MANURE MANAGEMENT USING PRECISION AGRICULTURE

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MANURE MANAGEMENT USING
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ABSTRACT

The overall purpose of this project was to develop and implement a manure application record system that was solely based on Global Positioning Systems (GPS). This system will have the ability to provide steering and position assistance for avoiding buffer areas and to keep accurate records of application location, dates and rates. The system had the ability to create electronic as well as hard copy application maps. The software portion system was also evaluated to determine how the collected electronic spreading can be used to generate regulatory required spreading reports.

The first step was to select the necessary components of the system. Components for the system were selected on the basis of product availability, user friendliness, ability to communicate with one another, and dealer support. Once the needed components were selected, a prototype system could be assembled. The prototype system consisted of an Ag Leader Insight monitor, Raven flow control valve, Krohne electromagnetic flow meter, and a Trimble Autopilot system. Once the system had been assembled, calibration could take place. Once a proper calibration was achieved, the system operated with very successful results.

CHAPTER 1

INTRODUCTION

In recent years, the cost of commercially produced fertilizer has fluctuated widely. This price increase, coupled with increasing numbers of hog production facilities, has made hog manure an attractive alternative to regular fertilizers. With the rising popularity of hog manure application, scrutiny by the general public and regulatory agencies has also increased. The Department of Natural Resources (DNR) is responsible for monitoring manure applications.

In this day and age close record keeping is essential in the manure management world. Through the use of soil sampling data, a manure management plan can be implemented. In addition, DNR requires specific setbacks, areas in which manure cannot be applied, from roads, waterways, and wells. A GIS based system can be used to compile together the spreading recommends from the manure management plan with the setback requires from DNR to create application information to be used by the producer when spreading manure. A GIS based system can also be used collect actual spreading rate and location data. From this actual spreading information, application data can be compiled and submitted to DNR for record keeping purposes.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Application of animal waste to crop land has been a generally accepted fertilization practice in agriculture for many years. Recently, the adoption of precision agriculture technology has opened the door for site specific management of manure application. These management practices have created a need for machinery equipped with the technology to control manure application is accordance with many regulations. The purpose of this chapter is to review the relevant literature regarding modern, site specific manure application equipment, as well as GIS and GPS systems necessary to create these systems.

2.2 History of the Global Positioning System

The Global Positioning System (GPS) was originally developed for military use, but has since found its way into many everyday applications. In 1978, the Department of Defense launched the first of eleven satellites, known as NAVSTAR. This technology was developed by the Department of Defense, Ivan Getting, and the Massachusetts Institute of Technology (MIT).

Although the first launch was in 1978, GPS technology development had begun much earlier. In the early 1950's, Dr. Ivan Getting, an MIT graduate, developed a three dimensional position finding system for Air Force intercontinental ballistic missiles. This technology coupled with other Air Force and Navy technology was put to use in 1973 to develop a satellite based navigation system. As previously stated, the first of the original GPS satellites was launched in 1978. In the years to follow, many improvements were made to the GPS constellation, including the launce of the Block I satellite in 1980. Sensors on this satellite had been specially designed to detect atomic explosions to monitor Soviet atomic weapon testing. Also in 1980, atomic clocks were activated on the satellites. These clocks are accurate to one-billionth of a second.

In 1983, President Ronald Reagan declassified the GPS and opened it for public use. The main reason was for use in civilian aircraft navigation. During the 1980's, the decision was also made to increase the number of satellites to 24. The system was once again classified in 1990 during the first Gulf War. Following the war, the system was once again declassified in 1993, and reached full operation in 1995 (Maps and GPS).

The Wide Angle Augmentation System (WAAS) was put in place in 2003. WAAS was developed by the Federal Aviation Administration (FAA) and the Department of Transportation (DOT) to give the accuracy needed to aircraft approaches. The WAAS system is comprised of 25 reference stations throughout the continental United States. These reference stations create an error correction for moving receivers. The correction factor reduces error from roughly 10 m for uncorrected GPS to less than 1 m (Maps and GPS).

These innovations in technology opened the door for the use of GPS in many applications. Today, there are many uses for GPS technology in aviation, marine, surveying, construction, and agriculture.

2.3 Site Specific Management Systems

2.3.1 Basics of a Site Specific System

Site specific application is the basis of modern precision agriculture. By definition, site specific crop management is the use of variability of soil and crop parameters to make decisions on the application of production inputs (John Deere Publishing, 1997). To determine variability of soil parameters, a soil sampling program is required. To achieve the ability to variable rate fertilizer inputs, a grid soil sampling program must be used. Grid soil sampling requires a field to be divided up into smaller square grids; 2.5 acres grids are often used. The first step in grid sampling a field is to create a field boundary. This can be obtained in a couple different ways. First, a boundary can be digitized using geographic information system (GIS) software. Using an aerial photo, the field boundary can be traced and then transferred to a laptop or handheld computer for use in the field. Another way to create a field boundary is to simply drive the edge of the field with a GPS equipped vehicle, generally an ATV. Once the field boundary has been established, the field grids can be created. Several GIS software packages are commercially available to create grid sampling schemes and aid in collecting the soil samples. Samples are then collected using GPS to mark the center of the grids. Once the samples are collected they can be sent to a lab for analysis. Results from the soil test can then be used to create fertilizer recommendations for variable rate application.

Variability of crop parameters also needs to be determined to implement a site specific management system. The best way to determine crop variability is to use a yield monitor in the combine. The use of a yield monitor will allow variability of crops to be seen in real time. With the addition of GPS mapping on a yield monitor, maps can be created and imported to GIS software to aid in making management decisions.

2.3.2 Nutrient Management Plans

In a manure management system, a nutrient management plan is essential. A nutrient management plan allows producers to maximize the nutrients in the manure as well as reduce the risk of environmental issues. Nutrient management plans are essential for site specific management practices. A good nutrient management plan covers all aspects of manure management on a farm, from feeding the animal to eventual field application (Fulhage, 2000).

In a Comprehensive Nutrient Management Plan, provisions are made for everything ranging from manure handling and storage, record keeping, application practices, as well as nutrient requirements. The plan can be separated in to two main sections. The first section of the plan involves collecting, storing, handling, and treating of the manure in accordance with the manure management plan. The second portion of the plan covers application of manure nutrients, as well as soil nutrient retention. This portion of the plan deals with the logistics of the nutrient content of the manure being applied. Knowing the nutrient content of the product allows fertilizer recommendations to be created based on a crop yield goal.

There are many tools available for nutrient management planning. In Missouri, The Department of Natural Resources has released the Missouri Concentrated Animal Feeding Operation Nutrient Management Technical Standard (MDNR, 2009) and is also found in Appendix A. This document contains all necessary information regarding manure application in the state of Missouri.

2.3.3 Implementation of Site Specific Management

In order to effectively implement a site specific nutrient management program, specific principles should be addressed. The main points that should be addressed are measurement, control, and documentation. From these points, four basic principles of site specific management have been developed: measure nutrient content, determine necessary application rates, control the application rate, and finally document where the application occurs (Ess et al., 2001).

In order to meet the previously mentioned criteria, there are some necessary components that need to be in place. Nutrient content can be either measured with portable meters, or analyzed in a lab. To control the application rate of the machine, a device to determine the discharge rate of the spreader is necessary. This can be accomplished by either measuring the flow, or by weighing the product leaving the tank. In a weighing system, load cells are placed under the tank and monitor the amount of weight leaving the tank. The use of load cells often produces an error of 2-8 percent. Electromagnetic flow meters are also commonly used in manure flow measuring situations. They are generally flange mounted in the main discharge line of the spreader, and often yield an error of less than half a percent (Ess et al., 2001).

In addition, the flow rate must be controlled based on the flow read by the meter. In a hydraulic drive scenario, a servo valve can be used to increase or decrease hydraulic flow to vary the rate accordingly. In a power take off (PTO) driven spreader, a hydraulic actuated valve in the main delivery line can be used to control flow. A control system is used in conjunction with the flow control and flow meter to achieve the final target flow rate. Early systems used programs created in Visual Basic to achieve control (Schellberg and Lock, 2008). Today, there are commercially available controllers capable of the task.

Producing an accurate application record is the final step in implementation of site specific management. Site specific data must be geo-referenced to be used. To geo-reference the data, some type of GPS receiver is used.

2.4 Conclusions

Site specific manure management is a practice that can become very valuable in nutrient management planning. The advent of new GPS and GIS technologies provide the tools needed to implement a site specific management system for nutrient management.

CHAPTER 3

OBJECTIVES

In recent years, many crop producers have adopted the use of precision agriculture technology in their farming operations. Through this adoption of technology and the increased regulation of manure applications, there is a necessity to merge the two fields. The need to combine the areas of manure management and precision agriculture lead to the following four objectives for this thesis.

The first objective is to select the equipment components needed to implement variable rate manure applications. The components selected should be common components. One of the main goals of this selection process is to ensure that the components are easily acquired and not parts that must be custom made.

Second, the selected components need to monitor manure application from both a rate and spatial perspective. The selected system must be able to control the application rate as well as document the application activities.

Third, the selected components need to have the ability to generate an application report. The system should have the ability to compile an application report with minimal data manipulation.

