long-range downstream effects. Ironically, increasing the prevalence of precision agriculture could potentially raise farmers' awareness of the long reach of water pollution generated by their operations, through increased familiarity with geographic information systems (GIS) and mapping of nutrient levels on a broader scale. As farmers become more familiar with technology and the scope of their geographic and scientific awareness increases, there is potential for them to become more open to discussion of environmental issues such as MM, if such conversations are inclusive and treat farmers as equal partners within the discourse.

Semantics – "Organic Matter" vs. "Soil Properties"

Looking in detail at some of our questionnaire's components included in the "Perceived Benefit Scale", it became apparent that the perception "Manure Improves Soil Properties" was related to increased manure application, whereas perceiving manure as a "Source of Organic Matter" was associated with reduced manure application.[13] This demonstrates that a relatively subtle difference in wording can indicate substantially different approaches toward the perception of an input application. Farmers using manure to "improve soil properties" in general appear to think "more is better", while those seeing manure as a "source of organic matter" take a notably more restrained manure-application approach. Subtle differences between words or phrases can thus be associated with very different mindsets.

Topics for Discussion with Groups of Farmers

If new technology allows identification of high nitrate concentrations, then working directly with farms where these occur could be an opportunity for mitigation of the N over-application challenge. Extension agents and other key people working with farmers could likely benefit from awareness of some of the factors we have identified here, in order to encourage their adoption of

[13] Correlation levels between these two indicators can be seen in Appendix A.

SNM practices. Agents working with farmers toward this end could target particular topics, and listen carefully to identify which factors they take interest in or respond to.

Candidate topics that might fit this role include things like:

- Where is your nearest source of available feedlot manure?
- How highly do you perceive the value of the manure you might apply?
- Do you have an expected yield for each field you're managing? And if so, does this relate to your choice of field to apply manure?
- How large are the fields where you plan to apply manure?
- Based in your experience of using manure and other fertilizers, how do you think about its effectiveness?
- How do you feel about the benefits of using manure vs. cover-crops for improving soil properties and/or enhancing crop yield?
- Does your sense of manure's value coincide favorably with its current market price?
- Do you have a clear sense of the nutrients already present in your fields?
- Are you comfortable restraining the level of nutrients to an amount the crop can likely utilize?
- How heavily do you typically apply manure, and how often do you reapply it to the same field?

In identifying these questions as relevant, I am suggesting that farmers need to be engaged in conversations that encourage targeting minimal, widely dispersed manure distribution, and that include serious consideration of how and whether it will be taken up by a crop. Group discussions are more likely to be effective, because while farmers like to think independently, they also tend to consider what their farming peers are doing, and what practices they think will be most beneficial (Osmond et al., 2012a; Osmond et al., 2012b). Osmond et al. (2012a) concluded that financially supported programs and incentives may be necessary to create such opportunities (Osmond et al., 2012b).

Directions for Future Research

There are multiple criteria as to where future research is needed and could be targeted. Areas of highly permeable soils are most at risk for aquifer contamination. Remoteness from population centers can lead politically to a lack of constituency around concern for water quality, as relatively few people may be directly affected by locally polluted groundwater. Areas that already have polluted groundwater may receive little attention from conservationist groups, unless there is a perceived need to restore an endangered ecosystem, or to counteract a perceived environmental injustice.

The areas we studied centered around ones that already had high levels of nitrate. Maurice Hall's research in these areas considered what would be necessary to restore them to normal levels of nitrogen (1996). Hall's simulation (1996) determined that pre-feedlot "normal" amounts of N could be restored if no additional N of any kind were introduced for a period of approximately 40 years. Obviously, this scenario is not likely under current political and economic conditions, which support the continued operation of livestock production through large-scale feedlots. Yet somehow the culture of operations in these areas needs to address the direct relationship between nutrient management and its impacts on the waters and watersheds downstream. If we, as a society attempting to live sustainably, choose to address the negative consequences of N accumulation, we will need to take multiple measures. These would include understanding and connecting with farmer networks, policy options adapted to local conditions, and whatever technical measures may be available or become available to reduce such accumulations.

