ASSESSMENT OF THE ECONOMICS AND LAND QUALITY BENEFITS OF USING URBAN COMPOST IN RURAL GRAIN PRODUCTION: AN OKLAHOMA, WINTER WHEAT CASE STUDY OF THE BIFFLE FARM

By

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Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

2001

Submitted to the Faculty of the
Graduate College of Oklahoma
State University as partial
requirement for the
Degree of
MASTERS OF SCIENCE
December 2005

ASSESSMENT OF THE ECONOMICS AND LAND

QUALITY BENEFITS OF USING URBAN

COMPOST IN RURAL GRAIN PRODUCTION:

AN OKLAHOMA, WINTER

WHEAT CASE STUDY

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ACKNOWLEDGEMENTS

I wish to express my sincere appreciation to my major advisor, Dr. Mike Myers, for his unwavering support through the masters program at OSU. His academic supervision, constructive guidance, drive, and friendship that offered me the opportunity to achieve success through my masters experience. I would like to extend my greatest appreciation to my other committee members, Dr. Jon Comer and Dr. Allen Finchum, for their individual friendships, academic counseling, and life management skills throughout the years. Without their support, this thesis would not be complete. Again, I would like to thank Dr. Myers for the research opportunity that has enhanced my academic performance as well as my personal achievement. I would like to extend special thanks to Kathy Williams.

I would like to thank all the people who helped with special information, editing, and numerous reads of the thesis: Stacey Frazier, Dr. Carlos Cordova, JoAnn Biffle, and Turner Biffle. Their contributions to this thesis and my life have been immeasurable.

I would like to extend a special thanks to my parents, Turner and JoAnn Biffle, for all of their love, academic support, and guidance. Their patience and understanding during my academic career has given me the opportunity to pursue my life dreams.

Finally, to the Department of Geography, my home away from home, I will forever be indebted to my friends made over the years. We enjoyed good times and participated in an unmatched quality of learning. This experience opened my eyes to

many possibilities allowed for my success today. Thank you also for all that you do to promote Geography as a discipline and a way of life.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

CHAPTER ONE

INTRODUCTION

Rationale of the Study

Global food supply is a concern today and a challenge for future planners. In order to meet the food supply challenge, researchers continue searching for ways to maximize output of agricultural land without undermining environmental quality or natural resources. The United Nations predicts the world population could reach nine to twelve billion people by the year 2050 (UN, 2000). Therefore, food production must double or even triple over the coming three to four decades to meet the demand of the growing world population. Food production must increase substantially to provide for future generations (Bindraban *et al*., 2000). Unless agricultural lands are allowed to expand into otherwise protected, environmentally sensitive areas, production must be increased on existing fields. Analyses show crop yields, even in developed countries, well below the theoretical maximums, mostly due to soil and water deficits, crop disease, and poor management practices (Bouma, 2002).

The geographer, by realizing the differences in regional population distributions and food production, can contribute to this analysis. The geographer can explore environmental, technical, economical, political, and cultural constraints, including cultural preferences for crop types, and construct strategies that increase overall effectiveness of agricultural development plans in relation to population distribution. At the same time, the geographer possesses the wherewithal to increase environmental awareness among policy advocates by focusing on balancing cultural conservation, survival, and protection of natural ecosystems with agricultural development.

With such an interdisciplinary/geographical approach in mind, the question still remains: How to feed a growing world population given the spatial constraints of environmental protection and cultural survival on the expansion of agricultural land?

Theoretical Framework

Purpose of the Study

The purpose of this case study is to evaluate the economic feasibility of using urban compost on rural farms. A composting program could augment and reduce the need for existing inputs or become a complete alternative given increased soil quality. Adding compost to soil increases cation exchange capacity, water holding capacity, aeration, organic nutrient content, and beneficial organism vectors that help with disease control (Bouma, 2002). This program would simultaneously divert urban organic waste from landfills, benefiting urban areas.

This case study includes ecological analyses of experiments using different depths of organic amendments as well as an economic analysis of the total cost of each depth compared to variations in yield, and the net profit that increase derives. Net profit provides a maximum acceptable price per cubic yard of amendment a farmer is able to pay before the application leads to a loss of farmer income. If farmers absorbed the cost of delivery, transportation costs are also considered to help understand an economically feasible distance from a compost source.

Significance of the Study

The global trend toward acquiring and farming new land to support growing populations could eventually deplete usable land area and undermine efforts to protect wildlife habitats (Bouma, 2002). Despite the possible negative impacts on the environment and public health, farmers continue the legacy of the Green Revolution by using synthetic fertilizers and pesticides to intensify production on existing fields. By focusing on alternative intensification strategies researchers could make it possible to decrease the need for fertilizers and pesticides, while limiting the need to expand into environmentally sensitive areas.

If found to be economical, urban areas that produce vast amounts of waste yet have limited landfill space for disposal, could use composting as an alternative disposal method. The compost produced through the above mentioned process could help solve agricultural production problems. Therefore, the significance of this case study is its assessment of the yield benefits versus the cost to farmers of applying urban compost to farmlands. The goal is to ascertain whether compost amendments are economical, and if so, at what distance from an urban area does the break-even point occur. Referring to the global problems mentioned above, perhaps this urban waste-to-farm production strategy could be a solution.

Agricultural benefits attributable to composting

The farming industry has come under scrutiny for its history of degrading the environment. The Green Revolution methods are a prime example. These methods include synthetic fertilizers, pesticides, and herbicides to increase yields. Unfortunately, these have proven to degrade soil and water quality, and reduce the nutritional value of foods (Pimentel and Tort, 1998). Large amounts of fertilizers are used to increase yield; however, rain leaches the non-absorbed fertilizer away. Consequently, excess fertilizer collects in streams, lakes, and ground water supplies.

Havlin *et al*. (1999) emphasize nutrients and pesticides as the primary source of contaminants for groundwater. Many contaminants cause health problems for humans exposed to too high a concentration. Pesticides and fertilizers can cause cancer, headaches, abnormal sensitivity to allergens, and weakened immune systems (Pimentel and Tort, 1998). Other complications include mild allergies, rashes, severe mental disorders, and even death. Approximately two percent of drinking water wells exceed the maximum standard limit of nitrogen set at ten ppm. Areas near farmlands tend to have increased percentages of nitrates in the water supply, some instances can be up to 20 percent higher than places not near agricultural lands. Exposure to levels of nitrogen above 10ppm has been shown to cause mortality in the biological life of smaller organisms (Havlin *et al.,* 1999). An estimated 40 percent of world deaths can be attributed to various environmental factors including chemical pollutants.

Furthermore, pesticides precisely target specific organisms; however, during this targeting process beneficial organisms could be destroyed. Scientists at the United Nations (UN, 2002) noted that while the use of insecticide burgeoned tenfold from 1945 to 1989, annual insect-related crop losses rose from 7 percent to 13 percent of the potential harvest. This heavy use of pesticides eliminates pests' natural enemies, while the heavy use of fungicides reduces fungal species. When insects' natural parasites are eliminated, the "bad" organisms can overcome the beneficial (Cowen, 1995). This cycle causes further degradation of the soil ecosystem and leads to epidemic development of crop pathogens as antagonists deplete from the soil.

Loss of topsoil and organic matter are other factors that degrade land resiliency. Continuous cultivation of land allows erosion agents such as wind and water to remove the fertile top layers of the soil. Crop rotations lessen this effect by using newer no-till methods. However, modern no-till methods rely heavily on herbicides to fight weed invasion (Brady and Weil, 1996). Additionally, scientists estimate that approximately 40 percent of agricultural lands currently depreciate by human-induced degradation via current agricultural practices (Dumanski and Pieri, 2000).

Human-induced degradation will continue as the world population increases. The population increase will heighten the demand for dietary standards, which threatens the quality of the soil, water, and air resources. To maintain sustainability, farmers must increase yields per unit of land, or expand production into potentially sensitive lands, such as steep slopes, floodplains, or critical habitat zones. Farmers use pesticides and fertilizers to increase their yields quickly, giving consistent returns. As a result, runoff from these fields can be toxic to surrounding organisms. Yet, synthetic fertilizers merely offer the soil an initial boost, with the bulk of the nutrients being used quickly by the plants.

Returning to the pre-industrial standard of farming could be considered the alternative organic amendment route to yield increases. However, organic amendments can take time to rebuild the soil, because these focus on the total health of the soil and the microorganisms living there. For decades, gardening applications have increased the use of such methods. This method requires the use of manures and/or composts to replenish the vital organic matter needed to improve soil productivity. Although most industrial farmers are unwilling to make the change, studies show that organic amendments serve to increase yields while improving ecological and human health (Brady and Weil, 1996).

Many scientific soil studies consider the hundreds of processes involved in crop production. Numerous studies have been conducted to show soil's stability with increased production (Jaenicke and Lengnick, 1998). Now, when the world's population is continually increasing at faster rates then ever before, these studies become more important. The world population could reach twelve billion in coming years, thus causing an increased demand for food (Brown and Flavin, 1999).

Increasing farmland area is one solution. However, the environmental impact could be serious. To avoid the before mentioned, researchers try to develop new way to increase crop yields while using the same quantity of land. However, factors such as the length of the growing season and crop management limit yields (Bell and Fischer, 1994). Considering the macro environment, humans have no control over growing season length. Fortunately, agriculturalists can improve crop management using research study information (Havlin *et al.,* 1999). Using more scientific and comparative information, farm and ranch managers will have more choices and be able to make better-informed decisions (Barbara *et al*., 1997).

Soil scientists, geographers, agriculturalists, economists, and rural planners contemplate solutions for a balanced increase in world food production. Numerous soil process studies and their contribution to plant growth have been published. All soil parameters such as nitrogen, pH, potassium, etc. play an integral role in the crop yield (Brady and Weil, 1996). Most soil scientists have decided that the soil complexity allows no model to be derived giving an explanation for all of the variables involved in the processes (Bouma *et al.*, 1998).

Hypotheses

The results of this case study will be useful in the evaluation of the economic feasibility of using the urban compost on rural farm crops. In order to address this goal, the following hypotheses for this case study are explored:

Hypothesis 1: Compost amendments will increase yield in both biomass and grain.

Test of Hypothesis 1: The quantitative method for testing biomass is the Normalized Difference Vegetation Index (NDVI). Photographs will add to the qualitative comparison between treated and untreated areas. The yield is captured by hand harvesting along with computer generated results based on yield comparisons from a combine.

Hypothesis 2: Compost amendments will produce an increase in land quality as defined by the Land Quality Indicators (LQIs) including an increase in water holding capacity, nutrient status, and organic matter content. Decreased bulk density will explain the increases in biomass and grain yields predicted in Hypothesis 1.

Test of Hypothesis 2: Pre- and post-amendment testing assess Land Quality Indicators and capture the change in organic material and nutrient content of the soil.

Assumptions and discussion of Hypotheses 1 and 2: Hypotheses 1 and 2 are related. Increases in LQIs caused by compost amendments should equate to higher yields as predicted by the LQIs.