Finally, a prototype GPS controlled tanker based manure application system will be developed. The system of components selected from previous objectives will be installed and operated on the farm of a local producer.

CHAPTER 4

OVERVIEW OF GPS BASED MANURE APPLICATION SYSTEM

To implement a GPS based manure application system, several components need to be in place. To illustrate the components needed in the system, the flowchart, shown in Figure 1, has been assembled. The flowchart shows the five major components that must be incorporated into a system along with the various options that can be selected for any given component. Without all five of these main components, the system will not function.

The first component needed is some type of GPS receiver. There are varying levels of accuracy available in today's GPS receivers, ranging from one foot accuracy all the way to sub inch accurate. To achieve the desired accuracy, there are three main correction signals. The proper receiver will be selected based on the desired accuracy.

One must realize that a dependable and acceptable GPS signal must be available and accessed in order to implement a GPS based manure application system. If a reliable and acceptable signal cannot be obtained, one can not implement this manure application system.

Second, a display interface must be selected. The display will be responsible for coordinating communication throughout the system. A display should be selected based on it's functionality as well as ease of use.

Next, some type of flow control device should be selected. Generally, a manure tank will either be hydraulic or PTO driven. Each type presents a unique challenge in selecting flow control devices. On a hydraulically driven machine, a servo type control valve will be used to regulate hydraulic flow. PTO driven machines will control product flow in a different manner. Since the product pump is located on the front of a PTO powered unit and PTO speed cannot be varied like hydraulic flow, flow control will be achieved through the use of a butterfly type valve actuated by a hydraulic cylinder. For this project, a hydraulically driven tank has been used.

To accurately control product flow a flow meter must also be used. There are several types of flow meters commercially available. In selecting a flow meter for a manure application system, it is necessary to consider the large volume of material that will be flowing through the device. There are many flow metering devices used in waste water facilities that can also be used in a manure application system.

The final component in the system is some type of guidance system. Because manure tanks are generally very long and have a relatively small swath width, a guidance system will allow the operator to skip passes and fill them back in. There are many options for guidance ranging from a simple lightbar system, to a fully integrated auto steering system.

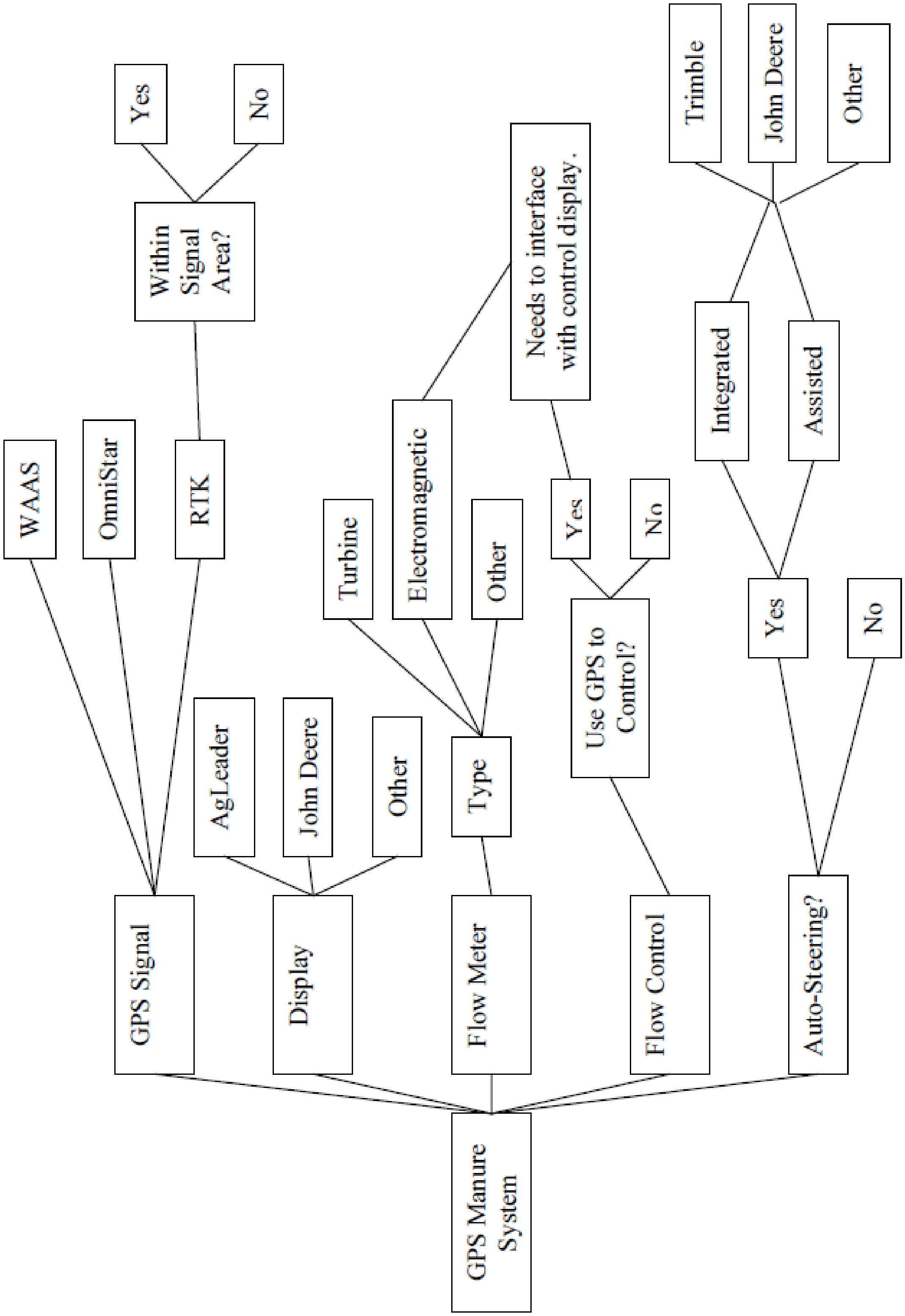

Figure 1. Flowchart of GPS Based Manure Management System

CHAPTER 5

SELECTION OF PROTOTYPE SYSTEM

The selection of the prototype system discussed in this chapter was completed in conjunction with the cooperating producer. So, some decisions were made with input and preferences of the cooperating producer because the producer was providing the majority of the financial support for creating the prototype system. Once the system was developed, the cooperating producer planned to use the system to apply manure on his large swine enterprise.

5.1 Selection of GPS Signal

The first consideration when planning the manure application record system was the level of GPS precision would be needed. Several levels of precision can be obtained by using different GPS components and signals. The lowest level of accuracy uses the WAAS system of correction. WAAS, which stands for Wide Area Augmentation System, uses ground referenced points to correct the satellite signal coming to the machine. A WAAS system is capable of reaching accuracies of six to eight inches pass-to-pass, and +/- three feet year-to-year repeatability. The greatest benefit of a WAAS system is that the signal is offered free of charge. The repeatability of systems operating with WAAS signal could become an issue if three feet year-to-year is too large of an error. Multi-path errors, errors caused by signal blockage by trees or buildings, can also become an issue with a WAAS system when used in close proximity to trees or buildings.

The next level of precision is known as the Omnistar HP signal. This signal works in a similar manor to the WAAS signal, except Omnistar is a subscription service. Omnistar HP is capable of two to four inch pass-to-pass accuracy with an eight inch year-to-year repeatability. This service is offered at a rate of $1,500/year, $750/ three months, and additional months at $190/month. Omnistar is capable of a greater level of precision than WAAS; however, it comes at a cost greater than the subscription cost only. The Omnistar signal has to have a period of convergence to gain greater accuracy. In a scenario where you would simply lose signal with a WAAS system, the Omnistar system would need to take time to reconverge before the higher level of accuracy would be available. It is also beneficial if the machine is stopped during the time that the receiver reconverges. There is a similar subscription based correction system available from John Deere, know as Star Fire 2.

The highest level of accuracy can be achieved through the use of Real Time Kinematics (RTK). An RTK system receives a correction signal from a base station that is located at a known reference point. The correction signal is then sent by radio waves to the rover unit. The issue with an RTK system is that fact that the base station equipment is very costly to own for most producers. However, RTK networks are becoming more common across the county. In an RTK network, a subscription fee is charged for use of the signal. RTK systems are capable of sub-inch pass-to-pass accuracy, with sub-inch year-to-year repeatability. Considerations must me made, however, to determine if all the necessary area would be covered by the RTK network if one must purchase a personal base station.

Recent developments have allowed producers in several states to have access to RTK corrections without the use of a radio based system. Many Midwest states have assembled a system of virtual reference stations. Generally, the state's Department of Transportation has funded these projects. This system of Continuously Operating Reference Stations (CORS) transfers correction data via cellular data rather than radio signal. This allows more distance between base stations. These networks are also offered free of charge to users. However, there is a charge for the data transferred via the cellular network. This charge will vary with providers. These stations will allow producers that are outside of traditional RTK network the opportunity to operate with RTK accuracy.

5.2 GPS Unit Interface

The GPS Unit Interface is commonly called the display for the GPS system. The display provides the user interface with all the various components within the overall GPS based system. However, two major other functions, communication and mapping, must be evaluated when selecting which display unit to select for the prototype system.

