DEVELOPING AND IMPLEMENTING SURVEILLANCE SYSTEM FOR FARM-RELATED INJURIES INVOLVING LIVESTOCK MANURE STORAGE, HANDLING, AND TRANSPORT EQUIPMENT AND FACILITIES WITH ANALYSIS AND IMPLICATIONS

by

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A Dissertation

Submitted to the Faculty of Purdue University

In Partial Fulfillment of the Requirements for the degree of

Doctor of Philosophy

Agricultural and Biological Engineering

West Lafayette, Indiana

December 2020

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"And whoever saves one – it is as if he had saved mankind entirely". Quran

Verse (5:32) sūrat l-māidah

We will continue to make major contributions and impact not only the occupational health and safety profession but more significantly the farmers, ranchers, farm workers, and their families who trust us with their health and safety. *Mahmoud Nour*

ACKNOWLEDGMENTS

I thank the Lord (Allah) for all the blessings of gratitude, “whoever does not thank the people (for their favors), does not thank Allah”. Prophet Muhammad (peace be upon him).

Foremost, I would like to express my sincere gratitude to my dissertation chair and adviser Professor William Field for his continuous support of my Ph.D. study. His patience and motivation at every step in my research were appreciated. Thank you for not giving up on me and inspiring me to work hard to improve my writing and my life. Besides my dissertation adviser, I would like to thank each member of my respected Ph.D. committee as they played a vital role in my program of study and for their relentless encouragement, and support: Dr. Ji-Qin Ni, Dr. Kingsly Ambrose, Dr. Michael Pate, and Dr. Shawn Ehlers.

I am very thankful to our collaborators within Purdue’s Agricultural and Biological Engineering Department for their technical support with data collection and processing. I thank the National Agrability Project staff; Paul Jones, Denise Heath, Edward Sheldon, and Stephen Swain for supporting and providing necessary resources that allowed me to conduct this research. I also must thank Nikki Zimmerman for her assistance, patience, and support during my Ph.D. program.

Sincerest thanks to all Professor Field’s previous graduate students Dr. Charlene Cheng, Dr. Salah Issa for their enthusiasm and guidance during my Ph.D. program. I also thank my fellow students, ABE mates, and colleagues for friendly support and motivating discussions.

I owe many thanks to all my former advisors from School of Health Sciences, Purdue University, Dr. Wells, Dr. Dydak, Dr. Rosenthal, Dr. Zimmerman, and the late Bob Walkup for their support and advice throughout the years and for introducing me to the incredible field of industrial hygiene.

Documenting and summarizing the data used in this study was made possible by funding from Purdue’s Agricultural Safety and Health Program, Bilsland Dissertation Fellowship, College of Agricultural, Purdue University, the National Children’s Center for Rural and Agricultural Safety and Health (Marshfield, Wisconsin), and the Central States Center for Agricultural Safety

and Health (Omaha, Nebraska). I am thankful to our collaborators at these organizations and programs for providing support for this effort.

Last but not least: my sincere thanks also go to my family for encouraging me on this journey: my late parents, my siblings, my in-laws, my wife Hayaam Osman and my loved ones: Mohammed, Ahmed and Omar.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Agriculture is a major industry in the U.S. with higher rates of mortality and morbidity due to occupational injuries when compared to other industries (BLS, 2016). Manure storage, handling, and transport facilities and equipment possess life threatening hazards on many livestock operations. These hazards include: 1) toxic manure gases generated within enclosed structures which can be fatal to both human and livestock due to direct exposure; 2) below and above ground liquid manure storage structures that have the potential risk for drowning and falling; 3) mechanical hazards associated with manure handling machinery, including entanglement and equipment failure, and 4) exposure to infectious agents found in livestock waste. Since the 1970's over 2400 involving agricultural confined space incidents including nearly 460 incidents involving manure storage, handling and transport have been documented as part of ongoing surveillance by Purdue University's Agricultural Safety and Health Program. There have been several efforts that have examined this data; however, few have attempted to monitor or summarize over time injuries and fatalities associated with livestock manure storage, handling, or transport equipment and facilities. In addition, no published work was identified that attempted to design or implement an agricultural-based surveillance method or consistent data classification/coding system that could be used to analyze cases involving manure-related injuries and fatalities. This research was designed to contribute to a better understanding of the problem of manure-related hazards, through development of a uniform coding system to classify these incidents, ongoing surveillance of individual cases of related injuries or fatalities, estimation of the frequency and severity of these incidents, identifying geographic distribution and primary farm type, victim characteristics, and causative factors including those related to both respiratory and machinery hazards associated with manure storage, handling or transport. Findings include, under reporting of incidents preventing a comprehensive understanding of the problem, 75% of documented cases were male with an average age of 35, approximately 20% of all documented incidents involved children and youth age 21 and younger. Findings from the analysis of cases documented to date and future cases will be used to develop more effective, evidence- based injury prevention and mitigation strategies and to develop a representative baseline for future assessment of these efforts. Outcomes from this research included: 1) consistent strategy to document, code, and summarize manure-related incidents; 2) means of classification of key causative contributing factors; 3) identification of new