Some food systems researchers have pointed out that feedlot-based livestock production is a significant contributor to environmental pollution and greenhouse gas emissions (Tully and Ryals, 2017; Velasquez-Manoff, 2018), because it accumulates large amounts of manure, often without a sufficient land-base to absorb and re-integrate it (Ribaudo et al., 2003b). This results partially from the separation between livestock operations and the crop-operations that support them. Some researchers advocate integrating livestock with cropping systems as a means for resolving this issue (Ribaudo et al., 2003b; Tully and Ryals, 2017).

In the introduction to this study, we discussed negative effects of excess water-borne nutrients for humans and for biodiversity within ecosystems. Managing manure to protect these resources would require some adaptation and adjustment on the part of farmers, and we will probably all need to share the additional costs if we choose for these changes to happen. As is the case for many environmental pollutants, non-visibility and a lack of immediate dramatic or catastrophically obvious damage typically prevents a strong public focus from forming. Research into the practical decision-making processes of farmers, and of other actors who function as environmental stewards, needs to include more study of relationship networks, so as to broaden our understanding of how social network structure shapes farm-level attitudes and decision making (Osmond et al., 2012b). Conservation practice adoption research shows that most farmers are willing to adapt to new conventions along with their peers once an innovation has proven to work for a sizable mainstream group (Osmond et al., 2012a). Financial incentives at various levels are also deemed necessary to make this transition possible.

Increasing the prestige value of operation profitability, rather than of high crop-yield at any cost, would go a long way toward reducing nutrient over-application while improving the farmer’s bottom-line. This would require an increased level of attention to cost-reduction per yield and may become more feasible as precision-agriculture becomes less costly and more prevalent. It would reflect a wider acceptance of the MERN approach described above. To reiterate that message, Amon-Armah et al. (2015) found that significantly reducing fertilizer expense to a minimized optimum level, would reduce crop-yield only slightly, while increasing profitability to a much greater extent, and while greatly reducing environmental pollution caused by nutrient over-application. Achieving this would involve a mindset change in the agricultural extension practice of creating nutrient management plans (NMPs). The Amon-Armah study found that MERN fertilizer rates were significantly lower than conventional NMPs typically prescribe (2015).

We specifically asked a CSU Extension agent who works regularly with farmers in the feedlot areas we studied if farmers are applying the MERN approach. That agent indicated that very few farmers seem interested, and that a clear majority of farmers are attached to maximizing yield even when the added expense is out of line with the limited yield increase. This echoes the research of Burton and Wilson (2006), which studied the “identity psychology” of farmers regarding conservation and concluded that “… despite much talk of an increasing 'conservationist' component to farming -- farmers' self-concepts are still dominated by production-oriented identities.” It is also reinforced by the research of Luloff et al. (2012) which cited the importance of “bragging rights” associated with high crop-yields.

As Sheriff (2005) and Houser (2018) have pointed out, using certain BMPs can actually lead to increasing the over-application of nitrogen rather than decreasing it, in the rational attempt to protect one's investment from the risk of not maximizing crop-yield. While this side-effect of promoting BMPs may be discouraging for those attempting to reduce the negative environmental consequences of modern agriculture, it does highlight the importance of more thoroughly understanding the social and psychological mechanisms at play in the culture of agricultural communities (Koger, 2013). One of the most important findings of this project has been to recognize the range and variability of factors affecting MM, and the importance of seeing each farm-operational situation in its uniqueness. Comprehensive solutions for nutrient overloading by agricultural players will need to accommodate a highly differentiated set of situations and conditions (Osmond et al., 2015; Vlaev, 2018).

