EVALUATING SPINNER-DISC CONTROL TECHNOLOGY FOR THE DISTRIBUTION OF POULTRY LITTER

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Clayton Marshall Campbell

Certificate of Approval:

John P. Fulton, Co-Chair
Assistant Professor
Biosystems Engineering

Wesley C. Zech, Co-Chair
Assistant Professor
Civil Engineering

Timothy P. McDonald
Associate Professor
Biosystems Engineering

Larry G. Crowley
Associate Professor
Civil Engineering

Charles W. Wood
Professor
Agronomy and Soils

George T. Flowers
Dean
Graduate School

EVALUATING SPINNER-DISC CONTROL TECHNOLOGY FOR THE DISTRIBUTION OF POULTRY LITTER

Clayton Marshall Campbell

A Thesis

Submitted to

the Graduate Faculty of

Auburn University

in Partial Fulfillment of the

Requirements for the

Degree of

Master of Science

Auburn, Alabama
May 9, 2009

EVALUATING SPINNER-DISC CONTROL TECHNOLOGY FOR THE DISTRIBUTION OF POULTRY LITTER

Clayton Marshall Campbell

Signature of Author

Date of Graduation

VITA

Clayton Marshall Campbell, son of Steve and Sherre Campbell, was born August 4, 1984, in Gadsden, Alabama. He graduated from West End High School in 2002, and then attended Snead State Community College, in Boaz, Alabama, for two years. In 2004, he enrolled at Auburn University where he graduated with a Bachelors of Biosystems Engineering degree in August of 2006. Directly after graduation, he entered the Auburn University Graduate School to pursue a Master's of Science degree in Civil Engineering. During graduate school he worked as a graduate research assistant in the Biosystems Engineering Department. He married Kimberly Jackson, daughter of Kem Jackson and Deborah Cunningham, on August 9, 2008.

THESIS ABSTRACT

EVALUATING SPINNER-DISC CONTROL TECHNOLOGY FOR THE DISTRIBUTION OF POULTRY LITTER

Clayton Marshall Campbell

Master of Science, May 9, 2009
(B.B.S.E., Auburn University, 2006)

150 Typed Pages

Directed by John P. Fulton and Wesley C. Zech

Technological advancements, such as variable-rate technology (VRT), in agricultural application equipment have led to the belief that application accuracy of crop inputs have improved. However, minimal research has been conducted to thoroughly validate this assumption; especially for organic fertilizers such as poultry litter which is inherently variable making it difficult to uniformly apply. Therefore, research was conducted to characterize and compare poultry litter mass and nutrient distribution patterns for a closed-loop system (CLS; spinner-disc control) and an open-loop system (OLS) determining: 1) whether spinner disc-control improves the distribution of litter, 2) the association of nutrient and mass patterns, and 3) if spread variability exists along the direction of travel. A typical litter spreader equipped with an electronically adjustable hydraulic flow control (proportional) valve was used to test the CLS and compare these results to the OLS, using a manual valve. Three application rates of 2242, 4483, 6725 kg/ha were selected for applying broiler litter using a two-dimensional pan matrix to assess spread distribution. The results indicated that the CLS was able to maintain more consistent spinner-disc speeds thereby producing less variable distribution patterns over the rates tested. The CLS also produced smaller coefficients of variation, 22% to 34%, for the majority of the mass and nutrient treatments improving spread uniformity by up to 17% over the OLS. Mass ($p = 0.0524$) and nutrient ($p = 0.0657$) pattern comparisons revealed that overall differences existed between the two systems. The nutrient patterns were highly correlated ($r > 0.98$) with their respective mass patterns indicating that even though particle size variability exists across the width of spread, the distribution of mass reflects nutrient distribution. The longitudinal results determined that variability along the direction of travel does exist when litter is applied; however, it was considered random. Overall, the CLS is recommended over the OLS especially if variable-rate application (VRA) is utilized or if application rates are changed frequently.

ACKNOWLEDGEMENTS

First and foremost, I thank God for guiding me through the good times and strengthening me though the bad, without Him I could do nothing. I would like to express my gratitude to all of those in the Biosystems Engineering Department that helped, in any part, toward the finishing point of my research. If it were not for those who helped in the field, Jonathan Griffith, Christian Brodbeck, Corey Kichler, Daniel Mullenix, Ajay Sharda, Tye Harbuck, Russell Davis, etc., I would not have made it to the completion of this thesis. My sincerest appreciation goes out to those who served on my committee, Dr. Tim McDonald, Dr. Wes Wood, and Dr. Larry Crowley, and to Dr. Wesley Zech for serving as the co-chair of this project. I want to especially thank Dr. John Fulton for advising me for the past two years. Thanks for all the leadership, patience, knowledge, and wisdom that you shared with me. Lastly, I would like to thank my wife (Kimberly), my parents (Steve and Sherre), and the rest of my family and friends for all the love and support that they have shown me throughout my academic endeavors.

Style manual used: Auburn University Graduate School Guide to Preparation and Submission of Theses and Dissertations

Computer software used: Microsoft Office 2002 - Microsoft Word 2002, Microsoft Excel 2002; SAS v. 9.1.3

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CHAPTER ONE

INTRODUCTION

1.1 PREFACE

In Alabama and across the United States, use of organic fertilizer has increased considerably over inorganic fertilizers due to recent escalating prices of manufactured fertilizers. Figure 1.1 illustrates fertilizer pricing in the U.S., for three of the most common types of fertilizer, from 1960 to 2007. From 2002 to 2007 alone, ammonium nitrate price increased by 49%, super phosphate by 47%, and potassium chloride by 41% (ERS-USDA, 2007; figure 1.1) leading producers to consider using organic fertilizers since they are typically cheaper while providing similar fertilizer value for producing crops.

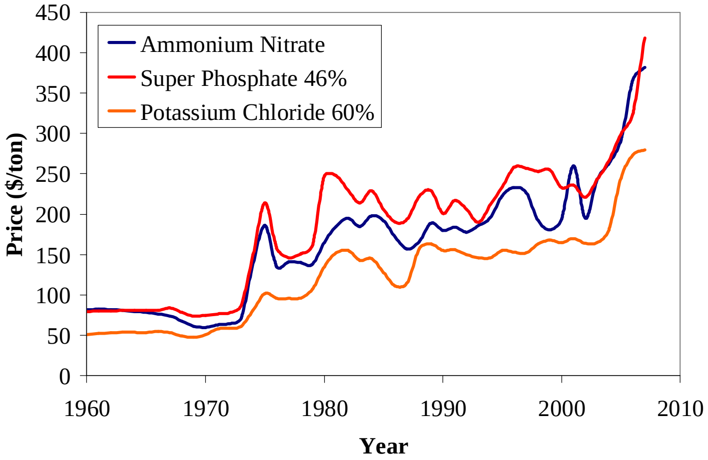


Figure 1.1. U.S. fertilizer pricing from 1960 to 2007 (ERS-USDA, 2007).

Similarly, poultry production, especially in Alabama, has also increased over the last decade. In Alabama, there was approximately 1.7 million tons of poultry litter produced during 2006 (figure 1.2; Mitchell et al., 2006). The quantity of litter produced in the state has become a problem due to the fact that the majority of poultry farms are located in the northern half of the state with 28% of poultry (broiler) production occurring in four neighboring counties: Blount, Cullman, Marshall, and Dekalb (NASS-USDA, 2007). Dense poultry production in this area promotes over-application of litter which is attributable to the high cost of transporting the litter to areas of low soil fertility.

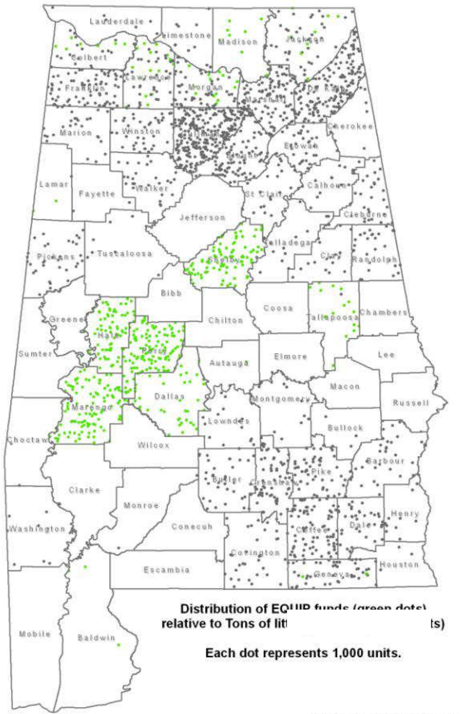


Figure 1.2. Amount of litter produced during 2006 Alabama (brown dots).

Several past and current research efforts have been conducted to offset rising fertilizer costs and more efficiently manage organic fertilizer production. However, limited research, if any, has addressed using variable-rate technology (VRT) to more efficiently apply organic fertilizers, such as poultry litter. VRT is growing among the agricultural community and in recent years has been recognized as a method to increase input use efficiency for applying inputs (seed, fertilizer, lime, pesticides, etc.) to cropland while improving environmental stewardship. The concept of applying poultry litter using VRT is a new method which has not been thoroughly investigated. This research makes a step toward the concept of variable-rate application (VRA) of poultry litter by testing the hypothesis that controlling spinner disc speeds when varying application rate on a standard spinner disc spreader will improve the distribution of poultry litter.

1.2 JUSTIFICATION

Limited research has been conducted to thoroughly investigate the application of poultry litter. Most studies have focused on synthetic fertilizers, such as urea, potash, ammonium nitrate, etc., with little attention toward organic fertilizers. With the increase in poultry litter production in Alabama and the potential negative environmental effects that are related with the over-application of litter, it is believed that measures need to be taken to improve distribution of poultry litter during application. Recent precision agriculture (PA) technology could have the potential to improve over-application issues associated with poultry litter.

Poultry litter is often used as a fertilizer and soil amendment even though it is inherently variable in its physical characteristics, making it difficult to maintain the desired uniform distribution using standard spinner-disc spreaders; the most common equipment used to land apply litter. In previous research, numerous tests have been conducted to determine the effects of certain spreading variables on the application of poultry litter but no attempt has been made to control the speed of the spinner discs of a standard litter spreader on-the-go. This type of technology is capable of providing a more desirable spread pattern, improving uniformity, and ultimately lowering the potential for environmental degradation especially if application rates are being changed.

Maintaining an acceptable distribution of litter is essential to reduce over-application of litter in environmentally sensitive areas. The foremost environmental concern with litter is its phosphorus (P) content. On average, litter has an average fertilizer rating of 3-3-2 ($N-P_2O_5-K_2O$; Wood, 1992), meaning that it contains as much P_2O_5 as it does nitrogen (N). This becomes a problem when farmers apply litter to meet N requirements which is typically much higher than the P requirement. This type of action leads to a buildup of P in the soil potentially causing harmful amounts of P to be deposited into surface waters via runoff. This is particularly an issue in Alabama where approximately 90% of litter generated is used to fertilize crop and pasture lands. Thus, more recently states are basing litter application on P to meet environmental regulations. If too much P reaches the surface water, the process of eutrophication can take place.

Eutrophication is simply an increase in chemical nutrients. In this case, P initializes rapid growth of algae in water, often known as an algae bloom. Microorganisms in the water then feed on the algae, taking in large amounts of oxygen, along with the decomposition of the algae, depleting the water of the required amount of oxygen for aquatic life to survive. This creates a harmful environment for aquatic life. The Phosphorus index (P index), a tool to assess P movement across the landscape, is used to help eliminate some of the hazards associated with P application.

When applied appropriately, poultry litter is a good fertilizer source providing all the major nutrients. Wilhoit et al. (1993) measured N and carbon (C) concentrations but not P and K. To effectively manage litter nutrients it is important to study the effects that all the macronutrients have on the spread pattern. Also, particle size can impact distribution and thus needs to be considered when taking the variability of litter into account. In most cases, particle size tends to affect the nutrient management in poultry litter. Koon et al. (1992) determined that the nutrient fraction for each of the macronutrients (N, P, and K), increased as the particle size fraction decreased. However, Wilhoit et al. (1993) reported that carbon (C) concentrations increased with increased particle size and nitrogen (N) content within each size fraction varied randomly. It is common for higher concentrations of nutrients to reside in the smaller particles when dealing with poultry litter. With this being the case and the fact that when using a spinner spreader, large and small particles are distributed differently across the swath, it is important to determine how nutrient and mass patterns interact with one another. Traditionally, only the amount of material applied (mass basis) is considered with no thought about how the nutrients may be distributed. If mass and nutrient distribution varies differently then maybe nutrient content rather than material mass should be considered when applying litter.

As previously stated, variability of poultry litter has been studied for mass, nitrogen, and carbon patterns. These studies however were only conducted in one location with one row of collection devices. More focus needs to be put on how to obtain a better understanding of uniformity as the applicator traverses a certain area. Multiple rows of collection devices would potentially inform the operator about the overall applicator performance both longitudinally (along the direction of travel) and transversely. This 2-D testing can better help understand variability of the spreader.

A key goal when applying fertilizer is to apply the desired amount. Utilizing VRT to vary application rate across a field can reduce over-application of litter by spatially applying the proper amount to meet local fertility needs. Due to the natural variability of litter, concerns exist that the use of VRT with spinner-disc control may actually have a negative impact on litter application. In essence, VRT might increase application errors associated with litter. However, if it does improve litter application, then it is assumed that it can improve distribution of synthetic fertilizers when VRT is implemented as long as the proper spreader and control settings are utilized. A new technology being considered to improve the distribution of granular or dry products by spinner spreaders is spinner-disc control. The idea behind this technology is that a closed-loop system is used to maintain the set spinner-disc speed no matter the mass flow of material conveyed onto the discs. Traditional spinner disc speed control uses an open-loop system which is unable to compensate for varying material flow onto the discs resulting in speed fluctuations. Therefore, maintaining the set speed could improve application uniformity.

1.3 OBJECTIVES

The overall goal of this research was to determine if maintaining a constant spinner disc speed via a closed-loop system (CLS) can improve the distribution of poultry litter compared to a traditional open-loop system (OLS) since speed variations can exist with the open-loop system. The objectives of this research were to:

1. Evaluate a traditional open-loop system (OLS) for spinner-disc speed control on a poultry litter spreader versus a closed-loop system (CLS) over a range of application rates.
2. Compare and contrast characterized litter mass and nutrient patterns to determine if nutrients are spread differently than mass along with assessing the difference between an OLS and CLS for spinner-disc speed control.
3. Determine if longitudinal variability exists when applying poultry litter with the open- and closed-loop systems over a range of application rates.

1.4 ORGANIZATION OF THESIS

This thesis is presented in manuscript format. Chapter 1 provides introductory statements justifying the emphasis that was put toward this research followed by the main objectives. Chapter 2 is an extensive literature review supplying information on the characteristics of poultry litter and poultry litter application. Each of the Chapters 3 through 5 represents an individual manuscript that focuses on different portions of this research. The results within these chapters illustrate the manner in which poultry litter is distributed using two spinner-disc speed control systems. Chapter 3 characterizes and assesses the mass distribution patterns provided by these systems; where Chapter 4 does the same for the nutrient distribution patterns and forms a comparison with the mass and nutrient patterns. Chapter 5 covers the variability that an applicator provides as it traverses longitudinally across an area. Chapter 6 summarizes the project, presents the overall conclusions, and includes suggestions for opportunities of future research. At the end of the thesis, a single Reference section and Appendices was developed.

CHAPTER TWO

LITERATURE REVIEW

With escalating prices of inorganic fertilizers, organic fertilizers, such as poultry litter, are being heavily utilized as a major source of crop nutrients. In recent years, this increasing trend has initiated research projects focusing on the different variables associated with using organic fertilizers. Several publications were reviewed to gain knowledge on the characteristics of organic and inorganic fertilizers, mainly focusing on poultry litter. These articles included physical and chemical properties, storage, and environmental impacts of poultry litter as well as its ability to be uniformly distributed during field application to cropland. However, limited research has been conducted to fully understand the fertilizer value of poultry litter and our ability to apply it accurately based on site-specific crops needs or fertility levels. Therefore, several manuscripts were reviewed to understand the use of variable-rate technology (VRT) to more efficiently spread granular fertilizers and lime. Other publications related to application distribution and uniformity were also reviewed to quantify the potential of using similar ideas when applying poultry litter.

2.1 POULTRY LITTER

In Alabama, 1.5 to 2 million tons of poultry litter are produced annually (Mitchell and Tyson, 2007). Approximately 90% of this litter is utilized as fertilizer by applying it to crop and pasture lands. Litter particles are variable in size and nutrient concentration making it difficult to uniformly apply based on crop and soil requirements. The majority of Alabama poultry production is located in the northern half of the state with production facilities densely located within a few counties with limited land around these facilities to apply litter. Therefore, since litter is not a dense material, it is not economical to transport over large distances resulting in litter being applied near these facilities and leading to multiple applications within the same field or pasture over the years. Transporting the material to locations of low soil fertility is an option but is generally a route that is not taken due to high fuel prices (Wood et al., 1992). Decades of over-application have led to environmental issues with high phosphorus (P) levels in surface water which initiated the creation and use of the P index to manage the application of litter.

2.1.1 PHYSICAL AND CHEMICAL PROPERTIES

When trying to attain the most efficient spread pattern, physical and chemical properties of the material being utilized are important since they can impact uniformity. Koon et al. (1992) conducted a study to determine if physical and chemical characteristics of pine shavings, used as a bedding material in a poultry house, changed over a four grow-out period. Samples were taken after each grow-out for a period of four grow-outs and analyzed for particle and chemical analyses. After each grow-out, fresh pine shavings were placed on top of the old litter, after samples were taken. Each sample was sieved, and then each size fraction was averaged and blended together for chemical analyses. Three samples of fresh pine shavings were also sieved and analyzed in the same manner. Results indicated there was little variation in particle size of the pine shavings poultry litter over the four grow-out period. As for chemical analyses, the nutrient concentration for each of the macronutrients (nitrogen (N), phosphorus (P), and potassium (K)) increased as the particle size fraction decreased However, the majority of nutrients were retained on the larger sieves resulting from more mass being retained on the larger sieves. In contrast, Wilhoit et al. (1993) reported that carbon (C) concentrations increased as particle size increased and the N content within each size fraction varied randomly. Pezzi and Rondelli (2002) noted that particle size of poultry litter seemed to decrease with longer storage times.

Glancey and Hoffman (1996) investigated physical properties of poultry manure and compost to determine bulk mechanical properties and their effect on material handling systems, such as spreaders. The properties investigated were bulk density, moisture content (MC), angle of repose, maximum lump size, and static frictional characteristics. Tests were conducted on fresh poultry manure clean-out and crusted material, crusted and clean-out poultry manure stored at 5 weeks and 14 weeks, and fresh compost material under three conditions: poultry manure composted with dead chickens, municipal solid waste (MSW) composted with dewatered sludge, and MSW composted with poultry manure. An analysis of variance determined that outside storage and an exposure to rainfall of poultry manure significantly increased the MC, static coefficient of friction, and wet bulk density (majority of the increase was within the first 5 weeks of outside storage). Outside storage did not affect the angle of repose or lump size of poultry manure. A dependence of wet bulk density on MC across all of the solid wastes evaluated was also determined. Results from this finding illustrated that MC is more important than knowing the source of waste material. There was little practical difference of the static coefficients of friction for poultry manure with a high or low MC with regard to designing material handling systems. However, it should be noted that unscreened waste has larger lump sizes and should be considered when designing these systems. Wilhoit et al. (1993) also determined the importance that litter MC and number of flocks raised on the litter can play when trying to attain uniform application when considering mass as well as nutrient content.

2.1.2 NUTRIENT MANAGEMENT

Many researchers over the years have studied ways to more efficiently manage broiler litter as a fertilizer (Coloma et al., 2004; Wood, 1992; Mitchell et al., 2007). Coloma et al. (2004) and Wood (1992) have both concluded that litter should be combined with an inorganic N fertilizer then applied. This blending will meet the soil P requirements as well as the crop nutrient requirements while minimizing environmental impacts. This blend would also cut down on the hauling expense of fertilizer to the field as well as the over application of P (Coloma et al., 2004). Wood (1992) also stated the reason poultry litter is often preferred over other manures is because of its high nutrient content and the fact that it can produce relatively equivalent yields as synthetic fertilizers but at lower costs.

Coloma et al. (2004) conducted tests on untreated broiler litter as well as treated (screened) to determine the available nitrogen (AN):P_2O_5 and C:N ratios. Results illustrated that screening the litter significantly lowered the bulk density of the retained fraction indicating a higher porosity in the retained fraction. However, the screened fraction contained a higher portion of nutrients. Results of the C:N tests indicated that the retained fraction was significantly higher than the untreated litter, however, for its use in composting there would still need to be some carbon material added to reach the desired C:N ratio. The results of the AN:P_2O_5 test showed the AN:P_2O_5 ratio for the screened litter was not significantly increased as compared to the untreated litter. In conclusion, they determined that the fraction of nutrients passing through the screen followed a similar pattern as the fraction of raw litter mass and by blending an inorganic fertilizer with the screened fraction could reduce the material application rate by 72% when compared to untreated broiler litter. This indicates that only a portion of the smaller fraction of litter after sieving would need to be used to supply the nutrient requirements of specific crops. This is based on the finding that nutrient concentration is higher in smaller particle sizes. This method would require added N fertilizer for crops or pastures but could help minimize environmental concerns associated with P runoff by reducing the amount of applied litter.

The NRCS Code 590 (USDA-NRCS, 2002) was created to manage all aspects of nutrient application to the soil by setting regulations on timing, amount, source, and placement of nutrients. Many laws were generated to attempt to reduce environmental pollution related to applying animal waste to the soil. The regulations that pertain to the application of poultry litter in Alabama are: application shall be 15.24 m from surface waters of the state, 30.48 meters from the nearest occupied dwelling, church, school, hospital, park, or non- potable water wells, 61 meters from Outstanding National Resources Water, Outstanding Alabama Water, potable water wells, or public water supply, and it is not to be applied across property boundaries unless the adjoining property owner consents in writing. All precautions should be taken to eliminate or minimize nonpoint source pollution to the ground and surface waters. Each site, farm, or field shall be evaluated using the P index and the Leaching Index to assess the movement of applied nutrients in the soil to protect the quality of the water resources in the state. For those fields that are located in environmentally high risk areas, erosion, runoff, and water management controls shall be installed. To determine the allowable amount of nutrients that can be applied, a soil test must be conducted using either the Auburn University Soils Testing Laboratory or an acceptable laboratory. Soil tests older than three years shall not be used for nutrient planning. It is recommended that soil amendments, such as lime, should be used to adjust soil pH prior to nutrient application. When it comes to nutrient application, it states that the application of nutrients needs to be based on current soil test reports and that the application shall not exceed 10% of the intended rates of the field. When applying organic by-products, such as poultry litter, the acceptable rate is generally based on the amount of P that can be applied to the soil due to the P index rating of the field. When the vulnerability rating (P index rating) is very low/low, litter can be applied to meet the N requirement even if it means the P rating exceeds 10% of the established application rate. However, when a rating above medium is determined, the litter should be applied to meet the P intended rate and in this case an additional source of N can be used to meet the N requirement. Organic by-products can not be applied in Alabama during the fall and winter seasons unless it is on actively growing crops. In north Alabama, no application can occur between November 15 and February 15 due to crop inactivity.

Mitchell et al. (2007) addressed issues of nutrient management when dealing with broiler operations to protect water quality. The authors discussed the need for a Comprehensive Nutrient Management Plan (CNMP) on every farm and the requirements needed to apply the CNMP. The nutrients of primary concern were N and P due to their leaching and runoff characteristics, respectively. There were five steps to this CNMP. The first being, estimate broiler litter amount (pounds of meat produced per year * ½ pound of litter per pound of meat), compost production, and storage facilities. Next, estimate the nutrient value of the litter and compost. Poultry broiler litter is generally a 3-3-2 fertilizer rating (Mitchell et al., 2007 and Wood, 1992). Then, map and calculate land area for spreading using an aerial photo or topo map. Next, determine the crop and nutrient needs for each field using recent soil tests. The P index also needs to be utilized to determine the amount of P that can be applied. Finally, determine uses for excess litter and compost.

Armstrong et al. (2006) examined irregular soil sampling on a field of long-term litter application to predict the areas of accumulation and loss of nutrients in a field. Soil samples from plots with different topography on an irregular grid were collected and analyzed for nutrient content. Nutrient accumulations for both fields were identified easily with the irregular soil sampling method. For field A, the elevation increased as the N and P concentrations decreased, however, field B had a positive relationship between elevation and N and P. This research determined that by using irregular soil sampling points and focusing on topography and landscape of a field that nutrient accumulation after long-term litter application can be determined. This was accomplished by examining topography and landscape positions to determine water movement via hydrological pathways. This type of sampling could help create more accurate nutrient management plans that in the long term would reduce surface and groundwater pollution in areas of long-term poultry litter application.

A study was conducted in north Alabama on pastures of long term litter application and on pastures with no litter application to determine the severity of litter application to the landscape (Wood, 1992). It was found that in the litter applied fields more nitrate (NO_3-N) was found below 50 inches indicating that excessive NO_3-N leaching occurs on litter applied fields. Also, in the long term litter applied fields the extractable P concentrations averaged 530% higher than the other fields in the upper 0.61 m of the soil. Wood (1992) concluded that long term litter application at the disposal rate degraded the environment and one way to minimize this degradation was to apply litter based on the soil P test which also decreased the NO_3-N leaching.