or emerging trends; 4) analysis of the existing data set; and 5) recommendations for addressing key contributing factors through: identifying desired core competencies that should be addressed in future educational activities; new or modified engineering standards and potential regulatory concepts, and enforcement of current OSHA workplace safety and health regulations.

Keywords: Livestock, confined space, fatality, manure pit, manure storage, manure spreader.

1. INTRODUCTION

1.1 Statement of the Problem

Agriculture remains one of the most dangerous industries in the U.S. and globally. Documented farm-related injury and fatality data is vital for comprehensive injury surveillance and prevention efforts. According to the U.S. Bureau of Labor Statistics (BLS), the fatal occupational injury rate in agriculture is the highest fatality rate of all other industries in the country. The overall U.S. agricultural fatality rate has been reported as 23.4 per 100,000 full-time equivalents, which is almost seven times greater than the fatality rate for all other industries (BLS, 2016). Unlike other industries in the U.S., farming is unique where residence and worksites often merge together. This unique characteristic of farming exposes farm workers as well as children and other non-working family members to workplace hazards where they physically live or when they visit family members (Gorucu & Pate, 2019). Enclosed storages, or agricultural confined spaces, have also historically been recognized as one of the most common hazards on farms and have been associated with the deaths of a large, but unknown numbers of farmers and their family members.

Livestock manure storage structures are among the most hazardous confined spaces in agricultural workplaces. These facilities pose several risks, including falls, toxic gas inhalation and asphyxiation, aspiration of liquid manure, infection, and explosion (Hallam et al., 2012). There have been numerous documented cases in which farmers, employees, or family members have died from exposures associated with livestock manure storage facilities (Donham et al., 2002, Beaver & Field, 2007; Hallam et al., 2012; Issa et al., 2016). The hazards associated with livestock manure storage, handling and transport have been recognized in the literature for seven decades from 1955 through 2020. Douphrate et al., indicated that some of the most common causes of death and serious injury on U.S. dairy farms involve heavy machinery, specifically tractors, silage bunker collapse, manure pit entrapment, tractor power takeoff (PTO) entanglements, and injuries from large animals (e.g., bulls) (Douphrate et al., 2013). It has been noted that additional research is needed to help farm owners/operators understand the dangers associated with working in and around agricultural confined spaces as most farm owner/operators do not understand, or underestimate the risks (Pate & Merryweather, 2012). Because there is no comprehensive or

mandatory reporting system that collects data on manure storage, handling, and transport incidents, it has been difficult to make evidence-based recommendations concerning the best strategies to reduce the frequency and severity of these incidents (Issa & Field, 2016).

With over a billion tons of livestock manure produced annually in the U.S. (Schroder, 2014), disposal of this valuable resource consumes a substantial amount of resources including both labor and equipment. Working around livestock farms involve numerous sources of occupational injury risks (Langley and Morrow, 2010). Livestock manure is potentially hazardous to both humans and animals if not managed properly (Li and Ni, 2020). Farmworkers who are engaged with storage, handling, and transport of livestock wastes are exposed to occupational, health, environmental, biological, and respiratory hazards. In 2012 livestock and poultry grown in the largest concentrated animal feeding operations (CAFOs) in the U.S. produced 369 million tons of manure, or almost 13 times the waste of the entire U.S. population, according to an analysis by USDA. Storing and disposing of these immense quantities of manure can lead to significant anthropogenic emissions of methane and Nitrous oxide (U.S. EPA 2007). Farm animal manure is the source of almost 18 million tons of annual methane emissions (Steinfeld et al., 2006). Between 1990 and 2005 in the U.S., methane emissions from dairy cow and pig manure rose by 50% and 37%, respectively (U.S. EPA 2007).