Hypothesis 3: Yields will increase beyond the control (non-amended) plots at all depths of application (1, 3, and 6 inches) and above the control average with a linear relationship between depth of amendment and yield. Deeper amendments will equal higher yields.

Test of Hypothesis 3: Yield data in biomass and grain will be disaggregated by plot type, graphed, and compared with the average of the control plot yields.

Assumptions and discussion of Hypothesis 3: This test will demonstrate whether the hypothesis is correct or needs to be adjusted. The hypothesis' correctness is not as important as the results of the test. The results should indicate what depth of amendment is actually required to make a yield gain higher than controls and the linear or curvilinear relationship between increased amendment depths and yield gains. This information should help calculate optimum application.

Hypothesis 4: Considering the one time cost of the compost application above the cost of the standard on-farm operations, while factoring out the cost of transportation of amendment to the farm, the compost application will prove economical (profitable) given the value of yield gain. This hypothesis also assumes no purchase cost for the amendment.

Test of Hypothesis 4: Calculate value of yield gain in biomass (cattle weight gain value) and grain harvest (value by bushel price), less the calculated total cost of on-farm operations involving the amendment.

Assumptions and discussion of Hypothesis 4: The yield gain value is calculated by extrapolating the test plot gains throughout the entire field (and on a per-acre basis). It is then compared with the added cost. On-farm operation costs are evaluated using Farm Service Agency assessments which include loading, spreading, plowing in, and planting. It is assumed that the on-farm analysis will show profit calculated on a per-acre basis. This hypothesis also assumes no purchase cost for the amendment.

Hypothesis 5: There will be no consideration of transportation cost for the amendment. The net benefit addressed in Hypothesis 4 will result in the maximum price a farmer would be willing to pay per cubic yard of amendment and that amount will be above zero without the transportation cost consideration.

Test of Hypothesis 5: A simple net benefit calculation will demonstrate whether or not the farmer would be willing to pay more than zero per cubic yard of amendment.

Assumptions and discussion of Hypothesis 5: It is assumed that a farmer would be willing to pay up to the amount calculated for net benefit. This is also considered conservative as it takes into account benefits after the first year, or increases in the amount of manure generated from increased stock rates if, in fact, such benefits are demonstrated by this study. There will be no consideration of transportation cost for the amendment.

Hypothesis 6: Adding the transportation variable will decrease the amount farmers would be willing to pay per cubic yard of amendment. The transport distance at which the economic threshold is reached (whereby willingness to pay becomes zero) will include rural farms.

Test of Hypothesis 6: A transportation cost evaluation based on hypothetical collection centers and distribution will be performed. Transportation costs include the shipping of the material only. Shipping costs will be compared to the farmers' willingness to pay (per truckload) to assess the distance at which transport costs become too high.

Assumptions and discussion of Hypothesis 6: Adding the transport variable cost will decrease the amount farmers should be willing to pay per cubic yard of amendment (calculated for Hypothesis 5), and that decrease will be proportional to transport distance. Furthermore, it follows that there will be a transport distance where willingness to pay becomes zero.

Definition of Terms

The following definitions are given for the reader's benefit:

Compost – Remains from an organic decaying process used for applications relating to plant production, which is often substituted for synthetic fertilizer.

Global Positioning System (GPS) – System of satellites and hand held receivers used to capture locations and attribute data for use with GIS.

In Season Estimated Yield (INSEY) – Equation devised by the Department of Plant and Soil Sciences allowing farmers to estimate crop yield before harvesting.

Land Quality Indicators (LQIs) – A holistic method used to determine complete land quality.

Normalized Difference Vegetation Index (NDVI) – A ratio of near infrared light to red light indicating the health of a plant and measured on a scale of 0 to 1 with 1 being perfectly healthy.

Photosynthetically Active Radiation (PAR) – Measure of incoming light usable for photosynthesis.

Soil – Decomposed rock and organic material formed over many years of weathering. It contains the nutrients needed for plant growth.

Soil amendment – Any substance (in this case study worm castings, derived from urban waste) used to enrich the health of soil for agriculture.

Sustainable Land Management (SLM) – A policy process that considers the entire land's health. It focuses less on individual soil characteristics and more on overall production.

Synthetic fertilizer – Human created form of nutrients processed and refined to enhance crop yield.

The Green Revolution – The mechanization and introduction of synthetic input technology in farming practices beginning in 1960.

Vermiculture – The practice of farming earthworms for the purpose of sale or compost production.

Worm castings – The feces earthworms produce when feeding on organic waste material. The material is nutrient rich and has a consistency similar to rich topsoil. It is often used as fertilizer on gardens, and home lawns.

Limitations of this Study

This study is limited to one south central Oklahoma farm with the assumption that the ecological results are applicable elsewhere. This is neither a longitudinal nor latitudinal study. The study timeframe is 11 months beginning August 23, 2003 and ending July 20, 2004. The researcher did not control weather variables, soil temperatures, pest infestation, or animal restraint, other than cattle. Germination tests were not performed on wheat seeds. The researcher did not assess the urban composting cost. There is no long-term soil quality assessment as a result of using compost. In future studies, the test plots should be larger in size along with an increased amount of plots. Adjustments such as this will help further support the case study findings. Each of these factors must be considered when viewing the results of this case study.

Summary

Based on the United Nations (2000) research, world population will reach nine to twelve billion people by 2050. Planners research methods to increase food supplies without increasing agricultural land area. Synthetic fertilizers and pesticides are effective and economical. However, they cause environmental problems and pose health risks. This case study evaluates an alternative method to increasing yields without using additional agricultural land, in the form of amendments derived from urban compost. Diverting organic waste to farms would benefit urban areas, because landfill space is limited.As today's farmers face tightening budgets with increasing fuel, labor, materials, and transportation costs, it becomes progressively more important to find economical alternatives. Given this suite of considerations, this case study evaluates the economics and land quality benefits of using urban compost on rural farms. The next chapter reviews the pertinent literature defining the problems and solutions associated with vermiculture.

CHAPTER TWO

LITERATURE REVIEW

Soil sustainability has been a research topic for many years. In the early 1990s, a summary of the international dialogue over this topic began to take form with the signing of a World Soil Charter developed by the Food and Agriculture Organization (FAO) of the United Nations and the signing of the Agenda 21 developed by United Nations Conference on Environment and Development (UNCED) (Pieri *et al.,* 1995). These agreements were designed to help the developing world manage its land resources more sustainably. They also provided technological initiatives to enhance already cultivated land and achieve greater yields. Soil quality was highlighted as a major component of sustainability.

Throughout history, farmers have experimented with numerous fertilizing techniques, as well as alternatives for improving soil quality other than the "Green Revolution" utilization of synthetic fertilizers. Composting is one strategy that has proven to be beneficial. Compost mixtures contain a combination of materials from household, outdoor, and animal waste. After these wastes are converted into compost, they make a rich amendment usable for improving the overall soil quality. However, the time involved in preparing compost poses major concerns. The process can take months before the compost is usable for soil amendment applications. The length of time to prepare compost compared to the short growth season of many crops, causes concern to farmers considering the use of compost. Therefore, vermiculture could prove beneficial in increasing the processing time of compost.

Vermiculture

Vermiculture is the practice of effectively managing earthworms for the increased production of castings. Vermicasting is a type of organic amendment produced by earthworms. The amendment applied in this case study utilizes a vermicasting type created by earthworms that digest compost material and produce nutrient rich feces, effectively referred to as castings. Production of this amendment takes little time when compared to other composting processes. The use of this urban waste compost emerges as beneficial, because of the shorter process time; Furthermore, production potential already exists for use in agricultural settings, especially in Oklahoma because of the short growing season. However, lack of strict scientific research on nutrient properties as well as the overall earthworm casting makeup poses a major concern (Subler, 1998).

Subler (1998) states that plant greenness demonstrates the improvements a single earthworm casting application can give to soil. However, within the scientific community, much debate still exists over the nutrient balance and earthworm casting composition. While these debates exist, the vermiculture industry makes large strides to decrease the waste flow into landfills and to create earthworm castings for consumer use. Vermiculture companies today may be building the infrastructure for the future of organic amendments used in agricultural production. Large scale vermiculture farms currently use worms to turn waste products into valuable castings ready for application.

Again, worms produce a ready product much faster than conventional composting. The traditional compost methods take several weeks to yield a low grade soil amendment. However, worms need only 48 hours to convert their weight of garbage into nutrient rich castings (Koerner, 1997). This case study selected vermiculture castings, because they appear to be a viable urban compost product and provide faster growth reaction than traditional compost methods.

This case study investigates the benefit of amendments in terms of increased yield. In general, if yields are increased and/or if reductions in synthetic fertilizers can be obtained, both farmers and the environment benefit. Urban compost might be used to increase soil health and crop production. This would aid material reduction in landfills and create a healthier environment. Economics cannot be ignored in farming today; grain prices are currently lower than the past few years, and farmers need avenues to minimize inputs and maximize output.

Land Quality Indicators

Land Quality Indicators (LQIs) provide an overall indication of soil health. Most LQI research focuses on the Netherlands and regions of cereal production. However, variables such as weather and soil type vary greatly from the Netherlands to Oklahoma. Lack of thorough LQI testing can explain the World Bank researchers' difficulty with successfully deriving LQIs. In response, some researchers are now evaluating individual case scenarios in which the LQIs are applied to actual yield tests and results are then compared (Steiner *et al.,* 2000).

Studies concerning the viability of LQIs in the Central Plains of the United States have used soil maps from the United States Geological Survey (USGS) to plot the soils. These studies focused heavily on the ability to accurately model soil variables for deriving the soil's LQIs (Brejda *et al.,* 2000). Brejda *et al.* (2000) also used the National Resource Inventory (NRI) to assess soils in the Great Plains. Based on the soil variability, it was impossible to rely solely on LQIs developed by the World Bank to properly model the complexity of the study area. The World Bank has a long range goal of using LQIs to display and monitor the path to improving land quality and developing a more resilient soil makeup.

Even though LQIs today are too general to meet World Bank requirements to be implemented on a micro scale, perhaps they can be calibrated to local conditions. Moreover, recording soil conditions in terms of the established LQIs allows the results of this case study, and of other studies, to be used more readily, particularly for comparisons within the current regional and global model.

As an aid to simplify, generalize, and standardize methodology, this project uses the LQIs developed by the World Bank (1998). Land Quality Indicators were developed to allow better land management and environmental impact studies for modeling purposes at the global and regional scales, but they do require verification or calibration at the local scale. The LQIs include photosynthetically active radiation (PAR), nutrient balance, and other soil characteristics, such as depth and water-holding capacity related to structure and texture (Dumanski and Pieri, 2000). Table 1 depicts the LQIs accepted by the World Bank. These are measured by direct observation, soil sampling, weather stations, and remotely sensed data collection techniques.