In recent years, producers have implemented some beneficial changes in MM. Over the last 6 to 7 years the normal range for spreading manure has increased through the use of semi-trailers that are used to haul large containers of manure up to 20 miles. The manure is then redistributed from its arrival location over the field. Also, trailer-spreaders operating behind farm tractors are becoming preferred over manure-spreader trucks of the past, because they are used seasonally. This avoids the costs of routine winterizing and engine maintenance for vehicles that are used only occasionally. While using semi-trailers provides access to a larger radius of fields and potentially lowers manure distribution density, it is unclear whether this strategy also sustains the previously noted pattern of heavier application on fields farther from the manure source. This process could potentially create additional nodes of heavy application and probably needs to be monitored in the same way as feedlot areas.

Future research should reconsider the assumption that each farmer used a single rate of manure application for all fields, or even within each particular field. In our study, that has typically been the assumption for most operations, within any specific crop-type. In reality, application rates have been highly variable at the field level. Although manure spreaders generally expel manure using a conveyor-belt type floor that moves at a steady rate, the amount of manure dispersed can vary considerably as the load gradually becomes smaller. Respondents in our survey considered “uneven spreading” and “unpredictability of nutrients in manure” to be medium-level problems (approximately 3 out of 5 on a Likert scale). Manure also varies greatly in its nutrient content, even within a single stockpile.

Technological Improvements in Conjunction with Policy Development

Testing manure for its nutrient content would be one element of addressing the variability of manure’s nutrient content. With this knowledge, stirring or mixing of manure for homogenization or some alternative form of manure processing would then be appropriate, while combining manure and commercial fertilizer application levels to achieve sustainable application rates (Moshia et al., 2016). Another approach would be to extract and separate particular nutrients from the source manure, such as nitrogen, phosphorus and potassium (N, P, and K), while leaving certain aggregated organic matter available for soil amendment purposes. Only around 20% of our farmer respondents reported practicing “manure nutrient crediting”, likely because of these inconsistencies and the non-predictability of nutrients applied.

Currently, as previously discussed, farmers tend to blanket-apply nutrients in order to avoid the risk of insufficient nutrients anywhere in their crops, especially when the latest commercial seeds might take advantage of extra nutrients to provide unexpectedly high yields (Stuart and Houser, 2018). This hope of ever-higher yields is likely very appealing to farmers and, given the unknowable conditions of weather and other variables in farming, it makes economic sense for them to apply enough nutrients for the best possible growth conditions, “just in case” (Sheriff, 2005; Stone, 2019).

Innovative Conservation Practices to Improve Farm-Level MM

New approaches to manure management, especially in an area where feedlots are concentrated and a lot of manure is prevalent, could help address the issue. One possibility for this would be cooperatively owned or managed equipment. Financial incentives for developing and using such facilities would probably be necessary.

McCann, Nunez, and Nowak discussed this concept in their 2006 article on MM. Costs of special manure handling equipment and transportation, as well as the extra time and physical inconvenience involved in manure application, may seriously reduce or eliminate a farm’s profitability for the season. Innovations could potentially be more affordable through economies of scale if the adopting unit is larger than the individual farm. McCann, Nunez, and Nowak suggested that groupings of contiguous operations might benefit by having shared access to manure management equipment through joint ownership, such as by forming a manure-processing cooperative (2006.) Large-scale innovations could be shared, such as equipment to turn composting windrows, or to reduce the water content of raw manure, which would substantially reduce the cost of transportation; or equipment to extract specific component compounds which could have higher marketable values and more targeted applications (McCann, Nunez, and Nowak, 2006). These types of innovations would require social/institutional changes. McCann, Nunez, and Nowak attribute the lack of such innovations to a serious market failure, namely the absence of firm requirements for environmental protection, which they believe would induce development of such environmentally oriented innovations (2006).