5.2.1 Capabilities for Communication

When considering components for a GPS controlled manure application system, it is important to choose items that can easily communicate with each other. The general components of the system are commonly used in other liquid monitoring scenarios, such as chemical application. The Ag Leader Insight system uses a Controller-area network (CAN) system to communicate information between the implement and the in cab monitor. The Controller Area Network (CAN) is a serial communications protocol which efficiently supports distributed real-time control with a very high level of security. Its domain of application ranges from high speed networks to low cost multiplex wiring (Bosch, 1991). CAN Bus networks are commonly found in automotive applications, with today's automobiles having as many as 70 electronic control units communicating via the CAN bus. This technology was developed in 1983 at Robert Bosch GmbH in Stuttgart, Germany. The Ag Leader system uses various modules to communicate information via the CAN system. For the Direct Command liquid system in place on the spreader an auxiliary module and a liquid module are being used. The liquid module is responsible for transmitting flow control and flow metering data to the auxiliary input module. In return, the auxiliary input module has the ability to manipulate product flow.

5.2.2 Importance of Mapping of Fields

Field boundaries are another issue that be addressed when making considerations for the application system. Because this system will be used to generate reports for submission to MDNR, it is important that field names are correct and easy to determine in the field. There are two ways to load field boundaries into the monitor. The first method is to simply drive the filed boundary with the piece of machinery. After driving around the perimeter of the field, the boundary will be created and can be saved accordingly. The other method of creating boundaries is to log them with another machine during the off season and load them to your monitor. This is often accomplished by driving the field perimeter with an ATV or truck equipped with a GPS system and then transfer them to the in cab monitor using its memory card.

In manure application situations, it is also important to address setback areas. It is crucial that manure is not applied in these designated areas. With a GPS controlled system, ensuring that these areas are left outside the manure spreading areas is easily accomplished.

The original intent was to have the Insight monitor display both the outside field boundary as well as any setback boundaries. Using ArcMap, a sample field boundary with a setback area was created and converted to a shape file to be loaded in to the Insight. ArcMap is a part of the ArcGIS software suite that is used to view and edit geospatial data. For this application, it was used to view and edit shape files. This technique proved to be incompatible with the Insight system. The monitor interpreted the setback boundary as an additional outside field boundary; giving it the impression that one field had two boundaries. To correct this problem, when creating field boundaries for a manure application system, the setback boundaries should be used for field boundaries. This will allow the operator to see the spreadable area on the screen in the cab, while still creating an outer boundary that the spreader will stay within.

5.3 Flow Meter Selection

To measure and control the flow of manure out of the tank, a flow meter and flow control valve are required. Accurate measurement and control of flow are essential elements to generating accurate spreading reports. In addition to accuracy, the components also needed to be easily adapted to the rest of the monitoring system. Since the Ag Leader Direct Command system is generally used in sprayer applications, it was known that devices with common connections would be easily adapted.

In order to be incorporated in the manure application system, the flow meter needed to meet some very specific requirements. These requirements included the following:

1. Must be able to handle large volumes of liquid.
2. Must be able to accurately measure volume of manure.
3. Must be easily adapted to system components.

Two types of flow meters are commonly used in agricultural applications: turbine style flow meters and electromagnetic flow meters.

All turbine flow meters operate based on the same principle, as the fluid moved through the meter body it acts upon the vanes on the impeller and causes the impeller to spin. The speed of rotation is used to determine flow rate. A given volume requires the turbine to spin a specific number of times. In terms of satisfying the previously mentioned requirements, the turbine type flow meter fills nearly all the needs. Large turbine type flow meters are readily available and are accurate with consistent liquids. Turbine type flow meters are also commonly used in many agricultural applications. A number of liquid application systems take advantage of this type of system, making them very compatible with the control components in the manure system. Because manure is made up of both solid and liquid, a turbine style flow meter could cause too much restriction in the line. The inconsistency of the fluid could also cause issues with the ability of it to flow through the vanes of the turbine. The flow concerns associated with turbine flow meters makes them a less than ideal choice for the manure control system.

Electromagnetic flow meters have no moving parts for the material to pass through to determine flow. Electromagnetic flow meters operate using Faraday's law of electromagnetic induction. This law states that as a conductor passes through a magnetic field, a voltage will be produced. In this case, the manure flowing through the meter becomes the conductor. The voltage that is produced as the manure flows through the magnetic field is directly proportional to the flow rate. Electromagnetic flow meters have the ability to measure flow in either direction with equal accuracy, since a current is produced either way the fluid is flowing. This type of flow meter excels in the measurement of liquids that other meters may not be able to, such as slurries. This makes an electromagnetic flow meter the natural choice for use in the manure control system.

The general design of an electromagnetic flow meter consists of a housing constructed of a non-magnetic material with an insulated lining. Magnetic coils are attached to the inside of the housing with a pair of electrodes piercing the housing and lining. These electrodes measure the voltage produced as the fluid flows through the meter.

5.4 Flow Control

As delivered from the factory, the manure tanker is set up to apply roughly a given rate at a given speed. Manure flow is typically not regulated to achieve the desired rate; rather, ground speed is adjusted to meet the rate desired. On the machine used for this study, the desired rate was to be achieved at roughly seven miles per hour. This target speed proved to be very undesirable. With East-central Missouri's rolling terrain and many small fields, seven miles per hour was too fast. When the operation was attempted at speeds between four and five miles per hour, the manure application was very erratic. The volume of liquid moving through the system was so large that the control system could never lock on to the target rate. The system would open the flow control until desired flow was achieved; however, the desired flow was reached so quickly that the flow control was not able to stop at the desired flow rate. The controller system could not respond fast enough. Therefore, the flow rate would over shoot the target level and then the flow control valve would close down to zero flow and start over. Visually, this uneven flow rate issue could be seen on the application maps by the skips in the coverage illustrated on the map. In that state, the machine was nearly unusable with such an inconsistent rate. One important lesson learned was that our system was capable of controlling the spreader, but limitations associated with the tanker needed to be addressed.

Once this flow control problem was determined not to be caused by the electronic control system, the tank manufacturer was contacted to verify if any alterations could be made to allow a slower ground speed while maintaining the desired target flow rate. The distribution manifold on the back of the tanker is where the manufacturer recommended making any alterations to restrict the flow. In fact, they offer a set of restrictor plates that reduce the orifice size to restrict liquid flow to the application tool. Once these plates were installed in the manifold, the application rate smoothed out and a lower ground speed was able to be achieved. This alteration alone did not completely correct the rate “jumping” issue discussed earlier. To further remedy this issue, the hydraulic flow from the tractor which provided power to the tanker manure pump had to be altered at the tractor.

5.5 Auto Steering

Once the accuracy decision was made, the next obstacle was to evaluate auto-steering options. Many precision agriculture companies were eliminated immediately, due to the lack of dealer support in the east-central Missouri area. The two companies with dealers in the area are John Deere and Ag

Leader/Trimble. When considering auto-steering options, there are really two main choices: assisted steering and automated steering. Assisted steering uses an auxiliary motor to operate the steering wheel on the vehicle. Automated steering, on the other hand, uses an integrated electric valve block in the hydraulic steering circuit. Assisted steering is the more economical choice of the two systems, however there are also some drawbacks associated with the system. Since the steering input occurs at the steering wheel, any play in the steering system will be reflected in the system performance. Older vehicles with more play in the steering system will show poorer steering response than a newer vehicle with a tighter steering system.

As previously stated, an automated steering is integrated in to the tractor hydraulic system to achieve the maximum amount of precision. There are four main components required for an automated steering system: display, GPS receiver, steering angle sensor, and vehicle interface, including hydraulic valves and navigation controller. The display chosen is generally based on what other duties the machine will be performing. Since the tractor will also be operating the manure system, a display that has the ability to control liquid application will be required. A GPS receiver is required for positional data. Type of correction signal used will determine exactly what receiver is required. A receiver with an update rate of 5 Hz or greater was required. A steering angle sensor is used to determine the angle that the steering wheels of the vehicle are positioned. This is what allows the machine to know how much correction is required to acquire the guidance line. Finally, the hydraulic valve and navigation controller are used to control handling of the machine. The electric solenoid valve operates the steering system on the machine based on information from the navigation controller and steering angle sensor. Many newer machines have an integrated auto-steering valve as factory installed equipment. The navigation controller can be compared to the brain of the automated steering system. The navigation controller corrects for roll, pitch, and yaw to give an accurate ground position.

The producer had specified that an integrated system was what he wanted. This ruled our assisted steering systems such as the John Deere Universal AutoTrac and the Trimble EZ-Steer. This left us with two possible choices, the Trimble Autopilot system and the John Deere integrated steering system.

The control and mapping systems were next to be addressed. Having settled on either Ag Leader or John Deere narrowed this search down quite a bit. John Deere's GS2 monitor would meet all the needs of controlling the auto-steering, controlling the spreader, and generating application maps. On the Ag Leader side, the Insight monitor was the natural choice, with the ability to control everything the GS2 monitor would. With the addition of Direct Command liquid control module, control of the spreader's flow control and flow meter would be no problem. With the options presented, the final decision was left up to the producer.