Land Quality Indicators	Use of Indicator
Nutrient Balance	Yield Trends and Variability
Land Use Intensity	Use Diversity and Land Cover
Soil Quality	Land Degradation or Improvement
Agro-Biodiversity	Soil microbial activity
PAR	Maximum biomass potential

Table 1. LQIs adopted by the World Bank. Adapted from Dumanski and Pieri (2000)

Need for Land Quality Indicators

The resource sustainability procedure continues to become a growing movement (Doran and Parkin, 1996). The emphasis varies from agricultural sustainability to natural resource sustainability, including the preservation of wildlife habitat. The exploding world population, especially that of developing countries, poses one reason for concern. Available land for cropping expansion exists; however, land required for sufficient food production in some developing countries remains scarce (Pieri *et al.,* 1995).

In the developing world, approximately 1,702,400,000 acres are classified as cropland. This could theoretically be increased to 1,904,000,000 acres if certain restrictions were relaxed on land use policies (World Bank, 1998). Cropland needed to feed the human population in 2050 will be roughly 1,400,000,000 billion acres, and is also likely to become limited (Raun, 2003). However, even the ability to increase cultivated land to the 1.4 billion acres would require advanced technology and great monetary expenditures to bring marginal lands into production (Raun, 2003). Another factor limiting agricultural lands is urbanization (Smith, 1992). The conversion of farmlands to office buildings and shopping malls eliminates the agricultural use of the land. The biggest disadvantage this conversion causes is that the transformed land cannot be reused as agricultural land without great expense and political difficulties.

Another limiting factor in the transformation of marginal lands into productive lands is erosion. Erosion is one of the most powerful land degradation factors in farming. It affects the overall land health and therefore the crop through the loss of vital nutrients. In the United States alone, approximately 6 billion tons of topsoil are lost each year (Smith, 1992). Researchers estimate erosion will cause a total loss of 11 to 28 million topsoil acres in the United States within the next 50 years (Smith, 1992). This poses a great problem for the agricultural community, because topsoil contains most of the beneficial nutrients and organisms needed for effective farming practices.

Along with erosion, continuous cropping causes severe soil nutrient problems (Smith, 1992). The impact caused by planting crops every year on the same land leads to various forms of land degradation, such as water source depletion, irrigated land salinization, soil fertility declines, and degradation in the land's biological condition (Pieri *et al.,* 1995). The rehabilitation cost for degraded areas has been estimated 10-50 times higher than the measures taken to prevent degradation (World Bank, 1998). Through early intervention, the soil fertility maintenance costs much less than waiting until extreme degradation symptoms appear. Because of this, researchers and organizations, such as the United Nations' Food and Agriculture Organization, the World Bank, and the European Union are attempting to develop indicators that provide overall land quality measurements and early indicators of adverse trends and problem area identification (Pieri *et al.,* 1995). Land Quality Indicators can also assess the effectiveness of attempts to increase soil health and overall productivity.

Levels of Application for Land Quality Indicators

Land Quality Indicators (LQIs) can serve as a useful soil assessment tool. However, soil provides only one set of factors affecting the overall crop health. LQIs also include specific land type used as well as the regional climate. LQI applications vary based on the scale at which tests or implementations are conducted. They are not only descriptive variables, but they are also used to monitor change. LQIs include four main levels; (1) farm level, (2) management of development projects level, (3) the national level, and (4) the international level. At the farm level, the indicators provide important supplements to local knowledge and can be used as guides for cropping decisions concerning land management (Pieri *et al.,* 1995).

Ranchers, for example, identify their land's needs and can supply the proper amounts of forage for their livestock. They opt to use LQI land management techniques to minimize severe land degradation, thus reducing livestock suffering and economic hardship. Within the farm level, smaller plot analyses can aid the farm manager by integrating LQIs into the overall farm-level management.

The LQI second level involves the management of a development project. At this level, the LQIs allow researchers, developers, and policy makers to assess the soil and land enabling prediction of damages or benefits. The LQIs permit the natural resource management more accurately. Not only is the soil's fertility considered, but this LQI level also takes the land's overall health into account. The third level reaches a national spectrum where the indicators monitor the effects federal policy changes have upon land resources (Pieri *et al.,* 1995). National Environmental Action Plans (NEAPs) use LQIs when policies evaluate effects on natural resources in economic terms (Schramm and Warford, 1989). LQIs could provide the essential quantitative basis for all economic analysis of natural resources and of land resources (Lutz, 1993). This method assesses the affect the policy has on the nation's natural resource base.

The final LQI level, and perhaps the broadest of the four, takes into account international concerns. At such an extensive level, the indicators could be used to make comparisons between a country's environmental and agricultural potential and changes in the increasingly global economy. These could then be applied to the policy and development efforts. The need for indicators such as this exists to provide a sound environmental policy analysis similar to the current economic and social trends (World Bank, 1998).

LQIs are becoming more and more useful as the World Bank requires they be used in any bank funded environmental projects having environmental and economic impacts (World Bank, 1998). A common LQI set can prove useful to scientists, researchers, and organizations enabling communication with a universal terminology.

The Pressure-State-Response (PSR) framework is another portion to explore. Its development allows LQIs to measure the pressures upon land resources, the effects on the state of the land quality, and society's response to these changes (Adriaanse, 1993). One common example of this framework considers the groundwater demands beyond the recharge rate. This applies in almost any natural resource system, where the demand could potentially overcome the supply.

LQIs are categorized according to the pressure-state-response framework and grouped into three indicators types (Adriaanse*,* 1993):

1. **Pressure indicators:** Indicators of pressure upon the land resource, resulting from human activities.
2. **State indicators:** Indicators about the condition (state) of the land resource, including the temporal aspects related to land management.
3. **Response indicators**: Indicators of the response by society to the pressures on land quality and changes in its state.

Figure 1 further depicts the pressure-state-response framework.

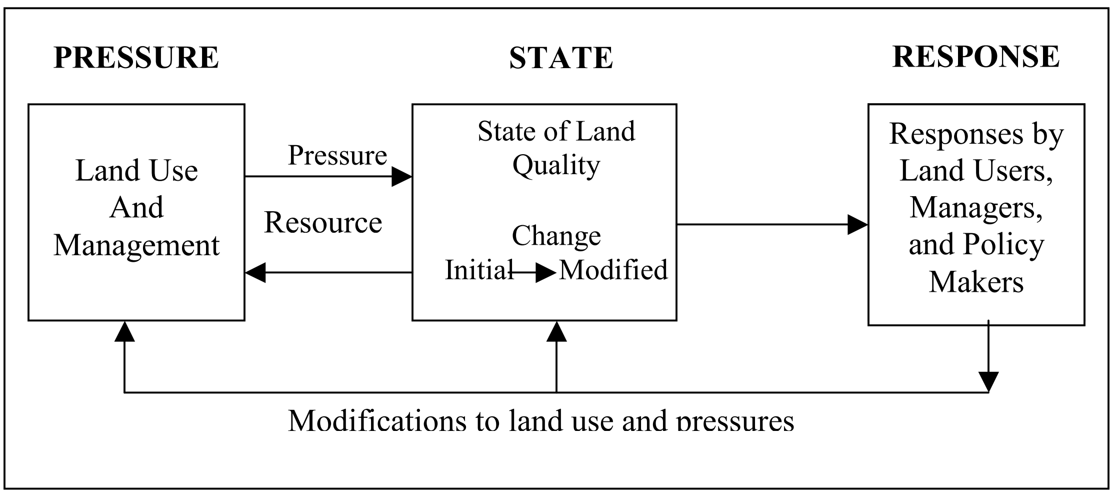

Figure 1. The pressure-state-response framework. Modified from Adriaanse (1993)

Steep slope farming accompanied by marked erosion increases, causes public concern and government policies mandating better slope farming practices best illustrate pressure indicators. The link to the pressure-state-response framework can be seen in other activities such as forestry, perhaps in terms of reduced forest area which may command conflict resolution between farmers and loggers. The society's demand placed on natural resources will always cause a response in the natural resource base, which in turn will effect the society's response (World Bank, 1998).

As for the state indicators (land state), there will always be effects over time induced by resource harvesting. A prime state indicators example considers the decrease in global forested land over the past 60 years (Dumanski and Pieri, 2000). Society's insistence causes a demand on wood-based products as well as clearance for agricultural purposes. This trend continues to provide society with material goods causing an increased demand for forest lands, despite the warnings by sustainability groups stating the possibility of complete deforestation around the world. The long term effect of the demand for wood products emerges as an example of a change in the LQI state indicators and their influence on response indicators.

The least desirable response indicators (those best avoided) include irreversible land degradation such as abandonment of land or economically enforced migration (Pieri *et al.,* 1995). Even the most deliberate policy adjustments are often seen as important evaluations. The government may use a typical shortsighted approach in semi-arid and heavily grazed areas. These will increase grazing, trampling of the soil, and the amount of water competition between agriculture and other uses. They may also ultimately reduce the available water supply exacerbating the original problem (World Bank, 1998). LQIs offer policy makers, researchers, and funding organizers an improved plan for managing land resources.

Current Research

Today, many more scientist, farmers, and agriculturists test and manage soil to gain the greatest crop yields and to conserve the soil's fertility and health (Doran and Parkin, 1996). The World Bank supplies scientists with grants for studies of LQIs in a greater depth (Bouma and Droogers, 1998). As stated above, these LQIs take into account the state of the land, including weather, water holding capacity, soil nutrients, organic matter content, crops grown, and yield (Bindraban *et al.*, 2000). Pressure-state-response indicators help assess broader management concerns. The world's scientists work toward setting common standard LQIs that can be accurately used in crop yield analysis and land use change.

The method used to derive LQIs causes a key concern for local LQI use. Can LQIs derived in the Netherlands be accurately applied to Oklahoma wheat fields? Scientists worldwide are trying to answer this question. The World Bank (1998) has designed a model that can be used to determine the optimal yield that farmers could produce regardless of the location.

There are certain variables modeled into the World Bank's LQIs, such as organic material, soil water holding capacity, and nutrient levels, which must have an equation to simulate yields and verify the model against observed production. This information makes it possible to test whether Oklahoma could reach the theoretical maximum yield the World Bank sets forth, about 70 to 80 percent of the maximum biomass, for local photosynthetically active radiation (PAR) under perfect conditions of soil, water, and freedom from disease (Doran and Parkin, 1996). It seems unlikely Oklahoma wheat farmers can reach this maximum yield without great input costs. However, LQIs can help explain these sub-potential yields.

Sustainability is important in LQI research. Many LQI studies evaluate avenues to increase yields as well as their sustainability (Bouma, 2002). With this approach, farmers will have a more accurate method for monitoring management effects on the production environment. Sustainability conserves natural resources valuable to humans and aids the ecosystem's stability and resilience.