When considering how to improve farmers' efficiency in applying crop-nutrients, one effective way to prevent or reduce over-application would be to limit the extra application of commercial fertilizers only to areas where the nutrients present are actually known to be insufficient. This could be achieved through "precision agriculture", where location-specific nutrient data is used to determine an appropriate fertilizer application-rate and thereby make application-rate adjustments in real time while fertilizer application equipment is progressing through the field (Cassman, 1999; Hong et al., 2007; Khosla et al., 2002; Raun and Johnson, 1999). Commercial fertilizer application-rates are much more easily adjustable than manure-spreading rates, so these will likely be addressed first. Precision agriculture lends itself to the MERN strategy of maximizing economic return for nitrogen as described previously, whereby yields may become slightly smaller and somewhat less uniform, but overall cost is much reduced along with the overloading of nitrogen. This results in significantly increased monetary return to the farmer's net income, as well as much less waste and resource pollution (Amon-Armah et al. 2015). Precision fertilizer application could, at a minimum, allow a more even distribution of nutrients, avoiding extreme levels in specific parts of a field where plenty of nutrients are already available to the plants, and adjusting the balance among the nutrients already prevalent in the soil at intervals as needed (Moshia et al., 2016). In the longer term, this approach can be one component of a strategy to limit nutrient losses.

As real-time geographic information becomes available that can pinpoint where in a crop-field the necessary nutrients are lacking, it is becoming possible to program variable fertilizer application-rates into the computerized tractors used. The immediate potential benefit of precision agriculture technology is the ability to control distribution of commercial fertilizer. Satellite imagery in conjunction with LiDAR is quickly becoming available that can detect plant vibrancy in real time. This data could be used to target fertilizer distribution specifically toward parts of a field where there is clearly a nutrient deficiency, for example where plant color or other indicators show that additional nutrients would increase yield. This approach might use commercial fertilizer only to supplement areas where nutrients are lacking, i.e. to fill in the gaps where applied manure or previously present nutrients are insufficient. Where manure has provided plenty of nutrients, satellite imagery and LiDAR are capable of recognizing this, such that fertilizer application could be suspended temporarily and resumed wherever the nutrients are lacking and can be absorbed by the plants.

We should note that precision agriculture is still somewhat expensive at this point in time, and smaller scale farmers are at a distinct disadvantage in terms of accessing this technology. Incentive programs might be a possibility to help gain acceptance for conservation practices that smaller scale operations would otherwise find impractical or prohibitively expensive.

In the future, as precision-farming technologies become more available and more prevalent, it seems likely that manure-spreading machinery could also include more precise application-rate adjustability and control. This would address one aspect of the vagueness in nutrient application rates associated with using manure. Manure nutrient-level testing would be appropriate in controlling application-rates to avoid nutrient overloading; but testing methods will require deliberate research and development work if they are to become routinely affordable.

Sociological Implications of this Study

Environmental sociology examines a wide range of issues where social structures and cultural forces lead to ecological degradation and environmental hazard. Rural environmental issues, where scarcity of human observation is often a key element, typically receive little attention. These complex issues can be described as “wicked problems”, wherein potential solutions are commonly mired by complexity, political controversy and unintended consequences. Sociologists tend to “pick their battles” in more visible arenas where larger populations are involved, and hence where public interest is more substantial. Between complexity and relative lack of visibility, rural and agricultural environmental issues are often under-examined and receive less attention than point-focused issues where concrete resolutions can be more readily identified.

Regarding analytical methods, studies regarding a range of sociological issues can likely benefit through using quantile regression (QR) analysis, as employed here in Chapter V, which can identify variations among relationships throughout the range of a response variable. QR is therefore likely capable of illuminating subtleties that traditional ordinary least squares (OLS) regression analysis would typically miss. A key benefit of QR is that few sociological relationships are truly linear, and this technique can assist researchers in recognizing distinctions as to which factor variables are more and less relevant at different ranges of a response variable.