2.1.3 ENVIRONMENTAL ISSUES

Even though poultry litter is a good source of fertilizer, it can potentially impact the environment (Wood, 1992; Coloma et al., 2004; and Armstrong et al., 2006). The majority of environmental contamination occurs in dense poultry producing regions such as the mountainous regions of Alabama and Arkansas. This problem originates because there is not enough land to safely spread all the litter that is produced, leading to over application in areas of high slope and shallow soils to the bedrock. Other hazards that are associated with broiler litter application are: poor timing of disposal, low efficiency of nutrient recovery, and lack of knowledge concerning nutrient, heavy metal, and soluble salt release (Wood, 1992).

Nitrate leaching and P runoff are the two major environmental concerns when discussing poultry litter application. When NO_3 reaches the groundwater it can have harmful effects on humans as well as livestock if too much of it is consumed (Armstrong et al., 2006 and Wood, 1992). Farmers often apply litter to meet the N requirement of their crop; however, in doing so they over apply P as well as N leading to the previously stated issue. This over application often leads to a buildup of P in the top layer of the soil and through runoff and erosion makes it to the surface water in terms of a pollutant, diminishing the water quality and putting the aquatic life into a hazardous situation (Coloma et al., 2004; Armstrong et al., 2006; and Wood, 1992). In certain regions, the environmental hazard related to litter could be controlled if the cost of the transportation was low enough to haul the material to areas of low soil fertility or high yielding crops.

2.1.4 PHOSPHORUS INDEX

The Phosphorus Index, commonly referred to as the P index, is nothing more than a tool utilized to assess the risk of P movement into surface waters. The P index is used widely across the agricultural community as well as many other environmental agencies. It is important for farmers, agronomist, engineers, etc. to understand the P index and its parameters. Without this knowledge it is easy to over apply and apply excess P that can be discharged into surface water. The main purpose of the P index is to identify sites that are of potential hazard to the environment. These hazards are associated with the potential risk of P movement to water bodies. The movement of P can be categorized into three main factors: transport, P management, and P source (USDA NRCS, 1994). Over the past many years the P index has become an exceptional tool when it comes to protecting and preserving the environment. Many versions of the P index exist due to differing regional and geographic conditions. Alabama’s P index determination method is somewhat different than the method proposed above by the NRCS. It incorporates other factors that are specific in nature to Alabama (USDA-NRCS, 2001). Best management practices (BMP) are being put into affect to reduce site vulnerability to P applications ultimately reducing the P index. Some of these BMPs are grassed waterways, setbacks from streams, filter strips, limited animal access to surface waters, and lower P applications (Mitchell and Tyson, 2007).

2.1.5 LITTER STORAGE

Each state has its own set of rules and suggestions when it comes to poultry litter storage. Regulations do seem to very from state to state; however, each state always seems to have one main point, environmental quality. Literature summarized below was selected from two states and the issue of environmental quality is addressed in each.

According to the Virginia Department of Environmental Quality (VDEQ), if poultry litter is not going to be used immediately it must be stored properly. The storage facility must be of adequate size and located where it will not cause environmental risk to water quality. The site must be 30.48-m from surface water, intermittent drainage, wells, sinkholes, and rock outcrops with a slope no greater than 7%. If litter is to be stored outside longer than 14 days it must be covered with an impermeable layer that will not allow storm water to run onto it or under it and it must resist wind. If it is to be stored where the water table is less than 0.61-m, then an impermeable layer should be placed underneath the litter. Acceptable layers are: 30.48-cm of compacted clay, 10.16-cm of concrete, or other impermeable layers with a minimum permeability rating of 0.0036-cm/hr. No one is permitted to store litter where the water table is less than 0.030-m. One must remove all litter residues from the storage area when storage is no longer needed.

The Alabama Cooperative Extension System (ACES) identified BMPs to help minimize litter storage in hopes to reduce possible environmental risks. Determining storage requirements and sizing storage structures is generally determined by estimating broiler production and the density of the litter (on average 500-kg/m^3). Managing litter can reduce the need for litter storage. BMPs for reducing litter storage include: schedule cleanouts so they can be land applied and reduce wet spots in the house by using more efficient drinker lines. There are many ways to store litter, such as, open stockpile (must be compacted), covered stockpile, covered stockpile with temporary ground liner, covered stockpile with permanent ground liner, and a roofed storage structure. No matter the storage method, the litter must be protected from rainfall, leaching, and runoff. Effective storage of litter retains nutrients in the manure as well as protects the environment (Donald et al., 1996).

2.2 CALIBRATION

Calibration is important to determine the rate and uniformity that the spreader is operating at and is a key component in maintaining a target rate. It also helps setup the hardware and software when using VRT. Fulton et al. (2005b) found that the simulated overlap plots displayed that pattern adjustments could be made to produce better distribution patterns for all applicators and also that overlap patterns should be generated at calibration to more efficiently quantify application uniformity. If improper calibration of an applicator is conducted then the applicator could be off target with the desired application rate and distribute material incorrectly. Proper calibration can also reduce environmental risk associated with applying poultry litter (Mitchell and Tyson, 2001). Marsh et al. (2003) and the Virginia Cooperative Extension stated that it is important to apply manure at the desired rate to meet, however not exceed, the nutrient requirements of a specific crop.

The American Society of Agricultural and Biological Engineers (ASABE) Standard, S341.3, Procedure for Measuring Distribution Uniformity and Calibrating Granular Broadcast Spreaders, provides a uniform method to test, analyze, and report performance data on spinner spreaders (most common type of fertilizer applicator). This standard establishes guidelines for test setup, collection devices, test procedures, determination of application rates, and effective swath width. Examples of a few of the standard test setup variables include ground slope (<2%), wind velocity (<8-km/h), and hopper fill level (at least 40% to 50% capacity) (*ASABE Standards*, 2004).

The ACES published an article identifying a procedure for calibrating poultry litter spreaders considering the large amount of litter produced in Alabama each year (Mitchell and Tyson, 2001). Many factors affect and should be monitored during calibration including: ground speed, power take off (PTO) speed, discharge opening, and swath width. Mitchell and Tyson (2001) discussed three methods of calibration. The first method was just to apply the litter uniformly over a field of known size and can only be accomplished if the litter load weight is known. The next method utilized a tarp to cover a known portion or the ground and then making three equally spaced passes (equal to swath width) over the tarp. Finally, the material on the tarp was weighed, divided by the tarp area, and converted to an application rate. The last method included setting pans out in the field and again making three passes over the pans. Then the material in the pans were weighed and plotted to determine the material distribution and uniformity. The Virginia Cooperative Extension proposes very similar calibrating procedures as the ACES. One of the major differences is they propose using the tarp method to determine uniformity and swath width rather than the pan method. To ensure the correct amount of litter is applied, do not change the spreader settings after calibration (Marsh et al. (2003)).

Parish (2000) used three commercial fertilizer spreaders and two products to compare delivery rates calculated from using collection trays with delivery rates from spreader calibration tests. Pattern tests were conducted on all the spreaders and pans were set out to conform to the ASABE S341.3 standard. The spreaders were passed over the pans three times and then the application rate was determined by converting the mass in the collections pans to kg/ha. Then calibration of the delivery system was conducted for each spreader. The distribution mechanism was removed from each of the spreaders to allow the material to be caught in a bucket and the application rate was determined. Results indicated that half of the comparisons between the rates determined by pattern data and rates determined by calibration were statistically significantly different. In most cases, the rates from pattern data were higher. This is assumed to be due to the fact that the tests were conducted on a hard surface causing the particles to bounce into the collection pans. In conclusion, the study confirmed that significant spreader delivery rate errors can be generated from pattern tests when conducted on a smooth surface; however, errors may or may not occur on a rough surface. Parish (2000) suggests that rate calibration be conducted after an effective swath width is determined by pattern testing.

2.3 VARIABLE-RATE TECHNOLOGY

Utilizing variable-rate technology (VRT) to more uniformly apply fertilizers can reduce over-application of nutrients by spatially applying the proper amount to meet local fertility needs. Studies have been performed to determine the affect of VRT on fertilizer application (Fulton et al., 2001; Lawrence and Yule, 2005; Molin et al., 2002). However, no literature was found on using VRT for applying poultry litter. It is assumed that if VRT can improve the application of inorganic fertilizers then it can be utilized to improve litter application.

Lawrence and Yule (2005) evaluated the different spreader testing protocols used throughout the world and the potential for the machine to perform VRT was assessed. A spreader truck with dual spinners operating at 750 rpm and urea application rates of 80, 100, and 150 kg/ha was tested. The protocols tested included two ISO standards, ASABE S341.3, European Standard, the ACCU-Spread, and the Spreadmark standard. A pan matrix of 1400 pans which represented 18 simultaneous tests was laid out to conduct the tests. The coefficient of variation (CV) was used to compare the different testing methods with a CV of 15% deeming an acceptable pattern. The conclusion made between the different testing methods was the only significant difference in calculating the maximum swath width of all the methods was with the ISO(i) and the Spreadmark methods. Also, single transverse tests did not fully represent the actual spread pattern, for this multiple tests need to be conducted. As for the potential for VRT, it was concluded that for variable-rate technology to be effective for spreading in the farming industry a greater understanding of the current spreading equipment performance would be required.

Fulton et al. (2001) used a spreader truck with dual rear spinner discs equipped with VRT to test variable-rate (VR) distribution and uniformity. The ASABE standard 341.2 was followed for all aspects of the testing. Multiple tests were conducted to determine fixed-rate application as well as variable-rate application of potash at high and low application rates. Analysis found that CVs over 20% were calculated for the average transverse patterns at high and low application rates. The uniform application at high and low rates was modeled from the average transversal spread patterns. It was determined that modeled application at the uniform rates and both rate changes predicted the actual application well. It was also noted that there was good uniformity at the low application rate but pattern changes occurred at the high application rate suggesting that modifications need to be made to the spreader to gain uniformity.

A study was conducted to determine the effect of VRT when using a three-point hitch mounted fertilizer spinner spreader (Molin et al., 2002). Tests using urea were conducted in the transversal and longitudinal directions where pans were set out to meet the ISO 5960 standard. The CV was chosen to compare results of the transversal tests, 15% being acceptable. For the transversal distribution tests, a swath width of 24-m resulted in the best uniformity at all application rates (50, 150, and 250 kg/ha). For the longitudinal tests, two treatments were run changing the application rate on-the-go to look at the effect of the change in rate using the VRT. These tests concluded that the response time for the VRT was 3.1 seconds to an increasing step and 5.6 seconds for a decreasing step. Finally, the flow rates obtained during the tests were found to be lower than the desired flow rate.

Lark and Wheeler (2003) tested two technologies, VRT of an input following a treatment map and yield monitoring to measure the crops response, to investigate the response of a combinable crop to an input. These technologies were used during fertilization and harvesting, respectively. The findings confirmed that local response functions can be estimated from designed fertilizer experiments harvested using commercial yield mapping. This technology can help farmers decide if they need to apply or not apply fertilizers or other inputs to maximize economic returns for each field.

Schueller and Wang (1994) described some of the different methods available for applying fertilizers. Typical methods used for these types of applications are Automatic Control (sensors sending feedback to a controller) and Temporally Separate Control (use of a prescription map). Global Positioning Systems (GPS) is often used for each of these methods and the accuracy of variable-rate application (VRA) depends on the accuracy of the GPS data utilized to map the fields (Chan et al., 2002). VR applicators are desired for this form of work and generally use some type of feed-forward control which allows the appropriate rate of fertilizer to be applied. Note the applicators tested were liquid applicators; however, with some modifications the same principles apply to dry applicators. The accuracy of these applicators depends on the immediate response to a command change which relates back to the time constant of the system. A simulation test was conducted on a desired spatially variable field and results indicated that the feed-forward control could reduce the error in application considerably. Without this pre-command technology, the use of spatially variable control will not reduce application errors (Schueller and Wang, 1994).

2.4 UNIFORMITY

Various research attempts have been made to improve uniformity of fertilizer application using standard spinner disc spreaders (Smith et al., 2004; Kweon and Grift, 2006; and Hofstee, 1995). Most of the studies used manufactured fertilizers not poultry litter, but knowledge can be gained by evaluating the investigations on manufactured fertilizers. Effects of wind speed and direction, along with other climatic parameters, on the uniformity of fertilizers have been examined. Parish (2002) determined that material flow increased while uniformity decreased. Also, many new technologies, such as feedback control, use of optical sensors, and Doppler velocity meters, have been tested to determine the parameters that most affect the spread pattern.

Smith et al. (2004) researched the effect of wind speed and wind direction on lateral and transversal spread uniformity of ammonium nitrate and potash, as well as the overlap pattern uniformities of triple 13 fertilizer using a spinner spreader truck operating at a spinner speed of 640 rpm. Pans were set out for all tests and results are presented using the progressive method of distribution. For ammonium nitrate, the CVs generally increased as the swath width increased for all wind speeds and wind directions while the potash CVs remained constant. The average CVs for the potash and ammonium nitrate tests were 19.2% and 21.1%, respectively at their respective effective swath widths. For the 13-13-13 tests, uniformity under cross wind applications were more uniform than head wind applications. Finally it was determined that the amounts of N, phosphate, and potash, in the triple 13 blend, collected in the pans were proportionately distributed in relation to the total deposit.

Researchers have worked toward providing improved distribution of granular materials over varying application rates without recalibration using automatic control systems; however, uniformity is not guaranteed (Kweon and Grift, 2006). Kweon and Grift (2006) utilized optical sensors, measuring velocity and particle size exiting a spinner spreader, to predict particle landing position and then send feedback to an algorithm which controls the feed gates of the material onto the spinners. Results indicated that without the feed gate adaptation method unacceptable patterns were produced at the high application rates with acceptable patterns at the low rates. When the feed gate adaptation (VRA) method (use of optical sensor and control algorithm) was used to simulate spread patterns, acceptable patterns were produced for both spreaders at any application rate. The authors stated that feed gate control needs to be field tested with the optical sensor and control algorithm before applying to every day use.

Hofstee (1995) studied the effect that physical properties of fertilizer have on uniformity when using spinner disc spreaders. An important factor that affects the behavior of the spread pattern is the motion of the particles on the vane surface with the most important physical property of the particles being the coefficient of friction on the vane surface. A simulation model and spreading tests were used to determine the influence of the particle parameters on the spread pattern. A pair of Doppler Velocity Meters was used to determine the velocity and direction of the particles that passed the measuring zone. Results indicated the effect of the coefficient of friction on motion of the fertilizer particles developed by the simulation model is not easily expressed through spreading tests. In conclusion, mass flow played the main role of the motion of the particles on the disc; however, it could not be modeled. After this finding it was suggested that when applying fertilizers on a site-specific basis, it would be better to vary ground speed rather than mass flow to maintain an optimum application rate.

2.5 DISTRIBUTION PATTERNS

The distribution patterns of fertilizer products are dependent upon the type of spreader and hardware settings being utilized. These patterns also vary depending on the type of fertilizer being spread. Researchers since the mid 1900's have studied distribution patterns of various fertilizers, including poultry litter, based on the variables previously mentioned to determine the most efficient way to distribute fertilizer based on mass as well as nutrients.

Parish (1999b) and (2003a) conducted tests to determine if ASABE S341.3 standard provided the best method to evaluate spinner spreader performance. Parish (2003a) compared pattern tests laid out by the ASABE standard to alternate tests where the applicator and collection devices were stationary, proposed by some spreader manufacturers. After analyzing both testing procedures, it was concluded that the stationary method was more difficult and yielded data inconsistent with the accepted ASABE S341.3 protocol. Parish (1999b) used multiple spreaders to test the theory laid out in the ASABE S341.3 that all tests should be conducted with the hopper filled and leveled at 40 to 50% capacity. When the hopper fill level was between 50 to 100%, there were no rate changes observed; however, when the fill level dropped below 50% highly significant changes occurred. The author concluded that hopper fill level can be a concern especially when the fill level drops to 10% capacity and that ASABE's requirement of 40 to 50% is acceptable.

In recent studies, some focus has been put toward the design of spinner discs on a spreader. Parish (2003b) theorized that impeller angle affected the distribution pattern of fertilizer by changing the material trajectory and drop location, ultimately changing the point where the particle leaves the impeller. In all cases as the impeller was angled upward patterns were skewed more to the right and as it was angled downward the patterns were skewed more to the left. The author suggests mounting a bubble level on the hopper of the spreader in view of the operator to ensure that the spreader stays level during operation. Yildirim (2006) focused on determining if vane number on a single disc rotary spreader affected the distribution patterns, of multiple fertilizers, over a range of application rates. Six different vane numbers (2, 4, 6, 8, 10, and 12) were used with orifice diameters of 30, 40, and 50-mm to allow for three flow rates. The author stated that single disc spreaders typically have six vanes where traditional twin disc spreaders have two vanes per spinner disc. Vane height was pre-selected for each fertilizer based on the finding that vane height did significantly affect uniformity. Tests showed that while vane number increased the CV also increased for each flow rate. This study also determined that for each vane number the CVs increased with increasing flow rate. Results illustrated that the best distribution patterns for all fertilizers tested were generated with two vanes at the lowest flow rate.

As it is stated previously the ASABE S341.3 outlines the acceptable method to test spinner spreaders; however, in some cases researchers believe there could be a better way to tests such applicators. Reed and Wacker (1970) studied the effect of indoor broadcast testing, justifying the process by eliminating environmental factors, such as wind. The tractor and spreader remained stationary while the collection pans were moved to simulate field operation. The authors concluded that indoor testing provided acceptable data and allowed for testing of many of the spreader variables. Kaplan and Chaplin (1997) proposed a new method to compare patterns generated by different sized collection devices concluding that it was acceptable compared to other methods. Parish (1999a) evaluated the effect of multiple passes over a single row of pans compared to a single pass believing that run-to-run variations could be averaged out with multiple passes. Results indicated that data will be consistent when using either a single test or multiple tests for spreader pattern testing.

2.5.1 GRANULAR FERTILIZER TESTING

Research on granule fertilizers is more common than organic fertilizer considering its usage from an agronomic standpoint. Many technologies have been proposed and utilized to assess their effect on the distribution patterns of these fertilizers. Fulton et al. (2005b) used VRA of muriate of potash with four applicators to differentiate the distribution patterns over different application rates. Two spinner spreaders and two pneumatic spreaders were utilized. Results indicated that the pneumatic applicators provided consistent patterns; however, the optimal swath width with the lowest CVs was produced by one of the spinner spreaders. Diallo et al. (2004) installed and tested an electronically actuated gate on a ground driven pull-type (buggy) spreader using granulated fertilizer. Results concluded the relationship between mass flow and gate opening were linear for all materials tested and CVs fewer than 15% were generated for swath widths 3-m or less. The author noted that a ground driven spreader cannot guarantee a stable spinner speed but still allowed for low CVs. Diallo et al. (2004) also compared truck spreader patterns to buggy spreader patterns and determined that they were similar when operated under comparable conditions.

New technology always seems to be on the rise to improve distribution. Grift and Hofstee (2002) developed a sensor with the capabilities of collecting data from all angles around the rear of the spreader to allow for real-time prediction of the spread pattern. This sensor mounts on and rotates around the rear of the spreader. Results showed the sensor produced an excellent indication of fertilizer dispersion behind the spreader and provided similar results on particle size diameter when compared to the hand measurements. It also demonstrated that the spread pattern was skewed to one side and found that the optimal swath width was lower than that of the manufacturer's recommendations. The author's stated that the sensor needs to be validated using the ASABE S341.3 testing standard.

2.5.2 POULTRY LITTER TESTING

Pezzi and Rondelli (2002) conducted a study on a prototype manure spreader to more efficiently distribute poultry litter by increasing the swath width and making it easier to fertilize orchards. The litter was composed of different degrees of composting and MC's. The spreader was pull type with an auger conveying system and tubular mixing mechanism in the hopper. Hydraulics were utilized to power the rear gate as well as the distribution system to allow for the drop location of material on the spinners to be adjusted. Vanes on the spinners were modified to extend approximately two inches past the spinner and a rear adjustable shield was put in place to allow for spreading in broadcast method or in bands. During testing, the spinner speeds, drop location, and rear shield were adjusted to determine the appropriate spreader settings. The CV was utilized to analyze the results with a CV of less than 30% considered acceptable. Results for broadcast distribution indicated high spinner speeds and drop locations away from center of the spinners were desired. This is ironic considering most manufacturers' recommend drop locations near the center of the spinners (Chandler Equipment Company, 2008). Based on the results the prototype spreader performed better when the percentage of large particles was the lowest (Pezzi and Rondelli, 2002).

Wilhoit et al. (1993) used a centrifugal-type broadcasting spreader to evaluate the distribution pattern of poultry litter based on weight along with studying the effect that particle size has on nutrient distribution across the swath. The spreader used had a ground driven chain with two spinners that ran off of the tractors hydraulic system and operated at 600 rpm. Litter samples within each pan were weighed and sieved, and then the samples were recombined and analyzed for nutrient content (N and C) at each location. A CV was used to assess uniformity. Bulk litter analysis illustrated that C concentrations increased with increased particle size and the N content within each size fraction varied randomly from 3.2 to 4.16%. The pan analysis found that both C and N concentrations were uniform across the swath indicating that even though variations occurred between particle size and nutrient content these variations did not affect nutrient uniformity. Other results illustrated that the smaller particles tended to land more directly behind the spreader (3.7-m to either side) with the larger particles being distributed farther out (6.1-m to either side). The manufacturers recommended swath width was not found to be the optimum width and results suggested that swath widths lower than the manufacturers recommendation may need to be utilized when applying poultry litter.

CHAPTER THREE

SPINNER-DISC TECHNOLOGY TO ENHANCE POULTRY LITTER APPLICATION

3.1 ABSTRACT

As technology advances for applicators, it is assumed that control and distribution of material should improve. A study was conducted to evaluate if spinner disc-control improves the distribution of poultry litter. A typical litter spreader equipped with an electronically adjustable hydraulic flow control (proportional) valve was used to test a closed-loop system (CLS), spinner-disc control, and compare these results to a traditional open-loop system (OLS), using a manual valve. Three application rates of 2242, 4483, 6725 kg/ha were selected for applying broiler litter. Litter was collected based on ASABE S341.3 testing protocol but modified to assess pattern uniformity using a two-dimensional pan matrix. Analyses included assessing variability and consistency of distribution patterns and spinner speeds between the two systems. The CLS was able to maintain more consistent spinner-disc speeds only allowing 1-6 rpm differences between the spinner-discs where the OLS allowed 1-12 rpm differences. The CLS also consistently provided smaller CVs (23% to 28%) over the range of application rates. However, pattern comparisons revealed no overall differences existed between the two systems. Based on the results, significant differences were found between the systems (p=0.0524) recommending the CLS when performing variable-rate application (VRA).

3.2 INTRODUCTION

The use of poultry litter as a fertilizer and soil amendment has increased recently due to the increasing prices of inorganic fertilizers. However, poultry litter is inherently variable in its physical characteristics making it hard to maintain the desired uniform distribution using standard spinner-disc spreaders; the most common equipment used to land apply litter. Recent precision agriculture (PA) technology could have the potential to improve the distribution of poultry litter. Over the past several years, various research attempts have been made to gain a better understanding of variables that affect distribution of granulated fertilizer products using various types of spreaders including spinner-disc spreaders. Most of these studies focused on manufactured fertilizers, such as urea, potash, ammonium nitrate, etc., with few focusing on organic fertilizers, such as poultry litter. Numerous tests have been conducted to determine how the spread pattern and uniformity is affected by spreading variables such as material chemical and physical properties, weather conditions, machine parameters, and the use of variable-rate technology (VRT). Further, environmental concerns associated with applying poultry litter must also be considered. Therefore, the ability to maintain acceptable litter distribution is needed to minimize the over-application of litter in environmentally sensitive areas potentially leading to runoff issues.

To maintain an acceptable distribution with poultry litter, it is believed that some control of the spinner-discs needs to be obtained during application. Many other spreading variables have been tested when using poultry litter, such as with the prototype spreader by Pezzi and Rondelli (2002), on-the-go feed gate control (Kweon and Grift, 2006), and variable ground speed rather than varying mass flow (Hofstee, 1995).

However, no research has been conducted on spinner speed control. By utilizing spinner speed control via a hydraulic flow control valve, the speeds of the spinners will remain constant rather than fluctuating as mass flow varies onto the discs allowing a more uniform and desirable application.

In Alabama, approximately 90% of the litter generated annually is used for fertilizing crop and pasture lands. Due to this heavy usage over the years, there has been an accumulation of phosphorus (P) in the soil potentially causing harmful amounts of P to be deposited into surface waters via runoff. Utilizing VRT to more efficiently apply fertilizers can reduce over-application of litter by spatially applying the proper amount of litter to meet local fertility needs. Due to the natural variability of litter, concerns exist that the use of VRT with spinner-disc control may actually have a negative impact on litter application by increasing application errors. However, the use of VRT for litter application could improve the overall distribution of litter across a field providing an alternative to reduce environmental concerns while maximizing yields.

3.3 SUB-OBJECTIVES

The objectives of this investigation were to: (1) characterize the distribution patterns of poultry litter and compare a closed-loop system (CLS) to an open-loop system (OLS) for spinner disc speed control over a range of application rates and (2) evaluate the accuracy of litter application under simulated field operation to determine if spinner speed control (CLS) improves the distribution of poultry litter.