Purdue University's Agricultural Safety and Health Program (PUASHP) has been documenting grain-related entrapment and engulfment cases since the 1960s. This ongoing effort to identify, document and analyze these incidents led to the development of the Purdue Agricultural Confined Space Incident Database (PACSID) which was designed primarily for analysis of grain entrapment and engulfment cases. Analysis of these data has led to multiple publications such as Freeman et al. (1998), Kingman et al. (2001), Roberts et al. (2011) and Riedel et al. (2013) and Issa et al. (2018). During the surveillance process, cases involving other non-grain related types of agricultural confined spaces were also documented but not added to the database due to its design limitations or the lack of relevant selection categories. These limitations included differences in terminology used to code case information in the (PACSID) and dissimilar causative and contributing factors. These cases included injuries and fatalities involving tower silos, bunker silos, wells, storage tanks and manure storage, handling and transport equipment, and facilities. Cases involving manure, including human exposure to toxic gases associated with manure decomposition, comprised the second largest category of incidents in the database

following grain-related cases. However, analysis of the manure related incidents has been limited to one summary of 77 fatalities (Beaver & Field 2007). A total of 232 cases involving manure storage, handling, and transport have been documented, dating since 1975. These cases were not previously analyzed due to the lack of a consistent coding system and financial resources. A review of the literature found that there was no published attempt to design an agricultural-based surveillance strategy or consistent data classification/coding system that would provide the ability to assess the frequency, severity and nature of the manure-related cases nationally. A consistent coding system and more useful approach to process and analyze manure-related incidents was needed to summarize the existing data and to develop a foundation for developing a more evidence-based response to the problem.

Results of this study will address the existing need for a more evidence-based approach to addressing injuries and fatalities that involve storage, handling and transport of manure. In addition, the results will allow quick analyses of manure-related injury trends, identify the causes of injuries, and identify potential preventative measures. Findings will shed light on how well the current data set on manure storage, handling and transport cases represent the actual nature of manure-related injuries and fatalities and the frequency of these incidents. It will also provide a deeper understanding of any potential biases the documented cases in the database might have and potentially address the problem of under reporting of manure-related incidents. The results should be applicable to all livestock production operations based on their common storage, handling and transport practices.

1.2 Review of Literature

Relevant occupational health and safety articles, extension/education publications, agricultural injury surveillance summaries, and on-line sources were reviewed. Key terms in this search included: manure, manure storage, manure pits/lagoons/ponds, manure spreader/tank incidents. No published research was found that included an attempt to complete a risk assessment of all types of manure-related injuries and fatalities or attempted to consistently monitor over time injuries or fatalities associated with livestock manure storage, handling, or transport. In addition, no published work was identified that attempted to design a surveillance method or consistent data classification/coding system that could be used to assess the frequency or severity of these events. In general, a summary of manure-related injuries and fatalities, and

evidence-based recommendations concerning the best strategies to reduce the frequency and severity of these incidents was lacking in the literature.

Considerable research has been conducted and published on the chronic and acute health effects of exposure to the toxic environments often found in confined livestock production facilities including concentrated feeding operations and their associated manure storage facilities (Cockcroft & Dosman, 1981; Morse et al., 1981; Donham et al., 1982; Hagley, 1983; Heederick et al., 1991; Donham, 2002; Ni et al. 2009; Hallam, 2012). The most significant hazards identified in these studies related to the chronic respiratory hazards for workers exposed to gases and aerosols that are released from decomposing or agitated liquid anaerobic digested livestock manure, especially liquid manure slurry. The most common hazard of enclosed manure structures to farm operators/workers is suffocation which is primarily due to buildup of toxic gases and depletion of oxygen. Manure pits are potentially dangerous, gas-containing confined spaces that may generate hazardous levels of hydrogen sulfide (Field, 1980; Murphy, 1991). Ni, et al. (2009), reported that Ammonia (NH_3), hydrogen sulfide (H_2S), carbon dioxide (CO_2), and sulfur dioxide (SO_2) are among those gases that pose the greatest environmental concern. Transfer of gases originating from manure in animal buildings to the atmosphere involves three major processes: production, release, and emission. Dai et al. (2015), indicated that dairy and beef manure released more hydrogen sulfide and sulfur dioxide which has been recognized as the most toxic of the gases released. Layer hen and swine manure released the highest levels of ammonia and carbon dioxide. However, none of the studies reviewed attempted to monitor on a continuous basis individual cases of injuries or fatalities, estimate the frequency or severity of these incidents, identify geographic distribution or primary farm type, or identify causative factors including those related to both respiratory and machinery hazards associated with manure storage handling or transport.