The Heckman Probit two-part approach used in Chapter VI also has considerable potential for addressing sociological issues, especially in situations where a research question seeks to differentiate between two general levels of an outcome, and where a significant portion of the sample registers zero for the response variable. In the current case we have distinguished between what was considered sustainable and what was not, but any binary grouping situation might be appropriate for such an approach.

Future work on the MM issue will only be effective if it connects directly with farmers and brings them, along with their community networks, into all phases of the discussion. Success in addressing nutrient-overloading will also require addressing the agricultural-industrial systems within which it takes place.

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APPENDICES

APPENDIX A

“Source of organic matter” vs. “Improves soil properties”

For farms where some manure was applied, the regression below compares how the benefit of “manure improves soil properties” (soilprop) with how the benefit of “manure is a source of organic matter” (orgmatt) are related to the amount of manure applied .

Note that the *p*-value cannot be considered statistically significant, but clearly the coefficients represent a considerable difference in how the two variables are related to the rate of manure application.

regress tonmanr orgmatt soilprop if tonmanr > 0

```
      Source |       SS       df       MS              Number of obs =     362
-------------+------------------------------           F(  2,   359) =    1.27
       Model |   1073.4433     2  536.721652           Prob > F      =  0.2826
    Residual |  151928.439   359  423.198995           R-squared     =  0.0070
-------------+------------------------------           Adj R-squared =  0.0015
       Total |  153001.883   361   423.82793           Root MSE      =  20.572

------------------------------------------------------------------------------
     tonmanr |      Coef.   Std. Err.      t    P>|t|     [95% Conf. Interval]
-------------+----------------------------------------------------------------
     orgmatt |   -.918168   2.153548    -0.43   0.670    -5.153323    3.316987
    soilprop |    2.54737   2.080896     1.22   0.222    -1.544907    6.639647
       _cons |   13.68228   5.728233     2.39   0.017     2.417169    24.94739
------------------------------------------------------------------------------
```

APPENDIX B

Summary Statistics for Some Variables Modeled

Variable	Mean	SD	Median	Min	Max
Manure's Perceived Value (Per Ton)	4.38	9.53	2.00	-30.00	50.00
Perceptions					
-- **Benefits of Using Manure** ("Importance as a Benefit" on a Scale of 1-5) –					
Inexpensive fertilizer	3.88	1.27	4.00		
Source of organic matter	4.22	1.06	5.00		
Improves soil properties	4.32	1.01	5.00		
Increases yield	4.06	1.15	4.00		
Reduces wind erosion	3.45	1.40	4.00		
Dispose livestock waste	3.60	1.46	4.00		
-- **Problems of Using Manure** ("Importance as a Problem" on a Scale of 1–5) –					
Causes weeds	3.55	1.25	4.00		
Salt damage	2.75	1.22	3.00		
Soil compaction	3.25	1.36	3.00		
Unpredictable nutrients	2.94	1.20	3.00		
Uneven spreading	2.90	1.21	3.00		
Lower crop yield	2.07	1.32	2.00		
Inconvenient to apply	3.13	1.24	3.00		
More tillage required	2.81	1.34	3.00		
Relationship with neighbors	2.28	1.37	2.00		
Water pollution	2.49	1.37	2.00		
Regulatory concerns	2.78	1.50	3.00		
Knowledge -- Practices Used -	(Proportion Checked)				
Crop yield goal	0.70	0.46	1.00		
Past experience	0.77	0.42	1.00		
Plant Tissue analysis	0.09	0.29	0.00		
Irrigation water analysis	0.16	0.37	0.00		
Manure credit	0.21	0.41	0.00		
Legume credit	0.16	0.36	0.00		
Consultant	0.17	0.37	0.00		
Field scouting	0.83	0.37	1.00		
Irrigation management	0.61	0.49	1.00		
Conservation tillage	0.46	0.50	0.00		
Water-flow control practices	0.15	0.35	0.00		
Demographics -- Farm/Farmer Attributes					
Percent of acres rented (computed) (percent)	46.8	89.2	33.3	0	55
Years in farming (years)	27.9	13.1	26.0	1	60
Education level (1 – 5)*	2.5	1.4	3	0	5