From the given information, the decision was made to use the Ag Leader/Trimble system. One reason for the decision is that local service and support are readily available. The fact that the Insight monitor easily produces as applied reports also weighed heavily on the final decision. Rather than importing data into another program, the Insight will generate a PDF file that can easily be saved or printed. Some concerns were noted with John Deere's Apex program. For a middle aged producer with very limited computer experience, eliminating as many steps as possible in the report generating process seemed to be the most ideal situation. With the Insight monitor, the application reports can be easily printed and assembled in to a packet for submission to MDNR.

CHAPTER 6

IMPLEMENTING PROTOTYPE SYSTEM

Once the manure system components were decided upon, the prototype system could be developed. As previously stated, the tank was ordered with a flow control valve and flow meter that had the ability to be easily adapted to precision agriculture monitors on the market today. Ensuring that these components have the ability to communicate with the desired monitor is a vital step in the process. By taking this step, time and resources can be saved by using all commercially available components. This system is made up of components readily available, with no custom cabling required.

6.1 SELECTED EQUIPMENT

The producer cooperating with the manure application trial had recently acquired a John Deere 8520 tractor, shown in Figure 2, and a Balzer 7500 hydraulic drive tanker, similar to tanker shown in Figure 3. Before the tanker was delivered, discussions were held with the dealer for the manure tanker. The dealer installed the flow meter and flow control systems at the dealership. Many brands of manure tanks have provisions for flow meter and flow control installation. It is possible to add these components to an older tank.

Figure 2. John Deere 8520 Tractor Used with Prototype System

Figure 3. Type of Balzer Hydraulic Manure Tanker Used in Prototype System

The installation procedures were carried out as outlined in the manufactures instructions (Ag Leader Technology 2006). The only complication with the Trimble Autopilot system was that the steering valve mounting bracket was too short, causing clearance problems with hydraulic hose routing. These clearance problems were corrected by welding an additional piece on the bracket, raising the valve about four inches. In addition to plumbing the steering valve and running the necessary cabling, a steering sensor was also added to the front axle. This sensor is responsible for communicating what direction the tires are pointed. This information is sent to the Nav Controller II, mounted in the cab of the machine, shown in Figure 4. In essence, the Nav Controller II is the "brains" of the Autopilot system, responsible for communication positional data and steering data to keep the machine on track. It continuously compensates for roll, pitch, and yaw using internal sensors.

Once the Autopilot system was installed, the Insight monitor was mounted in the cab in a convenient location, shown in Figure 5. Mounting location was crucial due to the fact that the touch screen would be used to engage the Autopilot system. If, after more use, it is decided that the touch screen engagement was not the best method to engaging the Autopilot, a remote switch will be added. Upon completion of the monitor and Autopilot installation, computer software was used to calibrate the machine.

Figure 4. Nav Controller II Mounted in Tractor Cab.

Figure 5. View inside Tractor Cab Showing Insight Display

With the tractor systems completed, the spreader systems were addressed next. As previously mentioned, the Balzer spreader was equipped with a Krohne flow meter and a Raven flow control valve. A Krohne six inch Model 4000 electromagnetic flow meter was the meter of choice (Khrone 2009). A Raven Fast control valve was also selected. The Fast valve has the ability to make change quicker than a standard valve (Raven Industries 2010). These components are common in many large sprayer applications. Precision agriculture practices have been used in the crop spraying sector for many years. With this knowledge, using these components in a manure application system was very feasible. Systems, such as Ag Leader’s Direct Command system have been used with great success on sprayers. In a manure tank application, the Direct Command system used data from the flow meter to operate the flow controller. This information is relayed to the Insight monitor through the Direct Command Liquid module.

The costs for the Manure Application System are shown in Table 1. The total cost for the entire system was $269,236. However the cost of the basic manure application system that includes only the manure tank (Balzer 7500 Eliminator and John Deere 8520 tractor) was $242,000. The cost of adding the GPS based capabilities adds less than 15% to the base system cost. So adding the GPS based capabilities is not likely to be an economically limiting factor for individuals considering implementation of the system.

Table 1. Cost Analysis for the Manure Application System

Manure Application Equipment	
John Deere 8520 Tractor	$150,000
Balzer 7500 Eliminator	92,000
Khrone Flow Meter and Flow Control Valve	8,000
TOTAL	***$250,000***
Manure Application Control System	
Insight Monitor	$3,995
Wiring Harness Kit/Switchbox	2,025
Raven Control Valve/Flow Meter Cable	78
Khrone Cable	23
TOTAL	***$6,121***
WAAS Steering System Option	
Trimble 252 w/ NAV II Controller	$8,000
Tractor Platform Kit	2,995
Hose Kit	800
AutoPilot Unlock	750
Insight to 252 cable	275
Antennae Mount Kit	295
TOTAL	***$13,115***
GRAND TOTAL	***$269,236***

6.2 TESTING AND CALIBRATION

Testing and proper calibration are vital steps in setting up a precision manure applicator. Without proper calibration, the data collected and subsequent maps generated are of no use. Proper calibration is without a doubt the most crucial step in the instrumentation of a system such as this. To begin calibration with the Insight monitor there must first be a Direct Command configuration set up.

The first step required in the configuration setup is to set the needed parameters in the Insight monitor. A vehicle profile must be added to the system, this is useful if the monitor will be used in multiple machines. These parameters include location of the GPS antenna in relation to the centerline of the vehicle, height of the antenna, distance from the rear axle, and distance from the drawbar. The distance from the drawbar to the point of product application is also included in the setup. An implement setup should also be created at this time. Information included in this setup includes implement attachment point, swath width, number of boom sections, and an implement name. Also included in the initial setup menu are a few other general operating parameters.

Once a suitable vehicle profile has been created, the parameters of the controller can be added to the monitor. First, enter the flow meter calibration number. This number is generally found on the flow meter and is measured in pulses per gallon. Next, the flow control valve type is selected from the menu. There are many different types of flow control valves, it is important to know what type of valve is used in a specific application. If this setting is not correct, calibration will be difficult or impossible to complete. When entering this setting there is an option in the Insight to close the control valve when there is a rate of zero. This box needs to be checked for this application. This feature is used in applications where there is no shut off beyond the flow control. For instance, in a sprayer application where there would be on/off valves at the boom, it is not necessary to shut off the flow control valve to discontinue product dispersal. Since there are no valves beyond the flow control on the manure tank application, it is necessary to shut the flow control valve off when the flow rate is zero. There is also an allowable error tab in the flow control section. This is used to input how much variance from the target rate is acceptable before the flow control valve makes an adjustment. An allowable error of 2% is recommended by the manufacturer as a starting point for system calibration. In the control valve setup menu there are values labeled Valve Response 1 and 2. Valve Response 1 represents how fast the control valve turns in order to meet the target rate. Valve Response 2 represents the speed that the control valve turns while the rate is within the response threshold. When these numbers are lowered, the valve makes adjustments more slowly. In a system, such as the manure system, where there are very high volumes of product flowing, the more gradual adjustments allowed the rate to lock in more solidly. See Table 2 for control valve settings used in the manure applicator.

Table 2. Control Valve Setting Required for Proper Prototype System Operation

Control Valve Type	**Inline Servo**
Flow Meter Cal	2 pulses/gallon
Valve Response 1	40%
Valve Response 2	10%
Allowable Error	9%

The Insight also needs to know if single or multiple products will be used in the given operation. For the manure application system, a single product will be used. The tank size will also need to be inputted to the monitor, and then this will allow the Insight to display the volume in the tank. Primary speed source will also need to be entered in the system. Generally, GPS will be used with either radar or wheel speed sensors as the backup. The rate outside of field section should also be adjusted during machine setup. This setting allows options for rate control when the machine is outside of the field boundary. For the manure system, the Zero setting will be used. This tells the flow control system to shut off when the machine is outside of the field. In a manure application scenario, this prevents manure from being applied in areas outside the field spreading area. There is also a rate display smoothing setting that can be selected. This setting keeps the display rate on the monitor constant as long as the actual rate is within 10% of the target rate.

Once the equipment parameters have been entered, actual calibration of the machine can take place. Before loading the tank with product, it is recommended to manually cycle the flow control valve to ensure that it is opening and closing properly. To achieve this, a manual speed is entered into the monitor. After a manual speed has been established, the rate can be manually adjusted through the Insight's Run screen by selecting the target rate and then selecting the manual setting. While the manual setting is selected, the operator can use the up arrow to increase the rate, while someone on the ground verifies that the control valve is opening. Once this has been verified, calibration of the spreader can take place. During the calibration of this specific spreader, a load of water was run through the machine to insure proper operation of all components. The concept of calibrating the spreader is fairly simple: divide the amount of product applied by the area covered. The first step in calibrating is to determine a known area. For this spreader, the swath width is 17.5 feet. Knowing this, it is possible to determine how long of a pass should be made to equal some portion of an acre. For a half acre, a pass that is 1244.6 feet should be made. To determine this length a measuring wheel or surveying tape should be used. Once this area has been determined and suitably marked, the spreader can be filled and calibrated.

After entering the correct flow meter calibration number, as well as the other controller settings, the calibration should be complete. A calibration run should always be made to ensure that the amount the machine is applying is the same as what the monitor reads. To calibrate the spreader, fill it to capacity and then spread the load in a field. The Insight monitor will log area as the load is spread. When the load is empty, divide the number of gallons by the number of acres covered. If there is a discrepancy, adjust the flow meter calibration number as needed. The flow meter calibration number is based off of pulses per gallon.