3.4 MATERIALS AND METHODS

A standard litter/shavings spreader manufactured by Chandler Equipment Company was used for this investigation (figure 3.1a). This pull-type spreader utilized hydraulically controlled dual rear spinner-discs and apron chain (figure 3.1b). The spreader utilizes 0.6-m diameter spinner discs with four uniformly spaced vanes. A John Deere 6420 tractor was used during testing to pull the spreader and was equipped with a John Deere GreenStar^{TM} AutoTrac^{TM} system using real-time kinematic (RTK) correction (Appendix A). Topcon's Zynx X20 computer/controller loaded with Topcon's Spreader Control software program (Appendix D) was used and provided both VRA and spinner-disc speed control capabilities. The X20 uses inputs such as spreader variables (ex. gate height), product density, and swath width along with ground speed to maintain the desired application rate. Sensors were mounted under both spinner-discs (52 pulses/rev) and on the rear shaft of the apron chain (360 pulses/rev) to control and monitor the speeds for the Spreader Control program. A Visual Basic (VB) code was developed to log these speeds during testing (Appendix F) and was loaded onto a Zynx X15 computer (Appendix D). The VB program wrote all data to a .TXT file.


(a) **(b)**

Figure 3.1. Tractor, litter spreader, and illustration of collection pan matrix utilized during testing (a) and rearview image of spreader showing spinner-discs (b).

Hydraulic flow control for the apron chain and spinner-discs was maintained using Brand proportional valves with the Spreader Control program using speed sensor feedback (CLS) to maintain the desired speeds. The apron chain speed was controlled by a 57-L/min valve (Model No. EFC 12-15-12) while the spinner-disc speed was controlled by a 76-L/min proportional valve (Model No. EFC 12-20-12; figure 3.2). A standard Brand, manual valve (open-loop with no flow compensation) was used as the traditional hydraulic control system for the litter spreader (figure 3.2; Appendix C). The manual valve does not allow for feedback flow adjustment; therefore, the spinner disc speeds can fluctuate as mass flow onto them varies.

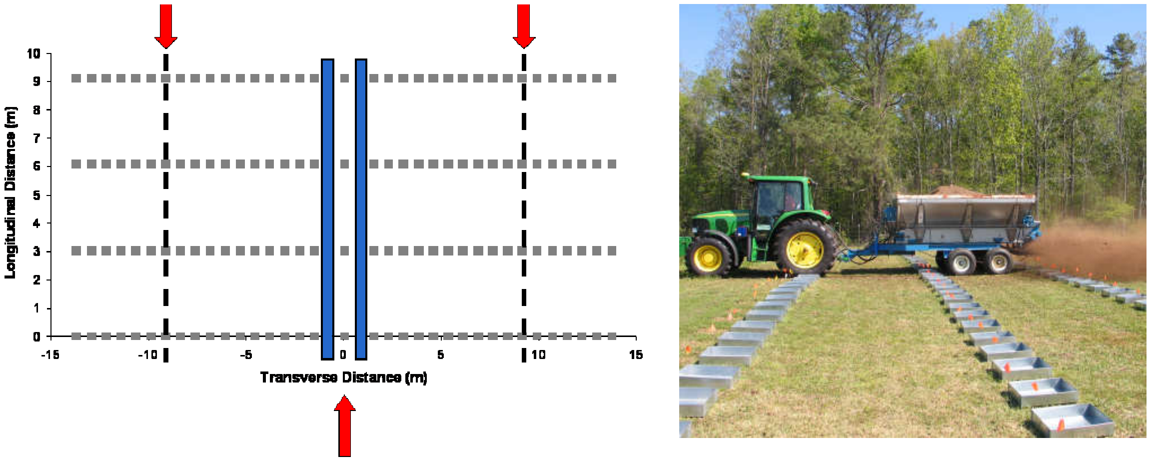
Figure 3.2. Illustration of the two different flow control valves used during testing with the proportional valve shown on the left and manual valve on the right.

Three application rates were selected: 2242, 4483, and 6725 kg/ha based on the recommended application range for poultry litter in Alabama. Therefore, a randomized complete block design was used with blocking based on the CLS and OLS with the three rates randomized within each block for a total of six tests. A block experimental design was needed since hydraulic hoses had to be disconnected between valves thereby minimizing potential oil spill. All tests were replicated three times with replications performed on different days.

Poultry litter was used for all tests. All tests were conducted to meet the requirements of the ASABE S431.3 testing standard (ASABE Standards, 2004). Prior to testing, both hardware and software calibration procedures were performed based on manufacturers' published literature. A single row of 35 pans, uniformly spaced at 0.8-m, was used during calibration. The pans were 50.8-cm long, 40.6-cm wide, and 10.2-cm tall. The pan on either side of the center pan was removed to allow the tractor and spreader to pass unobstructed. Calibration was conducted at the median application rate of 4483 kg/ha. Adjustments were made to the spreader until the most uniform application was accomplished. A swath width of 9.2-m was found to be the optimal, effective swath width for this spreader.

3.4.1 DATA COLLECTION

Four rows of pans were used for each of the six tests using a two-dimensional collection pan matrix (figure 3.3). A flag was placed at the front center of each pan to ensure the pan was placed in the same location for every test. A 3.1-m longitudinal and 0.8-m transversal pan spacing was utilized requiring a total of 140 pans.



(a) (b)

Figure 3.3. Pan layout for single-pass test (a) and equipment traversing pans (b).

Prior to testing, the spreader was loaded to meet the ASABE Standards (2004). Bulk samples of litter were collected randomly out of each hopper load to determine the moisture content (MC) and bulk density (BD). Only one load was required to run the six tests of an individual replication. All bulk samples were sealed in a plastic bag and labeled. Also prior to testing, three samples were taken and an average BD was measured, by a known volume container and digital scale, for input into the Spreader Control program. A gate height of 35.6-cm and a desired spinner speed of 600 rpm were used for all tests based on the calibration results. The spinner speed was programmed into the Spreader Control program for the CLS tests. For the OLS tests, the manual valve was hand-set to a flow that corresponded to 600 rpm when the spinners were loaded at the median application rate. Once the manual valve was adjusted to the desired setting, it was not adjusted again to ensure consistency for all replications. However, prior to each OLS test, observations were made to ensure that the proper spinner speed was being maintained. This procedure was also used for the CLS tests. For each test, the target application rate was entered into the Spreader Control program and a nominal ground speed of 6.4 kph was maintained. The wind speed was measured for each test and it never exceeded the 2.2 m/s maximum allowable wind speed for any test (table 3.1; ASABE Standards, 2004). The applicator was turned ON far enough in advance to allow the spreader to be at normal operating conditions prior to traversing the pans. The John Deere AutoTrac^{TM} guidance system was used during all tests to ensure the same path, over the center pans, was driven to minimize operator error.

Table 3.1. Wind Speeds observed during pattern testing.

System	Rate (kg/ha)	Rep 1 (m/s)	Rep 2 (m/s)	Rep 3 (m/s)
Closed-Loop	2242	1.61	0.27	0.00
	4483	0.89	1.21	0.00
	6725	1.34	0.45	0.00
Open-Loop	2242	0.67	1.25	0.00
	4483	0.89	0.89	1.12
	6725	0.80	1.12	0.89

3.4.2 DATA ANALYSIS

The material collected in each pan for each test was placed in a plastic bag, sealed, and labeled accordingly for laboratory analyses. A digital scale that measured to the nearest 0.01 g was used to weigh each sample. A mean mass measurement along with the standard deviation of the four rows at each transverse position was calculated, converted to an application rate, and used to generate the single-pass distribution pattern for each test. The 95% confidence interval (CI) was calculated for each transversal position and plotted to show the confidence around the mean. Microsoft Excel was used to summarize this data. Simulated overlap patterns, based on the progressive method (ASABE Standard, 2004), were also created from the single-pass patterns using the effective swath width. The mean, standard deviation, and coefficient of variation (CV) was computed and used to assess application uniformity. The mean and standard deviation was calculated by using every point in the overlap pattern. The CV was used to analyze the uniformity of the overlap patterns and was calculated by dividing the standard deviation by the mean. Perfect uniformity is defined by the overlap pattern resulting in a straight line when plotted or a CV = 0; indicating the same amount of material was applied across the swath. The single-pass patterns were then standardized based on the mean application rate computed using the overlap data to evaluate pattern similarities or shifts. The standardized patterns were determined by dividing each position in the spread pattern by the mean calculated rate from the simulated overlap patterns. For example, each position for the CLS low rate was divided by 2419 kg/ha (table 3.5) To assess the true nature of the spread pattern, the mean patterns for the three replications were averaged to generate overall mean patterns for the three different rates (2242, 4483, 6725 kg/ha). In the end there were three patterns for the CLS and the OLS.

Using the Statistical Analysis System (SAS Inst., NC), an analysis of variance (ANOVA) was conducted using the General Linear Model (GLM) to determine if statistical differences existed between the two different control systems based on the mean overlap patterns for each rate. The ANOVA compared the means between the systems, days (reps), and the rates as well as determined if an interaction occurred between the systems and rates (system by rate) and between the systems and days (system by day) (table 3.6). The Least Squares Means (LSM) procedure in SAS was used in conjunction with the ANOVA to confirm the possible significance of the overlap means. Pearson's Correlation Coefficients were calculated using SAS's CORR procedure to evaluate similarities or shifts between single-pass distribution patterns for each control system. An alpha value of 0.10 was used for statistical comparisons.

3.5 RESULTS AND DISCUSSION

The average MC and BD for the litter applied in each test was 25.8% and 542.5 kg/m^3, respectively (table 3.2). The litter used for calibration and replications 1 and 2 came from the same location even though there were slight differences in the litter from reps 1 and 2 according to the MC and BD data. These differences illustrate the natural variability of litter and how its physical characteristics can differ even when from the same farm. A different load of litter with similar physical characteristics was used for replication 3. When comparing the litter between replications, one can see that the BD from rep 3 was similar to that of rep 1 and rep 2 with only the MC being slightly less.

Table 3.2. Poultry litter MC and BD for each replication.

Replication	Moisture Content (%)	Bulk Density (kg/m^3)
1	26.7	538.9
2	27.1	550.6
3	23.7	538.2
Average	**25.8**	**542.5**

3.5.1 SPINNER SPEED ANALYSIS

During reps 1 and 2, an unusual characteristic was noticed when dealing with the spinner speeds. The hydraulic motors (Appendix B) that power the spinner discs were connected in series meaning the hydraulic fluid flows from the tank to the left motor (spinner 1), then to the right motor (spinner 2), and back to the tank. With the spinner discs operating with no load, they worked as expected with spinner 1 running slightly faster that spinner 2. However, once litter was conveyed onto the discs, spinner 2 was rotating faster than spinner 1 (Appendix G). In theory, this scenario is impossible considering the motors have equivalent displacement since they are matching gear motors. Unloaded spinner disc speeds were collected prior to each test for rep 3 (table 3.3). In all cases, spinner 1 ran faster than spinner 2 verifying the spinners were operating properly before being loaded, but this did not provide any explanation of what was observed during the tests. Another item to note is that the measured OLS pre-test speeds were approximately 50 rpm faster than the desired speed of 600 rpm. This higher speed was because the manual valve was set to run at the desired speed when the spinners were loaded at the middle application rate (2242 kg/ha). For the CLS, the spinner discs should operate at the desired speed since the proportional valve adjusts the hydraulic flow to maintain the desired speed whether loaded or unloaded.

Table 3.3. Summary of pre-test spinner-disc speed data.

System	Target (kg/ha)	Spinner 1 Mean (rpm)	Spinner 1 Std. Dev. (rpm)	Spinner 1 Diff. 1 [1] (rpm)	Spinner 2 Mean (rpm)	Spinner 2 Std. Dev. (rpm)	Spinner 2 Diff. 1 [1] (rpm)	Diff. 2 [2] (rpm)
Closed-loop	2242	601.1	3.9	1.1	595.5	4.2	-4.5	-5.5
	4483	603.2	1.8	3.2	598.7	1.7	-1.3	-4.4
	6725	601.3	0.8	1.3	596.1	0.6	-3.9	-5.3
Open-loop	2242	652.9	1.0	52.9	648.9	0.8	48.9	-4.0
	4483	655.7	4.2	55.7	654.5	1.1	54.5	-1.3
	6725	654.6	0.9	54.6	649.4	0.9	49.4	-5.3

1) Diff. 1 is the difference of the spinners from the desired speed of 600 rpm; positive and negative indicating when the actual speed is greater than or less than the desired speed, respectively.
2) Diff. 2 is the difference between spinners 1 and 2; negative indicating spinner 1 is faster.

Table 3.4 summarizes the speed results for the two different control systems over the three rates. The CLS was able to maintain spinner disc speeds near the desired 600 rpm (Diff. 1 column in table 3.2). Considering the magnitude difference between the three application rates, the CLS performed consistently with spinner 1 operating between 598 and 599 rpm and spinner 2 between 600 and 605 rpm. These are small differences when compared to the OLS results which varied more as shown by the higher standard deviations and speed differences (Diff. 2) between spinner 1 and 2. The CLS system also had smaller speed differences between the two spinner discs; 1 to 6 rpm. Of note, these values were the mean speed data over all replications. The speed differences between the spinners seemed to vary between replications, for both systems. However, the CLS provided more consistent spinner disc speeds over all the tests, the only exception coming during rep 2 where the OLS provided differences that were less than the CLS, from 1 to 5 rpm smaller (Appendix G). The reason behind this difference is unknown. For rep 2, spinner 2 operated uncharacteristically high, anywhere from 7 to 15 rpm, for all tests; however, this was not the case for reps 1 and 3.

Table 3.4. Summary of spinner-disc speed data computed for all replications.

		Spinner 1			Spinner 2			
System	**Target (kg/ha)**	**Mean (rpm)**	**Std. Dev. (rpm)**	**Diff. 1 [1] (rpm)**	**Mean (rpm)**	**Std. Dev. (rpm)**	**Diff. 1 [1] (rpm)**	**Diff. 2 [2] (rpm)**
Closed-loop	2242	599.5	6.4	-0.5	600.2	8.4	0.2	0.7
	4483	597.8	11.5	-2.2	604.1	13.5	4.1	6.4
	6725	598.7	9.6	-1.3	604.9	15.3	4.9	6.2
Open-loop	2242	630.4	15.2	30.4	631.5	14.6	31.5	1.1
	4483	602.1	11.8	2.1	613.6	13.7	13.6	11.5
	6725	598.3	25.5	-1.7	610.0	25.9	10.0	11.6

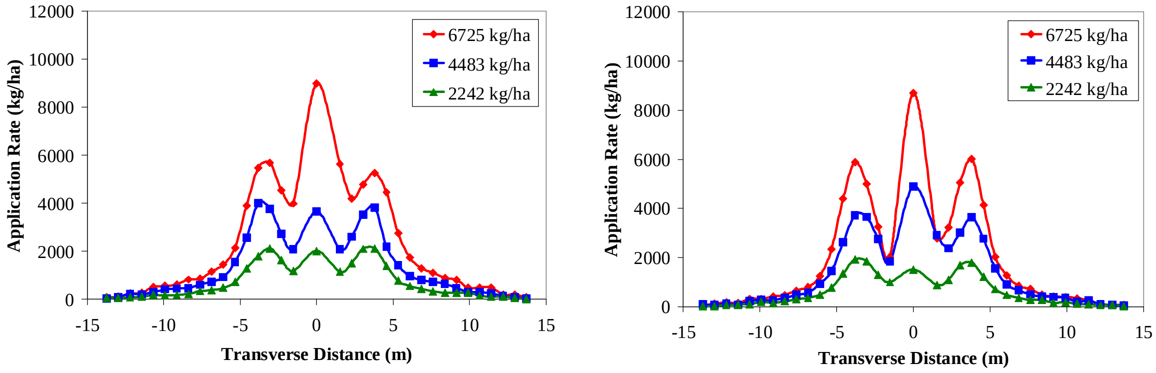
1) Diff. 1 is the difference of the spinners from the desired speed of 600 rpm; positive and negative indicating when the actual speed is greater than or less than the desired speed, respectively.
2) Diff. 2 is the difference between spinners 1 and 2; negative indicating spinner 1 is faster.

The main point about the spinner speed data is that the CLS was able to maintain the desired speed and a smaller differential speed between the spinner-discs when compared to the OLS. Initially, it was assumed the OLS would not be able to maintain the desired speed over a range of application rates without needing to reset the valve for each rate. The question then became, could the OLS maintain a constant spinner speed between the two spinner-discs better than the CLS, and it did not. These results indicated how an OLS was unable to maintain the desired and constant spinner speed allowing the speeds to vary as the load on the spinner-discs changed. However, no inferences can be made about if a CLS can improve the distribution of litter based solely on this data.

3.5.2 SINGLE-PASS ANALYSIS

The single-pass patterns for the closed- and open-loop systems are illustrated in figures 3.4a and 3.4b, respectively. A symmetrical pattern is desirable for spinner-disc spreaders since they rely on overlap from the adjacent passes. Thus, a symmetrical pattern will provide a more uniform distribution of material. When comparing the patterns of the two systems, the CLS patterns were more symmetrical and exhibited less variation along the center portion of the spread width (between -5 and 5 m) than those for the OLS. The patterns produced by both systems were "W" shaped. This type of pattern is usually undesirable due to its tendency to negatively affect the overlap pattern by generating non-uniform material distribution. This undesired shape is a prominent characteristic to note when trying to gain uniformity considering the center portion of the swath is where a majority of the material is applied, significantly impacting overlap patterns. Typically, hardware adjustments can be made to minimize or eliminate the "W" shape. Through extensive calibration of this spreader, no additional hardware adjustments were possible to minimize the final pattern shapes. However, Chandler has made adjustments to the hardware on the newer spreaders to minimize these errors.

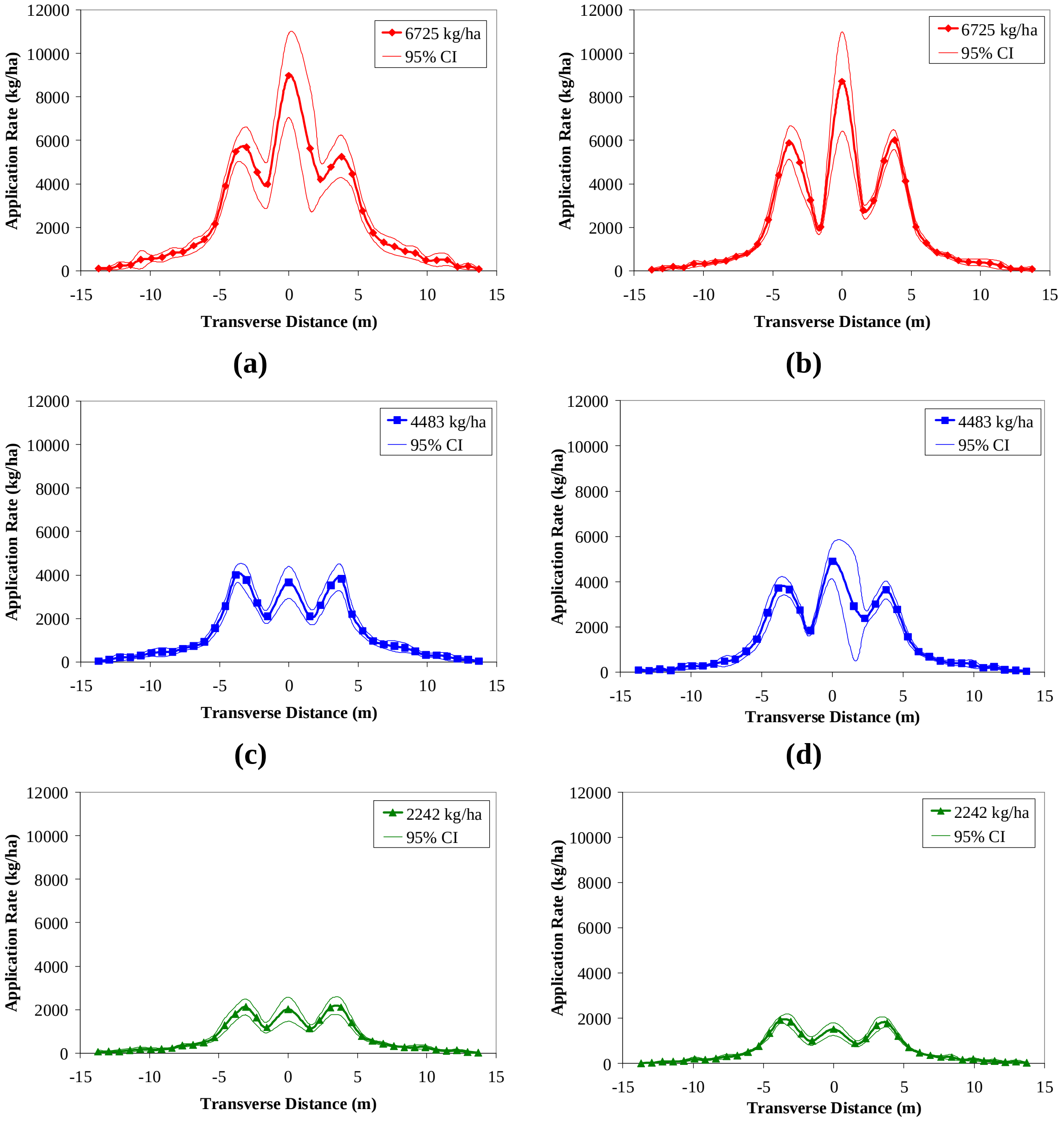
The single-pass patterns generated by the CLS were more desirable than the OLS patterns. Nevertheless, the CLS minimized the magnitude of the "W" shape for the two higher application rates. In comparison, the intensity of the "W" shape pattern increased with application rate for both systems which is typical when applying granular material. Another point of interest is the center peaks of the higher rates. The amount of material applied at these positions was much higher (approximately 2200 kg/ha) than the intended rate. The exact explanation behind this result is unknown. However, considering the over-application did not occur at the lower rates, it is possible that the spinners were overloaded with material bypassing the spinner disc and being deposited directly to the ground. Over-application is not desirable since it increases environmental risks following field application.



(a) Closed-loop system **(b) Open-loop system**

Figure 3.4. Overall mean single-pass distribution patterns for the two control systems.

The 95% confidence intervals (CI) were computed for each mean pattern to illustrate their variation. For the 2242 kg/ha rate, the CLS had a wider CI (figure 3.5e). This variation was also the case with the high application rate (6725 kg/ha; figure 3.5a); however, with the middle rate (4483 kg/ha) the OLS displayed the larger CI (figure 3.5d). In all cases variability decreased as the patterns extend to their outer limits and increased toward the center of the swath between ± 4.6 m. The greater variations resulted from larger amounts of material being applied at these locations as well as the uncharacteristic distribution of particle sizes (figures 3.5a and 3.5d). Normally, when applying poultry litter the larger particles are deposited on the pattern outer boundaries with the smaller



(a) **(b)**

(c) **(d)**

(e) **(f)**

Closed-loop system **Open-loop system**

Figure 3.5. Mean single-pass distribution patterns and 95% CI.

particles toward the center. With the CLS 6725 kg/ha pattern (figure 3.5a) and the OLS 4483 kg/ha pattern (figure 3.5d), large clumps of litter were deposited at the 1.5 m location in one of the tests resulting in a large CI around that point. This anomaly helps clarify that litter variability is difficult to control when spreading. In summary, the 95% confidence intervals revealed there was little difference in terms of variability about the mean pattern between the two systems.

3.5.3 OVERLAP-ANALYSIS

Table 3.5 presents the overall summary data for the simulated overlap patterns. Figure 3.3a illustrates the multiple passes needed to model the overlap patterns. In previous research conducted with inorganic fertilizers, a CV of 20% or less is considered acceptable. There was no literature found specifying an acceptable CV when applying poultry litter. All CVs were greater than 20%. Considering the inherent variability of litter compared to inorganic fertilizers, one would expect measured CVs to be higher thereby CVs up to 25% may be acceptable. Five out of the six tests produced CVs less than 30% with the middle rate for the CLS at 23%. This rate by far provided the best CV with the possible reason that the applicator was calibrated at this level. One would gather that this lower CV would also be the case for the OLS at the middle rate due to the same reason but it was not. For the OLS, the CVs increased going from the low to high rate.

None of the CLS CVs averaged higher than 28% and none of the OLS CVs averaged lower than 28% (table 3.5). While the low rate treatment CVs differed by only 1.6% (26.6% vs. 28.2%), this difference increased with the application rate to 7.0% for the middle rate and 10.8% for the high rate. Further, the OLS CVs ranged from 28% to 38% with the lowest CV (28.2%) occurring at the low rate and the higher two rates being equal to or greater than 30%. In contrast, the CVs for the CLS ranged between 26.6% and 27.6% being more consistent over the application rates tested. Therefore, the CLS provided improved uniformity over the OLS.

Comparing how close the mean rates were to the target rates showed that the CLS deviated more than the OLS for every rate. The CLS at the 6725 kg/ha rate over-applied by 739 kg/ha while the OLS under-applied for every rate (negative value in the Rate Diff. column). The rate differences tended to follow the same trend as the CVs with the lowest CV occurring at the CLS middle rate, the rate used for calibration, indicating improved spreader performance at the lower rates.

Table 3.5. Summary statistics for overall simulated overlap patterns.

System	Target (kg/ha)	Mean [1] (kg/ha)	Std. Dev. (kg/ha)	CV (%)	Rate Diff. [2] (kg/ha)
Closed-loop	2242	2419^d	644	26.6	177
	4483	4383^c	1009	23.0	-100
	6725	7463^a	2060	27.6	739
Open-loop	2242	2080^d	587	28.2	-162
	4483	4417^c	1326	30.0	-66
	6725	6500^b	2494	38.4	-224

1) Mean rates with similar letters indicate they are not statistically different at the 95% confidence level.