*** 1= High School; 2= Technical/vocational degree; 3= Some College; 4= Bachelor's Degree; 5= Graduate or Professional Degree**

Source Situation **(Number of Responses Depending on Whether Manure Was Used, or Source if Used)**

Did Not Use Manure	136
Used Manure from Own Livestock	72
Purchased Manure from an Outside Source	58
Accepted Manure Free or For Credit	27

APPENDIX C

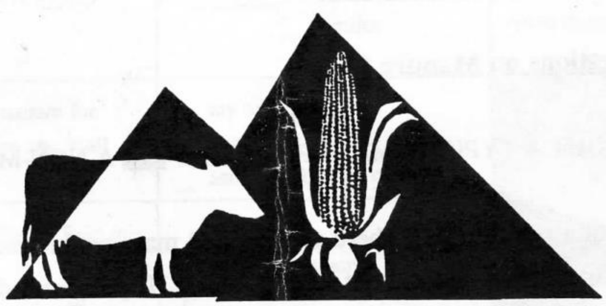
Questionnaire form:

Please let us know what you think about

Manure Management and Crop Production in Northeastern Colorado

by responding to this questionnaire.

- Thank you



Section A: General Farm/Ranch Information

1. About how many acres are in your total operation? __________ acres

2. Please list your major farming/ranching operations this year:

Farming

Crop (Include fallow, pasture, etc.)	Number of Acres

Livestock

Livestock Type	Average Number of Animals

3. What portion of the acres you operate are rented or leased from someone else? ______ % OR ______ acres

Section B: Questions on Manure Usage

QUESTIONS ABOUT A TYPICAL MANURED FIELD **and** A NON-MANURED FIELD

Please think about a typical field where you applied manure **this past season**, and also about a typical one where you did not apply manure. If you can't decide which of your fields is "typical," just pick the one that is furthest to the northeast to make the choice easy. You only need to answer the questions where they apply to you. For example, if you did not use manure anywhere, you don't need to answer the questions for a manured field.

QUESTION	ANSWER for typical MANURED FIELD	ANSWER for typical NON-MANURED FIELD
1. Do you irrigate this field? (Check one)	___Furrow ___Sprinkler ___No	___Furrow ___Sprinkler ___No
2. Size of the field	__________ acres	__________ acres
3. Do you own or rent this field? (Check one)	____ Rent ____Own	____Rent _____Own
4. Potential yield of this field in a good season for: **Corn:**	____ (bu, cwt, tons)/acre (Please circle units)	_____ (bu, cwt, tons)/acre (Please circle units)
Wheat:	____ (bu, cwt, tons)/acre	____ (bu, cwt, tons)/acre
5. Soil Type (Circle one)	Sand Loam Clay	Sand Loam Clay
6. Over past few seasons, weed problems in this field have been: (Circle a number)	Minor .... Severe 1 2 3 4 5	Minor .... Severe 1 2 3 4 5
7. Amount of N from commercial fertilizer applied last season	______lb. actual N/acre	______lb. actual N/acre
8. Crop grown on field this last season		
9. How far is it from this field to:	the source of manure you used _____ miles	closest source of manure (even though not used) _____ miles
10. Where did you get the manure for field this past season? (Please check all that apply.)	__ my own livestock __ purchased __ accepted for free or credit	
11. Amount of manure applied to field this past season.	________ tons/acre	
12. Who hauled and spread the manure for this field?	_Hauled it myself _Hired hauler/spreader _Feedlot delivered	

Price, Cost and Manure Use

We would now like for you to answer ONE of the following three blocks of questions depending on how and whether you apply manure. Please answer the questions only in the one block that applies to you.