The biggest hurdle faced while calibrating this particular manure spreader, was getting the flow control valve to lock in on the desired target rate. The issue the researchers faced was that the rate would spike very high, making the control valve close too fast, overshooting the bottom end of the target rate. The rate would continually spike from high to low, ranging from 0 to 10,000 gallons per acre. Figure 6 illustrates an example of a less severe rate bouncing that was encountered. This issue was very challenging to diagnose. To aid in diagnosing the issue, a Raven 440 controller was connected to the system rather than the Insight, this was done to determine if the issue was in the Insight or the machine itself. After running the Raven and running into the same issue, it was determined that the issue must be machine related.

Since the application system is hydraulically controlled, the hydraulic system of the tractor and spreader were the next logical areas to examine. It was determined that all components on the spreader were in good working order. With the rest of the system functioning properly, the only place to look was the tractor hydraulics. The tractor had the ability to adjust the flow rate to individual selective control valves (SCVs). The flow rate was turned down on the SCV controlling the pump impeller on the spreader. Tuning down the hydraulic flow rate from the tractor to the pump caused a noticeable improvement in the performance of the spreader and stabilized the application rate.

Figure 7 pictures the tractor and spreader system on its initial calibration run.

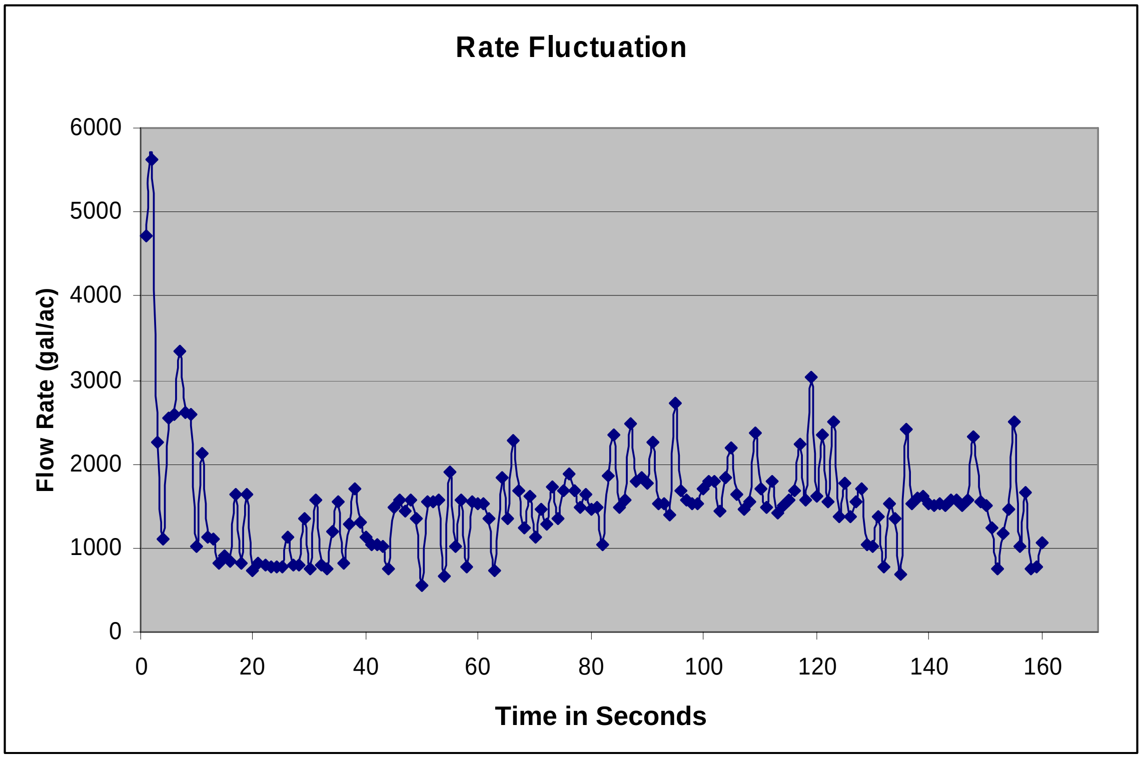

Figure 6. Chart Showing Flow Rate Fluctuation during Calibration with Improper Tractor Hydraulic Flow Setting

Figure 7. Manure Application System on Initial Calibration Run.

6.3 RECORD GENERATION

As outlined in the objectives, the ability to generate spreading maps based on application data was a requirement. Without the ability to generate maps based on application data, the system would be generally useless. For sake of easy data transfer, the system needed to have the ability to generate both hard copy records and electronic records. One major reason that the Ag Leader Insight system was used was for its easy report generation feature. The Insight monitor has the ability to generate an application report that lists all the information required by the Department of Natural Resources. The best thing about this feature is that it is automatic. The operator simply tells the monitor to generate the report, and a PDF application report is generated. This information can then be transferred using the memory card to a computer for printing. These application maps can easily be grouped according to farm and field and submitted to the necessary agencies.

According to the Missouri Concentrated Animal Feeding Operation Nutrient Management Technical Standard (MDNR, 2009), several criteria are required to be recorded every time manure is applied from a manure storage structure. They are as follows:

1. Date of manure application
2. Source of manure
3. Weather and soil conditions at time of application
4. Field ID receiving manure
5. Rate of manure application per acre

6. Plant available nitrogen and phosphate in manure applied to field
7. Method of application
8. Acres receiving manure
9. Total tonnage or volume of manure applied

With the record system in place, all of the necessary information can easily be input in the system and recorded electronically from the tractor cab. Having the ability to generate an application report with all of the previously stated information as well as an as applied map allows producers to effortlessly create application reports.

CHAPTER 7

LESSONS LEARNED AND FUTURE CONSIDERATIONS

As with any project, aspects of the manure application system could be changed to help performance of the system. Several lessons were also learned that should be taken care of before implementing a new manure application system. This section will address changes and considerations that should be made in future systems.

The first lesson learned that should be addressed is the need for orifice plates in the manure tanker's distributor. This issue can be addressed by the tank dealer. The proper orifice size should be selected based on the desired application travel speed and application rate. The second lesson related to the encountered fluctuating flow issue caused by the tractor hydraulic flow rate. This problem was somewhat unexpected, but once addressed essentially corrected the rate bouncing that was encountered. A mismatch between the hydraulic flow rate delivered by the tractor and the hydraulic flow requirement of the tanker hydraulic power unit will likely have a different effect on different machines. The important point is to ensure that the flow rate delivered from the tractor is acceptable for the hydraulic power unit needs on the spreader tank.

Another consideration that must be addressed when selecting components for the manure application system is compatibility of components. If the flow meter and flow control components will not communicate properly, the system will not function correctly. This issue can be compared to issues often encountered between Windows and Mac computers. Careful consideration of components will eliminate any communication issues.

When installing the electromagnetic flow meter, a proper ground is essential. Without a quality ground, the flow meter will supply erratic data to the monitor causing erratic application. The signal converter on the flow meter can also be an area of concern. Care should be taken while washing the machine, power washing the converter could cause internal damage. If the signal converter is damaged, it will not supply the necessary voltage to the monitor to make flow control corrections.

Although the system functioned as desired, there are still some areas that could use some future research and development. The first area is the boundary displayed on the monitor. Ideally, the user would be able to create manure setback map with GIS software showing both the field boundary and the setback boundaries. Currently, the system will display one or the other, but not both. Another issue that is being addressed is the use of the Ag Leader display in high flow applications, such as manure application. The large volume of product in a manure system presents a challenge from a rate control stand point. Although the system works, there is still room for improvement.

Finally, with the CORS RTK system coming in to use, sub inch accuracy will be practical for more operations. With RTK accuracy, the opportunity to side dress crops with manure becomes a possibility. With the proper application equipment, a crop that was planted with RTK corrections could easily be side dressed with minimal crop damage. The year to year repeatability will also allow producers more application options. The tracks from the previous year's application could be split, or manure could be applied on the same track.

APPENDIX A

Nutrient Management Technical Standard from Missouri Department of Natural Resources

MISSOURI
DEPARTMENT OF
NATURAL RESOURCES

Missouri Concentrated Animal Feeding Operation Nutrient Management Technical Standard

March 4, 2009

Division of Environmental Quality

Water Protection Program

I Introduction

A. Authority and Purpose

Missouri statutory requirements for Concentrated Animal Feeding Operations (CAFOs), located within 640.700 to 640.758 RSMo., grants the Missouri Department of Natural Resources and the Missouri Clean Water Commission authority and jurisdiction to promulgate rules regulating the establishment, permitting, design, construction, operation and management of Class I CAFOs. The department's CAFO regulations require the development and implementation of a field specific Nutrient Management Plan (NMP), meeting the criteria prescribed in 10 CSR 20-6.300(5)(A)-(I), at all Class I CAFOs.

In accordance with 10 CSR 20-6.300(3)(G)3., this Nutrient Management Technical Standard (NMTS) has been developed to provide a framework for the protocol(s) and method(s) that CAFOs should utilize when determining the form, source, amount, timing, and method of application on individual land application fields. Furthermore, this NMTS represents the department's best professional judgment regarding how to satisfy and/or implement the specific NMP criteria G, H and I within 10 CSR 20-6.300(5)(A). This framework seeks to achieve realistic production goals while ensuring appropriate agricultural utilization of the nutrients in the manure, litter, or process wastewater while also minimizing movement of nitrogen, phosphorus, and other potential water contaminants into surface and/or ground water.