The term sustainable land management (SLM) uses a set of concepts that shapes the LQI research agenda (Steiner *et al.,* 2000). Sustainable land management is a total process of evaluating the "soil" and the "land" as a whole. A difference can be seen between the "soil" and "land" concepts. "Land," a more general term, depicts the "whole" landscape and environmental picture including its management. "Soil" is the underlying base of crop production operations and land use policies (Steiner *et al.,* 2000). LQIs serve to monitor the land's condition relative to the land use requirements, including agricultural and forestry production, resource conservation, and overall environmental management (Dumanski and Pieri, 2000).

LQI and SLM research continues, and many studies have been published since 1995. Scientists investigate LQI use to determine soil health and help close the yield gap limiting cereal crop yields. Universities, government, and private companies conduct research projects concentrating on LQIs. The World Bank offers large funding opportunities to researchers.

Dumanski and Pieri (2000) conducted research in the Netherlands using the Food and Agriculture Organization of the United Nations Soil Map of the World Data CD (FAO CD). The FAO CD resolution ranges five arc minutes by five arc minutes, approximately one twelfth of a decimal degree (Food and Agriculture Organization, 1996). Using this scale, the logical move is to a finer scale where the variables can be more precisely monitored and controlled, and the model can more closely represent real-world variables once calibrated for the specific local conditions.

The World Bank funded research primarily focuses on agricultural production along with ground water leaching as a side effect of fertilization practices. Nitrite leaching, a significant environmental threat, causes this focus (Food and Agriculture Organization, 1996). This also helps shape the way LQIs are devised.

Studies involving LQIs often operate on a very broad scale and are unable to provide the type of precision needed for case studies such as conducted for this thesis. Researchers use LQIs as a predictive measure to avoid land degradation and the increasing cost for land remediation. Researchers also look at specific indicator sets to determine which variables should be introduced into the assessment protocol.

Current research remains unavailable for the investigation of urban compost use to increase LQIs. However, significant research focuses on the yield gap representing the difference between observed yields and the yields produced under perfect agronomic conditions for a given crop under local conditions of solar radiation (Bindraban *et al.,* 2000). To calculate the yield gap, researchers compare the actual cereal crop yields to the maximum possible under perfect conditions given local PAR over the growing season. The gap is then related to deficits, for example, as nutrients decrease the yield will generally decrease (Johnson *et al.,* 2000). As these nutrients increase, the crop yield will increase, although not proportionally due to the possibility of other deficient factors (Johnson *et al.,* 2000).

Another limiting factor causing crop yield to decrease is low soil water. When soil moisture decreases, the yield decreases, and when the soil moisture increases, the yield generally increases as long as sufficient drainage capacity is evident allowing prevention of prolonged saturation (Johnson *et al.,* 2000). Figure 2, assists the visualization of each component effecting yield and aspects preventing yields from reaching their maximum. Although Figure 2 excludes disease, it illustrates that actual yield would increase to its potential considering all variables are optimal.

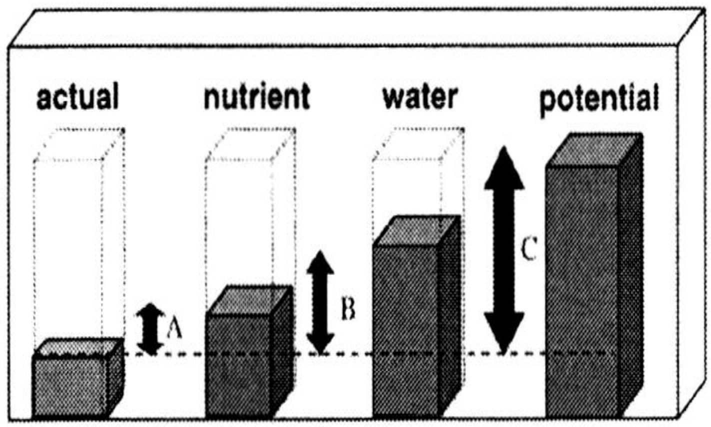

Figure 2. Yield gap due to nutrients (A), water (B), compared to potential (C). Adapted from Bindraban *et al.* (2000)

Researchers currently rally for LQI use by asking policymakers to adjust administrative policies. These policies would be based on the monitoring of long term effects and real world LQIs testing applications (Brown and Flavin, 1999). Bindraban *et al.* (2000) found three main levels exist in their land quality research depicted in Table 2. The results help explain the differing scales that LQIs can be implemented with respect to specific uses. Each level has a potentially different use for the LQIs, although there could be duplicate uses for each level.

Scale	Objectives	Detail	Example
Continent Country/district	Create awareness Identification of problem areas to focus research and target specific action	Broad qualitative classes Qualitative classes	Stoorvogel and Smalling, 1990 Smalling *et al.*, 1993
Community Level	Discussion around sustainability of agricultural production systems	Nutrient losses in kg/ha, year or net nutrient gains from amendments	Van der Pol, 1993
Farm Level	Development of alternative, more sustainable production systems	Nutrient losses in kg/ha, year (considering only management related flows) / or net nutrient gains from amendments	DeFour *et al.*, 1996

Table 2. Examples of the purpose of the soil nutrient balance LQI at different scale levels. Adapted from Bindraban *et al.* (2000)

Current research turns away from the heavy reliance on soil testing as the main focus for land quality. Soil nutrients are highly responsible for yield and crop performance as well as the overall land health. However, if the soil nutrients are sufficient, but there is less than adequate soil moisture or extreme compaction, then the crop could be yielding far less than if these conditions were optimized.

LQIs are being developed for policy analysis and strategic land degradation monitoring planning, assessing preventative measures, and land improvement strategies. Researchers hope to use LQIs to show how policy will effect, or does effect, the land's sustainability. Most researchers, particularly Dumanski and Pieri (2000) who work directly with the World Bank, assume agricultural production will be forced to increase by as much as three times the current rate over the next few decades, and that those yields must be sustained. Clearly, land degradation will have to be curbed, and existing farmland yields increased to avoid new farmland expansion into environmentally sensitive areas, while feeding our growing population. The goal of LQI research is to assist this effort by developing LQIs as monitoring and assessment tools in reference to a more diverse geographical regions than only the Netherlands.

Summary and Connection to Methods

The literature and studies presented all have a common theme: LQIs can be used to monitor land quality including both negative trends to land degradation and positive trends related to strategic land improvement policies. Furthermore, LQIs can also be used to predict crop yields. This predictive model, though developed in the Netherlands, could be calibrated for local conditions. This calibration would be accomplished by comparing predicted yields with actual yields. After the comparison, the values assigned to the LQIs would be adjusted. This would bring the predictive model closer to local reality. This thesis uses the language and logic of the World Bank LQI model to investigate the soil improvement and yields in relation to soil amendments in the form of vermicompost. The objective is to demonstrate the agronomic benefits of using urban organic waste to improve farm lands, though no attempt will be made here to calibrate the LQI predictive model to the local conditions. This thesis provides data on LQI changes and yields brought about by amendments added to the soil, so future investigations could use the results of this study to calibrate the predictive LQI model to local conditions and presumable, to calibrate it for vermicast as a specific soil amendment type. Overall, the LQI model developed in the Netherlands should not be applied as a predictive model for yields elsewhere without the caveat that regional and even local-scale calibrations would be required. Case studies such as this provide the raw data required for such calibration, and future work could use such case studies to improve the global predictive model the World Bank currently employs.

Ultimately, LQI research could have a great deal of influence over agricultural/ environmental policy. The World Bank is a main LQI supporter as an overall indication of land quality. Policymakers can base their strategic planning on LQI scales. Banks can use LQIs for loan purposes as the predictive model can show the potential benefits of specific land management strategies. Once the LQIs are tested, and the model improved in terms of the gross calibration needs, there are numerous applications for sustainability efforts.

In this case study, specific LQIs will be monitored for change and related influence on yield. The specific LQIs are soil nutrients, organic mater content, and water holding capacity. Vermicast use should increase these LQI variables and, in turn, increase biomass and grain yield. Ultimately, this thesis turns to the economic consideration of yield benefits versus total amendment strategy costs, such that the willingness to pay for the amendment per unit of input and/or the willingness to pay for its transport can be assessed, along with the transport distance that is economical.

This study will allow future researchers to calibrate the World Bank LQI predictive model for winter wheat production in Oklahoma. More importantly, however, it will determine the distance at which it would be economical to transport urban organic waste, as vermicast, to farmlands. If farm soils are to be improved by the application of such amendments, it must be economical to do so.

Urban landfill space is an ever growing problem. Urban organic waste typically sent to a landfill is a potential resource for farmlands, for which the amendment should improve soil-related LQIs. This case study will attempt to determine the degree of improvement and the distances from urban areas that farms could still benefit economically from the soil amendment, given the burden of transportation costs. LQIs also provide a framework drawn from current literature on sustainable land management, for understanding and communicating the methods and results of this case study.

CHAPTER THREE

METHODS

Research Design

To analyze all aspects of this case study, a complementary set of methods is required including control test plots, amended test plots, soil testing, network analysis, crop and yield biomass, data gathering, and cost-benefit economic analysis.

Study Area

The study area is Stephens County, Oklahoma on a farm approximately 12 miles from an Oklahoma Mesonet weather station. This gives a reasonable representation of weather variables around the study area test plots. The farm has a longer growing season than the northern part of the state. Soils are relatively homogeneous, minimizing soil variability in the model. It would be possible to analyze yield based on observed changes. However, assessing the amendment's effect in terms of LQIs will assist future comparisons of the results at the regional and global scales. In this area of south central Oklahoma, there is an abundance of winter wheat grown not only for grain harvest but also to help feed cattle throughout the winter season until spring grasses emerge. Cattle weight gain proves more profitable to the farmer than the grain harvest.

Ecological Framework

The selected case study test plot site is approximately 15 feet from a dirt road and encompasses an area in the field's center. This selection was made to help control the variables surrounding the field's outer edges, and thus allows for the elimination of "edge effect." Edge effect is the degradation caused to the field's edges by invasive species like trees or brush, or other conditions such as extra compaction, bug infestations, runoff from road toxins, and increased wind speeds. This location also provides easy main road access, and is a relatively flat portion of land. The area's soils are homogeneous, which assisted in maintaining minimum variability. The test site location has produced wheat for the past ten years.

Once the large test site was determined, 12 smaller plots were sectioned off within the test site including the non-amended controls and amended plots. For all test plots, synthetic fertilizer application remained consistent with that used in previous years. The traditional fertilization method for the entire site was completed using a 34-0-0 blend (nitrogen- phosphorus-potassium blend of synthetic fertilizer) at the rate of 150 pounds per acre. The following sections detail the specific methods used in this case study.