If you **DID NOT APPLY MANURE** to any of your fields in the last three seasons, please answer the questions in **BLOCK I (Next Page).**

If you **DID APPLY MANURE** to some of your fields in the last three seasons, **AND** if you got most of that manure **FROM YOUR OWN LIVESTOCK,** please go to **BLOCK II (Page 5).**

If you **DID APPLY MANURE** to some of your fields in the last three seasons, **AND** if you got most of that manure **FROM SOMEONE ELSE** (feedlot, hauler, etc.), please go to **BLOCK III (Page 6).**

BLOCK I.

(Please answer only **if you did not apply manure.)**

1. On how many of your cropped acres are your soils and crops reasonably suitable to apply manure?

________ acres.

2. Assuming manure was available at the right price, how often do you think you would apply manure to your suitable fields? (Answer for the typical situation).

___ Every year ____ Every other year

___ Every third year ____ Never ____ Other ______________ (please specify)

3. Even though you don't currently use manure, we'd like to get an idea of what the right price would be for you. Regardless of what people in your area currently pay for manure, or are paid to accept it: What is the **most you would pay**, or the **least you would have to be paid**, to have manure delivered and spread on the appropriate part of your land?

– Please answer in one box only –

I would pay up to $ ____ per ton to have manure delivered and spread if I could get it.	**OR**	**Someone would have to pay me at least $________ per ton to accept manure spread on my land.**

Please go ahead to Section C on page 7. (Skip past Blocks II and III.)

BLOCK II

(Please answer only if you mostly use manure from your own livestock)

1. On any one field where you apply manure, do you typically apply it:

___ Every year ___ Every other year ___ Every third year Other ______________
(please specify)

2. On how many of your cropped acres did you apply manure last year?

__________ acres.

3. We'd like to get an idea of how much value you put on your livestock manure. What would it take for you to let someone else haul away your manure instead of you using it?

– Please answer in one box only –

I would sell manure to them for _________ $/ton.	**OR**	**I would pay up to _________ $/ton to have manure taken away.**

Please go ahead to Section C on page 7. (Skip past Block III.)

BLOCK III

(Please answer only **if you mostly use manure from a source other than your own livestock.)**

1. On any single field to which you apply manure, do you typically apply it:

___ Every year ___ Every other year ___ Every third year Other _______________
(please specify)

2. On how much of your cropped acreage did you apply manure this past season?

__________ acres.

3. I typically have been paid or credited $__________ / ton to receive the manure I apply,

OR

I typically pay $_________ /ton for manure, delivered and applied.

4. Regardless of what you have been paid or credited for taking manure, or what you've paid to get it: What is the **least you would have to be paid or credited** to take it, or the **most you would pay** to get it?

– Please answer in one box only –

The least I would accept to have manure delivered and spread would be $_________ /ton	**OR**	**The most I would pay to have manure delivered and spread would be $_________ /ton**

Please continue with Section C on the next page.

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Section C: Your Views on Using Manure

Whether you apply manure or not, we'd like to know what you think are some potential benefits and problems of using it. To the extent something is a real and significant benefit or problem to you (something that really happens), circle a number towards the left (1) end of the scale. On the other hand, if a benefit or problem doesn't matter to you (or doesn't really happen), circle a number towards the right (5) end of the scale.

POTENTIAL BENEFITS OF APPLYING MANURE	Real and significant to me				Does not matter to me (or doesn't really happen)
1. Inexpensive fertilizer	1	2	3	4	5
2. A way to reduce wind erosion	1	2	3	4	5
3. Source of organic matter	1	2	3	4	5
4. Improves soil properties	1	2	3	4	5
5. Increases yield	1	2	3	4	5
6. Way to dispose livestock waste	1	2	3	4	5
7. Other ________________ (Please specify)	1	2	3	4	5