2) Positive and negative rate differences indicate over- and under-application, respectively.

Based on the LSM and ANOVA results, the mean application rates within each system were significantly different from one another as expected since a range of very different rates were chosen for the experiment (table 3.5 and 3.6). The letters next to the mean values in table 3.5 indicate whether there is a significant difference or not between the means. When comparing between systems, a significant difference was found only for the high rate. Differences between these control systems at the high rate are illustrated in the overlap patterns (figure 3.6). A p-value of 0.0524 was attained from the ANOVA for the systems illustrating there is a significant difference in the two control systems. Overall there was no statistical interaction between the systems and the rates denoted by a p-value of 0.1478 (P>0.10). However, figure 3.6 displays that a slight interaction did occur but still demonstrates that the systems responded in a similar fashion when applying the three different rates. The interaction could have been caused by the fact that the systems were calibrated at the middle rate. There was a significant difference in the Day (replication) response (p = 0.0617) indicating the need to block the replications into different days. Even though a difference was found for Day there was no 'System by Day' interaction identifying that the systems performed similar in nature.

Table 3.6. ANOVA results for the overlap pattern data.

Source	DF	Sum of Squares	Mean Square	P-value
System	1	804,347	804,347	0.0524
Day (Rep)	2	1,250,557	625,278	0.0617
Rate	2	67,373,417	33,686,709	<.0001
System by Rate	2	761,620	380,810	0.1478
System by Day	2	53,669	26,834	0.8444

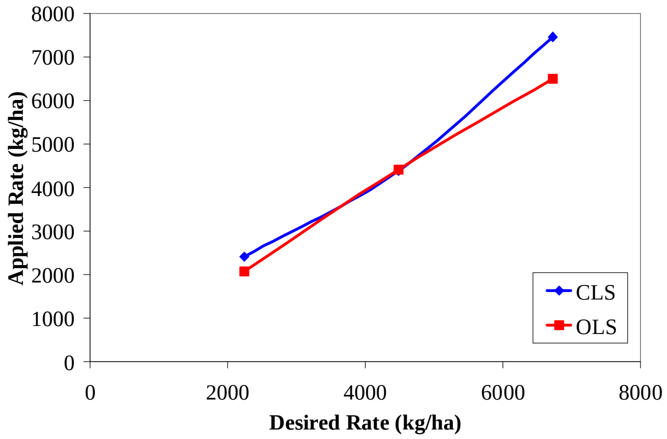
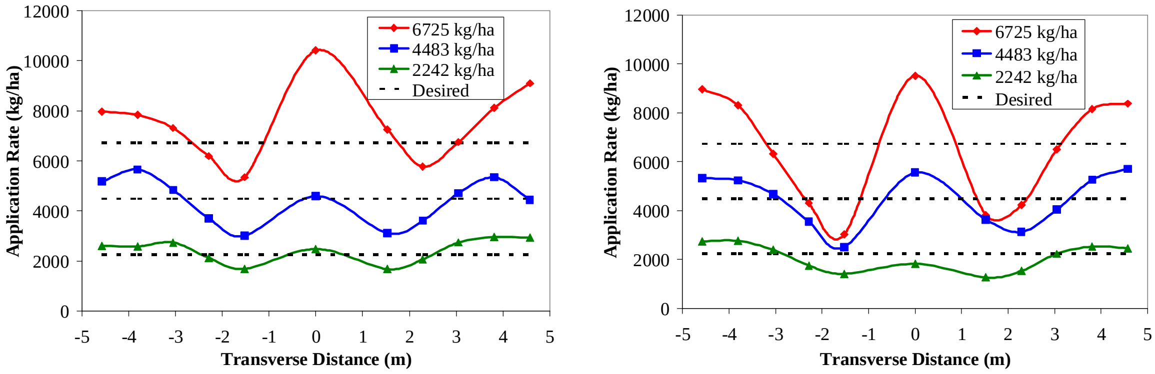


Figure 3.6. Illustration of System by Rate interaction.

Figure 3.7a and 3.7b depict the overlap patterns of the CLS and OLS, respectively. One can observe that the CLS produced more uniform spread patterns and that the overlap patterns followed the same "W" shaped pattern as the single pass patterns. For the CLS, the middle application rate again showed the least variation around the actual mean with both sets of patterns increasing in magnitude as the application rate increased. This proved that with the swath width of 9.2 m the single pass patterns directly affected the uniformity when using the progressive method of application. For the overall average patterns, the most uniform pattern illustrated by the lowest CV (23%) was the 4483 kg/ha rate for the CLS. The pattern with the worst uniformity was the 6725 kg/ha rate for the OLS (figure 3.7b).



(a) Closed-loop system (b) Open-loop system

Figure 3.7. Overall simulated overlap distribution patterns.

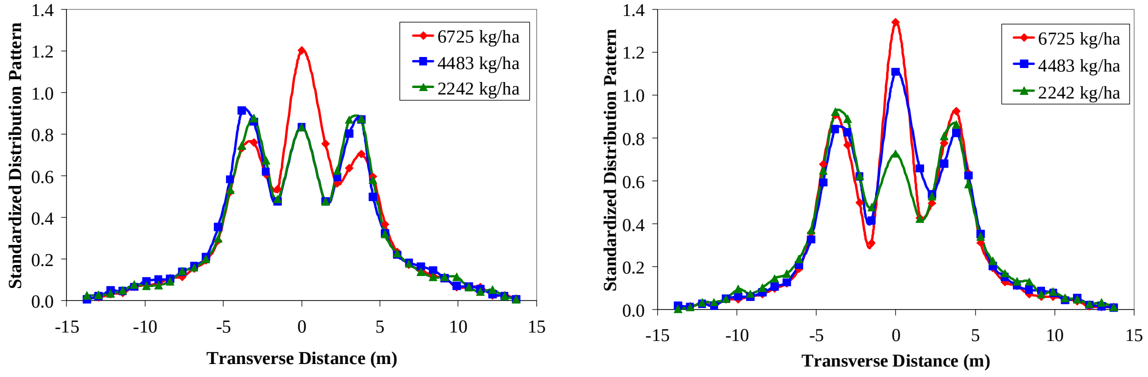
A horizontal line represents perfect uniformity (CV = 0) and is desired when analyzing overlap patterns. To obtain this type of scenario with this data the high rate values need to be shaved off to fill in the low areas for each pattern, considering the mean application rates are, for the most part, close to the desired rates. This relocation of material across the swath could require hardware adjustments on the spreader; such as, gate height, spinner speed, and divider location or a change in effective swath width. It is important to note that results of this investigation highlight the need for spinner speed control when implementing variable-rate application (VRA) of litter. As application rates change under a VRA scenario, spinner speed control can maintain the desired spinner speed as flow rate onto the disc varies, resulting in a more uniform distribution of material.

Overall the CLS provided an improved distribution over the OLS by generating smaller CVs for every application rate. This uniformity improvement was directly related to the CLS ability to maintain constant spinner disc speeds, via the proportional valve, of approximately 600 rpm rather than the speed variation allowed by the OLS. The OLS did provide less variation in actual rate compared to the desired rate and overall a significant difference was found between the two systems. If VRA is to be utilized then the CLS is recommended.

3.5.4 DISTRIBUTION PATTERN COMPARISON BETWEEN SYSTEMS

To be able to effectively compare the distribution patterns of each system at the different application rates, standardized patterns were analyzed. Figures 3.8a and 3.8b illustrate the standardized patterns plotted for the CLS and OLS, respectively. Both systems generated consistent patterns over the rates tested with slight pattern shifts taking place in both systems. The standardized patterns of the CLS showed some similarities and differences between the different rates. The 4483 and 2242 kg/ha patterns were consistent with one another with only a slight difference on the left peak. The 6725 kg/ha pattern illustrates a few more differences the most noticeable occurring with the center peak. This issue was brought about earlier with the single-pass analysis with the possible cause being that the spinner discs were being loaded to heavy too maintain speed. The

OLS standardized patterns also demonstrated similarities and differences. The left and right peaks for each rate seem to be fairly consistent with one another however some minor shifts occurred toward the center of the spread patterns. Again the most prominent difference with these patterns occurs at the center peaks. This is a trend with both systems and is directly related to the large amounts of material being deposited at the center location in return creating greater variability.



(a) Closed-loop system **(b) Open-loop system**

Figure 3.8. Overall standardized distribution patterns.

It was difficult to determine which system provided the most consistent patterns, so a correlation was conducted in SAS using the Pearson correlation procedure. Table 3.7 displays the results of the Pearson correlation. The low, mid, and high labeling represent the 2242, 4483, and 6725 kg/ha rates, respectively while the P and M are representative of the proportional and manual valves which are utilized in the CLS and OLS, respectively. The values under the correlation values (<.0001) in table 3.7 are the probability levels associated with each correlation. The results indicated the two control systems performed similarly over the range of tested application rates. The 2242 kg/ha rates of the two systems were highly correlated with a correlation value of 0.9851 with the 4483 kg/ha rates also being highly correlated (r = 0.9746). Even though the LSM results indicated that the means for the 6725 kg/ha rates were significantly different, the Pearson correlation showed the patterns were correlated (r = 0.9578).

Table 3.7. Pearson Correlation coefficients comparing the mean single-pass distribution patterns of each system.

	Low P	**Mid P**	**High P**	**Low M**	**Mid M**	**High M**
Low P	1.0000	0.9906	0.9466	0.9851	0.9714	0.9461
		<.0001	<.0001	<.0001	<.0001	<.0001
Mid P		1.0000	0.9448	0.9938	0.9746	0.9548
			<.0001	<.0001	<.0001	<.0001
High P			1.0000	0.9223	0.9879	0.9578
				<.0001	<.0001	<.0001
Low M				1.0000	0.9620	0.9411
					<.0001	<.0001
Mid M					1.0000	0.9790
						<.0001
High M						1.0000

3.6 SUMMARY

The distribution patterns of two spinner-disc speed control systems, CLS and OLS, were characterized and statistically analyzed to determine if the CLS provided an improved distribution over the OLS. The patterns from both systems were "W" shaped with the OLS patterns having a more defined shape exhibiting more variation. Spinner-disc speed analysis concluded that the CLS allowed for less spinner speed variation between the two spinners, generated consistent speeds, and maintained the desired speed of 600 rpm better than the OLS. Pattern comparison results determined that no overall interaction was found between the systems and the rates indicating the systems responded in a similar fashion over the range of rates; however, differences were found between the

6725 kg/ha rates. Statistically, the systems performed different based upon the low p-value of the ANOVA results (p = 0.0524). Pattern correlations concluded that the CLS and OLS patterns were all highly correlated.

Simulated overlap analysis was carried out to evaluate the uniformity of each system. The 4483 kg/ha application rate for the CLS provided the most uniform pattern with a CV of 23% with the worst CV of 38% coming from the 6725 kg/ha pattern of the OLS. The overall CVs for the CLS patterns did not exceed 28% and the OLS CVs never made it below 28% concluding that the closed-loop system provided an improved distribution over the open-loop system.

The speed variations negatively affected the distribution of litter highlighting the importance of maintaining constant spinner speeds when making rate changes or as flow rate changes due to litter physical variability. The CLS is recommended over the OLS based on practical and statistical significance and due to the improved CVs for the CLS. Spinner speed control with the CLS is suggested for VRA use and standard use. This type of control would be beneficial even if VRT is not available especially if farmers are applying litter on multiple fields that require different application rates.

CHAPTER FOUR

EVALUATING THE APPLICATION OF POULTRY LITTER ON A NUTRIENT BASIS

4.1 ABSTRACT

Poultry litter is typically difficult to uniformly apply because of its natural variability in moisture content, particle size, and density. Nutrient concentrations tend to increase with decreasing particle size initializing a concern regarding spreading litter based on its nutrient content rather than mass. A study was conducted to determine nutrient distribution (N, P_2O_5, and K_2O) in relation to the traditional mass distribution while comparing a closed-loop system (CLS), spinner-disc control, to an open-loop system (OLS). Three application rates of 2242, 4483, 6725 kg/ha were selected for applying broiler litter. Litter was collected based on ASABE S341.3 testing protocol but modified to assess pattern uniformity using a two-dimensional pan matrix. The CLS provided more uniform nutrient patterns with coefficient of variations (CVs) ranging from 22% to 34% compared to 26% to 39% generated by the OLS. Based on pattern comparisons the nutrient patterns were highly correlated with their respective mass pattern indicating that even though particle size variability exists across the width of spread, the distribution of nutrients reflects mass distribution. Practical and statistical differences were found between the two systems ($p = 0.0657$) concluding the CLS provided CV improvements up to 17% and it is thereby recommended over the OLS.

4.2 INTRODUCTION

Poultry litter has become a reliable source of fertilizer in many parts of the country due to its nutrient value. On average, poultry (broiler) litter has a 3-3-2 (nitrogen (N)-phosphorus (P)-potassium (K)) fertilizer rating (Wood, 1992). The litter utilized during this research had a fertilizer rating or 3-6-5. One of the key goals when applying fertilizer is to apply the proper amount to meet crop or forage requirements. In certain parts of the Southeast where poultry production is dense, litter is used as the sole fertilizer to meet all nutrient requirements. This use of litter as fertilizer has produced environmental issues in some areas due to the over-application of P to the soil. In the past, poultry litter has been applied to meet the N requirement leading to the over-application of P considering the similar concentrations of N and P in the litter and the minimal P requirement for crops. Armstrong et al. (2006) stated that application of litter to meet N requirements causes an over-application of P, causing water quality issues ultimately creating a potential to harm aquatic life. Thus, many states are now basing litter application on P to meet environmental regulations.

The environmental issue associated with over-application of P is called eutrophication. When excessive P is applied to the landscape, the soil is not able to retain all of it; therefore, in some cases harmful amounts of P is deposited into nearby surface water via runoff. The P initializes the rapid growth of algae in the water, often known as an algae bloom. Microorganisms in the water feed on the dead algae, taking in large amounts of oxygen depleting the water of the required amount of oxygen for aquatic life to survive. The Phosphorus index (P index), a tool to assess P movement across the landscape, is used to help eliminate some of the hazards associated with P application.

Particle size tends to affect nutrient management in poultry litter. Koon et al. (1992) determined the nutrient fraction for each of the macronutrients (N, P, and K), increased as the particle size fraction decreased. However, Wilhoit et al. (1993) reported that carbon (C) concentrations increased with increased particle size and nitrogen (N) content within each size fraction varied randomly. They also determined the variation in the litter moisture content (MC) and the number of flocks raised on the litter can play an important role in attaining a uniform application when it comes to mass as well as nutrient content.

Only a few research attempts have been made to determine the spread pattern of nutrients in conjunction with the mass pattern of poultry litter. Wilhoit et al. (1993) measured N and C concentrations but not P and K. To simultaneously manage litter nutrients and protect the environment, it is of importance to know how macronutrients are being distributed. Many researchers have studied the effect of mass distribution with such granular fertilizers as ammonium nitrate, potash, urea, etc (Fulton et al., 2005b; Diallo et al., 2004; Grift and Hofstee, 2002). For many granulated fertilizers, nutrients are equally distributed with mass; however, poultry litter nutrient uniformity can be affected by variation in particle size. When applying litter with a spinner disc spreader it is common that the larger particles are distributed more towards the outer boundaries of the swath with the smaller particles applied at the center. Therefore, it is important to know how the nutrient patterns correlate with the mass patterns to determine if adjustments need to be made to more uniformly apply litter based on nutrient content.

4.3 SUB-OBJECTIVES

The objectives of this investigation were to: (1) compare and contrast characterized nutrient and mass distribution patterns of poultry litter for both an open-loop system (OLS) and closed-loop system (CLS), (2) evaluate the uniformity of nutrient application to determine if spinner disc speed control (CLS) improves the nutrient distribution of poultry litter, and (3) determine particle size distribution across the swath width along with its impact on nutrient application.

4.4 METHODOLOGY

A Chandler litter/shavings spreader equipped with hydraulically controlled dual rear spinner discs and apron chain was utilized for this investigation. Two spinner disc speed control systems, CLS and OLS, were used to conduct three tests each for three replications. Topcon's Zynx X20 computer/controller loaded with its spreader control program provided spinner speed control for the CLS. Four rows of 35 pans (140 total pans) were used to collect litter samples at three application rates (2242, 4483, and 6725 kg/ha) for the two systems. Rather than analyzing all 140 samples for each test, the samples were combined at each transversal location after weighing was completed (figure 4.1). All samples were analyzed for N, P, and K.

One load of litter was required to complete each replication. Three bulk samples were collected from each load of litter and analyzed for moisture content (MC), bulk density (BD), and nutrients. Twenty sub-samples were taken from the bulk samples of each replication totaling sixty sub-samples. For each replication, ten samples were analyzed for nutrients (N, P, and K). The other ten samples were sieved with each particle size class analyzed for nutrients. The sieving process was conducted to determine the nutrient concentration of each particle size class and used to determine the particle size distribution across the swath width.

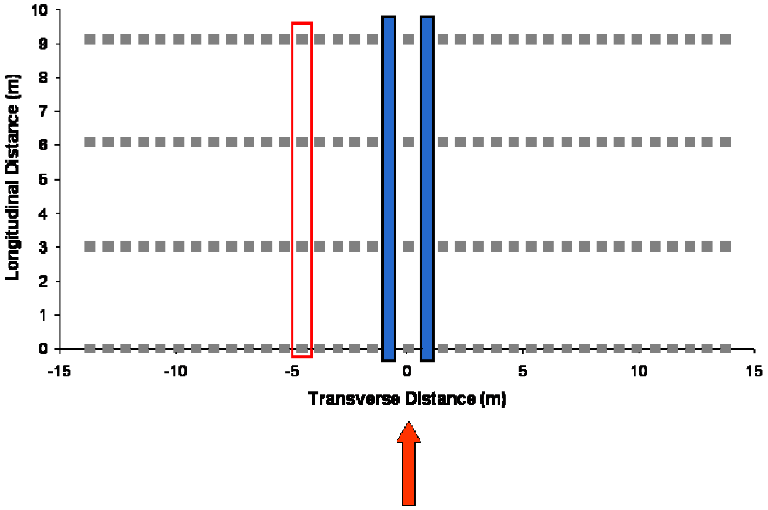


Figure 4.1. The red rectangle illustrates how longitudinal pans were combined prior to the nutrient analysis procedures.

4.4.1 SAMPLE PREPARATION FOR NUTRIENT ANALYSIS

All litter samples were refrigerated prior to preparing them for nutrient analysis. After the samples were combined at each transversal location, they were oven dried for 48 hours. Following the drying process, all samples were ground pass a 1-mm sieve for performing the nutrient analysis with the exception of all the 4483 kg/ha treatment samples (6 or 1/3 of all tests conducted) which were initially analyzed for particle size and then nutrients.

Samples were segregated into four particle size classes using a standard mechanical sieving method. The sieve sizes utilized were a No. 4 (4.75-mm), No. 10 (2-mm), and a No. 60 (0.25-mm). The particle size ranges produced were: x>4.75 (retained on the No. 4 sieve), 2.00<x<4.75 (retained on the No. 10 sieve), 0.25<x<2.00 (retained on the No. 60 sieve), and x<0.25 (collected in the pan). Each sample was placed on the No. 4 sieve with the set of sieves placed on and agitated using a Ro-Tap testing sieve shaker, Model B (Tyler Combustion Engineering Inc.) for approximately two minutes. Material collected on each sieve and in the pan were weighed and then summarized in Microsoft Excel. Subsequently, each sample was then recombined and ground to conduct overall per sample nutrient analysis. The bulk samples were not recombined but instead were analyzed for nutrients within each particle size class.

Grinding was done with a Thomas-Wiley Laboratory Mill, Model 4 (Thomas Scientific Inc.). Each sample was individually placed in the grinder hopper and ground until it passed a 1-mm mesh screen. Once each sample was ground, it was placed in its original sealed bag. The mill was then cleaned with air before grinding the next sample to eliminate possible cross contamination of samples.

4.4.2 LECO AND ICAP PROCEDURES

Once grinding was completed, nutrient analysis was performed. The samples were first weighed into bullets measuring approximately 0.1-grams and then analyzed for total C and N via dry combustion using a LECO TruSpec CN (LECO Corp., St. Joseph, MI). Final results provided the percentage of N contained within each sample and associated it with its respective pan location along the swath. The ICAP procedure provided the P and K concentrations within each sample and reported them as percentages on an ash free basis. First, a 50-ml Pyrex beaker was weighed, for ash purposes; then approximately 0.5-grams of the dry sample were placed in the beaker. Next, the beakers were placed into a muffle furnace and heated to 450ºC for at least 4 hours or until all the carbon was burned off. The beaker with sample was re-weighed to obtain the ash weight (beaker plus dry sample weight – beaker weight). Then, 10-mL of 1 normal nitric acid (HNO_3) was added to the beaker, placed on a hot plate, and allowed to evaporate until dry. Next, 10-mL of 1 normal hydrochloric acid (HCL) was added to dissolve the residue and then warmed to near boiling on a hot plate. The sample was then filtered using Whatman #42 filters into a 100-mL volumetric flask. The beaker was washed three times with small amounts of distilled water to remove any leftover sample. Next, the flask was filled to a volume of 100-mL with distilled water. Finally, the ICAP machine measured P, K, Ca, Mg, Mn, Cu, Fe, and Zn (Hue and Evans, 1986) with the P and K results only of interest for this investigation.

4.4.3 DATA ANALYSIS

Single-pass and overlap patterns were generated for the nutrients based the LECO and ICAP analysis. Typically when a fertilizer is characterized, the fertilizer rating (ex. 13-13-13) consists of N-P_2O_5-K_2O values (%) rather than elemental N-P-K values. For consistency, the measured P and K values were converted to P_2O_5 and K_2O concentrations (%). These concentrations (N, P_2O_5, and K_2O) were then multiplied by the mass application rate (kg/ha) at each particular transversal pan location to compute the amount of macronutrients applied at that location. The macronutrient single-pass and overlap patterns were then generated based on these calculations with the overall application rate mean, standard deviation, and CV computed using the overlap data. The CV was utilized to evaluate application uniformity to compare the application rate-nutrient combinations of the two control systems. These statistics were also used to assess the potential in-field spread variability of the nutrients. Standardized patterns were also generated from the single-pass patterns for each of the nutrients to allow for the detection of pattern shifts or similarities as well as for comparison with the mass patterns. The standardized patterns were computed by dividing the single-pass pattern by the mean rate from the simulated overlap patterns. For example, each position in the CLS 6725 kg/ha N pattern was divided by 152.7 kg/ha (table 4.1). If the nutrients are distributed similarly to the mass, then the patterns will align with one another.

Using the Statistical Analysis System (SAS Inst., NC), an analysis of variance (ANOVA) was conducted using the General Linear Model (GLM) to determine if statistical differences existed between the two different control systems based on the mean nutrient overlap patterns for each rate. The ANOVA compared the means between the systems, rates, and the nutrients as well as determine if an interaction occurred between the systems and the rates (system by rate) and between the systems and the nutrients (system by nutrients; table 4.2). The Least Squares Means (LSM) procedure in SAS was used in conjunction with the ANOVA to confirm the possible significance of the nutrient overlap means (table 4.1). Means with equivalent letters indicate no significant difference at the 95% confidence level. Pearson's Correlation Coefficients were also calculated using SAS's CORR procedure to evaluate similarities or shifts between single-pass distribution patterns for each control system. This correlation test was also used to compare the nutrient and mass patterns. The standardized patterns allowed for the visual comparison between the mass and nutrient patterns. An alpha value of 0.10 was utilized for statistical comparisons.