The researcher used ArcView 3.3 to locate the entire field on a one-meter digital orthophoto quad (DOQ) from the USGS. The field was delineated using a large polygon, on-screen digitized around the field's image on the DOQ. A smaller rectangular polygon, drawn digitally, represents the sampling area used to select random plots. With the use ESRI's random point script ("random points generator"), 12 random points were generated inside the small polygon. These points were then used as the center points for each of the individual test plots. A GPS unit was used to locate each of the 12 center points. Figure 3, shows the entire 24 acre field boundary, as well as the inner boundary

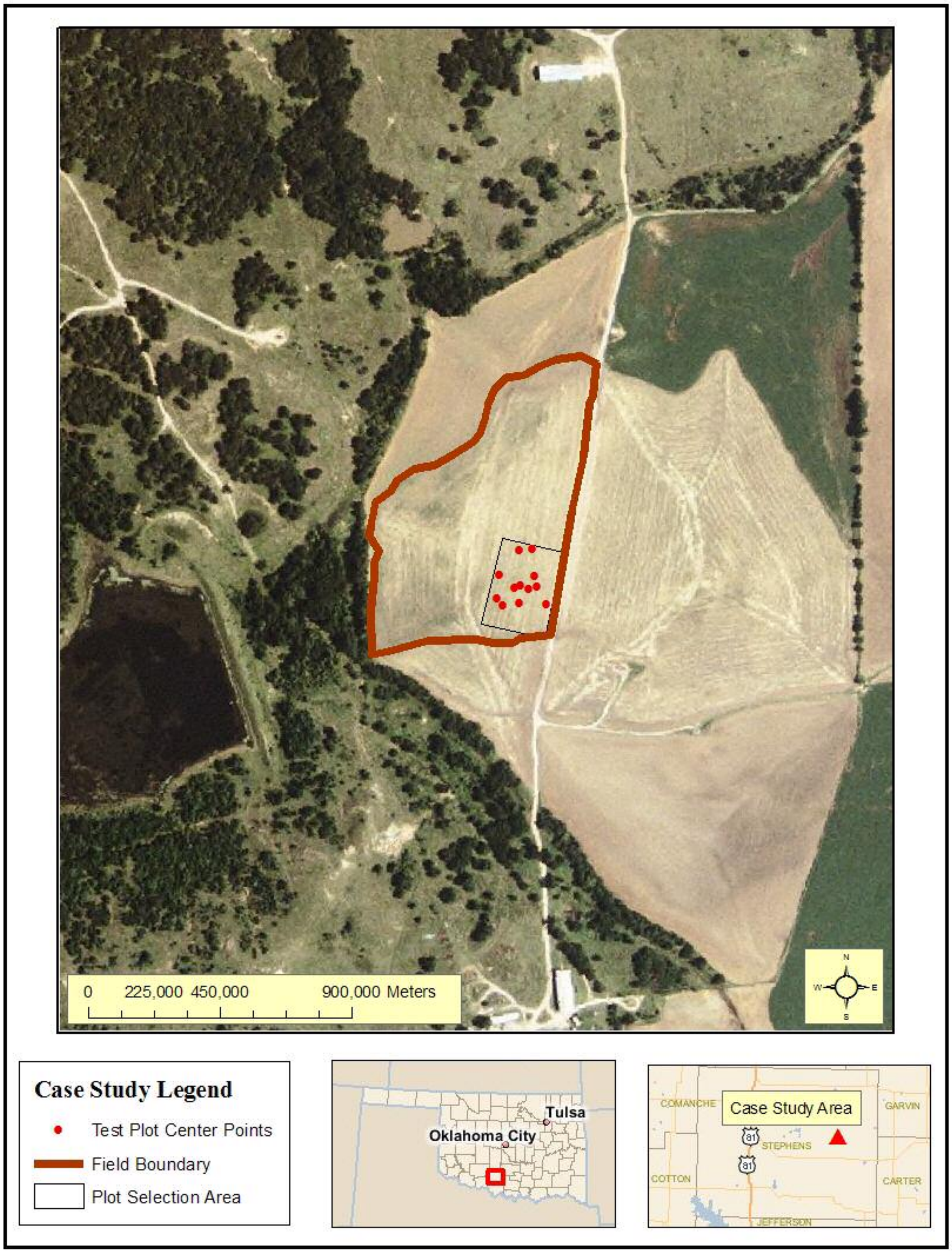

Figure 3. Study Area

for the random selection of plots and the center points for each of the 12 test plots.

Using a measuring tape, one meter was measured from each point in cardinal directions to establish the position for the test plot's four sides. This created 12 two-by-two meter plots. These were selected to allow six control and six amended plots. All plots were prepared identically to that of the entire wheat field, including the yearly soil bed's planting preparation.

Two of the amended plots received an application rate of six inches (on top of the ground) of organic amendment. Two others received an application of three inches of organic amendment, and two more received an application of one inch of organic amendment. Different depths were used to determine if, and to what extent, the amount of organic amendments affects the yield. The researcher added organic amendments to the soil bed's top. For example, six inches of the organic compost was placed on top of the ground.

After each amendment depth was applied on top of the ground surface, each depth was incorporated into the first six inches of the soil bed by plowing. The six inch plowing depth appears best for winter wheat roots (Brady and Weil, 1996). The same tractor and plow was also used for the remainder of the farm field.

After plowing, center point soil tests were drawn for each of the 12 plots. These soil samples were taken eight months after the plots were amended. A standard soil probe was used to sample the first six inches of the soil bed (Johnson *et al.,* 2000*).* The samples were sent to the Oklahoma State University (OSU) soils laboratory in Stillwater, Oklahoma for analysis. The soil-testing lab at OSU tested for nitrogen, organic matter, pH, calcium, potassium, and phosphorus. Results from the soil tests revealed the effects of amendments to soil LQIs and can be found in Table 2.

The Custer variety of hard red winter wheat was selected for the case study. Although there are several varieties of wheat, Custer tends to be the best yielding in south central Oklahoma (Raun *et al.,* 2003). The entire field (test plots included) was mechanically planted at a rate of 107 pounds per acre by a John Deere 4450 tractor and a John Deere 860 planter.

The field's planting date was September 13, 2004. Two days before planting, a two and a half inch rain provided optimal planting conditions. One week after the planting date, an additional half-inch of rainfall aided in gestation.

Due to time constraints, and to verify the yield's results, hand held scanning devices, calibrated by the Department of Plant and Soil Sciences and NTech Company of Stillwater, Oklahoma, were used for estimation. The scanner, an active sensor, pulses light onto the target vegetation. This light is reflected by the vegetation and received by the sensor lens. The sensor is connected to a Compaq iPAQ handheld computer that has software to calculate Normalized Difference Vegetation Index (NDVI) from the red and near infrared bands of the spectrum sensed by the device. The following equation is a ratio between the Near Infrared (NIR) band and the Red (R) band of the electromagnetic spectrum. The result indicates plant health and biomass production levels.

$$(NIR-R) / (NIR+R) = NDVI$$

The following figure depicts the feekes stages and the process each stage encompasses. Feekes stages four through six displays a period of rapid growth in the wheat plant. Obtaining sensor readings before or after the feekes stages greatly degrades the NDVI and ultimately the biomass calculation results.

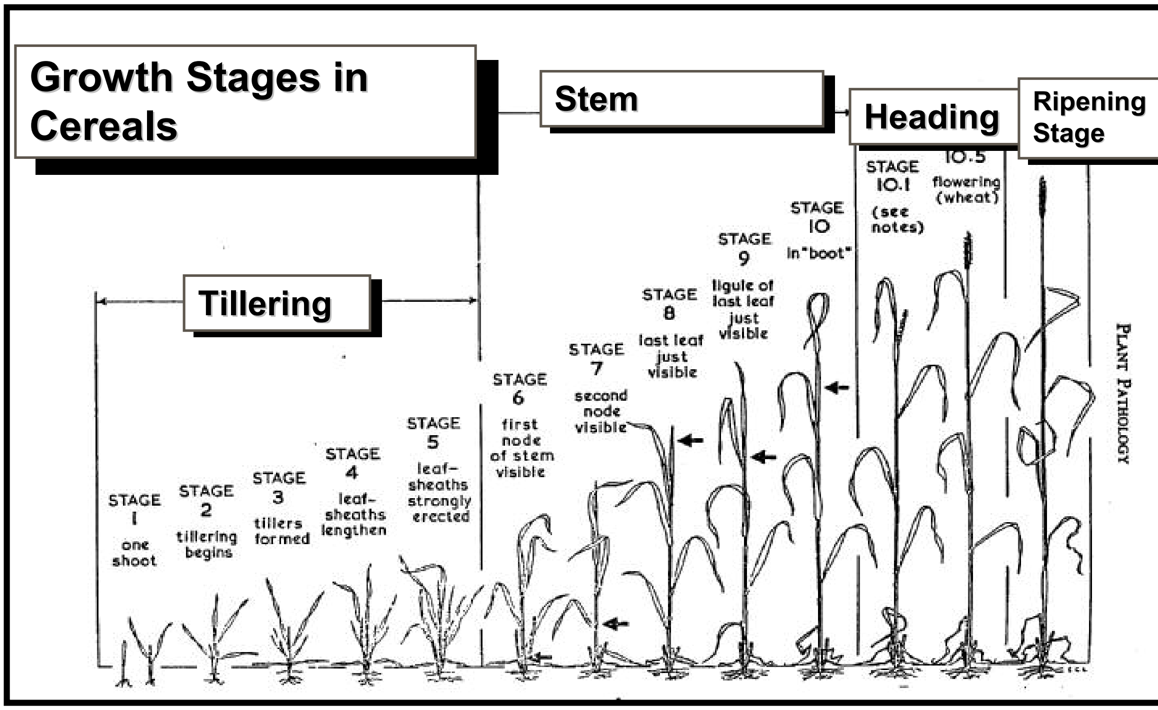

Figure 4. Feekes growth stages in wheat. Adapted from Raun (2003)

In the following equation, it is assumed the number of days from planting to sensing were days in which the temperature was above freezing (Raun *et al.*, 2003). The in-season estimated yield (INSEY) equation listed below, devised by the Oklahoma State University Department of Plant and Soil Sciences, calculates the yield between feekes stages four and six (Raun *et al.*, 2003).

$$INSEY = NDVI / (GDD)$$

The equation allows for the INSEY to be calculated using the NDVI sensor as long as growing degree days (GDD) are also recorded for later calculations. Actual yield can then be used for sensor method verification. The NDVI sensing performed one year prior to the actual harvest listed in this case study served to support the actual yield results recorded in the thesis test plots. When planting began, the date was recorded along with the harvest date and plot yield. Yield records were kept on each plot as was the wheat's market price on the harvest date.

Economic Framework

The study's economic aspects consider the amendment's benefit in terms of increased yield. If yields increase and/or if reductions in synthetic fertilizers are obtained, both farmers and the environment ultimately benefit. This study only recorded yield comparisons.

The economic analyses determine the cost versus yield variables as they apply to farm management. These include: recording the time spent amending the plots, preparing the soil bed, planting the crop, labor costs, and equipment costs (tractors, plows, drills, combines, and fuel). Since the case study utilized small plots, it was necessary to extrapolate the time and expenses of the procedures to a one acre area.