The National Institute for Occupational Safety and Health (NIOSH) published two reports on two incidents in 1989 involving seven workers who died due to exposure to oxygen deficient manure storage facilities on dairy farms. Five of the victims died attempting to rescue the initial victims (CDC reports, 1989[89-46,89-44]). There was, however, no known attempt by NIOSH to determine the frequency of these incidents. In 1990, a second NIOSH alert was released entitled “Request for Assistance in Preventing Deaths of Farm Workers in Manure Pits” to promote awareness of the risks of manure storage and the potential for multiple fatalities to occur. The second NIOSH alert again described the seven earlier deaths from asphyxiation (suffocation)

that occurred during two incidents involving entry into manure pits. This alert was developed to target injury-prevention efforts among farm workers who were at risk or may be unaware of the danger of entering manure pits.

Hallman reported on a New York case study that was investigated by the NIOSH Fatality Assessment and Control Evaluation (FACE) program that illustrated the hazards of power take off operated manure pumps (Hallman, 2005).

Though not typically or historically identified as manure storage-related incidents, fatalities and injuries identified through the (PACSID) surveillance effort involving the transfer, pumping, agitation, and transport of liquid manure appeared to be more common than reported in the literature.

Based upon a convenience sample of cases documented by (PUASHP), Beaver and Field analyzed 77 fatal U.S. cases that were documented between 1975 and 2004 (Beaver & Field, 2007). In addition, 21 severe injuries and 14 international cases were documented during the same period. The findings showed a greater proportion of events occurring at dairy operations (54.5%) versus at swine operations (44%). All the fatal cases documented were male, and 27% of the cases involved non-working children or workers 21-years-old or younger, and 21% involved youth under the age of 16. The largest portion of fatalities (34%) occurred to persons conducting repairs or maintenance activities on manure handling equipment such as liquid manure pumps and agitators. It was also found that 22% of those fatally injured had entered a manure storage or handling facility in an attempt to rescue the original victim within the manure storage structure. The seasonal period of peak incidents occurred during the hottest part of the summer and were associated with transferring of manure for application to crop ground. Beaver and Field also documented that operators and farm workers working around manure storage, handling and transport facilities knew these facilities were unsafe yet failed to follow basic recommended work practices, such as those found in general extension education resources and ASABE Standard EP-470 titled (Manure Storage Safety) (ASABE, 2019). One of the recommendations from the study was to develop a centralized reporting system for these incidents and to conduct more in-depth investigations of incidents involving multiple victims. The authors concluded that, while farm operators and workers knew that manure pits were unsafe, they did not perceive them to be so unsafe as to cause them to worry or follow recognized safe work practices. This summary represented one of the first attempts to obtain a more detailed

understanding of the magnitude of the problem of manure related injuries and fatalities rather than a response to specific incidents. However, the authors recognized that the study was severely limited due to the small population size, the fact the cases analyzed were all fatal, and they were limited in geographic scope.

In another report, four European incidents with 10 deceased victims involving manure pits, an outdoor open space beside a manure pit, and inside a biogas plant were reported (Oesterhelweg et al., 2008). Three of the four cases had multiple victims that all involved rescue attempts of unconscious co-workers or family members. The authors warned that in high concentrations, hydrogen sulfide, a gas identified in the reports cited, led to a rapid loss of consciousness.

Hallam et al. (2012) summarized research on fatalities and injuries related to exposure to livestock manure with an emphasis on prevention strategies for decreasing mortality and improving facility design to reduce exposure to toxic gases. The authors recommended that workers have access to self- contained breathing apparatus (SCBA), lifelines, external observers, and other confined space access precautions. However, no longitudinal study of U.S., incidents or attempts to determine frequency were mentioned.

Park et al. (2006) summarized 17 incidents related to manure storage and transport in which 30 workers died and 8 were injured between 1998 and 2013 on Korean farms. Cases were identified through newspapers and online searches, with the fatalities being primarily caused by asphyxiation. The authors recommended that additional surveillance efforts were needed, since there was no formal ongoing process in place to document and summarize these events.