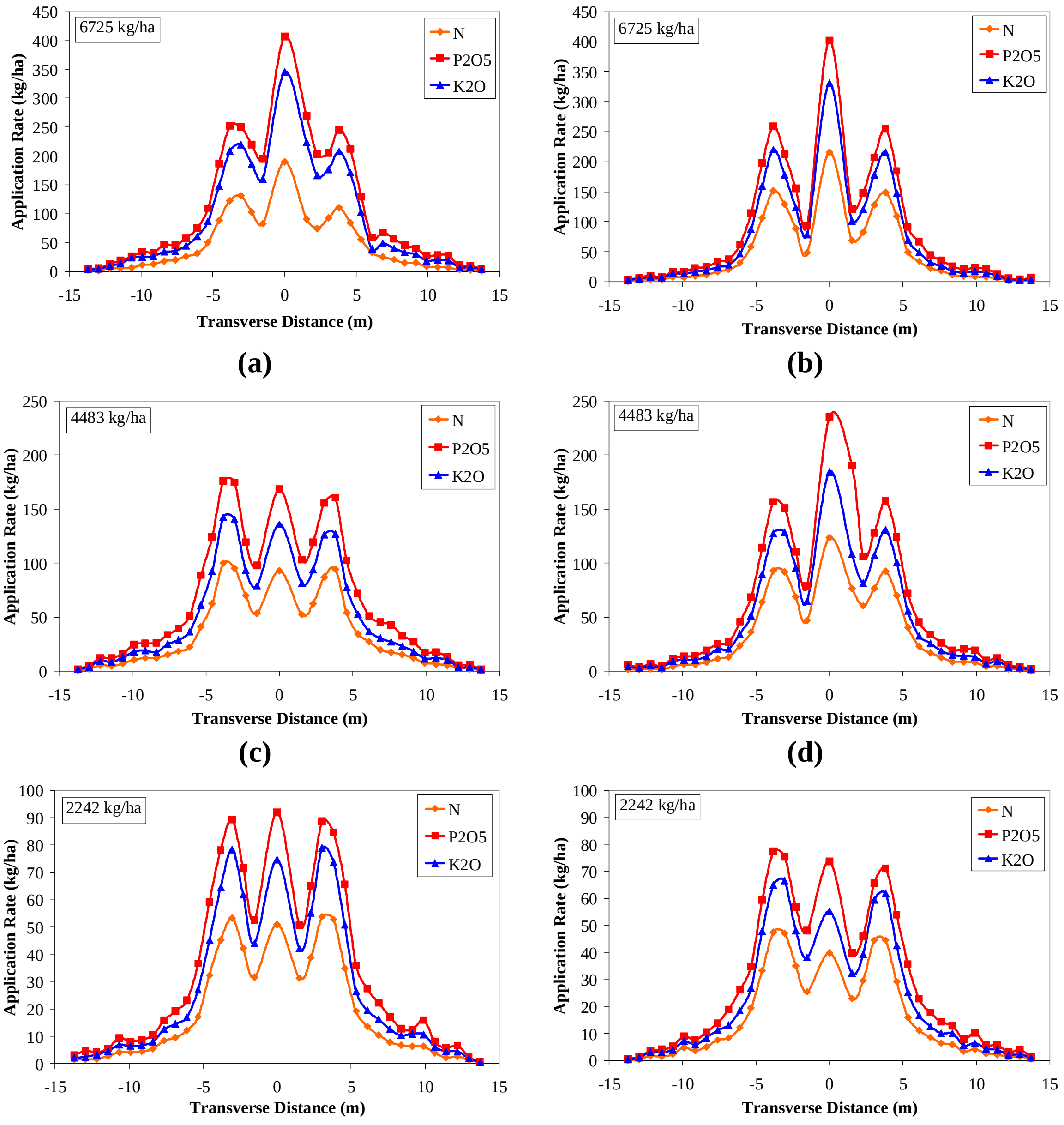
4.5 RESULTS AND DISCUSSION

The nutrient results indicated an overall fertilizer rating of 3-6-5 (N-P_2O_5-K_2O) for the litter utilized. These values specify that twice the amount of P_2O_5 exists in the litter as compared to N. This difference highlighted the potential over-application of P when spreading litter based on N requirements.

4.5.1 SINGLE-PASS ANALYSIS

Figure 4.2 illustrates the nutrient single-pass patterns by application rate and system. Overall the CLS provided less variation and better symmetry for all nutrients and application rates. The "W" shape pattern existed in all the patterns for both systems which were also observed in the mass patterns, again noting that Chandler has made adjustments for these errors (figure 3.4). However, the CLS did minimize the magnitude of the "W" shape in the higher two application rates. As expected, these patterns show that the predominant nutrient applied was P_2O_5 with K_2O second and N third.

For the OLS, the magnitude of the "W" shape and the center peaks increased with application rate for each nutrient indicating the most desirable patterns for the OLS occurred at the 2242 kg/ha application rate (figure 4.2f). The 4483 kg/ha rate appeared to provide the most desirable patterns for the CLS demonstrating the least variation at the center portion (±4.6 m) of the pattern (figure 4.2c). This result was expected since the spreader was calibrated at the 4483 kg/ha rate. At each specific rate-system combination, the N, P_2O_5, and K_2O patterns illustrated little if any pattern shifts.



(a) **(b)**

(c) **(d)**

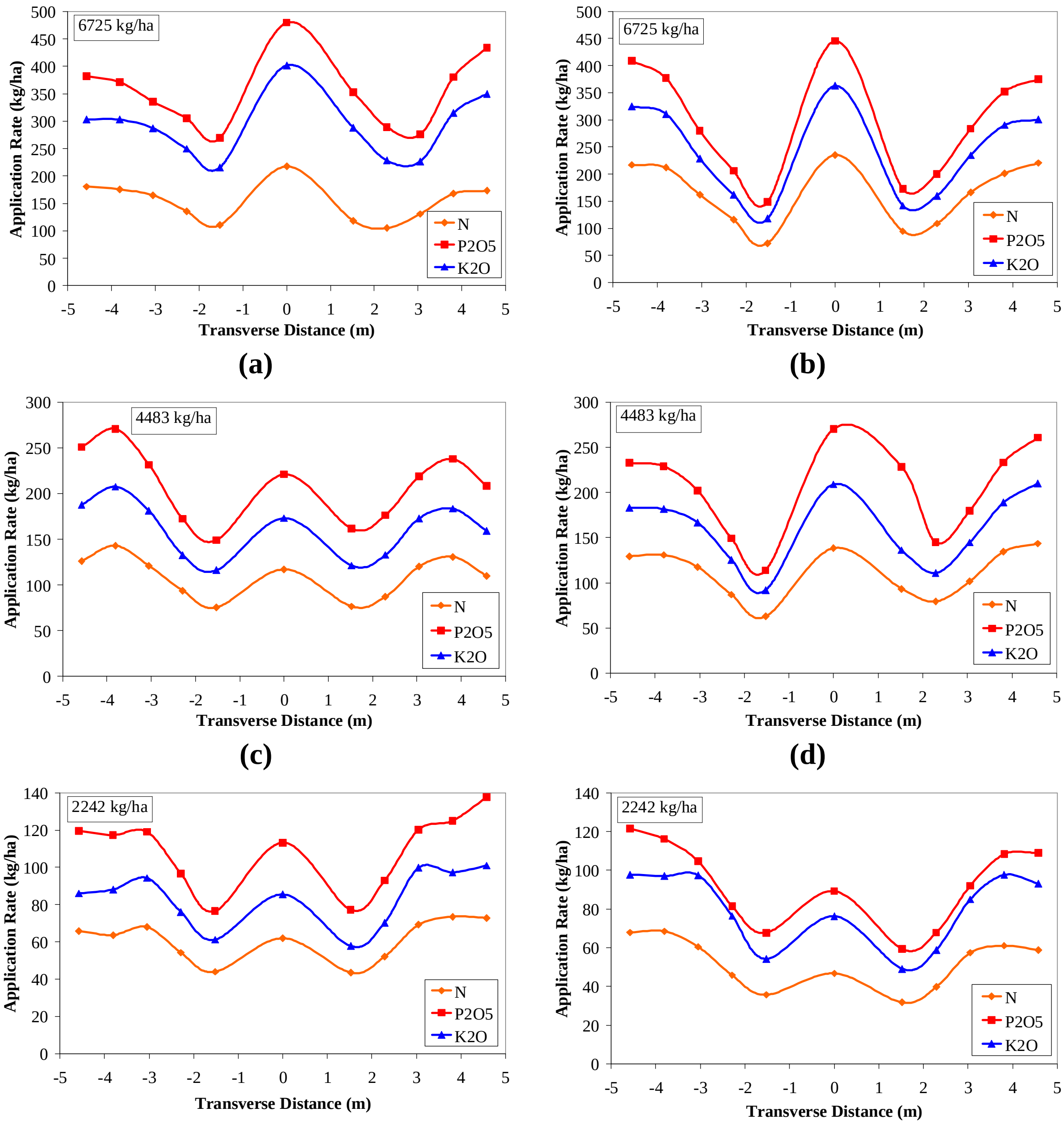
(e) **(f)**

Closed-loop system **Open-loop system**

Figure 4.2. Overall mean nutrient single-pass distribution patterns for the two control systems.

4.5.2 OVERLAP ANALYSIS

The results of the overlap pattern analysis indicated that the CLS improved nutrient distribution over the OLS (figure 4.3). The same conclusions were drawn from these patterns that were drawn from the single-pass patterns. All patterns exhibited the undesirable “W” shape with higher variations occurring with the OLS and spread uniformity decreasing as rate increased. The most uniform patterns were generated at the 4483 kg/ha rate for the CLS again attributed to calibration (figure 4.3c).



(a) (b)

(c) (d)

(e) (f)

Closed-loop system **Open-loop system**

Figure 4.3. Overall nutrient simulated overlap patterns for each control system by application rate treatment.

Table 4.1 presents summary statistics for the nutrient simulated overlap data. The CLS produced CVs less than 30% for all but one test, the 6725 kg/ha nitrogen pattern (CV = 34.4%). In contrast, the OLS only generated CVs less than 30% at the lowest rate. The low rate tests for each system resulted in similar CVs. In fact, the 2242 kg/ha K_2O rate was the only case in which the OLS generated a lower CV (= 26.7%) than the CLS (CV= 28.9%) Of interest, the CLS P_2O_5 pattern produced the lowest CV for each rate where for the OLS the N pattern produced the lowest CV for each rate. The rationale behind this result is unknown; however, the litter variability was most likely the cause. Overall, the CLS generated lower CVs in return provided better spread uniformity than the OLS.

The LSM results determined that all the nutrient means within a specific rate were found to be different (table 4.1). Six out of the nine comparisons between the systems resulted in no statistical differences. The three comparisons generating statistical differences were the 2242 kg/ha P_2O_5, 6725 kg/ha P_2O_5, and 6725 kg/ha K_2O treatments. No differences were found for any of the means at the 4483 kg/ha rate which was the same for the mass results (table 3.5). Of interest, based on the mass LSM analysis differences existed between the high rates with no differences between the low rates. Similar results can be drawn from the nutrient LSM results. The majority of the means at the low rates were not different with differences occurring for the majority of the means at the high rates. These results lead to the assumption that the nutrient results parallel the mass results and that the spreader performs better at the lower application rates.

Table 4.1. Summary statistics for overall nutrient simulated overlap patterns.

System	Rate (kg/ha)	Nutrient	Mean[1] (kg/ha)	Std. Dev. (kg/ha)	CV (%)
Closed-loop	2242	N	60.8^{l}	15.9	26.2
		P_2O_5	108.7^{i}	27.8	25.6
		K_2O	83.4^{k}	24.1	28.9
	4483	N	109.2^{h}	25.5	23.4
		P_2O_5	209.0^{e}	45.9	22.0
		K_2O	160.7^{g}	39.0	24.3
	6725	N	152.7^{f}	52.5	34.4
		P_2O_5	352.2^{a}	92.6	26.3
		K_2O	287.9^{c}	82.0	28.5
Open-loop	2242	N	52.2^{l}	13.8	26.5
		P_2O_5	92.5^{j}	24.8	26.8
		K_2O	80.3^{k}	21.4	26.7
	4483	N	110.7^{h}	34.1	30.8
		P_2O_5	204.0^{e}	78.9	38.7
		K_2O	159.0^{g}	50.7	31.9
	6725	N	164.1^{f}	61.6	37.5
		P_2O_5	295.4^{b}	112.7	38.1
		K_2O	239.4^{d}	92.6	38.7

1) Mean rates with similar letters indicate they are not statistically different at the 95% confidence level.

Table 4.2 provides ANOVA results for the nutrient simulated overlap data. The application rates were significantly different ($p<0.0001$); the same results occurred for the mass ANOVA analysis (table 3.6). The nutrients were also determined to be different from one another ($p<0.0001$) which was expected since different concentrations of the nutrients (3-6-5) were measured for the litter. Statistical differences between the control systems were found based on the nutrient analysis ($p = 0.0657$) with the same conclusion stated based on the mass data ($p = 0.0524$; table 3.6). Overall, no interaction for system by rate (p = 0.4104) or system by nutrient (p = 0.3031) existed identifying that the systems responded similarly when applying the nutrients at different rates.

Separate ANOVA's were conducted on each individual rate to determine if the systems operated differently over the range of application rates. These results are presented in the bottom three rows of table 4.2. When applying at the high and low rates, the systems were found to have a significant difference with p-values 0.0303 and 0.0379, respectively. However, the median application rate (4483 kg/ha) produced a p-value of 0.8207 concluding that no differences existed between the systems when operating at this rate. Again, this result can be accredited to calibration at this level. On the other hand, further research is needed to better understand the affect of calibration on each system when operating at a rate different than the calibrated rate. These results, along with the CV results, suggest that calibration is needed for the manual valve (OLS) across the range of expected application rates possibly requiring hardware adjustments at each rate to maintain the best spread uniformity. Based on the mean square errors, real-time hardware adjustments may need to be made to maintain the desired rate and distribution.

Table 4.2. ANOVA results for the nutrient simulated overlap pattern data.

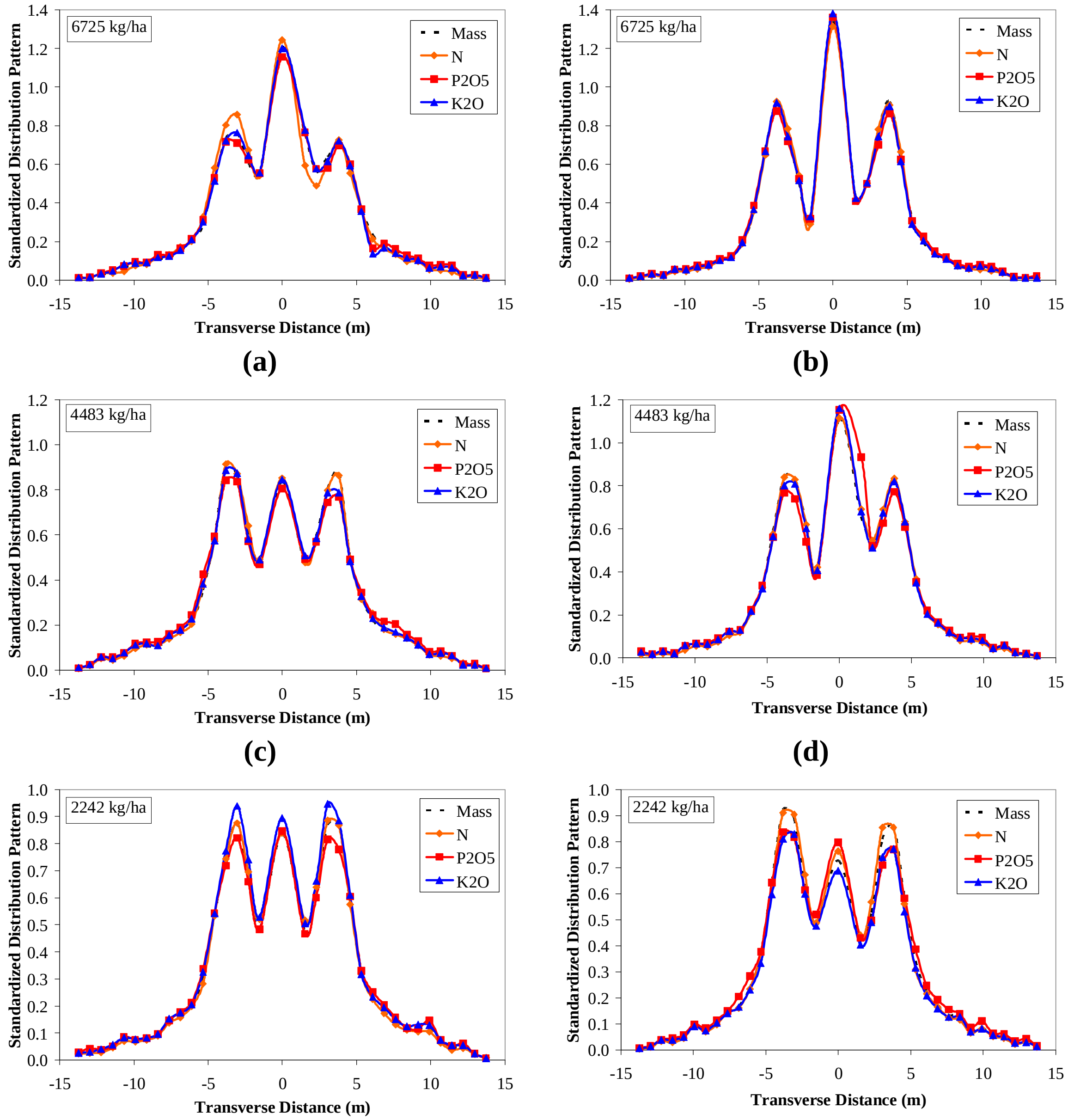
Rate	Source	DF	Sum of Squares	Mean Square	P-value
Overall	System	1	3,327	3,327	0.0657
	Rate	2	259,667	129,834	<0.0001
	Nutrient	2	89,265	44,633	<0.0001
	System by Rate	2	1,698	849	0.4104
	System by Nutrient	2	2,291	1,146	0.3031
2242 kg/ha	System	1	1,179	1,179	0.0303
4483 kg/ha	System	1	14	14	0.8207
6725 kg/ha	System	1	3,833	3,833	0.0379

4.5.3 COMPARING MASS AND NUTRIENT PATTERNS

Figure 4.4 provides the standardized mass and nutrient patterns for the CLS and OLS by application rate. By observing the plots, one can see little if any differences that exist between the mass and nutrient patterns. A few differences can only be seen at the peaks and valleys of the patterns but are considered small. Additionally, the Pearson correlation results confirmed the observations that the nutrient patterns (N, P_2O_5, and K_2O) were highly correlated with one another as well as with the mass pattern for all system-rate combinations. None of the coefficients were less than 0.98. These results indicated that mass distribution directly reflects how the macronutrients are distributed. Therefore, one can characterize the mass patterns and use the fertilizer value of litter to develop macronutrient patterns, if needed.

4.5.4 PARTICLE SIZE ANALYSIS

The particle size analysis concluded that nutrient concentration varied with particle size (table 4.3). N varied the least with P_2O_5 differing the most. The smallest particle size (pan) consistently contained the highest nutrient concentrations as found in previous research (Koon et al., 1992; Wilhoit et al., 1993). For N, the concentrations were consistent (approx. 3.0%) in the larger size fractions (sieve 4, 10, and 60). Of interest, the concentrations for each nutrient increased with decreasing particle size, disregarding sieve 4. The higher concentrations in sieve 4 for P_2O_5 (6.5%) and K_2O (4.8%) indicate that the largest particles also have a sizeable concentration of these nutrients.



(a) (b)

(c) (d)

(e) (f)

Closed-loop system **Open-loop system**

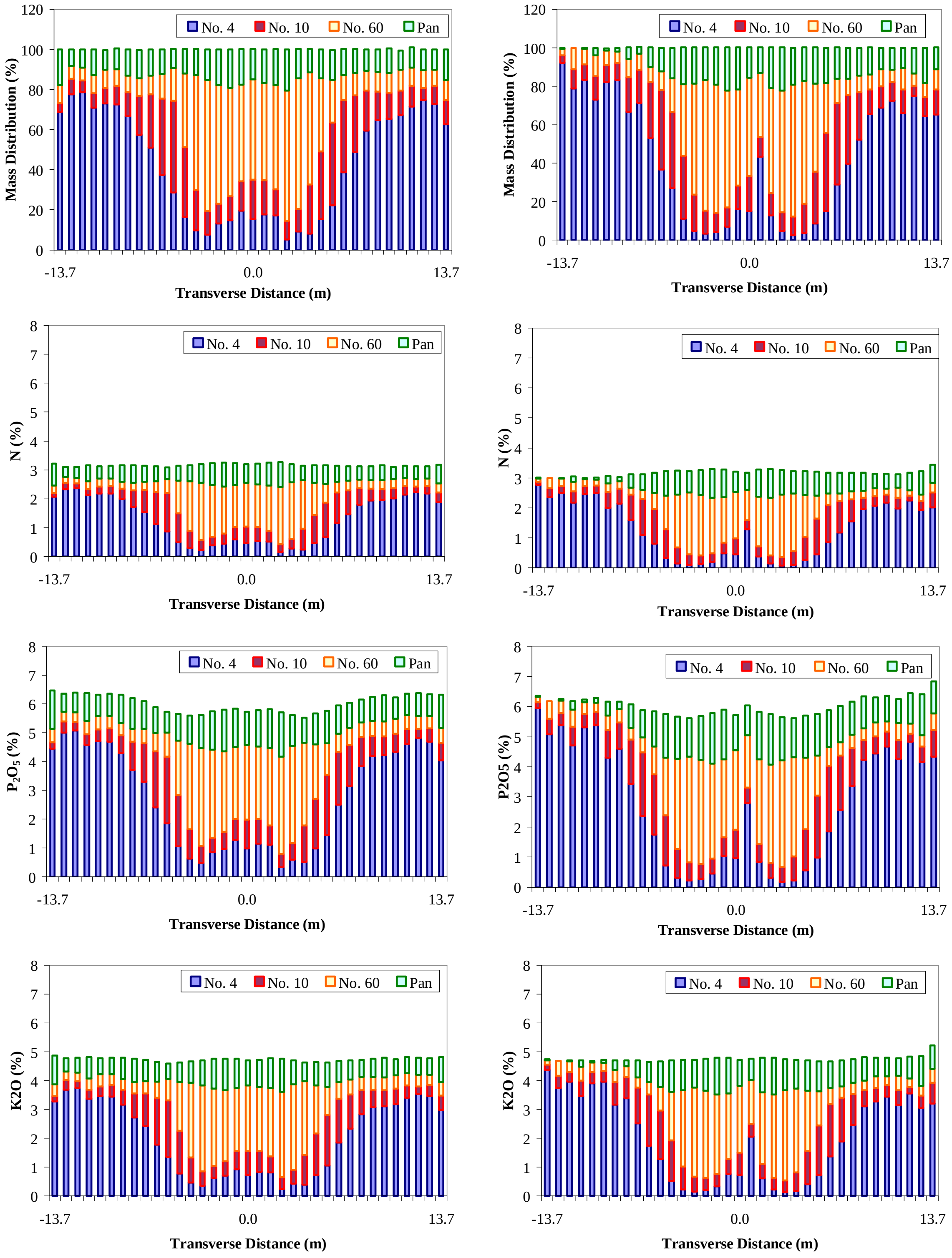
Figure 4.4. Comparison of the mass and nutrient standardized distribution patterns for both control systems at each test rate.

The transverse variability of particle size is illustrated in figure 4.5 for both mass and nutrients. The mass distribution plots display particle distribution with respect to the amount of material applied at each transverse position. One can see that there is particle size distribution variability when applying poultry litter with a spinner-disc spreader. The largest particles tend to be applied further from the center of the pattern denoted by the higher percentages for the No. 4 sieve at the outer limits. Conversely, the smaller are applied at the center of the pattern; however, the smallest particles seem to be distributed in small amounts across the entire swath not aggregated in one area of the swath. Hence, these plots indicate that the majority of each particle size is applied at specific areas across the swath.

Table 4.3. Overall measured poultry litter nutrient concentrations.

	N (%)	**P_2O_5 (%)**	**K_2O (%)**
Sieve 4	3.0	6.5	4.8
Sieve 10	2.9	5.1	4.3
Sieve 60	3.0	5.2	4.6
Pan	4.3	7.5	5.7
Total	3.4	5.9	5.0

Concerns if particle distribution affects nutrient distribution can also be addressed from the plots in figure 4.5. N, P_2O_5, and K_2O are presented as the actual particle size percentage they were applied with respect to the amount of mass applied at each transverse position, a more effective representation of nutrient concentration versus particle size. For example, the -13.7 transverse position (farthest position to the left) on the CLS P_2O_5 plot consists of 6.5% P_2O_5, meaning that 6.5% of the mass at that position is P_2O_5. This percentage was then broken down to determine the P_2O_5 percent within



a) Closed-loop system **b) Open-loop system**

Figure 4.5. Transverse particle size distribution categorized by sieve size.

each particle size at each position. In the case of the -13.7 position, the No. 4 sieve contains 4.45%, the No. 10 sieve contains 0.23%, the No. 60 sieve contains 0.46%, and the Pan contains 1.33% of the P_2O_5. It was determined that even though particle size does affect nutrient concentration (table 4.2), it does not affect nutrient distribution (figure 4.5). The mass-nutrient comparisons concluded that nutrient distributions followed the mass distribution for both systems.

4.6 SUMMARY

Nutrient distribution patterns of two spinner-disc speed control systems, CLS and OLS, were characterized, statistically analyzed, and compared to the mass distribution patterns to determine if the nutrient patterns were directly related to the mass patterns. The nutrient patterns for both control systems were “W” shaped, the same result as the mass patterns. As expected, P_2O_5 was applied at the highest quantity with K_2O second followed by N with overall nutrient concentrations for the litter measured at 3-6-5. The nutrient pattern comparison results determined that no overall interaction was found between the systems by rates ($p = 0.4104$) or systems by nutrients ($p =0.3031$); however, differences between the systems were found at the 2242 ($p = 0.0303$) and 6725 kg/ha ($p = 0.0379$) rates. Overall, a statistical difference between the systems was determined based on the nutrient patterns. Pattern correlations concluded that the CLS and OLS nutrient patterns were highly correlated with their respective mass patterns indicating that mass directly affects nutrient distribution.

Simulated nutrient overlap analysis was conducted to evaluate spread uniformity of each control system to determine if the CLS provided an improved distribution over the OLS. The CLS produced lower CVs in every case but one, the 2242 kg/ha K_2O. The CLS also generated CVs less than 30% for all tests except one, the 6725 kg/ha N pattern (CV = 34.4%). From these results, it was concluded that the CLS provided improved spread uniformity over the OLS when applying over different rates.

Based on particle size analysis, the nutrients varied with particle size with the highest concentration of nutrients in the lowest particle size. Particle size variability existed transversely across the width of spread. The highest concentrations of larger particles were found toward the outer limits of the spread pattern with the smaller particle concentrations applied at the center. Even though particle size did affect nutrient concentration, nutrient distribution was not directly impacted by particle size. All of the nutrients were distributed in a similar relation to the mass.