The use of Farm Service Agency (FSA) (Doye *et al.,* 2004) literature allowed for the determination of economic costs based on current farming expenses. The FSA has literature outlining costs for numerous farming applications based on years of research. These FSA figures cover several different farming practices, and give price per acre costs for specific tasks. By using these figures and research, this case study's costs (amending plots) are determined for a one acre area. Then the FSA figures can be extrapolated over a larger farm area.

The rate of yield increase related to the amendment depth is assessed to determine whether or not it is economically feasible for farmers to implement urban compost amendments as part of a management program (relevant to Hypothesis 3, Chapter 1).

Reason for concern emerges because the deeper the amendment depth, the higher the input costs. If a lesser amount of compost raises the yield by a set amount, and is still economical, then it may be more optimal to use that depth (relevant to Hypothesis 3). The application depth cost must add the total economic analysis to make certain all costs and incomes are considered (relevant to Hypothesis 4).

The case study will determine whether or not this is a viable option at varying distances from the compost source (relevant to Hypothesis 6). The farther away from the source, the more the cost increase affects the economic viability of procuring and using the amendment. The distance cost is calculated by multiplying the cost per mile of transportation by the total distance, essentially calculating the cost ceiling for the amendment and on-site delivery. Noting larger urban areas as the source for the compost, Oklahoma City and Tulsa were chosen as the starting positions for theoretical collection points in the urban composting program. Although there are no actual collection centers in these cities based on population, these are the largest urban areas in Oklahoma. They are also the most likely to have the ability to support a large scale urban composting and distribution program.

The transportation and amendment costs are then added to the application cost. This is the total cost for the amendment testing and must therefore be overcome by the yield gains at the time of harvest to be proven economical for rural farm application (relevant to Hypothesis 5 and 6).

The following chapter will discuss the results developed from these case study methods. It also depicts which LQI variables increased and how these affected yield and biomass production.

CHAPTER FOUR

CASE STUDY RESULTS AND DISCUSSION

LQI variables were monitored to help explain the potential increases in yield and biomass production. Each of the hypotheses is related because they build on one another's results. For easier explanation of the results, this chapter is organized by the six hypotheses proposed earlier and how these results affect hypotheses 1 and 2.

Hypothesis 1: Compost amendments will increase yield in both biomass and grain.

Results of the test of Hypothesis 1: The method for testing biomass and grain yield was Normalized Difference Vegetation Index (NDVI) and grain harvest weights. Photographs also gave a qualitative impression of the biomass differences. The grain yield was captured by hand harvesting and combine. The combine yield result for the remainder of the field was 22 bushels per acre, just one bushel per acre above the control. This further verifies the extrapolation of the two-by-two meter plot to an acre. The following table shows the yield based on the NDVI reading, combine readings, and lastly the hand gathered yield for the different amendment depths.

Test Plot/Field	N	Average NDVI Reading (0-1 scale)	INSEY Results	Yield bu/ac
Combine	Entire field	0.72	21	22
Controls	6	0.72	21	21
1"	2	0.73	22	21
3 "	2	0.78	25	24
6 "	2	0.82	32	31

Table 3. Pre-harvest NDVI and post harvest yield results

The results for the three inch application plot recorded a 0.78 NDVI reading. The three inch plot demonstrates an increase compared to the control and one inch plots. The six inch application has an NDVI of .82. This indicates a measurable difference in the vegetation amount and could give enough extra biomass to add an additional cow per acre (Biffle, 2005). The biggest gain shows between the one inch and the six inch application depths.

The control plots yielded 21 bushels per acre. At the current market price of $3.50 per bushel, a 24 acre field (easily accessible by a road and borders the case study area), would gross $1,764.00 or $73.50 per acre. The one inch plot yielded the same results as the control plot, with the exception of a slightly denser biomass production. The three inch plot had a three bushel per acre increase, raising the gross profit to $2,016.00 or $84.00 per acre, a 14 percent increase.

These results indicate a six inch application provides the best yield in this case study. There was a ten bushel per acre increase in yield versus control totaling a gross profit of $2,604.00 or $108.50 per acre; a 48 percent increase over the control test plots. Therefore, Hypothesis 1 is accepted.

Hypothesis 2: Compost amendments will produce an increase in the land quality as defined by LQIs including an increase in water holding capacity, nutrient status, and organic matter content. Decreased bulk density will explain the increases in biomass and grain yields predicted in Hypothesis 1.

Results of the test of Hypothesis 2: The LQI testing was performed by pre-soil testing and post amendment soil testing capturing the change in organic material and nutrient differences. A soil moisture probe was used to test the first 12 inches of the soil bed for water holding capacity. The moisture results demonstrated an increase in the three and six inch plots. The one inch plot was the same as the control. Table 5, illustrates the soil moisture percentages for each test plot. The soil moisture percentages total 100 percent representative of complete water. The soil moisture testing was performed on April 15, 2003. Lastly, the measures in Hypothesis 1 (yield differences) were used to evaluate increases in production. One of the most important LQI variables, organic matter, increases 1.3 percent in organic matter associated with water holding capacity. The following tables summarize soil quality improvements which are also indicators of LQIs.

Nutrient	Control Plot Results	Six Inch Test Results	Percent Change
pH	7.4	7.4	0
Nitrogen	49 lbs/acre	58 lbs/acre	18
Calcium	2764 lbs/acre	2804 lbs/acre	1
Magnesium	742 lbs/acre	760 lbs/acre	2
Organic Matter	1.31 percent	3.01 percent	1.7
Phosphorus	26 lbs/acre	29 lbs/acre	12
Potassium	222 lbs/acre	238 lbs/acre	7

Table 4. Average control plot and post amendment test results for the six inch plots

Test Plot	Soil Moisture Percentage
Control	56.21
1	56.45
3	61.56
6	65.13

Table 5. Soil moisture percentages

Yield	Bu/ac
Combine	22
Control	21
1”	21
3”	24
6”	31

Table 6. Hand yield results and combine results

The control plot results are suitable to growing winter wheat, yet still demonstrate room for improvement. The post amendment results indicate the organic matter is higher than the control plots (1.7 difference), which would contribute to water holding capacity and nutrient status. The increase for the organic matter is a pure difference in the new value minus the old value; it is not the percent increase calculation like the other nutrients in Table 4.

Synthetic fertilizers are used to get an increase in yield or soil nutrients for a crop. After application, the plant, runoff, and the atmosphere deplete the initial boost. In comparison, organic amendments are more stable because the organic material strengthens the soil nutrients resulting in less atmospheric depletion of nutrients (World Bank, 1998).

One LQI, soil organic matter, measures overall soil health. As indicated in Table 4, the control plots are lower in organic matter than the six inch plots. Even a field where wheat stubble is plowed into the soil, the organic matter is broken down by years of cropping. However, after one application, the organic amendment increased the organic matter from 1.31 percent to 3.01 percent, a 1.7 difference.

One year after the study's completion, a summer of soil preparation, and planting had taken place, the test plots can still be seen as green clusters in the field. This increase appears to be a lasting increase (although the length of time is unknown) that has not been noted in these same fields with synthetic fertilizers (Biffle, 2005).

Nitrogen, which has an instant effect on the crop, increased from 49 to 58 pounds per acre, an 18 percent increase. The calcium grew by over 40 pounds per acre (one percent) and magnesium increased from 742 to 760 pounds per acre, a two percent increase. The phosphorus improved from 3 pounds per acre to 29, a 12 percent increase, while the potassium rose from 222 to 238 pounds per acre, a seven percent increase. All nutrients and water holding capacities increased, and these led to enhanced yields and biomass production. These nutrient increases will therefore raise the LQIs and overall soil quality. Based on these results, Hypothesis 2 is accepted as study variables were correctly predicted.

Hypothesis 3: Yield will increase beyond the control (non-amended) plots at all depths of application (1, 3, and 6 inches) and above the control average with a linear relationship between depth of amendment and yield. Deeper amendments will equal higher yields.

Results of the test of Hypothesis 3: By plotting the yield against the amendment depth, the relationship can be obtained as to the efficiency of the differing amendment depths on yield. The control plots and the one inch plots both yield 21 bu/ac. However, when the six inch application is plotted it raises the yield in a non linear (power) function.

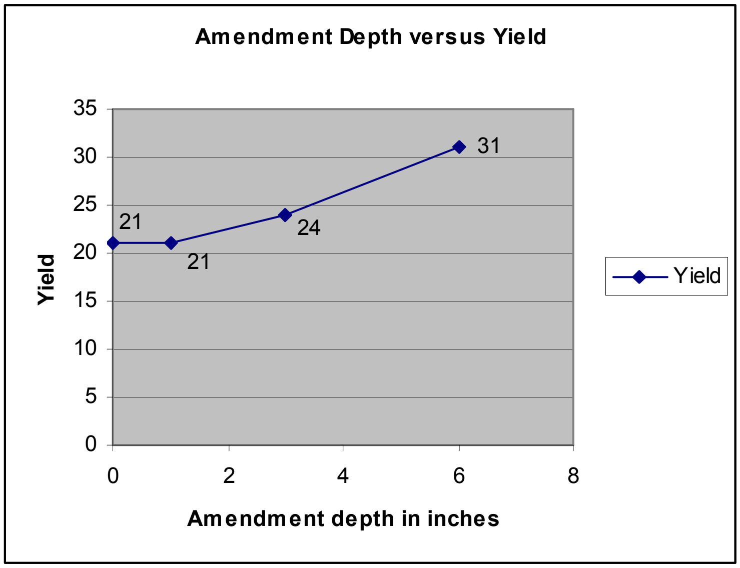

Figure 5. Depth versus yield relationship

The following results describe the increased crop yield in the amended plots relative to the controls. Each plot was hand harvested to determine the plot yield and then compared to the control validated by the combines computer generated results from the entire field (minus the test plot areas).

Plot	% Increase above control
Combine	4
Control	0
1" plot	0
3" plot	14
6" plot	48

Table 7. Yields on selected plots

Table 7, demonstrates that the six inch application appears to be well above the average production of the other plots. The following photographs reveal differing wheat heights of the plots. The plot photographs visually support the quantitative results in the above tables.

Figure 6. Photograph depicting a control plot.
By Robert Biffle on November 22, 2003

Figure 7. Photograph depicting a one inch application plot.
By Robert Biffle on November 22, 2003

Figure 8. Photograph depicting a three inch application plot. By Robert Biffle on November 22, 2003

Figure 9. Photograph depicting a six inch application plot. By Robert Biffle on November 22, 2003

The control plot's average wheat height was 12 inches. The one inch application plot had an average height of 15 inches. The three inch application plot was approximately 18 inches, and the six inch application was 19 inches. As can be seen from the preceding photographs, there is a marked difference between the control plot and the six inch application, not only in height but in fullness. The six inch plot created a larger increase in biomass. This increase could support more cattle in the winter months and produce a higher yield for the summer harvest. Yet, the one inch application did not raise grain yield above the control. Therefore, Hypothesis 3 is rejected as formulated. However, all amended plots did produce more biomass, and the three and six inch amended plots produced more grain than the control though not in a linear relationship in terms of the ratios between amendment depth and yield.