Numerous extension/education publications and on-line sources were reviewed; however, none addressed attempts to assess the frequency of manure-related injuries and fatalities or strategies for conducting risk assessment of all types of manure storage, handling, and transport practices to which workers are exposed. In numerous publications, the same high-profile incidents involving multiple victims were referenced, but no overall scope of the problem was provided. The primary focus of these educational resources was on exposure to toxic environments associated with livestock manure storage structures.

The American Society of Agricultural and Biological Engineers (ASABE) published several engineering practice standards for workers who enter manure storages and facilities or for addressing specific ventilation strategies (Murphy, 2012). The existing engineering practices and standards are (ASAE EP-470) on “Manure Storage Safety” in 1992 (ASABE, 2011), (ASABE EP-

270) recommendations for ventilation systems in barns above manure pits, and (ASAE S317.1, R2020) “Improving safety on enclosed mobile tanks for transporting and spreading agricultural liquids and slurry” (ASABE, 2012). Also, ANSI and ASABE published a consensus standard (ANSI/ASABE S607) for enhanced ventilation in 2010 on “ventilating manure storages to reduce entry risk” (ASABE, 2011).

The National Institute for Occupational Safety and Health (NIOSH) Fatality Assessment and Control Evaluation (FACE) program is a research program designed to identify, investigate and study fatal occupational injuries across the nation and in states participating in federal and state-based programs and then formulating and disseminating prevention strategies to those who can intervene in the workplace. These participating states voluntarily notify NIOSH of traumatic occupational fatalities resulting from targeted causes of death that have included confined spaces, electrocutions, manure machinery-related entanglement, falls in lagoons, and logging. The (FACE) programs conduct on-site fatality investigations of high-risk scenarios for workplace injuries and fatalities. Investigations conducted through the (FACE) program allow the identification of factors that contribute to fatal occupational injuries. Several (FACE) reports identified number of cases related to performing hazardous activities associated with manure storage, handling, and transport. This information is used to develop comprehensive recommendations for preventing similar deaths. In addition, (NIOSH) funds agricultural safety and health centers (Ag Centers) across the U.S. These (Ag Centers) conduct surveillance activities via grant-funded projects to examine the injury burden and emerging issues in farm safety and health and provide education and outreach to farm communities in the geographic regions they serve (Patel, 2016).

1.3 Primary Goal

The goal of this research was to develop, test and evaluate a more consistent method to code, document and classify injuries and fatalities that involve livestock manure storage, handling, and transport facilities and equipment for the purpose of developing evidence-based injury prevention strategies to reduce the frequency and severity of these incidents. The research targeted injuries and fatalities among farmers and farm workers who are at high risk of experiencing on-farm livestock manure structures and equipment injuries.

1.4 Objectives and Methods of Research

This goal was accomplished through completing the following specific objectives:

1. Review and summarize the literature to identify previously reported causative and contributing factors associated with livestock manure storage, handling, and transport injuries and fatalities.
    a. Use Boolean logic to conduct cyber searches of relevant research, and to validate the accuracy of incident coding and classifying process.
    b. Conduct an in-depth analysis on published cases related to livestock manure structures and equipment and summarize the data from these incidents to better understand the manure injury events.
    c. Investigate causative and contributing factors previously identified for agricultural manure-related injuries that related to both respiratory and machinery hazards.

    Methods: A comprehensive literature review focusing on livestock manure injuries and fatalities; injury risks associated with livestock manure handling and transport equipment; and health risks associated with toxic gases exposure was completed. Also, a classification and documentation system was developed and tested for identifying and categorizing manure-related incidents. A Boolean logic model was used to select the specific cyber search terms used and to identify key search factors and their relative significance. A special effort was made to collect additional case studies in published articles and on-line sources. A consistent and more reliable method was developed to document, code, analyze, and summarize all historical and future injuries and fatalities related to the storage, handling, and transport of livestock manure with special consideration for analyzing the frequency, severity, demographics, distribution, and trends of these events.