Overall, the spinner-disc speed variations generated by the OLS, tended to negatively affect the nutrient distribution as was found with the mass analyses. The CLS is recommended over the OLS when multiple application rates are being utilized based upon the statistical and practical differences in the systems and the lower CVs that were generated by the CLS. The differences in the systems at the low and high application rates indicate the OLS needs to be calibrated at each rate to perform at the level of the CLS. This would require hardware settings for each rate. Even when multiple rates are used, the CLS only requires calibration at the median rate and generates improvements in CVs up to 17% when compared to the OLS.

CHAPTER FIVE

APPLICATION UNIFORMITY ALONG THE DIRECTION OF TRAVEL

5.1 ABSTRACT

Poultry litter is a variable material making it hard to spread uniformly using spinner-disc spreaders. One variable with regards to spreading litter that is not well documented is evaluating spread uniformity in the longitudinal direction of travel. A study was conducted using a two-dimensional pan matrix consisting of 4 rows to determine if spread uniformity in the direction of travel occurred when applying poultry litter at three application rates (2242, 4483, and 6725 kg/ha). Distribution tests were conducted in accordance to ASABE Standard S341.3 testing protocol and applied using a standard pull-type spinner-disc spreader while also comparing two different spinner-disc control systems; closed-loop system (CLS) and open-loop system (OLS). Results indicated spread variability existed in the longitudinal direction; however, the variability was considered random

5.2 INTRODUCTION

When attempting to assess spread variability of spinner spreaders, different methods have been proposed recently, mostly to better understand the impact of technology such as variable-rate on application accuracy. Most of these methods focused on characterizing distribution patterns at a specific application rate and possibly report variability about the mean pattern. However, no research has been conducted to evaluate how spread patterns may vary, if any, in the direction of travel (longitudinally), especially with poultry litter. Further, this information is important to obtain a better understanding about nutrient distribution variability in the direction of travel.

The ASABE S341.3 testing procedure (ASABE Standards, 2004) only recommends one row of collection devices for calibrating or testing, primarily focusing on pattern uniformity and only allowing for the assessment of transverse variability. Past researchers have utilized multiple rows of collection devices to test spinner spreader variability (Fulton et al., 2001; Lawrence and Yule, 2005). However, no attempt has been made to characterize the variability in the direction of travel. Fulton et al. (2001) assessed the distribution of a VRT spinner spreader using the mean pattern generated from the multiple sampling rows. Lawrence and Yule (2005) focused on determining the correct spread width using a two-dimensional pan matrix. These investigations illustrate how the applicator performs at a single location in a field; however, they do not provide information about how the applicator performs spatially.

It is important to understand how an applicator performs in the direction of travel to fully evaluate spread uniformity over an entire field. With a product such as poultry litter, uniformity can vary greatly from test to test. Thus, when only one row of collection devices is utilized, actual spread uniformity in two-dimensions cannot be determined. Multiple rows of pans are required to determine the performance of an applicator, longitudinally. Knowledge from this type of testing could determine if the mass and nutrient distribution is varying as the field is traversed.

5.3 SUB-OBJECTIVE

The objective of this investigation was to determine if application variability exists in the direction of spreader travel when applying poultry litter.

5.4 METHODOLOGY

For this investigation, a Chandler litter/shavings spreader (Chandler Equipment Co., Gainesville, GA; Appendix A) equipped with hydraulically controlled dual rear spinner-discs and apron chain was utilized. Topcon's Zynx X20 computer/controller loaded with Topcon's Spreader Control software program (Appendix D) was used and provided both VRA and spinner-disc speed control capabilities. Litter samples were collected, using a two-dimensional pan matrix, at three application rates (2242, 4483, and 6725 kg/ha) with two control systems, the CLS and OLS (3 X 2 design). A total of 140 pans were used and divided into four rows spaced at 3.1-m with each row containing 35 pans spaced at 0.8-m. Prior to each test, two of the transverse pan locations, one on either side of drive path were randomly selected for analysis (figure 5.1). Samples for the four pans making up these transverse pan locations were kept separate to perform individual nutrient analysis for litter collected in each pan. Three replications were conducted for the rate and control system combinations (18 total tests) generating 36 transverse locations to perform the assessment of applied mass and nutrient variability in the direction of travel. Since the two transverse locations were randomly selected for each test, the locations were not the same for replicated tests.

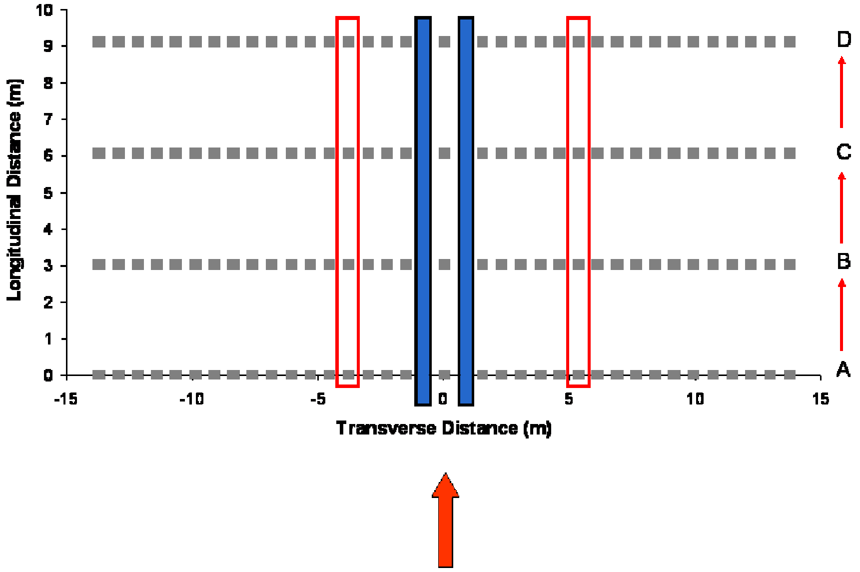


Figure 5.1. Pan layout and selected positions for replication 1 CLS 2242 kg/ha test.

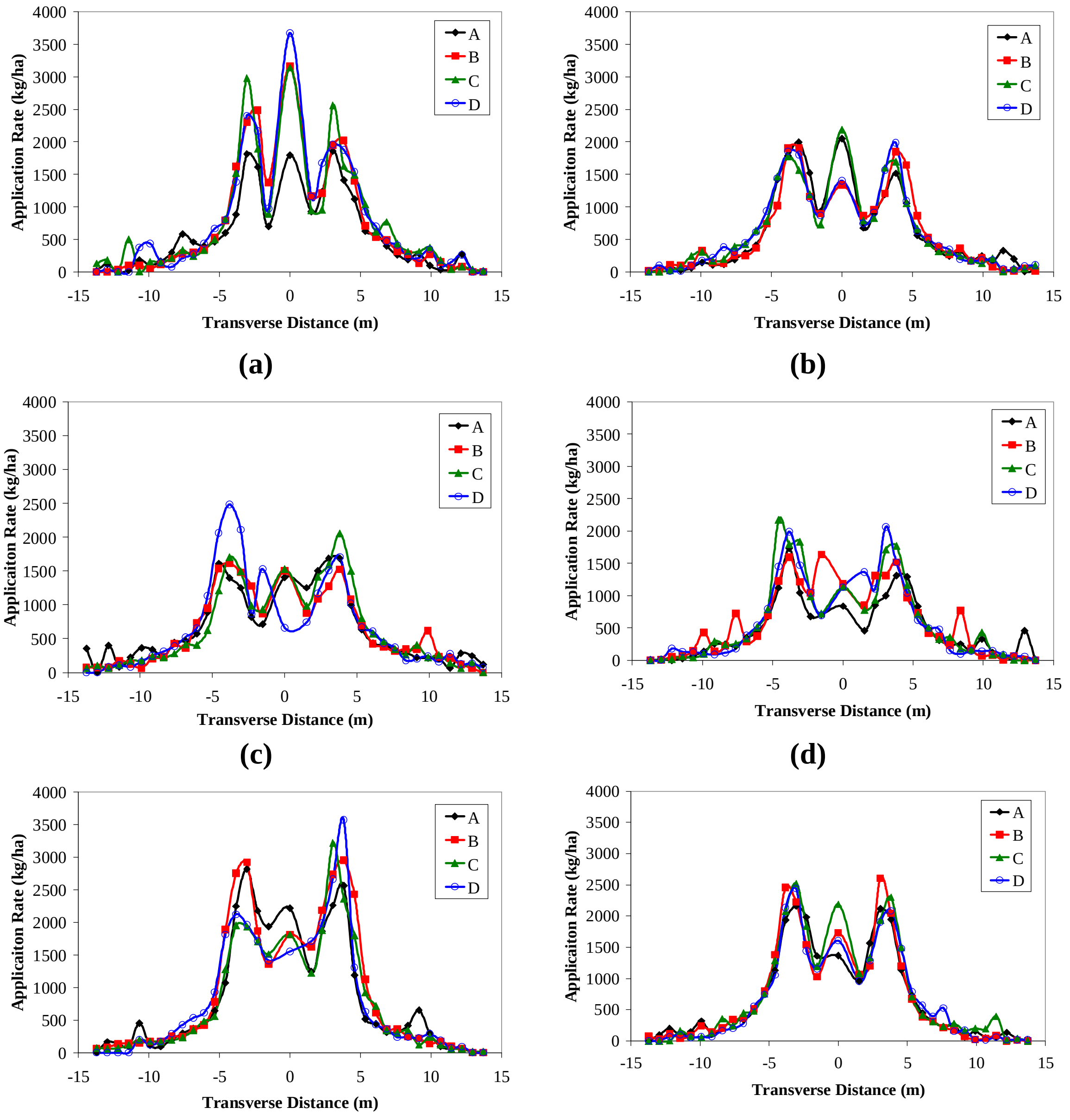
5.4.1 DATA ANALYSIS

Three methods were used to present longitudinal variability. First, single-pass distribution patterns were plotted for each individual row in a single test (figure 5.2). All four rows, A thru D, were plotted on the same chart to visualize variation between the rows. Next, application surfaces were generated to illustrate the variability. The different colors in the surfaces represent the different range of rates (kg/ha) that were applied. The 2242 kg/ha patterns, for all replications, are displayed because they provided a detailed representation of the variability for all rates. Finally, a residual analysis was conducted to determine if there were similarities and/or differences in variability from one location to another, longitudinally. First the mass measurements for the four rows at each selected longitudinal position were summarized in a table in

Microsoft Excel. Therefore, there were four weights (kg/ha) accounted for at each position. An overall mass mean (kg/ha) was calculated for each position. The overall mass mean is an average of the weights at a specific position from each replication. For example, if the position of 4.57-m in the swath was chosen for this analysis then the four weights at the location from each replication would be averaged to attain the overall mass mean for this position making a total of 12 values to be averaged. After the overall mass mean was calculated, the weights from the four rows were subtracted from overall mean to form a residual (table 5.1 and Appendix J). The residuals were then plotted to determine if visual differences existed in the direction of travel between the rates and control systems.

5.5 RESULTS AND DISCUSSION

The single-pass patterns, application surfaces, and the residual plots illustrate the longitudinal data for all tests (figures 5.2, 5.3, and 5.4). The farther the points are from the zero line (dotted line in plots) in the residual plots indicates greater variability. In the same regard, the greater the difference in the single-pass patterns demonstrates more variability in the direction of travel. The single-pass patterns, application surfaces, and the residual plots display longitudinal variability within each system; however, there seems to be no particular trend to conclude that the variability increases or decreases as the spreader traverses the field. The variability appeared to be random and strictly controlled by the physical characteristics of the litter. Based on the results from Chapter 4 it is assumed that longitudinal variability of nutrients will be the same as the mass since the nutrient distribution is based on the mass distribution. Therefore, only the mass data was analyzed and discussed for the direction of travel variability.



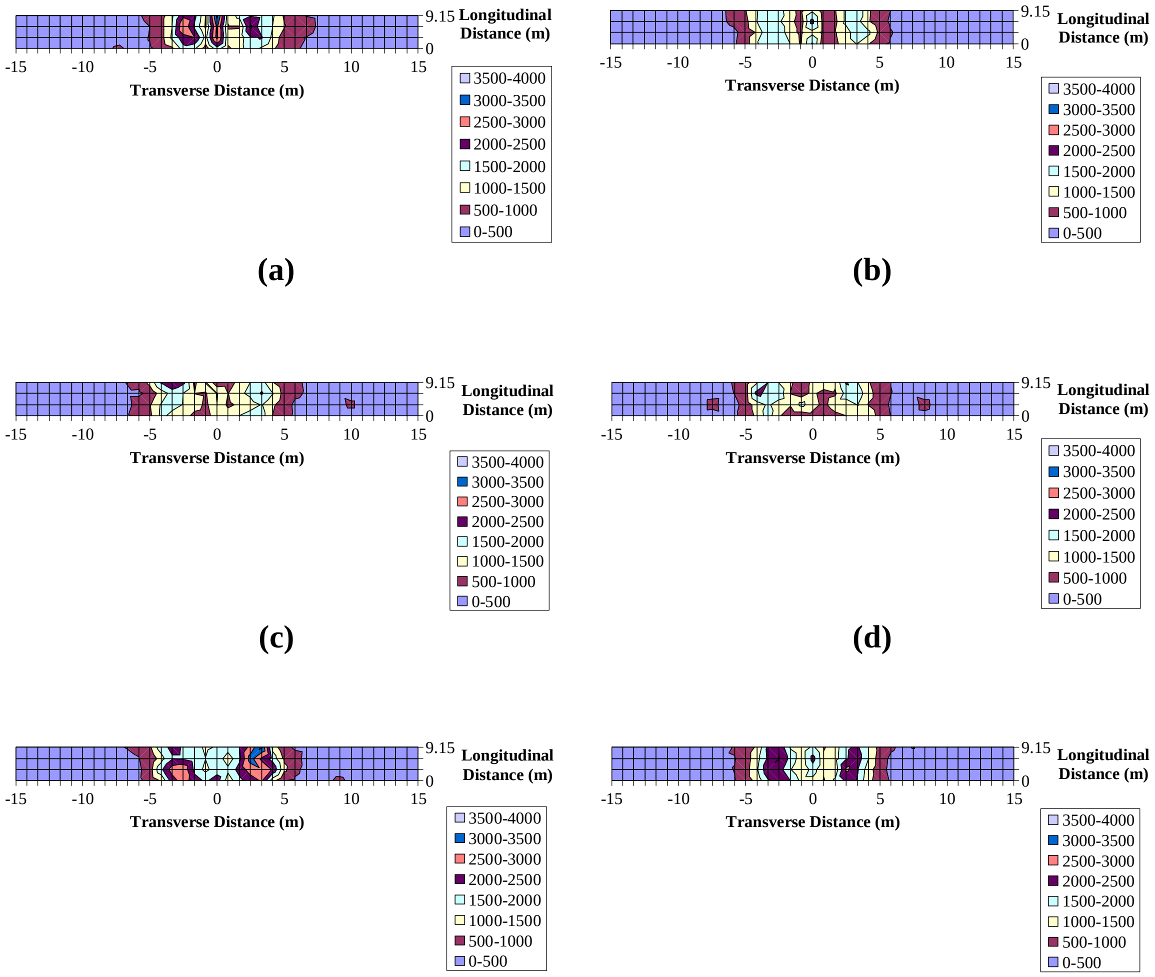
(a) (b)

(c) (d)

(e) (f)

Closed-loop system Open-loop system

Figure 5.2. Single-pass mass patterns for the 2242 kg/ha application rate separated by row to analyze variability along the direction of travel.



(a) (b)

(c) (d)

(e) (f)

Closed-loop system **Open-loop system**

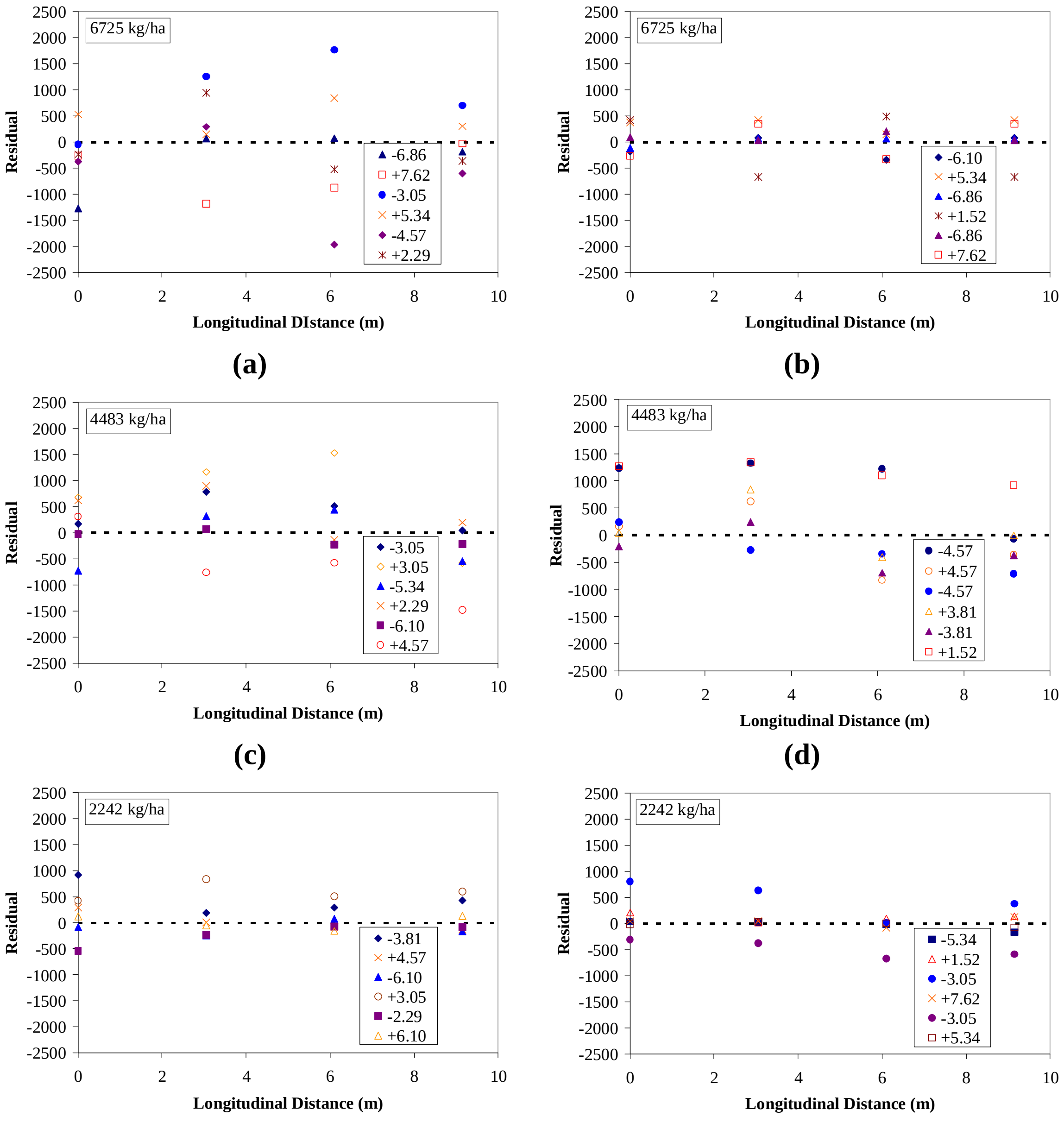
Figure 5.3. Application surfaces for the 2242 kg/ha application rate to visualize the variability along the direction of travel in kg/ha.

The data in table 5.1 represents the residual data from the CLS 2242 kg/ha tests. The selected locations from each replication are displayed. The last four columns in the table symbolize the residuals for rows A thru D. The closer the residual is to zero indicates less variation at that location. The data from table 5.1 can be directly related to the CLS 2242 kg/ha plot in figure 5.4. This data helps to verify that the variation from row to row is random displaying no visual trends (Appendix J).

Table 5.1. Example residual calculations at selected pan locations for the CLS 2242 kg/ha tests showing the 4 rows, labeled A, B, C, and D with A representing the first row receiving litter by the spreader.

			Applied Rate				Residual			
Rep	Pan Loc	Overall Mass Mean	A	B	C	D	A	B	C	D
	(m)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)
1	-3.81	1805.8	885.4	1616.8	1520.0	1384.3	920.3	188.9	285.8	421.4
1	4.57	1404.9	1117.9	1398.9	1490.9	1539.3	287.0	6.1	-86.0	-134.4
2	-6.10	485.8	575.4	735.3	410.8	657.8	-89.6	-249.5	75.1	-172.0
2	3.05	2104.0	1684.7	1272.9	1597.5	1510.3	419.4	831.1	506.6	593.8
3	-2.29	1630.6	2173.9	1863.9	1704.0	1713.7	-543.3	-233.3	-73.5	-83.2
3	6.10	555.3	439.8	609.3	715.9	425.3	115.4	-54.1	-160.7	130.0

A longitudinal variability comparison was made between the systems as well as between the rates (figure 5.4). The systems compared well with one another for the lower two application rates but for the higher rate the CLS exhibits more longitudinal variation (figure 5.4a). The lower rates of the systems seem to provide the least variation (figures 5.4e & 5.4f). Comparisons can also be made between the positions of the left and right side of the swath and in a few cases between equivalent and symmetrical positions. There seem to be no overall trends between the positions of the left and right sides of the swath. For example, the data from the left side does not end up as all positive or all negative residual values signifying a random distribution of points around the mean. When comparing the few instances where the symmetrical positions (ex. +6.1 and -6.1) were plotted on same chart some similarities were found. Similar trends were found between symmetrical positions for the CLS 2242 ±6.1 m positions, OLS 2242 ±5.34 m position, and the OLS 4483 ±3.81 m positions. However, similarities were not found for all of the symmetrical position comparisons. Similar results were also formed when comparing equivalent positions (positions at the same transversal location from different replications). In some instances, similarities were found between the positions where in others no similarities were observed. The lack of similarities can be attributed to the natural variability in the poultry litter.



(a) **(b)**

(c) **(d)**

(e) **(f)**

Closed-loop system **Open-loop system**

Figure 5.4. Residual plots for each control system and test rate.

5.6 SUMMARY

The distribution of poultry litter was analyzed to determine if it exhibited longitudinal variability when using closed-loop and open-loop spinner-disc control systems. The single-pass patterns, application surfaces, and the residual analysis determined that litter did in fact vary longitudinally; however, no systematic trends were found between the rates or the systems concluding that the variation is random. For the most part, the CLS and OLS performed similarly at the lower and middle application rates with the CLS generating greater variability at the high rate. Similarities and differences were observed when the equivalent positions from the left and right sides of the swath were compared. These results indicate that when poultry litter is applied there will be variability in application as the spreader travels across the field. These results are based on a level testing surface, greater variability could occur when spreading on uneven terrain.

CHAPTER SIX

CONCLUSION

6.1 CONCLUSIONS

Mass and nutrient distribution patterns for poultry litter, over a range of application rates, were characterized to evaluate differences between a closed-loop system (CLS), providing spinner-disc speed control, and an open-loop system (OLS) to address objective 1. A two-dimensional pan matrix was used to characterize distribution patterns and spread variability for the two control systems. Topcon's Zynx X20 computer/controller running a spreader control software program permitted testing the spinner-disc speed control technology (CLS) on a standard Chandler litter spreader. The OLS utilized a manual valve with no feedback for controlling spinner-disc speed.

Mass and nutrient pattern characterization showed that both control systems generated undesirable "W" shape patterns for all tests with more variation and less symmetry illustrated by the OLS. Based on the spinner-disc speed analysis, the CLS maintained the desired spinner-disc speed of 600 rpm and produced less speed variation between the two spinner-discs, 1 to 6 rpm compared to 1 to 12 rpm allowed by the OLS. The coefficient of variation (CV) was used to assess application uniformity. Results indicated that the CLS provided lower CVs (22% to 34%) than the OLS (27% to 39%). The CLS 4483 kg/ha patterns generated the lowest CVs, ranging from 22% to 24%, for the mass and nutrient patterns illustrating the most desirable patterns. Overall, statistical differences were found between the two control systems based on the mass (p = 0.0524) and nutrient (p = 0.0657) results. Comparisons for both the mass and nutrient patterns revealed no overall interaction (p = 0.1478 and 0.4104, respectively) between the systems and test rates (System by Rate) pointing out that although differences were found between the control systems, they responded in a similar fashion over the rates tested.

The second research objective aimed to determine if the nutrients were spread differently than mass by comparing and contrasting the litter distribution patterns along with assessing the difference between the CLS and OLS. Comparisons determined that the CLS and OLS patterns were highly correlated and that the nutrient patterns were all highly correlated to their respective mass pattern concluding that mass, not particle size, distribution directly reflects nutrient distribution. Differences were found between the two control systems at the low (p = 0.0303) and high (p = 0.0379) rates based on nutrient analysis indicating the need for individual calibration at each rate for the OLS. Compared to the OLS, the CLS provided lower CVs for all nutrient tests but one, the 2242 kg/ha K_2O treatment. These results parallel those found under objective 1 that spinner-disc control provided improved spread uniformity for the application of poultry litter using a spinner spreader, especially at the calibrated rate (4483 kg/ha).

The final objective of this research focused on determining if longitudinal spread variability existed when applying poultry litter using both the OLS and CLS over a range of application rates. Results concluded that variability did occur when applying poultry litter at each application rate for both control systems. However, no specific trends were observed leading to the notion that the variability along the direction of travel was random and not systematic. This result indicated that when poultry litter is utilized, application inconsistency will occur as the spreader traverses the field.