This NMTS will be used by the department and partnering federal agencies as a guide for determining when precipitation-related discharges from CAFO land application fields are exempted as "Agriculture Stormwater Discharge" as allowed within 10 CSR 20-6.300(2)(B)7. CAFOs will qualify for the Agriculture Stormwater Discharge exemption when they can demonstrate compliance with this NMTS at the time of a precipitation-related discharge from land application areas.

B. Applicability

In Missouri, all confinement operations with 1,000 animal units or greater are Class I CAFOs and must follow the requirements set forth in this NMTS in accordance with the regulations found in 10 CSR 20-6.300. New and expanding CAFOs that apply for a construction permit after February 26, 2009 must have a nutrient management plan that complies with this NMTS developed prior to issuance of an operating permit. For purposes of this paragraph, an expanding CAFO is a CAFO that is adding a manure storage structure or confinement barn and expanding the total animal capacity of the operation. All other CAFOs must develop nutrient management plans that meet this NMTS prior to renewal of their permit.

NOTE: An operation may choose to use alternative protocols other than those established in this standard, however, it must be able to demonstrate that such alternative protocols provide both a reliable and a technically valid basis for achieving the nutrient management objectives.

II. Definitions

Manure - For the purposes of this document the term "manure" will refer to any form of litter, manure, wastewater, animal mortality byproduct or other organic residuals collected from the production areas of animal feeding operations.

Missouri Phosphorus (P) Index – The Missouri P-index is designed to help identify fields that have a high probability of phosphorus loss from the combined effects of erosion and high soil test phosphorus. The Missouri P-index integrates field information including current soil test phosphorus level, tillage type, anticipated land cover, soil hydrologic category, distance of the field from a receiving body of water along with an estimate of soil loss derived from the NRCS erosion prediction software, RUSLE2 (Revised Universal Soil Loss Equation Version 2). The Missouri P-index may be utilized when the soil test phosphorus level is "High" or "Very High" and must be conducted in accordance with the University of Missouri (MU) Guide G9184. The Missouri P-index is currently distributed as a Microsoft Office Excel spreadsheet available on the Web at *www.nmplanner.missouri.edu*

Missouri Soil Test Phosphorus Rating - The soil test phosphorus rating is found on a Missouri Soil Test laboratory report and indicates the relative level of plant-available phosphorus in the soil for a particular field. The soil test rating will indicate the probability that an application of phosphate on a particular field is likely to result in an increase in crop yield. A soil test phosphorus rating must be obtained from a lab accredited by the Missouri Soil Testing Association (list of accredited labs can be found at *http://soilplantlab.missouri.edu/soil/mstacertified.htm*) using procedures recommended by the University of Missouri Soil Testing Laboratory.

Surface Application – Land application method by which manure is broadcast or sprayed via mechanical equipment onto the ground surface. Surface application does not include manure that is injected into the soil profile.

Vegetated Buffer - A permanent strip of dense perennial vegetation established parallel to the contours of and perpendicular to the dominant slope of the field for the purposes of effectively slowing water runoff, enhancing water infiltration, and minimizing the risk of any potential nutrients or pollutants from leaving the field and reaching surface waters.

III. Nutrient Management Requirements:

Objective A. Land application fields in the nutrient management plan shall use the following protocols to determine the field-specific placement, timing and rate of manure application so that (a) they do not exceed the annual plant available nitrogen need of the crop, and (b) they are in accordance with the results of a field-specific phosphorus assessment.

A1. Soil and manure testing and fertilizer recommendation protocols.

(1) Soil sampling protocols to determine soil test phosphorus, cation exchange capacity (CEC) and soil organic matter should be based on the following criteria:

a. MU Guides G9215 (for pastures) and G9217 (for row and hay crops);
b. The average field area represented by a soil sample should be approximately 20 acres or less;
c. Each soil sample should be comprised of a well-mixed subsample derived from at least 15 representative cores from the sampled field area; more cores are recommended on pastures or where phosphorus has been band applied;
d. As an alternative to the conventional soil sampling approach in A1(1)c., operations may elect to use a geo-referenced grid soil sampling method instead. Grid size should be less than three acres and at least 10 cores should be obtained from within 15 feet of the central grid point;
e. Soil sampling depth should be six to eight inches;
f. Fields should be re-sampled before manure application when:
    i. The soil test is greater than five years old; or
    ii. Phosphate surplus (actual applied phosphate minus actual removed phosphate) for the field has exceeded 500 lbs/acre since the last soil test;
g. Soil samples should be analyzed at soil testing laboratories accredited by the Missouri Soil Testing Association (see a current list of accredited labs at *http://soilplantlab.missouri.edu/soil/mstacertified.htm*) using procedures recommended by the University of Missouri Soil Testing Laboratory.

Note: Soil sample results that meet all of the above criteria shall be considered "current soil test results".

(2) Fertilizer recommendations should be based on the following:

a. Justified field-specific yield goals. Yield goals should be based on crop yield records from multiple years for the field. Good judgment should be used to adjust yield goals to counteract unusually low or high yields. When a field's yield history is not available another referenced source may be used to estimate yield goal;
b. Current soil test results;
c. University of Missouri fertilizer recommendations should be utilized. University of Missouri recommendations can be obtained on-line using current soil sample results at *http://soilplantlab.missouri.edu/soil/scripts/manualentry.aspx*;
d. When necessary, nutrient removal rates should be based on MU Guide G9120 or alternatively can be based on measured plant analysis records from the farm. If nutrient removal rates are based on

plant analysis records, document how the crop is sampled and how plant analysis records are used to estimate nutrient removal for a crop;

e. Published nutrient removal estimates from other land grant universities in adjoining states are also acceptable.

f. Field-Level Fertilizer Applications – Fertilizer recommendations used to develop nutrient budgets shall be based on 20-acre field areas. When fertilizer recommendations are similar (within 10% or 10 pounds per acre, whichever is greater) for adjoining 20-acre field areas, they may be combined for purposes of fertilizer application and nutrient budgeting. Field areas of up to 80 acres may be combined using this guidance. Larger field areas may be combined if justification for this decision in documented in the nutrient management plan.

(3) The following protocols describe how and when sources of manure should be sampled and how manure testing results will be used to estimate nutrient concentration in manure.

a. CAFOs are required to sample each unique source of land-applied manure at least once per year;

b. All manure samples should be tested for total nitrogen, ammonium nitrogen, total phosphorus, and total potassium. When lab results are reported on a dry basis manure samples should also be tested for dry matter or total solids (moisture content). Nitrate nitrogen is typically not present in manure samples but should be tested for if an innovative manure handling system is likely to create aerobic conditions where nitrate will persist in manure;

c. Samples should be collected and handled following the guidelines outlined in MU Guide Publications EQ215 and G9340 (for poultry litter);

d. When possible, sample and analyze manure just prior to the time for land application of manure so current results are available for calculating manure application rates.

A2. All manure applications on land application area(s) shall meet all three of the following criteria:

(1) Annual nitrogen application from all sources should not exceed the recommended nitrogen application rate for non-legume crops and the nitrogen removal capacity of legume crops by more than 10 pounds per acre or 10 percent, whichever is greater.

a. The recommended nitrogen application rate for non-legume crops should be based on University of Missouri nitrogen fertilizer recommendations derived from a current soil test result for the field and a realistic yield goal. The nitrogen fertilizer recommendation must be adjusted using nitrogen credits for a preceding legume crop, residual fertilizer nitrogen value of manure applications from the previous year and, when appropriate, excessive residual inorganic nitrogen in the soil profile as quantified by the preplant soil nitrogen test. If University of Missouri does not provide a specific nitrogen recommendation for a non-legume crop, recommendations from other land grant universities should be used. Information on calculating residual fertilizer value of manure applications is available in MU Guide Publication G9186. Information on the appropriate use of the preplant soil nitrogen test is in MU Guide Publication G9177;

b. The nitrogen removal capacity of legume crops should be based on the estimated nitrogen content of the harvested crop as defined in MU Guide G9120 and a realistic yield goal. The estimated nitrogen content of the crop must be adjusted using nitrogen credits for residual fertilizer nitrogen value of manure applications from the previous year and, when appropriate, excessive residual inorganic nitrogen in the soil profile as quantified by the preplant soil nitrogen test. If MU Guide G9120 does not provide an estimate of the nitrogen content of legume crop, recommendations from other land grant universities should be used. Information on calculating residual fertilizer value of manure applications is available in MU Guide Publication G9186. Information on the appropriate use of the preplant soil nitrogen test is in MU Guide Publication G9177;

c. The nitrogen contribution of manure should be based on a calculation of plant-available nitrogen (PAN). Plant-available nitrogen is calculated by adjusting the inorganic and organic nitrogen concentrations using procedures outlined in MU Guide Publication G9186, and is available on the Web at *http://nmplanner.missouri.edu/tools/pan_calculator.asp*

(2) Manure application rates must comply with the results of a field-specific phosphorus loss assessment.