Hypothesis 4: Considering the one time cost of the compost application above the cost of the standard on-farm operations, while factoring out the cost of transportation of amendment to the farm, the compost application will prove economical (profitable) given the value of yield gain. This hypothesis also assumes no purchase cost for the amendment.

Results of the test of Hypothesis 4: Using literature from the Farm Service Agency on equipment and labor cost, the cost for amendment application was calculated and added to the other costs associated with wheat production. With standard methods, from preparation through harvest, the cost was $48.62 per acre, and the additional amendment application cost was $104.87 per acre. This cost was calculated using the FSA manual based on the average per acre operation cost of a manure spreader. The $2.60 rate is based on a single-load application, but the load number required for a six inch application is 40.33, for a total additional cost of $104.87, increasing the grand total cost to $153.49 per acre, which remains less than the economic benefit: at the six inch application rate, a profit of $635.00 per acre can be gained above the total production costs. This increase is a combination of the grain yield ($35.00) and the cattle income gain ($600.00).

Based on an interview with Harold Biffle, farmer/rancher in Stephens County, Oklahoma, the normal steer capacity sustained on his wheat field is approximately one head per acre. He concludes that based on the six inch application (and possibly the three inch application) that the number of head could be doubled. This 100 percent increase in cattle production boosts income and contributes to the profitability of the grain harvest mentioned in the preceding paragraph. The concomitant doubling of cattle waste could also lead to increased output, but that is beyond the scope of this thesis and is a subject for future research. Nevertheless, it is assumed that the number of cattle could be doubled. The NDVI result indicates a ten percent increase in biomass production, enough to support doubling the amount of cattle (Raun *et al., 2001*). The final result of the biomass increase is a doubling of the cattle number to be supported. This in turn would allow each steer to gain 400 pounds, or 800 total pounds per acre. At $1.50 per pound, an additional $600.00 profit per acre can be assessed. Combining the $35.00 per acre grain profit with the $600.00 per acre of cattle income, the farmer gains a $635.00 per acre increase in profit.

The application, or spreading of the amendment over the field, poses a one time cost. To accomplish this, farmers use a manure spreader costing $104.87 per acre. This cost encompasses spreading all 40 loads of organic material over one acre in addition to standard practices. Application occurs prior to plowing, thus no need for additional tilling exists.

Costs associated with the process of growing winter wheat include plowing the field, applying synthetic fertilizers, planting, and harvesting. Plowing incorporates any amendment and turns the stubble from the previous harvest into the soil. Based on the Farm Service Agency (FSA) (Doye *et al.,* 2004), plowing costs $7.04 per acre. The field will be plowed twice. The first will incorporate the previous year's stubble, and the second will prepare the planting bed. Synthetic fertilizer application costs $13.02 per acre, while planting the crop costs $7.48 per acre, and harvesting costs are $14.04 per acre producing a total cost of $48.62 per acre.

With 43,560 square ft. per acre, there is a total of 4,840 square yards. A six inch application, one sixth of 4,840 cubic yards, would equal 806.7 cubic yards of amendment per acre. A truck unloads manure onto the standard spreader used for these calculations. The spreader carries 20 cubic yards of manure and would require 40.33 loads to cover a single acre in a six inch amendment. At $2.60 per load (accounting for the equipment, labor, and fuel costs), the additional cost of applying compost equals $104.87. Added to the $48.62 per acre cost from the preceding paragraph, the grand total becomes $153.49 per acre. Therefore, the total winter wheat cost is $153.49 per acre, compared to the increased profit of $635.00 per acre with cattle and grain profit together. This leaves a net benefit for the six inch application depth of $481.51 per acre.

The results of Hypothesis 4 are accepted as the amendment proves profitable without considering transportation costs.

Hypothesis 5: There will be no consideration of transportation cost for the amendment. The net benefit addressed in Hypothesis 4 will result in the maximum price a farmer would be willing to pay per cubic yard of amendment and that amount will be above zero without the transportation cost consideration.

Results of the test of Hypothesis 5: Using results of Hypothesis 4 ($481.51profit) the willingness to pay per cubic yard for the amendment can be calculated. Based on the six inch application depth (the greatest profit increase), there would need to be 806.7 cubic yards per acre. Dividing the per acre profit $481.51 by the number of cubic yards required per acre, results in a willingness to pay $0.59 per cubic yard. Since the truck holds 20 cubic yards, there is a willingness to pay up to $11.94 per truck load (break even price of the amendment). An assumption of this Hypothesis is no cost for the transportation of the amendment. Hypothesis 6 directly addresses the results of transportation of the amendment.

An increase in grain profit of $35.00 per acre at the six inch application can be calculated. The three inch amendment yielded a three bushel per acre increase, which elevated the profit by $10.50 per acre. The one inch plot exhibited a slight increase of a few cents. Therefore, at a six inch depth, the farmer would be required to use 806.7 cubic yards of amendments to obtain a $35.00 per acre increase from grain and a $600.00 per acre increase from cattle production. These results indicate cattle production has a greater benefit to the farmer than the harvesting yield increase, because there is less input cost for grazing steers verses combining the wheat field (Biffle, 2005). In Oklahoma and surrounding states, it can be observed that may farms grow winter wheat. With such preparation, planting, and harvesting costs, grain farmers make little profit. Most farmers are also ranchers with their own cattle. However, they may also allow other ranchers to feed their cows on their wheat land for a nominal price. The typical farmer will grow wheat to increase the amount of weight his cows and calves gain each season. The more weight gain, the more profit when the cows are sold at market. Winter wheat grows during the season in which most other plants are dormant. Due to this, farmers run their cattle on the winter wheat for two main reasons. First, the cows need to be fed during the winter to ensure the proper nutrition, and wheat can be substituted for more expensive hay as well as requiring less time from the farmer. Second, the cows will rapidly gain weight while on the wheat. For these reasons, winter wheat can help the farmer take heavier cows to the market. Normally, cattle are allowed to graze or consume the leaves off wheat plants throughout the winter months. Around March, or when the season changes from winter to spring, the farmer removes the cattle from the wheat field allowing the plants to produce grain heads. In June, the wheat is harvested and the cattle are sold. This maximizes the profit from both grazing and harvesting the wheat crop As can be seen from the case study, wheat grain yield income is minimal; the profit from cow grazing is much greater.

This lends the case study to accept the hypothesis based on the results that the farmer should be willing to pay $0.59 per cubic yard, and that price is above zero.

Therefore, Hypothesis 5 is accepted as the amendment is worth $0.59 per cubic yard. Furthermore, this estimate is considered conservative, since benefits beyond the first year of operation are not considered. As an investment, the farmer should be willing to pay more than $0.59 per cubic yard.

Hypothesis 6: Adding the transportation variable will decrease the amount farmers would be willing to pay per cubic yard of amendment. The transport distance at which the economic threshold is reached (whereby willingness to pay becomes zero) will include rural farms.

Results of the test of Hypothesis 6: Transportation costs include the shipping cost of the material, not material cost. Based on an interview with Mike Prater, owner of Sooner Trucking in Velma, Oklahoma, the rate for transportation is $1.50 per transport mile per truckload. With the willingness to pay at $11.94 per load, either for the material itself, or the transportation cost, not both, the transport cost becomes prohibitive for farmers anywhere other than at the distribution centers. The transportation cost prohibits the amendments from being used on rural farms located beyond the urban compost source, but is viable on peri-urban farms located close to the compost source.

The average transportation cost of the material varies based upon the material's water weight. This case study used dry material eliminating the transportation cost of water weight. At $1.50 per loaded mile (derived from the same FSA publication used for on-farm expenses and an interview with Mike Prater), semi-truck can haul 20 cubic yards. From Tulsa to Velma, Oklahoma, the amendment transportation cost totals $286.50 for the 191 mile trip per truck. In comparison, from Oklahoma City to Velma, Oklahoma, the cost equals $133.50 for the 89 mile distance. After transportation costs are considered, the cost becomes economically prohibitive to rural farms, but those geographically next to the composting site would benefit.

Based on the test results of Hypothesis 6, it is evident that transportation costs cause the hypothesis to be rejected. The transportation cost is too expensive for rural farmers to afford. However, farmers adjacent to the composting site should be willing to pay up to $11.94 per truckload. If municipalities found it economical to move urban compost-based vermicast to peri-urban farms as a substitute for hauling the same to landfills and using limited landfill space, then farmers would be willing to pay $11.94 per truckload for the service. This is $11.94 per load more than the cities currently receive for their organic waste while conserving landfill area.

Cities that establish composting sources just outside their borders could extend the profitability to peri-urban farms since the farms are now closer to the composting site. Some small to medium size cities in Oklahoma have farmlands that border the city boundaries. These farms will benefit most from the amendment applications.

Summary

This case study's results indicate a measurable increase of yield in biomass and grain. The compost amendments produced an increase in the LQIs. Yields were raised beyond the control plot average at all application depths. When combined, these measures demonstrated an increase in the biomass production on the field as well as an increase in the grain yield.

The compost application proved economical, resulting in the maximum price a farmer is willing to pay. However, adding the transportation cost decreased the amount farmers are willing to pay per cubic yard of amendment as distance is increased from the composting site. This suggests rural and peri-urban farmers would only be willing to pay for the amendment if someone else, for example the municipality that was the source of the compost, paid the transportation costs.

This case study provides several future research possibilities, all of which will be discussed in the future research section. One research potential is analyzing additional cost savings allowing the organic amendments to be worth more. This case study only considered specific amendment and transportation costs. Landfills may provide the municipality with cost savings. First, the city would need to assess the distance that trucks haul to their landfill. This hauling distance might be greater than the distance to a closer farm that is willing to pay $11.94 per load of organic amendment. Second, there are costs associated with landfill management. These include costs covering labor to regulate access to the landfill, the daily deposits at the landfill, and possibly the most important, space savings at the landfill site. In a time of growing population, a city's space becomes a precious commodity generating tax revenues for the city. If the city has to increase its landfill area, then that land is not generating taxes. Although beyond the scope of this case study, these costs should be studied as future research that could potentially add value to the organic amendments.

Organic amendments are demonstrated within the case study to be economically feasible without considering transportation costs. Due to amendment transportation costs, the organic amendments are not economically feasible for rural farms. The amendment could be worth up to $0.59 per cubic yard to the farmer.

CHAPTER FIVE

CONCLUSIONS

This case study used conventional methods to test soil quality and to assess the input costs versus the yield benefit to assess the amendment's profitability applied to winter wheat/cattle production on an Oklahoma farm. The case study also assessed soil-level LQI changes to demonstrate how they affect profits. Those interested in the possibilities of a yield increase through vermicasted urban compost application can utilize this information to determine the potential profitability of the application as well as constraints such as distance from source and related transport costs.