In conclusion, spinner-disc speed control provided an improved distribution of poultry litter which had a fertilizer rating of 3-6-5. The spinner-disc speed variations allowed by the OLS negatively affected the distribution highlighting the importance of maintaining the set spinner speed when making rate changes. Improvements up to 17% in spread uniformity were measured for the CLS over the OLS; however, variability along the direction of travel existed with both control systems. Therefore, spinner-disc speed control is recommended over an OLS when one changes application rates regularly and especially when implementing variable-rate application (VRA). Results suggested that the OLS needs to be independently calibrated at each of the expected application rates. This additional calibration process will be more labor intensive and time consuming with different hardware settings for each rate to maintain the desired spread uniformity. Finally, since spinner-disc speed control technology improved spread uniformity of litter (variable material), then improvements, possibly more, would also be expected when applying inorganic fertilizers.

6.2 PRACTICAL CRITERIA FOR CONTROL SYSTEM SELECTION

Table 6.1 summarizes some variables that one should consider when selecting a control system for their particular dry applicator. It briefly highlights important information that was learned through this research as well as experiences when dealing with a spreader equipped with VRT. These variables include calibration procedures, uniformity improvements, overall investment consideration, as well as others.

Table 6.1. Evaluation criteria for selecting a control system.

	CLS	OLS
Valve	Electronically Adjustable Pressure Compensated Hydraulic Flow Control	Pressure Compensating Hydraulic Flow Control (Manual adjustment for flow)
Calibration	Controller and spreader calibration but only at median application rate	Spreader calibration over the range of expected application rates
Speed Control	Maintain desired spinner speed as mass flow changes	None; spinner speed will vary as mass flow changes
Uniformity	Improves CVs up to 17%	
Investment	Valve: $240 to $1165 Controller: $4000 to $7200	Valve: $90 to $150

6.3 OPPORTUNITIES FOR FUTURE RESEARCH

Based on the results, improvements need to be made to provide better uniformity when applying poultry litter. Hardware settings need to be further investigated for the Chandler spreader to minimize the measured “W” shape patterns. The hardware settings were maxed out on the current setup not allowing the litter to be properly conveyed onto the spinner discs. Adjustments to the configuration of the flow divider are essential to improve uniformity. Real-time divider control could immensely improve distribution. Also, on-the-go rear gate height control could improve the conveyance variability of litter from the hopper in return providing a more uniform distribution. Testing the number of different vanes on the spinner-disc could minimize application variability.

Different hardware calibration can be conducted for the OLS at each of the tested application rates to determine if the measured spinner speed differential would be minimized. Each rate would then have its own individual valve setting. Spreader calibration also needs to be conducted at each application rate to determine if calibration truly affects the systems at each rate as it does for the 4483 kg/ha treatment in this research. This procedure would require the settings to be changed prior to testing at a particular rate; however, it would determine the impact calibration makes when using spinner-disc speed control as well as resolve the question if the OLS can perform at the same level as the CLS when calibrated at each rate.

The development of a statistical model to assess the variability along the direction of travel is needed to further analyze the applicators ability to maintain uniformity as it travels down the field. Finally, other materials, such as inorganic fertilizers, that use a different type of spinner spreader need to be tested using spinner-disc speed control to determine if this type of control improves distribution uniformity for other materials as it did for poultry litter.

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APPENDIX A

TRACTOR AND SPREADER SPECIFICATIONS

A.1 JOHN DEERE MODEL 6420 TRACTOR

Figure A.1. John Deere 6420.

Tractor Power:

PTO rated, kW:	70.3

Engine:

Manufacturer:	John Deere
Fuel:	Diesel
Aspiration:	Turbocharger with intercooler
Cylinders:	4
Displacement, L:	4.5
Rated engine speed, RPM:	2300
Cooling:	liquid
Oil capacity, L:	15.9
Hydraulic flow rate, LPM:	96

Transmission:

Type:	Infinitely Variable Transmission

Mechanical:

MFWD:	Yes

Dimensions:

Weight with ballast, kg:	5715
Front, kg:	2490
Rear, kg:	3234
Wheelbase, mm:	2400

Other:

Equipped with a John Deere GreenStar AutoTrac system with the capabilities of using SF1, SF2, or RTK correction services. The system has an Integrated Terrain Compensation Module (ITCM). RTK level correction was used during this research.

A.2 CHANDLER EQUIPMENT COMPANY C/L LITTER AND SHAVINGS SPREADER

Figure A.2. Chandler Equipment Co. litter spreader.

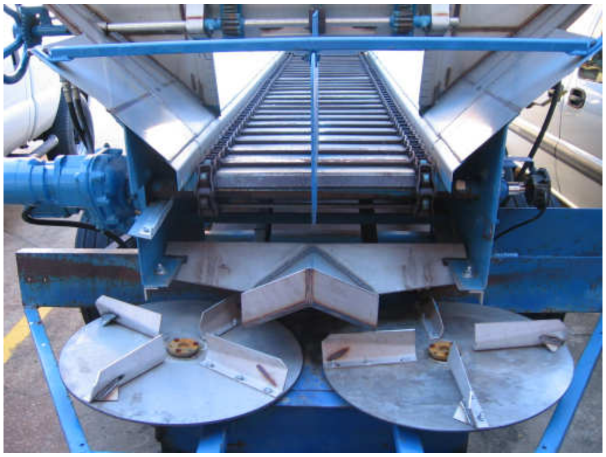


Figure A.3. Litter spreader rear gate, conveyor chain, flow divider and spinners.

Manufacturer:	Chandler Equipment Company
Dimensions, m:	3.66
Oil capacity, L:	121
Tire size:	12.5L - 15
Chain width, cm:	60.96
Spinner diameter, cm:	60.96
Vane height, cm:	7.62
Vane length, cm:	22.96
Max gate height, cm:	35.56
Height of spinner from ground, cm:	74.93

APPENDIX B

SPREADER PARTS

B.1 HYDRAULIC SPINNER MOTORS

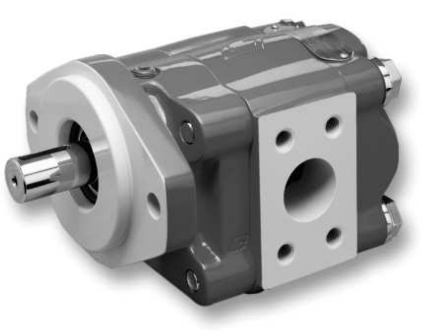


Figure B.1. Parker hydraulic spinner motor.

Manufacturer:	Parker
Series #:	PGM030A997BEIF20-43
Part #:	312-9310-820
Displacement, CI/REV:	3.94
Max pressure, PSI:	2250

B.2 PRINCE HYDRAULIC PTO PUMP

Figure B.2. Prince hydraulic PTO pump.

Manufacturer:	Prince
Model #:	HC-PTO-1AC
Displacement, CI/REV:	9.9
Flow rate, LPM:	81@ 500 PSI; 79.5@ 1000, 1500, and 2000 PSI
Input power, HP:	8.4@ 500 PSI; 16.1@ 1000 PSI; 23.8@ 1500 PSI; 32.1@ 2000 PSI
Speed rating, RPM:	540
Max pressure, PSI:	2250

B.3 CROSS HYDRAULIC RELIEF VALVE

Figure B.3. Hydraulic pressure relief on the input to the conveyor valve.

Manufacturer:	Cross Hydraulics
Model #:	RD15D
Description:	Adjustable
Pressure relief setting, PSI:	2500

APPENDIX C

HYDRAULIC FLOW CONTROL VALVES

C.1 BRAND HYDRAULICS: ELECTRONICALLY ADJUSTABLE PROPORTIONAL PRESSURE COMPENSATED FLOW CONTROL VALVE

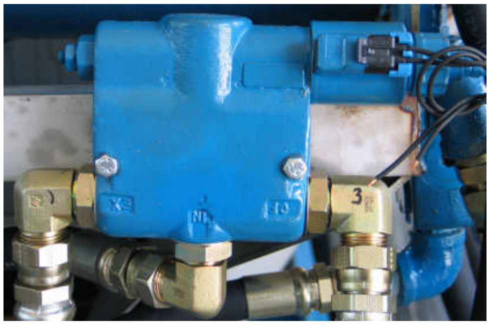


Figure C.1. Brand proportional valve used for spinner and conveyor control.

Manufacturer:	Brand Hydraulics
Spinner valve:	Operated by pulse width modulation (PWM)
Part #:	EFC12-20-12
Flow Rate, LPM:	0 to 75.7
Conveyor valve:	Operated by pulse width modulation (PWM)
Part #:	EFC12-15-12
Flow Rate, LPM:	0 to 56.8
Coil Voltage, volts:	12
Max pressure, PSI:	3000
Pulse frequency, HZ:	90 to 115

C.2 BRAND HYDRAULICS: MANUAL FLOW CONTROL VALVE

Figure C.2. Brand manual valve used for spinner control.

Manufacturer:	Brand Hydraulics
Part #:	FCR51-3/4-2000
Flow setting, LPM:	0 to 113.6
Max pressure, PSI:	3000
Description:	Adjustable ball spring pressure relief

APPENDIX D

ZYNX X15 AND X20

D.1 KEE TECHNOLOGIES ZYNX X20 CONSOLE

Figure D.1. X20 console with Spreader Control software.

Console:

Processor:	1 GHZ
Memory:	512 Mb
Operating system:	Windows XP PRO SP2
Display size:	213 mm (8.4 in.)
Solid state drive:	2 GB
Audio:	1.5 Watt stereo audio amplifier
External line:	Input/Output and microphone
Mounting bracket:	RAM mount
USB ports:	4 x USB 2.0
Serial RS232 ports:	4
PS2 ports:	2
VGA ports:	1
10/100 Base T Ethernet port:	1

Spreader Control Software:

Version:	1.48
Capabilities:	Variable-Rate Application (VRA) Spinner-Disc Control

D.2 KEE TECHNOLOGIES ZYNX X15 CONSOLE

Figure D.2. X15 console used for collecting speed and pressure data.

Processor:	300 MHz
Memory:	256 MB
Operating system:	Windows 98
Display size:	162 mm (6.4 in.)
Solid state drive:	1 GB
Audio:	Mono
External line:	Output only
Mounting bracket:	RAM mount
USB ports:	2 x USB 1.0
Serial RS232 ports:	4
PS2 ports:	1
VGA ports:	1
ISO 11783 Canbus ports:	1

APPENDIX E

SENSORS AND ELECTRONIC SPECIFICATIONS

E.1 INDUCTIVE PROXIMITY SENSORS

Figure E.1. Sensors to monitor spinner speeds.

Manufacturer:	Automation Direct
Part #:	AE1-AN-4A
Type:	Unshielded
Sensing range, mm:	0 to 4
Output state:	N.O.
Logic:	NPN
Operating voltage:	10 to 30 VDC

E.2 DICKEY JOHN ENCODER

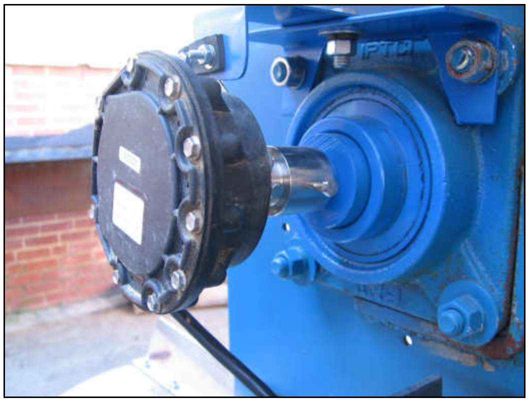


Figure E.2. Encoder to monitor conveyor speed.

Manufacturer:	Dickey-john Corporation
Model #:	46436-1170A
Type:	Application rate sensor
Output:	360 pulses per revolution
RPM range:	2 to 2500
Operating voltage:	12V

E.3 PRESSURE TRANSDUCERS

Figure E.3. Hydraulic pressure sensor.

Manufacturer:	Honeywell
Series:	SPT
Part #:	SPT4V3000PS5W02
Supply Voltage, V:	10 to 24 VDC
Pressure range, PSI:	0 to 3000
Proof pressure, PSIA:	9000
Burst pressure, PSIA:	10000
Output, V:	0 to 4
Response time, ms:	5

E.4 MEASUREMENT COMPUTING USB 1608FS

Figure E.4. USB data logger for pressure data.

Analog Input:

A/D converter type:	16-bit successive approximate type
Number of channels:	8 single ended
Resolution:	16-bit
Input ranges:	±10V, ±5V, ±2V, ±1V
Sampling rate:	0.6 S/s to 50 kS/s software programmable

Digital Input/Output:

Digital type:	CMOS
Number of channels:	8
Input high voltage:	2.0V min, 5.5V absolute max

External Trigger:

Trigger mode:	Edge sensitive: user configurable for CMOS compatible rising and falling edge.
Trigger latency:	10µs max
Trigger pulse width:	1µs min
Input high voltage:	4.0V min, 5.5V absolute max
Input low voltage:	1.0V max, -0.5V absolute min
Input leakage current:	±1.0 µA

External Clock Input/Output:

Type:	Bidirectional
Direction:	input/output, software selectable
Input clock rate:	50kHz max
Clock pulse width:	Input: 1µs max Output: 5µs max

Counter Section:

Type:	Event counter
Resolution:	32 bits
Max input frequency:	1MHz

Microcontroller:

Type:	High performance 8-bit RISC
Program memory:	16384 words
Data memory:	2048 bytes

Power:

Supply current:	<100mA, USB enumeration
USB power:	4.5V min, 5.25 V max
Output current:	350 mA max

APPENDIX F

VISUAL BASIC PROGRAMS

F.1 PROGRAM TO COLLECT SPEEDS

The following Visual Basic code was used to collect speed data for all of the tests conducted. This program displayed and logged spinner-disc speeds, the chain conveyor speed, and ground speed.

```
Public OPENFILE As Boolean
Dim BoardName As String
Dim BoardNum As Integer
Dim Ulstat As Long
Dim TempBoard As String
Dim TempNum As Integer
Dim filelocation As String

Private Sub Command1_Click()
End
End Sub

Private Sub Form_Load()

CommonDialog1.InitDir = "C:\"
CommonDialog1.DefaultExt = ".txt"

End Sub

Private Sub MSComm1_OnComm()
'MSComm2 ROUTINE DEFINES OPERATIONS ON NEW SERIAL MESSAGE FOR CNTR
BOARD

    On Error Resume Next

    If MSComm1.CommEvent = comEvReceive Or (MSComm1.CommEvent =
    comEvRing) Then 'CHECK FOR NEW MESSAGE RECEIVED
        BUFFER_LENGTH = MSComm1.InBufferCount
    Else
        BUFFER_LENGTH = 0
    End If

    While BUFFER_LENGTH > 5
        BUFFER_ARRAY = BUFFER_LEFTOVER & MSComm1.Input       'ADD NEW
        MESSAGE TO BUFFER
        START_POS = InStr(BUFFER_ARRAY, "%") 'DEFINE START OF MESSAGE
        STRING AT CHANNEL 1
        END_POS = START_POS + 7 'InStr(BUFFER_ARRAY, "!")     ' DEFINE
        END OF MESSAGE STRING
        BUFFER_LENGTH = END_POS - START_POS 'Len(BUFFER_ARRAY)
        'BUFFERLENGTH SET EQUAL TO LENGTH OF MESSAGE

        If START_POS = 0 Then Exit Sub
        If END_POS = 0 Then Exit Sub
```

```
        'DATA_STRING = BUFFER_ARRAY

        DATA_STRING = Mid(BUFFER_ARRAY, START_POS + 1, END_POS -
        START_POS + 1) 'SPLIT DATA STRING
        DATA_ARRAY = Split(DATA_STRING, ",")

        CounterID = DATA_ARRAY(0)
        Frequency = DATA_ARRAY(1)

        COUNTER(CounterID).Text = Frequency
        Spinner1.Text = COUNTER(1) * 1.2
        Spinner2.Text = COUNTER(2) * 1.2
        Chain.Text = COUNTER(3) / 6 'PLACE CHAIN SPEED CONVERSION VALUE
        HERE
        GSRSpeed.Text = COUNTER(4) * 0.0177 'PLACE GSR VALUE HERE FOR
        CONVERSION

        'If (LogData.Value = 1) And (OPENFILE = True) Then
        '          Write #1, count1.Text, count2.Text, count3.Text,
        count4.Text, count5.Text, count6.Text
        'End If

        BUFFER_LEFTOVER = Right(BUFFER_ARRAY, END_POS + 1) 'COLLECT
        UNUSED BUFFER

        If (LogData.Value = 1) And (OPENFILE = True) Then
            Write #1, Spinner1.Text, Spinner2.Text, Chain.Text,
        GSRSpeed.Text

        End If
     Wend

End Sub

Private Sub ChooseFilename_Click()
    On Error Resume Next

    CommonDialog1.DialogTitle = "CHOOSE DATA FILENAME"
    CommonDialog1.ShowOpen
    FilenameDisplay.Text = CommonDialog1.FileName

    Open CommonDialog1.FileName For Append As #1

    Print #1, " SPINNER1, SPINNER2, CHAIN, GSRSPEED"
        'Prints labels at the top of text file

    OPENFILE = True
    LogData.Enabled = True

End Sub

Private Sub OpenPort_Click()
MSComm1.PortOpen = True

End Sub
```

F.2 PROGRAM TO COLLECT SPEEDS AND PRESSURES

```
Public OPENFILE As Boolean
Dim Ulstat As Long
Dim BoardName As String
Dim BoardNum As Integer
Public org_time As Long
Dim TempBoard As String
Dim TempNum As Integer
Dim filelocation As String
Private Declare Function GetTickCount Lib "Kernel32" () As Long
Dim Con As Integer

Private Sub Command1_Click()
End
End Sub

Private Sub Command2_Click()
    On Error Resume Next
    'Student = InputBox("Please enter your name.")
    'des = InputBox("Please enter the testdescription.")
    CommonDialog1.DialogTitle = "Choose Data FILENAME"
    CommonDialog1.ShowOpen
    FilenameDisplay.Text = CommonDialog1.FileName

    Open CommonDialog1.FileName & ".txt" For Append As #1
    Print #1, "Student Name.", Student
    Print #1, "Test Description.", des
    Print #1, "Date", Date
    Print #1, "Time, SPINNER1, SPINNER2, CHAIN, GSRSPEED, Pressure,
    Pressure1, Pressure2, Pressure3 "
    'Print #2, "Student Name.", Student
    'Print #2, "Test Description.", des
    'Print #2, "Date", Date
    'Print #2, "Time, Average"
    OPENFILE = True
    LogData.Enabled = True
End Sub

Private Sub cmdStartConvert_Click()

   cmdStartConvert.Visible = False
   cmdStopConvert.Visible = True
   cmdStopConvert.Default = True
   tmrConvert.Enabled = True
End Sub

Private Sub cmdStopConvert_Click()
   tmrConvert.Enabled = False
   End
End Sub

Private Sub Form_Load()
    MSComm1.PortOpen = True
    CommonDialog1.InitDir =
```

```
    "C:\DocumentsandSettings\Christian\Desktop\Ajay\Data"
    CommonDialog1.DefaultExt = ".txt"
    LogData.Enabled = True
    org_time = GetTickCount
    BoardNum = 0    '<======this is the default board number
                    'change it to what IstaCal has assigned for your
USB/PMD-1608FS

    BoardName = "                         "
    Ulstat = cbGetBoardName(BoardNum, BoardName)
    Myboard = BoardName
    Myboard = Trim$(Myboard)
    bdlen = Len(Myboard) - 1
    Myboard = Left(Myboard, bdlen)
    If (Myboard <> "PMD-1608FS") And (Myboard <> "USB-1608FS") Then
        MyMessage = "A USB/PMD-1608FS was not assigned to Board " &
        BoardNum & " in InstaCal." & Chr$(13) _
                & "Please run InstaCal to verify the board number" &
        Chr$(13) _
                & "and/or change BoardNum = " & BoardNum & " in the
        Form_Load event" & Chr$(13) _
                & " to the correct board number.  Then re-run this
        program."
        r = MsgBox(MyMessage, vbExclamation, "USB/PMD-1608FS not
        detected.")
        End
    End If


   Ulstat = cbErrHandling(PRINTALL, DONTSTOP)
   If Ulstat <> 0 Then Stop

   ' If cbErrHandling is set for STOPALL or STOPFATAL during the
   program
   ' design stage, Visual Basic will be unloaded when an error is
   encountered.
   ' We suggest trapping errors locally until the program is ready for
   compiling
   ' to avoid losing unsaved data during program design.  This can be
   done by
   ' setting cbErrHandling options as above and checking the value of
   ULStat
   ' after a call to the library. If it is not equal to 0, an error has
   occurred.

End Sub

Private Sub tmrConvert_Timer()

    ' Collect the data with cbAIn()

    '  Parameters:
    '    BoardNum%    :the number used by CB.CFG to describe this board
    '    Chan%       :the input channel number
    '    Gain       :the gain for the board.
```

```
'    DataValue%  :the name for the value collected

Chan% = 1          'Set input channel. In Single Ended you can set
                    'Chan%' between 0 and 7
                    'In Differential Input mode, you can only set
                    'Chan%' between 0 and 3.
                    'You can set 'Chan%' to a different value to
                    suit you needs

Range = BIP5VOLTS  'Set the input range for the PMD-1608FS.
                    'When in Singled Ended you MUST use this range.

'cbAIn returns a value in counts (a value between 0 and 4095 for a
12 bit converter).
Ulstat = cbAIn(BoardNum%, Chan%, Range, DataValue%)
If Ulstat <> 0 Then Stop
'-------------------------------------------------------------------
Range = BIP5VOLTS
'DataValue% comes from the cbAIn function above
'EngUnits! is the value calculated from the DataValue%

'Use the cbToEngUnits function to convert the raw counts value to
volts (engineering units)
Ulstat = cbToEngUnits(BoardNum%, Range, DataValue%, EngUnits!)
If Ulstat <> 0 Then Stop

ShowData.Text = DataValue%   ' print the counts
ShowVolts.Text = Round(EngUnits!, 2) & " Volts" ' print the voltage
ShowPressure.Text = Round(EngUnits! * 750, 2)
'Image1.Visible = False
ShowTime.Text = Time
ShowDate.Text = Date


Chan% = 2          'Set input channel. In Single Ended you can set
                    'Chan%' between 0 and 7
                    'In Differential Input mode, you can only set
                    'Chan%' between 0 and 3.
                    'You can set 'Chan%' to a different value to
                    suit you needs

Range = BIP5VOLTS  'Set the input range for the PMD-1608FS.
                    'When in Singled Ended you MUST use this range.

'cbAIn returns a value in counts (a value between 0 and 4095 for a
12 bit converter).
Ulstat = cbAIn(BoardNum%, Chan%, Range, DataValue%)
If Ulstat <> 0 Then Stop
'-------------------------------------------------------------------
Range = BIP5VOLTS
'DataValue% comes from the cbAIn function above
'EngUnits! is the value calculated from the DataValue%

'Use the cbToEngUnits function to convert the raw counts value to
volts (engineering units)
```

```
Ulstat = cbToEngUnits(BoardNum%, Range, DataValue%, EngUnits!)
If Ulstat <> 0 Then Stop

ShowData1.Text = DataValue%   ' print the counts
ShowVolts1.Text = Round(EngUnits!, 2) & " Volts" ' print the
voltage
ShowPressure1.Text = Round(EngUnits! * 750, 2)

Chan% = 3           'Set input channel. In Single Ended you can set
                     'Chan%' between 0 and 7
                     'In Differential Input mode, you can only set
                     'Chan%' between 0 and 3.
                     'You can set 'Chan%' to a different value to
                     suit you needs

Range = BIP5VOLTS   'Set the input range for the PMD-1608FS.
                     'When in Singled Ended you MUST use this range.

'cbAIn returns a value in counts (a value between 0 and 4095 for a
12 bit converter).
Ulstat = cbAIn(BoardNum%, Chan%, Range, DataValue%)
If Ulstat <> 0 Then Stop
'-----------------------------------------------------------------
Range = BIP5VOLTS
'DataValue% comes from the cbAIn function above
'EngUnits! is the value calculated from the DataValue%

'Use the cbToEngUnits function to convert the raw counts value to
volts (engineering units)
Ulstat = cbToEngUnits(BoardNum%, Range, DataValue%, EngUnits!)
If Ulstat <> 0 Then Stop

ShowData2.Text = DataValue%   ' print the counts
ShowVolts2.Text = Round(EngUnits!, 2) & " Volts" ' print the
voltage
ShowPressure2.Text = Round(EngUnits! * 750, 2)

Chan% = 4           'Set input channel. In Single Ended you can set
                     'Chan%' between 0 and 7
                     'In Differential Input mode, you can only set
                     'Chan%' between 0 and 3.
                     'You can set 'Chan%' to a different value to
                     suit you needs

Range = BIP5VOLTS   'Set the input range for the PMD-1608FS.
                     'When in Singled Ended you MUST use this range.

'cbAIn returns a value in counts (a value between 0 and 4095 for a
12 bit converter).
Ulstat = cbAIn(BoardNum%, Chan%, Range, DataValue%)
If Ulstat <> 0 Then Stop
'-----------------------------------------------------------------
Range = BIP5VOLTS
'DataValue% comes from the cbAIn function above
'EngUnits! is the value calculated from the DataValue%
```

```
    'Use the cbToEngUnits function to convert the raw counts value to
    volts (engineering units)
    Ulstat = cbToEngUnits(BoardNum%, Range, DataValue%, EngUnits!)
    If Ulstat <> 0 Then Stop

    ShowData3.Text = DataValue%   ' print the counts
    ShowVolts3.Text = Round(EngUnits!, 2) & " Volts" ' print the
    voltage
    ShowPressure3.Text = Round(EngUnits! * 750, 2)

    'If (LogData.Value = 1) And (OPENFILE = True) Then
     '   Write #1, ShowTime.Text, Spinner1.Text, Spinner2.Text,
    Chain.Text, GSRSpeed.Text, ShowPressure.Text, ShowPressure1.Text,
    ShowPressure2.Text, ShowPressure3.Text
    'End If

End Sub

Private Sub MSComm1_OnComm()
'MSComm2 ROUTINE DEFINES OPERATIONS ON NEW SERIAL MESSAGE FOR CNTR
BOARD

    On Error Resume Next

    If MSComm1.CommEvent = comEvReceive Or (MSComm1.CommEvent =
    comEvRing) Then 'CHECK FOR NEW MESSAGE RECEIVED
        BUFFER_LENGTH = MSComm1.InBufferCount
    Else
        BUFFER_LENGTH = 0
    End If

    While BUFFER_LENGTH > 5
        BUFFER_ARRAY = BUFFER_LEFTOVER & MSComm1.Input    'ADD NEW
        MESSAGE TO BUFFER
        START_POS = InStr(BUFFER_ARRAY, "%") 'DEFINE START OF MESSAGE
        STRING AT CHANNEL 1
        END_POS = START_POS + 7 'InStr(BUFFER_ARRAY, "!")    ' DEFINE
        END OF MESSAGE STRING
        BUFFER_LENGTH = END_POS - START_POS 'Len(BUFFER_ARRAY)
        'BUFFERLENGTH SET EQUAL TO LENGTH OF MESSAGE

        If START_POS = 0 Then Exit Sub
        If END_POS = 0 Then Exit Sub

        'DATA_STRING = BUFFER_ARRAY

        DATA_STRING = Mid(BUFFER_ARRAY, START_POS + 1, END_POS -
        START_POS + 1) 'SPLIT DATA STRING
        DATA_ARRAY = Split(DATA_STRING, ",")

        CounterID = DATA_ARRAY(0)
        Frequency = DATA_ARRAY(1)
```

```
        COUNTER(CounterID).Text = Frequency
        Spinner1.Text = COUNTER(1) * 1.2
        Spinner2.Text = COUNTER(2) * 1.2
        Chain.Text = COUNTER(3) / 6 'PLACE CHAIN SPEED CONVERSION VALUE
        HERE
                GSRSpeed.Text = COUNTER(4) * 0.0177 'PLACE GSR VALUE
        HERE FOR CONVERSION


        'If (LogData.Value = 1) And (OPENFILE = True) Then
                '    Write #1, count1.Text, count2.Text, count3.Text,
        count4.Text, count5.Text, count6.Text
        'End If

        BUFFER_LEFTOVER = Right(BUFFER_ARRAY, END_POS + 1) 'COLLECT
        UNUSED BUFFER

        If (LogData.Value = 1) And (OPENFILE = True) Then
            Write #1, ShowTime.Text, Spinner1.Text, Spinner2.Text,
        Chain.Text, GSRSpeed.Text, ShowPressure.Text,
        ShowPressure1.Text, ShowPressure2.Text, ShowPressure3.Text
        End If
     Wend

End Sub
Private Sub OpenPort_Click()
    If MSComm1.PortOpen = True Then
        MsgBox "The Port Is Already In Use"
        Exit Sub
    End If
    MSComm1.PortOpen = True
    End Sub
```

APPENDIX G

SPINNER SPEED DATA

G.1 SPINNER SPEED DATA FOR INDIVIDUAL REPLICATIONS

Table G.1. Replication 1 spinner speed summary.