a. Manure application rates can be based solely on nitrogen criteria (nitrogen-based management) if:
   i. The Missouri soil test phosphorus rating from a current soil test is very low, low, medium or optimum; or
   ii. The Missouri P-Index rating is low or medium.

b. Manure application rates cannot exceed the annual planned phosphate removal capacity of the crop by more than 10 pounds per acre or 10 percent, whichever is greater (phosphorus-based management) if:
   i. The Missouri P-index rating is high; or
   ii. The Missouri soil test phosphorus rating from a current soil test is high and the field has not been assessed using the Missouri P-index.

c. Multi-year phosphorus application – When phosphorus-based management is necessary, manure applications can exceed the annual planned phosphate removal capacity of the crop. However, application rates must comply with the following conditions:
   i. Rates shall not exceed the recommended nitrogen application rate during the year of application, or estimated nitrogen removal capacity in the harvested crop during the year of application when there is no recommended nitrogen application, and
   ii. the amount of phosphorus banked in the soil will not exceed four years of crop removal for the planned rotation using the criteria found in section A1.(2) above, and
   iii. the actual application rate shall not exceed 10 pounds per acre or 10 percent of the planned multi-year phosphorus application rate, whichever is greater.

d. No manure will be applied on a land application field if:
   i. The Missouri P-index rating for the field is very high; or
   ii. the University of Missouri soil test phosphorus rating from a current soil test is very high or excess and the field has not been assessed using the Missouri P-index.

The Missouri P Index is described in MU Guide Publication G9184 and is available as a Microsoft Office Excel spreadsheet at *http://nmplanner.missouri.edu/tools/pindex.asp*

(3) The timing, soil conditions and placement of all manure applications shall meet the following criteria:

a. Manure applications shall comply with all manure application setbacks defined in Table A1;

b. No surface application of manure is allowed if precipitation, likely to create runoff, is forecasted to occur within 24 hours of the planned application;

c. Manure will not be applied on land with a slope greater than 20 percent;
d. Manure will not be surface applied to frozen, snow-covered or saturated soils;
e. Manure applications must be monitored such that target application rates are met and any malfunction in the operation of the equipment is detected and corrected before any over-application of manure occurs on the land-application site;
   i. Wastewater and liquid manure applications must be conducted so as to prevent surface runoff of wastewater and liquid manure beyond the edge of the field during land application. Steps to insure no runoff of manure during land application include:
      1. Adjusting surface application rates to meet infiltration rate and water holding capacity of the soil;
      2. Irrigation systems must have automatic shut-off devices in case of pressure loss and/or an operator on-site at all times during operation to monitor application equipment.
   ii. All land application equipment should be calibrated at least annually;
   iii. The perimeter of all fields receiving manure should be checked regularly during operation of land application equipment to confirm manure is not running off the field or entering waters of the state.

Table A1. Manure application setback distances. For streams, lakes and wetlands the setback distance is measured from the defined edge of the water feature.

Setback Feature	Application Conditions	Setback Distance (feet)
Public or private drinking water well or other wells including un-plugged abandon wells	All applications methods	300
Public or private drinking water lake or impoundment	All applications methods	300
Public or private drinking water intake structure	All applications methods	300
Classified waters of the state not used as a water supply as defined in 10 CSR 20-7.031(1)F	Permanently vegetated buffer[1]	35
	No or insufficient vegetated buffer	100
Other public and privately owned lakes and impoundments not used as a water supply including impoundments with no outlet	Permanently vegetated buffer[1]	35
	Up-gradient, no or insufficient vegetated buffer	100
	Down-gradient, no or insufficient vegetated buffer	35
Other perennial streams, other intermittent streams, canals, drainage ditches and wetlands	Permanently vegetated buffer[1]	35
	Up-gradient, no or insufficient vegetated buffer	100
	Down-gradient, no or insufficient vegetated buffer	35
Tile line inlet (if left un-plugged during manure application)	Up-gradient, permanently vegetated buffer[1]	35
	Up-gradient, no or insufficient vegetated buffer	100
	Down-gradient	0
Losing stream	All applications methods	300
Cave entrance	All applications methods	300
Spring	All applications methods	300
Active sinkhole	All applications methods	300
Non-owned occupied residence	Spray irrigation only	150
Public use area including non-owned businesses	Spray irrigation only	150
Public road	All applications methods	50
Property boundary	All applications methods	50

[1] See definition of vegetative buffer in the definitions section of this document.

Objective B. Operations shall maintain the following records to document implementation of appropriate nutrient management plan protocols.

B1. Annual nutrient management monitoring and record keeping requirements.

(1) **Manure Storage Operational Monitoring**– Record the following information for each manure storage structure:

a. Weekly records of the depth of manure and process wastewater in liquid storage structure(s).
b. The date, time, and estimated volume (gallons) of any overflow(s) from the storage structure.
c. Record the following information for every manure application event from a manure storage structure:
    i. Date of manure application
    ii. Source of manure (indentify the storage structure)
    iii. Weather and soil condition at time of application
    iv. Field ID receiving manure
    v. Rate of manure application per acre (tons/acre, gallons/acre, or acre-inch).
    vi. Plant Available Nitrogen (PAN) and phosphate in manure applied to field (pounds/acre).
    vii. Method of application (injection, surface applied, etc)
    viii. Acres receiving manure
    ix. Total tonnage or volume of manure applied (tons or gallons)

d. For all manure transfers (sales or giveaway) off the farm record the following:
    i. Date of transfer
    ii. Name and address of recipient
    iii. Storage source of manure transferred
    iv. Amount of manure transferred (tons or gallons)

(2) **Manure Nutrient Monitoring** - For each unique source of manure.

a. Date(s) for manure sampling
b. For each sampling date report total nitrogen, ammonium nitrogen, total phosphate (P_2O_5), total potash (K_2O); report percent moisture or dry matter and nitrate nitrogen when appropriate and relevant
c. Report or identify the actual manure nutrient concentration used for calculating manure application rates. If different manure sampling results were used for different parts of the year then provide the range of dates when each sample result was used. If estimates are used, provide information as needed to justify the use of estimate(s) of manure nutrient concentrations

(3) **Field Soil Test Monitoring** - For each individual field in the land application area that receives manure record the following:

a. Year of the last soil test
b. Current soil test results reporting at a minimum soil test phosphorus, cation exchange capacity (CEC) and soil organic matter (%)

c. Fertilizer nitrogen and phosphate recommendations (pounds/acre)

(4) **Land Application Operational Monitoring** - For each individual field in the land application area that receives manure record the following:

a. Field ID receiving manure
b. Total acres in each field receiving manure
c. Planned crop(s) (corn, soybeans, fescue, pasture,…etc)
d. Projected yield
e. Actual yield
f. For each field complete an annual nitrogen inventory including:
    i. Total Planned Fertilizer Nitrogen Requirement for the crop in pounds/acre (fertilizer nitrogen for non-legumes or the nitrogen removal capacity for legumes as described in section A2 (1) of this standard)
    ii. Plant Available Nitrogen (PAN) from manure applied to field (lbs N/acre)
    iii. Nitrogen applied from other sources (lbs N/acre)
    iv. Total applied plant available nitrogen from all sources (lbs N/acre)
    v. Difference between total applied plant available nitrogen from all sources and planned crop nitrogen requirement (lbs N/acre)

g) For each field complete an annual phosphate inventory including:
    i. The soil test phosphorus rating for the field
    ii. The Missouri Phosphorus Index (P-index) rating, if applicable
    iii. Actual phosphate applied as manure (lbs phosphate/acre)
    iv. Actual phosphate applied from other sources (lbs phosphate/acre)
    v. Planned phosphate removal from crops harvested this year (lbs phosphate /acre)
    vi. Actual phosphate removal from crops harvested this year (lbs phosphate /acre)
    vii. Phosphate balance for the year (actual applied minus planned removal; lbs phosphate /acre)
    viii. On fields where "multi-year phosphorus application" is utilized, report the cumulative phosphate balance for the multi-year planning period. (the cumulative balance equals the actual phosphate applied minus planned phosphate removed in lbs phosphate /acre)

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APPENDIX B

Sample Raw Data Set From Calibration Run

Data Line column on each of the following pages is to align the data from each page. So the data from data line one on each of the pages corresponds to a single line of data from Ag Leader unit.