POTENTIAL PROBLEMS OF APPLYING MANURE	Real and significant to me				Does not matter to me (or doesn't really happen)
1. Causes more weeds	1	2	3	4	5
2. Damage to plants from salts	1	2	3	4	5
3. Inconvenient to apply	1	2	3	4	5
4. Unpredictable nutrient content	1	2	3	4	5
5. Doesn't get spread evenly	1	2	3	4	5
6. Lower crop yields	1	2	3	4	5
7. Relationship with neighbors	1	2	3	4	5
8. Possible water pollution	1	2	3	4	5
9. Regulatory concerns	1	2	3	4	5
10. Soil compaction	1	2	3	4	5
11. Additional tillage required	1	2	3	4	5
12. Other ________________	1	2	3	4	5

Section D: Questions on Farming Practices:

1. Please check all practices that you use for determining nitrogen fertilizer or manure application rates.

___ Soil test analysis	___ Manure credit
___ Crop yield goal	___ Legume credit
___ Past experience	___ Consultant
___ Plant tissue analysis	___ None of these used
___ Irrigation water analysis	___ Other (specify) ______________

2. Please check any of the following practices that you use in your farming operations:

__ Field scouting (for insects, diseases, etc.)
__ Irrigation management (conservation practices, e.g., irrigation scheduling, surge valves, LEPA, line ditches)
__ Conservation tillage
__ Water-flow control practices (e.g., terraces, buffer strips, etc)

3. Do you use groundwater (well-water) for any of the following? Please check all that apply:

___ Crop irrigation
___ Livestock watering
___ Drinking-water well

4. Recently there has been discussion about high levels of groundwater nitrate in drinking water. Do you see this discussion as: (Please mark scale below.)

Nonsense?		Some truth but not important?		A real problem that needs addressing?
1	2	3	4	5

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5. Who (if anyone) do you believe should address such groundwater issues?
(Please check all that apply.)

___ Livestock producers ___ Local government ___ Federal government
___ Crop producers ___ State government ___ Other (specify: ↓)
___ No problem, nothing needs to be done ______________

Section E: Personal information

1. How many years have you been farming or ranching?
_____ years

2. Please check your highest level of education.
___ High School
___ Technical/Vocational Degree
___ Some college
___ Bachelor's degree
___ Graduate or Professional degree

3. Please check the category for your annual gross sales from farming and ranching.

___ less than $50,000 ___ $250,000 - $499,000
___ $50,000 - $99,000 ___ $500,000 - $1,000,000
___ $100,000 - $249,000 ___ over $1,000,000

4. Do you have another job off the farm/ranch?

___ No
___ Yes ----> Approximately how many hours per week do you work the other job(s)?
_____ hours per week.

THANK YOU very much for taking the time to answer this questionnaire. Please return the completed survey in the enclosed postage-paid envelope. Feel free to use the space below to give us any comments you may have. Remember, your answers are confidential and anonymous.

LIST OF ACRONYMS

AFO	Animal Feeding Operation
BMP	Best Management Practice
CAFO	Concentrated Animal Feeding Operation
CDPHE	Colorado Department of Public Health and Environment
CNMP	Comprehensive Nutrient Management Plan
CWA	Clean Water Act
EM	Ecological Modernizaton
EONR	Economically Optimal Nitrogen Fertilizer Rate
EPA	Environmental Protection Agency
MERN	Maximum Economic Rate of Nitrogen
MM	Manure Management
N	Nitrogen
NIFA	National Institute of Food and Agriculture
NMP	Nutrient Management Plan
NPS	Non-Point Source
NRCS	Natural Resources Conservation Services
NUE	Nitrogen Use Efficiency
OLS	Ordinary Least Squares
P	Phosphorus
PTO	Power Takeoff
QR	Quantile Regression
SARE	Sustainable Agriculture Research and Education
SMM	Sustainable Manure Management
SQR	Simultaneous Quantile Regression
USDA	United States Department of Agriculture
US EPA	United States Environmental Protection Agency
USGS	United States Geological Survey

WQCC	Water Quality Control Commission
WTA	Willingness to Accept
WTP	Willingness to Pay