This case study did not alter the synthetic fertilizer application over the case study test plots. There are two reasons: first, farmers will not be willing to completely eliminate their time-tested fertilizing techniques. Farmers took years to adopt the Green Revolution technologies. Such a culture leaves very little room for error considering crop yields. If a crop does not produce, the farmer absorbs all growing costs for the crop. In the case of Oklahoma, the farmers depend on the wheat not only for grain production, but also for the beef cattle production. If the wheat crop fails because synthetic fertilizers are not applied, then the farmer will be forced to feed his cattle with hay, which is very cost intensive. This change from synthetic to organic amendments will take time for farmers to adopt. In the meantime, there can be a reduction in the amount of fertilizers used. This will lead to less groundwater contamination and more healthy soil. There is also an increased potential for the cost saved from synthetic chemical applications, which could increase the organic amendment willingness to pay. This would also further increase the distance farmers are willing to ship the material. The need for this, as demonstrated in the future results section, is beyond the scope of this thesis. The charge of LQIs is to divert the costs associated with synthetic fertilizers to an organic method. This should increase LQIs leading to overall soil health increases and decreases in soil, water contamination, and a possible reduction in overall agricultural chemicals.

Second, fertilizing, being the same over the entire field, allows the case study to evaluate a constant difference. This suggests that even without synthetic fertilizers, the results of this thesis can still stand. They will decrease, but by the same amount as to not skew the numbers. In future studies, there should be an effort to reduce the amount of synthetic fertilizers used. This will help give more representative (organic) results.

Since this case study did not reduce the amount of conventional synthetic chemical inputs applied to the test plots compared to standard operations, it might be possible to do so and still maintain yields, given the yield increases demonstrated in this study. Such a synthetic chemical input reduction might decrease chemical hazards near cities, where the majority of population resides. Improved soil quality may also increase the value of near-urban agricultural lands, perhaps slowing the loss of those lands to urban sprawl.

Nonetheless, two events must be present for large scale urban composting and farm applications to occur. First, farmers will have to be shown profitability of composting amendments on their crops. Secondly, municipalities will have to become aware of economically viable strategies for diverting urban organic landfill wastes into a composting program. This thesis has addressed the first issue; it is left to future studies to address the second.

Furthermore, there may be cultural constraints to overcome in order to get municipalities to compost. If such constraints are conquered and the economics are shown to be viable, then large scale programs can be implemented. These programs would require start up costs, some of which could be subsidized by the reduced cost of landfill space requirements. However, this is also a topic to be addressed in future studies.

As stated in the economic section of this case study, the biomass increase is perhaps the most important factor in the winter wheat arena allowing farmers to feed more cattle per acre. Farmers will also see an organic matter increase in the soil not only from amendment residuals, but also from the fact that there will be more cattle on the crop depositing organic matter as manure. As stated previously, there would also be benefits beyond the first year of the organic amendment application, as residual benefits would continue. Again, for the case study test plots, there were still visible differences in the second year, and yet, it is unknown as to how many years the residual will continue to benefit the crop. Although this thesis estimated willingness to pay based on a single year's profit, it should be noted that residual benefits should increase that estimate.

It is hoped this case study will be used to increase awareness and use of urban composts for improving agricultural lands. Then, this study could aid the redefinition of current crop production methods, at least near urban areas.

Two significant findings of this case study are: first, the amendments markedly increased grain yields (up to 48%), and second the biomass production of wheat increased enough to double the cattle grazing on winter wheat fields. Cattle weight gain is often considered the most important economic factor for Oklahoma winter wheat production. However, from the results in the case study, evidence demonstrates that amendments are not economically viable for rural farms located beyond the urban compost source without special considerations of a city's landfill practices and costs.

If cities were to start a composting program to divert organic wastes away from the landfill, farmers adjacent to the composting site should be willing, economically speaking, to incorporate that compost into their farming practices. Therefore, rather than a landfill, the urban "waste" deposit site becomes a resource site for neighboring farms. The city could then reduce its landfill needs, reduce labor costs, and help reduce the growth of landfills. Farmers could also bid to have the material brought to their fields by the municipality, which should be economical for the city as long as the transport distance is not far beyond the landfill distance.

Another aspect of significance to this case study is the crop chosen for the amendments. Custer, a winter wheat variety, harvested on June 12, 2003 rendered approximately $3.50 per bushel. Even at much higher prices and increases from amendments, wheat is still less profitable when compared to tomatoes, strawberries and other "truck crop" farming. Crops such as these tend to be closer to the market since they are worth more in value, rot faster at ripening, and can be readily sold inside the city. Farmers, who produce high net worth crops, would also have the ability to apply the amendments to individual plants or rows rather than blanketing the entire field, decreasing amendment requirements and costs. This study has demonstrated that the diversion of urban organic waste is not profitable for the rural farmer. For higher value crops, the willingness to pay increases, but the distance is offset by the increase in organic material purchased by the peri-urban farmer.

Yield increases attributed to organic amendments would be accompanied by an organic material decrease going into the landfills. These increases, along with overall soil and environmental quality, would bring the world closer to sustainability. Increasing yield enhances support for the increasing population without cultivating additional land. This becomes part of the overall solution to the impending problems of sustainably matching food resources to population growth. Consequently, if synthetic chemicals could be reduced as a result of the compost amendments, then the majority of the population living in urban areas would be exposed to fewer agrochemicals from the near-urban farms.

It should be noted that extensive research has been focused on managing and improving agricultural lands. This research demonstrates that increasing farmland amounts may not be the most desirable way to increase food supplies. It suggests that peri-urban farmers can use more ecologically sound, yet economically viable strategies to increase yields, such as urban organic waste as amendments. However, as this study also demonstrates, such would not be economical for a low value crop, which as Von Thünen suggests, will be far outside the city (von Thünen, 2002). Therefore, there are definite spatial limitations to the viability of this idea.

To directly address the LQI variables, the case study demonstrated increases in all these measures. In Oklahoma, there could be more research to develop a scale of LQIs. This scale could be used in land valuations, loaning information for banks, and could be disclosed on the deeds for future buyers. LQIs could be used for subsidies; the federal government currently subsidizes American farmers, to produce wheat. If the government had a LQI scale that tested overall land quality health and environmental practices, then monies could be distributed to those farmers complying with federal regulations. As predicted, the organic amendments increased LQIs and this may also be used to assist policy makers in offering subsidies to cities to start urban composting programs.

Future Research

Studies such as this could be the basis for cities' proposals to implement urban composting programs decreasing landfill costs, and aid farmers by supplying organic waste to their fields or allowing free or low cost pick-up. This could help increase the farmland productivity, reduce synthetic chemical leaching into water supplies, and increase overall environmental (and human) health.

Some infrastructure to develop composting/vermicasting programs already exists in Oklahoma and other states. For example, a Wes Watkins foundation grant focused on southeastern Oklahoma funds vermiculture operations to process both city and farm/livestock waste. Many farmers and gardeners throughout the state have also implemented vermiculture operations; these farmers could provide models for successful vermicast programs for urban centers.

Future studies should assess the economically-viable distances for various crops and map those existing farms, which have potential to benefit from applying urban waste. As stated earlier in the case study, there are many costs associated with landfills not assessed in this study. Therefore, future research should be conducted relating to specific landfill costs for a city. These will include labor costs for landfill workers, as well as transportation costs. Another research area concerns new site locations. A new site will not initially produce tax dollars, which help cities function. If the wastes could be diverted to peri-urban farmers, the amendment should be economically viable.

Related to landfill future research, a citywide composting program would have to be established. This study would be strictly a geographic study in that the culture of the citizens will have to be studied to devise un-intrusive ways to implement a composting program. All costs discussed above, culture, and environmental concerns must be evaluated for tying together a successful city program. Cultural studies should include the farmers in the surrounding geographic areas to determine their farming practices. As discussed earlier, farmers have a distinct method for their operation. These customs have been passed down for generations, and still work with today's technologies. Farmers will have to be shown these studies' results to aid them through the conversion process.

Studies should be conducted that determine groundwater contamination decreases. This factor is of great concern with climate changes and increased population strains. Geographers could not only evaluate groundwater contamination, but should also study downstream pollution rates. Synthetic chemicals leach into water bodies, rivers and lakes, and are carried to destinations miles away. The spatial interaction between farmers and the cities downstream is a concern that organic amendments can help resolve. Data from USGS monitoring sites could be used to evaluate agricultural chemicals and how they effect the downstream inhabitants, both human and animal.

Future studies should be designed to make the results more acceptable to various disciplines. To improve the validity of the results, there should be a greater number of study plots. This will allow the research to have a larger amount of data that can be cross verified and increase the study's strength. Along with a larger number of plots, the study plots should encompass several farms in Oklahoma. Considering this, the study should have larger study plots. Larger plots would require more inputs, but the study also should be longitudinal over four or more years. These results would be more representative of the true results across the entire farm and across the entire state.

Many geographical studies could lend to the case study's results. Studying various crop types outside the city based on Von Thünen and his agricultural land use model, would be useful in determining a farmer's willingness to pay per cubic yard of amendment (von Thünen, 2002). As Von Thünen states with his agricultural land use model, the higher net worth crops, often called truck crops, are sold at the local market and bring a much higher price than a bushel of wheat (von Thünen, 2002). Wheat production usually occurs in the outer edge of the farming rings from the city. Wheat is worth less at the market and must be sold in bulk to gain a slight profit. The truck crops would be able to afford more amendment, but the economic threshold will not change because the extra profit is used to buy more amendment. A study of beef cattle production can be tied with this study's results. In Oklahoma, beef cattle production is one of the main factors for winter wheat. A longitudinal study should be conducted concerning beef production profitability with respect to composting programs on a rural farm.

Continued studies should be conducted to gain better understanding of all variables concerning not only LQI implementation, but also possibilities for increasing the distance farmers would be willing to transport urban organic waste. Using a broad range of available tools, geographers become the best suited to evaluate the studies' spatial and cultural natures.

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VITA

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Thesis: ASSESSMENT OF THE ECONOMICS AND LAND QUALITY BENEFITS OF USING URBAN COMPOST IN RURAL GRAIN PRODUCTION: AN OKLAHOMA, WINTER WHEAT CASE STUDY OF THE BIFFLE FARM

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Pages in Study: 62 Candidate for the Degree of Master of Science

Scope and Method of Study: This study is aimed at urban composting and its applicability to increase crop yield. The study addresses the differences both economically and ecologically in urban compost and synthetic fertilizer. The case study portion of the thesis is directed at the results of urban composting in Oklahoma from a soil nutrient standpoint, while using software to test if the new urban waste application is economically feasible for farmers to use on rural farms as an alternative or as a complement to man made fertilizers.

Findings and Conclusions: Urban composting program was found to be highly beneficial to increasing Land Quality Indicators (LQI) and individual soil nutrients. There is still profitability on the farms with the added cost of application, however, when the transportation cost was added it became uneconomic on rural farms. It is still profitable on the urban scale for gardening and higher net worth crops. Cities and farmers could set up a bidding system where the city would haul the compost to the farm for a set price, simply redirecting the materials from landfills to nearby farms, adding little or no cost of transport.

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