Data Line	Longitude	Latitude	Field	Dataset	Product
1	-91.7387	39.05321	Callaway East	R3: (2007221955)	10#manure
2	-91.7387	39.05321	Callaway East	R3: (2007221955)	10#manure
3	-91.7386	39.05321	Callaway East	R3: (2007221955)	10#manure
4	-91.7386	39.05321	Callaway East	R3: (2007221955)	10#manure
5	-91.7386	39.05322	Callaway East	R3: (2007221955)	10#manure
6	-91.7385	39.05322	Callaway East	R3: (2007221955)	10#manure
7	-91.7385	39.05322	Callaway East	R3: (2007221955)	10#manure
8	-91.7385	39.05322	Callaway East	R3: (2007221955)	10#manure
9	-91.7384	39.05322	Callaway East	R3: (2007221955)	10#manure
10	-91.7384	39.05322	Callaway East	R3: (2007221955)	10#manure
11	-91.7384	39.05322	Callaway East	R3: (2007221955)	10#manure
12	-91.7383	39.05321	Callaway East	R3: (2007221955)	10#manure
13	-91.7383	39.05322	Callaway East	R3: (2007221955)	10#manure
14	-91.7383	39.05321	Callaway East	R3: (2007221955)	10#manure
15	-91.7383	39.05322	Callaway East	R3: (2007221955)	10#manure
16	-91.7382	39.05321	Callaway East	R3: (2007221955)	10#manure
17	-91.7382	39.05322	Callaway East	R3: (2007221955)	10#manure
18	-91.7382	39.05321	Callaway East	R3: (2007221955)	10#manure
19	-91.7382	39.05321	Callaway East	R3: (2007221955)	10#manure
20	-91.7381	39.05321	Callaway East	R3: (2007221955)	10#manure
21	-91.7381	39.05321	Callaway East	R3: (2007221955)	10#manure
22	-91.7381	39.05321	Callaway East	R3: (2007221955)	10#manure
23	-91.738	39.05321	Callaway East	R3: (2007221955)	10#manure
24	-91.738	39.05321	Callaway East	R3: (2007221955)	10#manure
25	-91.738	39.05321	Callaway East	R3: (2007221955)	10#manure
26	-91.738	39.05321	Callaway East	R3: (2007221955)	10#manure
27	-91.7379	39.05321	Callaway East	R3: (2007221955)	10#manure
28	-91.7379	39.0532	Callaway East	R3: (2007221955)	10#manure
29	-91.7379	39.05321	Callaway East	R3: (2007221955)	10#manure
30	-91.7379	39.0532	Callaway East	R3: (2007221955)	10#manure
31	-91.7378	39.0532	Callaway East	R3: (2007221955)	10#manure
32	-91.7378	39.0532	Callaway East	R3: (2007221955)	10#manure
33	-91.7378	39.0532	Callaway East	R3: (2007221955)	10#manure
34	-91.7377	39.0532	Callaway East	R3: (2007221955)	10#manure
35	-91.7377	39.0532	Callaway East	R3: (2007221955)	10#manure
36	-91.7377	39.0532	Callaway East	R3: (2007221955)	10#manure
37	-91.7376	39.0532	Callaway East	R3: (2007221955)	10#manure
38	-91.7376	39.0532	Callaway East	R3: (2007221955)	10#manure
39	-91.7376	39.0532	Callaway East	R3: (2007221955)	10#manure

Data Line	Obj. Id	Track(deg)	Swth Wdth(ft)	Distance(ft)	Duration(hr)	Elevation(ft)
1	1	88	17.5	5.315	0.00028	814.01
2	2	90	17.5	5.249	0.00028	813.67
3	3	86.32	17.5	5.545	0.00028	813.26
4	4	88.16	17.5	6.004	0.00028	812.81
5	5	90	17.5	5.807	0.00028	812.53
6	6	90	17.5	5.676	0.00028	812.11
7	7	91.8	17.5	5.61	0.00028	811.77
8	8	90	17.5	5.84	0.00028	811.73
9	9	90	17.5	5.873	0.00028	811.53
10	10	91.64	17.5	6.89	0.00028	811.25
11	11	92.73	17.5	7.382	0.00028	811.09
12	12	90	17.5	7.579	0.00028	811.03
13	13	92.63	17.5	7.579	0.00028	810.85
14	14	90	17.5	7.579	0.00028	810.85
15	15	92.73	17.5	7.644	0.00028	810.68
16	16	90	17.5	7.513	0.00028	810.51
17	17	92.73	17.5	7.644	0.00028	810.43
18	18	92.63	17.5	7.612	0.00028	810.36
19	19	92.73	17.5	7.644	0.00028	810.44
20	20	90	17.5	7.546	0.00028	810.32
21	21	92.73	17.5	7.612	0.00028	810.26
22	22	92.73	17.5	7.841	0.00028	810.26
23	23	92.54	17.5	8.005	0.00028	810.11
24	24	92.63	17.5	8.104	0.00028	810.02
25	25	92.54	17.5	8.136	0.00028	809.91
26	26	92.63	17.5	8.301	0.00028	809.8
27	27	95.08	17.5	7.94	0.00028	809.79
28	28	90	17.5	7.841	0.00028	809.65
29	29	95.26	17.5	7.94	0.00028	809.59
30	30	90	17.5	8.268	0.00028	809.36
31	31	92.54	17.5	7.94	0.00028	809.27
32	32	92.54	17.5	7.874	0.00028	809.03
33	33	92.54	17.5	8.202	0.00028	808.85
34	34	92.63	17.5	8.202	0.00028	808.66
35	35	92.54	17.5	8.104	0.00028	808.46
36	36	92.63	17.5	8.366	0.00028	808.07
37	37	92.54	17.5	8.629	0.00028	807.87
38	38	92.54	17.5	8.235	0.00028	807.63
39	39	95.08	17.5	8.005	0.00028	807.4

Data Line	Area Count	Diff Status	Time	Y Offset(ft)	X Offset(ft)
1	On	Yes	8/14/2008	0	0
2	On	Yes	8/14/2008	0	0
3	On	Yes	8/14/2008	0	0
4	On	Yes	8/14/2008	0	0
5	On	Yes	8/14/2008	0	0
6	On	Yes	8/14/2008	0	0
7	On	Yes	8/14/2008	0	0
8	On	Yes	8/14/2008	0	0
9	On	Yes	8/14/2008	0	0
10	On	Yes	8/14/2008	0	0
11	On	Yes	8/14/2008	0	0
12	On	Yes	8/14/2008	0	0
13	On	Yes	8/14/2008	0	0
14	On	Yes	8/14/2008	0	0
15	On	Yes	8/14/2008	0	0
16	On	Yes	8/14/2008	0	0
17	On	Yes	8/14/2008	0	0
18	On	Yes	8/14/2008	0	0
19	On	Yes	8/14/2008	0	0
20	On	Yes	8/14/2008	0	0
21	On	Yes	8/14/2008	0	0
22	On	Yes	8/14/2008	0	0
23	On	Yes	8/14/2008	0	0
24	On	Yes	8/14/2008	0	0
25	On	Yes	8/14/2008	0	0
26	On	Yes	8/14/2008	0	0
27	On	Yes	8/14/2008	0	0
28	On	Yes	8/14/2008	0	0
29	On	Yes	8/14/2008	0	0
30	On	Yes	8/14/2008	0	0
31	On	Yes	8/14/2008	0	0
32	On	Yes	8/14/2008	0	0
33	On	Yes	8/14/2008	0	0
34	On	Yes	8/14/2008	0	0
35	On	Yes	8/14/2008	0	0
36	On	Yes	8/14/2008	0	0
37	On	Yes	8/14/2008	0	0
38	On	Yes	8/14/2008	0	0
39	On	Yes	8/14/2008	0	0

Data Line	Rt Apd Liq(gal(US)/ac)	Pass Num	Speed(mph)	Prod(ac/hr)	Date
1	4709.7	1	3.624	7.687	8/14/2008
2	5618.4	1	3.579	7.592	8/14/2008
3	2257.9	1	3.78	8.019	8/14/2008
4	1102.6	2	4.094	8.683	8/14/2008
5	2538.6	2	3.959	8.399	8/14/2008
6	2587.3	3	3.87	8.209	8/14/2008
7	3336.4	3	3.825	8.114	8/14/2008
8	2617.9	3	3.982	8.446	8/14/2008
9	2600	3	4.004	8.494	8/14/2008
10	1020.3	3	4.698	9.964	8/14/2008
11	2126.2	3	5.033	10.68	8/14/2008
12	1126.2	3	5.167	10.96	8/14/2008
13	1097.4	3	5.167	10.96	8/14/2008
14	822.31	3	5.167	10.96	8/14/2008
15	907.17	3	5.212	11.06	8/14/2008
16	830.7	3	5.123	10.87	8/14/2008
17	1629.6	3	5.212	11.06	8/14/2008
18	819.96	3	5.19	11.01	8/14/2008
19	1639.6	3	5.212	11.06	8/14/2008
20	720.15	3	5.145	10.91	8/14/2008
21	823.49	3	5.19	11.01	8/14/2008
22	798.6	3	5.346	11.34	8/14/2008
23	781.13	3	5.458	11.58	8/14/2008
24	768.68	3	5.525	11.72	8/14/2008
25	769.24	3	5.548	11.77	8/14/2008
26	1119.5	3	5.659	12	8/14/2008
27	788.82	3	5.413	11.48	8/14/2008
28	794.2	3	5.346	11.34	8/14/2008
29	1358.9	3	5.413	11.48	8/14/2008
30	752.37	3	5.637	11.96	8/14/2008
31	1573.8	3	5.413	11.48	8/14/2008
32	789.3	3	5.369	11.39	8/14/2008
33	758.18	3	5.592	11.86	8/14/2008
34	1190.8	3	5.592	11.86	8/14/2008
35	1539.9	3	5.525	11.72	8/14/2008
36	822.13	3	5.704	12.1	8/14/2008
37	1278	3	5.883	12.48	8/14/2008
38	1715	3	5.615	11.91	8/14/2008
39	1313.3	3	5.458	11.58	8/14/2008

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