		Spinner 1			Spinner 2			
System	**Target (kg/ha)**	**Mean (rpm)**	**Std. Dev. (rpm)**	**Diff. 1[1] (rpm)**	**Mean (rpm)**	**Std. Dev. (rpm)**	**Diff. 1[1] (rpm)**	**Diff. 2[2] (rpm)**
Closed-loop	2242	599.8	5.9	-0.2	597.7	6.6	-2.3	-2.1
	4483	597.2	12.1	-2.8	598.0	11.3	-2.0	0.8
	6725	599.4	5.4	-0.6	599.8	5.9	-0.2	0.3
Open-loop	2242	624.7	5.1	24.7	636.0	5.0	36.0	11.3
	4483	597.7	4.5	-2.3	606.6	5.7	6.6	8.9
	6725	609.6	10.5	9.6	623.3	6.5	23.3	13.8

Table G.2. Replication 2 spinner speed summary.

		Spinner 1			Spinner 2			
System	**Target (kg/ha)**	**Mean (rpm)**	**Std. Dev. (rpm)**	**Diff. 1[1] (rpm)**	**Mean (rpm)**	**Std. Dev. (rpm)**	**Diff. 1[1] (rpm)**	**Diff. 2[2] (rpm)**
Closed-loop	2242	599.3	6.2	-0.7	607.5	6.6	7.5	8.2
	4483	597.7	11.2	-2.3	614.9	13.1	14.9	17.2
	6725	598.6	13.9	-1.4	614.7	23.5	14.7	16.1
Open-loop	2242	648.7	4.3	48.7	643.7	4.3	43.7	-5.1
	4483	613.0	4.5	13.0	629.2	6.8	29.2	16.2
	6725	618.2	7.9	18.2	629.2	5.9	29.2	11.0

Table G.3. Replication 3 spinner speed summary.

		Spinner 1			Spinner 2			
System	**Target (kg/ha)**	**Mean (rpm)**	**Std. Dev. (rpm)**	**Diff. 1[1] (rpm)**	**Mean (rpm)**	**Std. Dev. (rpm)**	**Diff. 1[1] (rpm)**	**Diff. 2[2] (rpm)**
Closed-loop	2242	599.2	7.5	-0.8	596.1	7.5	-3.9	-3.1
	4483	598.8	10.5	-1.2	602.7	9.3	2.7	3.8
	6725	598.0	8.8	-2.0	602.8	9.8	2.8	4.8
Open-loop	2242	614.4	6.5	14.4	610.3	5.5	10.3	-4.1
	4483	594.9	15.0	-5.1	604.3	11.1	4.3	9.4
	6725	565.3	14.4	-34.7	575.4	15.0	-24.6	10.1

1) Diff. 1 is the difference of the spinners from the desired speed of 600 rpm; positive and negative indicating when the actual speed is greater than or less than the desired speed, respectively.

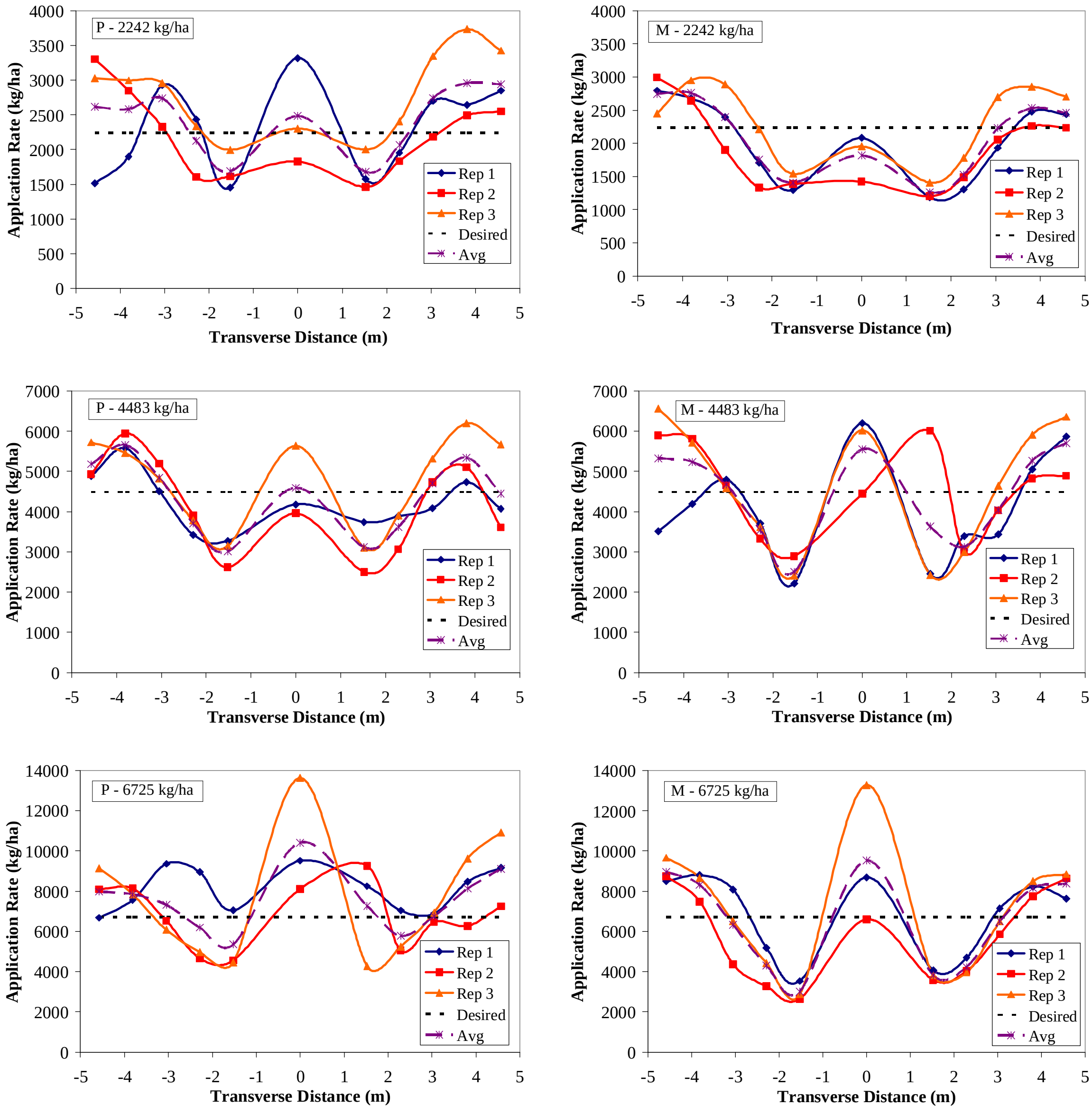
2) Diff. 2 is the difference between spinners 1 and 2; negative indicating spinner 1 is faster.

APPENDIX H

MASS DISTRIBUTION DATA

H.1 MASS OVERLAP DISTRIBUTION PATTERNS

The simulated overlaps patterns in figure H.1 illustrate the differences occurring between replications. The results in Chapter 3 are based upon the mean of these patterns for the three replications.



a) Closed-loop control system **b) Open-loop control system**

Figure H.1. Mass overlap patterns for each replication by type of control system and application rate.

The data in the following tables corresponds to the patterns illustrated in figure H.1 with data presented for each replication.

Table H.1. Rep 1 simulated mass overlap pattern summary statistics.

System	Target (kg/ha)	Mean (kg/ha)	Std. Dev. (kg/ha)	CV (%)	Rate Diff. [1] (kg/ha)
Closed-loop	2242	2297	646	28.1	55
	4483	4214	674	16.0	-269
	6725	8081	1078	13.3	1356
Open-loop	2242	2027	582	28.7	-215
	4483	4072	1289	31.7	-411
	6725	6778	2001	29.5	53

Table H.2. Rep 2 simulated mass overlap pattern summary statistics.

System	Target (kg/ha)	Mean (kg/ha)	Std. Dev. (kg/ha)	CV (%)	Rate Diff. [1] (kg/ha)
Closed-loop	2242	2185	581	26.6	-57
	4483	4141	1131	27.3	-342
	6725	6758	1565	23.1	33
Open-loop	2242	1903	591	31.0	-339
	4483	4523	1124	24.9	40
	6725	5723	2241	39.2	-1002

Table H.3. Rep 3 simulated mass overlap pattern summary statistics.

System	Target (kg/ha)	Mean (kg/ha)	Std. Dev. (kg/ha)	CV (%)	Rate Diff. [1] (kg/ha)
Closed-loop	2242	2776	598	21.5	534
	4483	4795	1115	23.2	312
	6725	7553	3000	39.7	828
Open-loop	2242	2311	564	24.4	69
	4483	4656	1579	33.9	173
	6725	7001	3138	44.8	276

1) Positive and negative rate differences indicate over- and under-application, respectively.

APPENDIX I

NUTRIENT SIMULATED OVERLAP DATA

I.1 SUMMARIZED NUTRIENT SIMULATED OVERLAP DATA

Tables I.1, I.2, and I.3 summarize the simulated nutrient overlap data for the three replications. The average of the data in these three tables was used to compute the results reported in Chapter 4. Note the CV differences between replications which highlight the variability of litter and the difficulty of uniformly applying litter.

Table I.1. Rep 1 simulated nutrient overlap pattern summary statistics.

System	Rate (kg/ha)	Nutrient	Mean (kg/ha)	Std. Dev. (kg/ha)	CV (%)
Closed-loop	2242	N	57.0	16.2	28.5
		P_2O_5	110.9	29.7	26.8
		K_2O	84.2	24.6	29.2
	4483	N	102.5	16.6	16.2
		P_2O_5	203.2	29.7	14.6
		K_2O	143.6	22.1	15.4
	6725	N	132.5	25.0	18.9
		P_2O_5	357.5	67.3	18.8
		K_2O	309.4	62.6	20.2
Open-loop	2242	N	51.1	13.8	26.9
		P_2O_5	91.7	25.0	27.2
		K_2O	72.5	20.0	27.5
	4483	N	102.3	32.9	32.1
		P_2O_5	179.8	60.8	33.8
		K_2O	141.9	47.9	33.7
	6725	N	174.3	50.2	28.8
		P_2O_5	315.6	87.8	27.8
		K_2O	251.8	70.4	28.0

Table I.2. Rep 2 simulated nutrient overlap pattern summary statistics.

System	Rate (kg/ha)	Nutrient	Mean (kg/ha)	Std. Dev. (kg/ha)	CV (%)
Closed-loop	2242	N	56.8	15.2	26.8
		P_2O_5	95.9	25.5	26.6
		K_2O	77.3	19.8	25.6
	4483	N	106.1	29.4	27.7
		P_2O_5	202.2	60.1	29.7
		K_2O	151.9	43.0	28.3
	6725	N	140.9	40.1	28.5
		P_2O_5	335.2	76.6	22.8
		K_2O	257.6	61.6	23.9
Open-loop	2242	N	47.8	13.6	28.4
		P_2O_5	80.7	23.5	29.1
		K_2O	63.0	18.7	29.7
	4483	N	117.9	29.4	25.0
		P_2O_5	222.3	95.2	42.8
		K_2O	161.5	40.4	25.0
	6725	N	144.6	56.6	39.2
		P_2O_5	253.9	98.2	38.7
		K_2O	202.6	79.4	39.2

Table I.3. Rep 3 simulated nutrient overlap pattern summary statistics.

System	Rate (kg/ha)	Nutrient	Mean (kg/ha)	Std. Dev. (kg/ha)	CV (%)
Closed-loop	2242	N	68.5	14.7	21.4
		P_2O_5	119.2	25.2	21.1
		K_2O	102.9	21.7	21.1
	4483	N	119.0	28.0	23.5
		P_2O_5	221.5	44.5	20.1
		K_2O	186.6	37.1	19.9
	6725	N	184.6	69.9	37.8
		P_2O_5	353.3	139.1	39.4
		K_2O	288.2	117.1	40.6
Open-loop	2242	N	57.6	13.5	23.5
		P_2O_5	105.0	21.4	20.4
		K_2O	88.0	19.2	21.8
	4483	N	112.1	40.5	36.1
		P_2O_5	209.8	78.2	37.3
		K_2O	173.4	61.1	35.2
	6725	N	173.5	76.0	43.8
		P_2O_5	316.6	142.9	45.1
		K_2O	263.7	117.6	44.6

APPENDIX J

LONGITUDINAL ANALYSIS REPORTING THE SUMMARIZED RESIDUAL DATA

Table J.1. Summarized residual data from the CLS 2242 kg/ha application rate.

Rep	Pan Location (m)	Overall Mass Mean (kg/ha)	Row A Rate (kg/ha)	Row B Rate (kg/ha)	Row C Rate (kg/ha)	Row D Rate (kg/ha)	Row A Residual (kg/ha)	Row B Residual (kg/ha)	Row C Residual (kg/ha)	Row D Residual (kg/ha)
1	-3.81	1805.8	885.4	1616.8	1520.0	1384.3	920.3	188.9	285.8	421.4
1	4.57	1404.9	1117.9	1398.9	1490.9	1539.3	287.0	6.1	-86.0	-134.4
2	-6.10	485.8	575.4	735.3	410.8	657.8	-89.6	-249.5	75.1	-172.0
2	3.05	2104.0	1684.7	1272.9	1597.5	1510.3	419.4	831.1	506.6	593.8
3	-2.29	1630.6	2173.9	1863.9	1704.0	1713.7	-543.3	-233.3	-73.5	-83.2
3	6.10	555.3	439.8	609.3	715.9	425.3	115.4	-54.1	-160.7	130.0

Table J.2. Summarized residual data from the CLS 4483 kg/ha application rate.

Rep	Pan Location (m)	Overall Mass Mean (kg/ha)	Row A Rate (kg/ha)	Row B Rate (kg/ha)	Row C Rate (kg/ha)	Row D Rate (kg/ha)	Row A Residual (kg/ha)	Row B Residual (kg/ha)	Row C Residual (kg/ha)	Row D Residual (kg/ha)
1	-3.05	3771.9	3602.8	2987.6	3263.7	3728.7	169.1	784.3	508.2	43.2
1	3.05	3524.9	2852.0	2362.8	1999.5	4111.4	672.9	1162.1	1525.4	-586.5
2	-5.34	1554.3	2290.1	1239.0	1117.9	2101.2	-735.8	315.2	436.3	-546.9
2	2.29	2605.0	1989.8	1713.7	2745.4	2411.2	615.2	891.3	-140.5	193.8
3	-6.10	927.4	958.1	861.2	1161.5	1151.8	-30.7	66.2	-234.1	-224.4
3	4.57	2191.2	1883.3	2953.7	2769.7	3675.4	308.0	-762.5	-578.4	-1484.2

Table J.3. Summarized residual data from the CLS 6725 kg/ha application rate.

Rep	Pan Location (m)	Overall Mass Mean (kg/ha)	Row A Rate (kg/ha)	Row B Rate (kg/ha)	Row C Rate (kg/ha)	Row D Rate (kg/ha)	Row A Residual (kg/ha)	Row B Residual (kg/ha)	Row C Residual (kg/ha)	Row D Residual (kg/ha)
1	-6.86	1159.9	2435.4	1093.7	1088.9	1350.4	-1275.5	66.2	71.0	-190.5
1	7.62	1112.3	1379.5	2299.8	1989.8	1147.0	-267.2	-1187.5	-877.5	-34.7
2	-3.05	5679.9	5734.0	4426.2	3917.6	4983.3	-54.1	1253.7	1762.3	696.7
2	5.34	2752.3	2227.2	2609.8	1917.2	2454.8	525.1	142.5	835.1	297.5
3	-4.57	3899.9	4280.9	3612.5	5874.5	4508.6	-381.0	287.4	-1974.6	-608.7
3	2.29	4201.8	4440.8	3258.9	4731.4	4571.5	-239.0	942.9	-529.6	-369.7

Table J.4. Summarized residual data from the OLS 2242 kg/ha application rate.

Rep	Pan Location (m)	Overall Mass Mean (kg/ha)	Row A Rate (kg/ha)	Row B Rate (kg/ha)	Row C Rate (kg/ha)	Row D Rate (kg/ha)	Row A Residual (kg/ha)	Row B Residual (kg/ha)	Row C Residual (kg/ha)	Row D Residual (kg/ha)
1	-5.34	768.8	735.3	740.1	783.7	938.7	33.5	28.7	-14.9	-169.9
1	1.52	883.0	677.2	861.2	788.6	745.0	205.9	21.8	94.5	138.0
2	-3.05	1848.5	1045.3	1214.8	1834.8	1471.5	803.3	633.7	13.7	377.0
2	7.62	278.0	231.5	236.4	357.5	154.0	46.4	41.6	-79.5	123.9
3	-3.05	1848.5	2159.3	2227.2	2522.6	2440.3	-310.8	-378.6	-674.1	-591.7
3	5.34	708.6	725.6	672.3	706.2	788.6	-17.0	36.3	2.4	-79.9

Table J.5. Summarized residual data from the OLS 4483 kg/ha application rate.

Rep	Pan Location (m)	Overall Mass Mean (kg/ha)	Row A Rate (kg/ha)	Row B Rate (kg/ha)	Row C Rate (kg/ha)	Row D Rate (kg/ha)	Row A Residual (kg/ha)	Row B Residual (kg/ha)	Row C Residual (kg/ha)	Row D Residual (kg/ha)
1	-4.57	2618.7	1384.3	1292.3	1394.0	2687.3	1234.3	1326.4	1224.7	-68.6
1	4.57	2764.0	2605.0	2140.0	3593.1	3123.3	159.0	624.0	-829.1	-359.2
2	-4.57	2618.7	2377.3	2890.8	2963.4	3331.5	241.4	-272.1	-344.7	-712.8
2	3.81	3635.1	3588.3	2793.9	4038.7	3641.5	46.8	841.2	-403.6	-6.5
3	-3.81	3716.2	3922.5	3476.8	4411.7	4087.2	-206.3	239.4	-695.5	-371.0
3	1.52	2905.2	1631.4	1558.7	1805.8	1980.1	1273.8	1346.5	1099.5	925.1

Table J.6. Summarized residual data from the OLS 4483 kg/ha application rate.

Rep	Pan Location (m)	Overall Mass Mean (kg/ha)	Row A Rate (kg/ha)	Row B Rate (kg/ha)	Row C Rate (kg/ha)	Row D Rate (kg/ha)	Row A Residual (kg/ha)	Row B Residual (kg/ha)	Row C Residual (kg/ha)	Row D Residual (kg/ha)
1	-6.10	1235.8	1423.1	1064.7	1582.9	1161.5	-187.3	74.3	-347.1	74.3
1	5.34	2031.4	1660.4	1389.2	1888.1	1612.0	371.0	419.4	143.3	419.4
2	-6.86	803.5	924.2	861.2	745.0	735.3	-120.7	68.2	58.5	68.2
2	1.52	2786.6	2367.6	2435.4	2304.7	3462.3	419.0	-675.7	482.0	-675.7
3	-6.86	803.5	715.9	851.5	599.7	774.0	87.6	29.5	203.8	29.5
3	7.62	715.9	987.2	648.1	1050.1	376.8	-271.3	339.1	-334.2	339.1

APPENDIX K

PRESSURE DATA

To be able to gain a better understanding of the hydraulic system on the spreader and determine why spinner 2 was operating at a higher speed than spinner 1, pressure transducers were installed to determine if the pressure drops across each of the motors were equal. The pressure tests were conducted after the data collection tests. Below is the data for the pressure tests. The CLS speed data (table k.1) is not consistent with the data collected during data collection. Something occurred with either the tractors hydraulic system, the CLS flow control valve, or the control algorithm not allowing the controller to maintain a consistent spinner speed when material was being applied. The OLS data (table k.2) was similar to the data collected during the actual field tests; however, there is still no definite evidence to conclude why spinner 2 runs faster than spinner 1.

Table K.1. Summarized spinner-disc speed and pressure data for the CLS.

Load (kg/ha)	Spinner 1 (rpm)	Spinner 2 (rpm)	Diff.[1] (rpm)	Chain (rpm)	GSR (mph)	Input Press. (psi)	Spinner 1 Input (psi)	Spinner 2 Input (psi)	Output Press. (psi)	Spinner 1 Press. Drop (psi)	Spinner 2 Press. Drop (psi)
None	598.3	599.2	1.0	0.0	0.0	281.2	241.4	150.9	73.7	90.4	77.3
2242	607.6	633.8	26.2	4.8	3.5	777.3	733.7	416.2	87.8	317.5	328.4
4483	596.3	674.5	78.1	11.3	4.0	1426.1	1368.6	707.0	105.7	661.5	601.4
6725	530.1	642.5	112.4	17.2	4.1	1899.9	1848.3	1027.6	103.7	820.7	923.9

1) Diff. 1 is the difference between spinners 1 and 2; negative indicating spinner 1 is faster.

Table K.2. Summarized spinner-disc speed and pressure data for the OLS.

Load (kg/ha)	Spinner 1 (rpm)	Spinner 2 (rpm)	Diff.[1] (rpm)	Chain (rpm)	GSR (mph)	Input Press. (psi)	Spinner 1 Input (psi)	Spinner 2 Input (psi)	Output Press. (psi)	Spinner 1 Press. Drop (psi)	Spinner 2 Press. Drop (psi)
None	658.0	657.8	-0.2	0.0	0.0	2611.2	275.2	178.6	82.4	96.7	96.2
2242	638.4	637.4	-1.0	5.7	4.1	2612.9	447.3	274.1	81.0	173.2	193.1
4483	584.5	606.2	21.7	11.3	4.0	2605.7	710.0	373.5	80.3	336.5	293.3
6725	569.4	585.5	16.0	17.2	4.0	2602.2	830.3	429.4	79.9	401.0	349.5

1) Diff. 1 is the difference between spinners 1 and 2; negative indicating spinner 1 is faster.