    A reliability test of the existing data was conducting with an extensive on-line search for relevant cases for comparison with the existing (PACSID) database. The draft coding scheme tool was developed and evaluated by applying and testing the system on approximately 39 documented cases documented in 2017 and entered in the (PACSID) database. The resulting coding tool is a form that can categorize information about the work activity during the incident and surrounding conditions. The coding scheme tool is attached as Appendix 1. Types of information that can be collected include age group, year, sex,

state, region, incident category, injury agent/facility/equipment category, and nature of injuries (i.e., fatal or non-fatal). This objective was completed in 2018 and resulted in an article published in Agromedicine Journal. (Mahmoud M. Nour, William E. Field, Ji-Qin Ni & Charlene Cheng (2018): Development of methodology to document and code farm-related injuries and fatalities involving manure storage, handling and transport - with summary of 2017 incidents, Journal of Agromedicine, DOI: 10.1080/1059924X.2018.1539420).

2. A search of the PACSID database was conducted and the finalized coding system used to summarize all documented livestock manure-related cases for purpose of in-depth analysis that would assist in the development of evidence-based injury prevention and mitigation strategies.

   Methods: The (PACSID) database was mined for any term that would imply livestock waste, such as manure, slurry, manure spreader or farm septic tank. Special efforts were made to collect additional input for cases with inadequate information in order to enhance the quality of incomplete incident reports. A comprehensive search was conducted using an internet content detection and notification service (Google alert system), on-line sources, news clippings, OSHA confined space incident reports, and published articles to identify new cases that might be included in the database, in addition to the 238 cases previously documented in the PACSID. Currently, the database includes 469 documented cases from 1975 through 2020 which means the number of cases were doubled. The new coding system was utilized for identifying and categorized all manure documented cases in the (PACSID) dataset. Manure-related data was summarized for the causative factors and other parameters and submitted for publication.

3. Test the model coding process by targeting incidents involving children, youth and beginning workers age 21and under.

   Methods: The (PACSID) database was mined for all cases of children, youth, and beginning workers at age 21 and under who were killed or injured while exposed to livestock manure storage, handling and transport facilities and equipment. Identified Children and youth cases were documented, coded and analyzed for defining the causative factors and the extent of the problem. This objective was completed in 2020 and resulted

in an article published in Agromedicine Journal: Mahmoud M. Nour, William E. Field, Ji-Qin Ni & Charlene Cheng (2020). Farm-Related Injuries and Fatalities Involving Children, Youth, and Young Workers during Manure Storage, Handling, and Transport. Journal of Agromedicine, DOI: 10.1080/1059924X.2020.1795034.

4. Categorize and summarize all documented livestock manure-related cases in the seven central-state region between 1975 and 2019.

   Title: "Summary of Seven Central-State Region Injuries and Fatalities Involving Livestock Manure Storage, Handling and Transport Operations: 1975-2019".

   Methods: The current (PACSID) database was mined for all seven central-state region cases. The seven central-state region includes NE, IA, SD, ND, KA, MO, and MN which were served by the Central States Center for Agricultural Safety and Health (CS-CASH). No fewer than 133 cases were identified where a victim was killed or injured while exposed to livestock manure storage, handling and transport facilities and equipment. Identified seven-state region cases were documented, coded and analyzed for defining the causative factors and the extent of the problem. Findings were summarized and submitted for publication to the journal of the Agricultural Safety and Health (JASH). (Mahmoud M. Nour, Ed Sheldon, Charlene Cheng, Ji-Qin Ni & William E. Field. Summary of Seven Central-State Region Injuries and Fatalities Involving Livestock Manure Storage, Handling, and Transport Operations: 1976-2019).

5. Summarize all documented manure-related cases in the (PACSID) between 1975 and 2019.

   Title: "Summary of Known U.S. Injuries and Fatalities Involving Livestock Manure Storage, Handling and Transport Operations: 1975-2019".

   Methods: The PACSID consisted of the original 241 cases extracted from (PACSID) database. Efforts were made to collect additional input for cases with inadequate information in order to enhance the quality of incomplete incident reports. In addition, the original data pool was expanded by 221 cases that were documented and added consecutively during completion of the study with the enhanced search method since 2017.

6. A set of evidence-based recommendations, including desired core competencies for training and addressing preventative measures and promoting regulatory, engineering and educational efforts were developed for the target population.

   Methods: Recommendations were developed based on the analysis of the collected livestock manure-related incidents. A panel of experts were used in a DACUM-style format to assist in prioritizing the desired core competencies. The recommendations focus on safety and health programs and on developing new livestock manure facilities and equipment standards. The final list of recommendations will be incorporated into published papers in a relevant journal, agricultural extension materials, agricultural safety curriculum, educational content and final granted reports.

1.5 Limitations

As with many types of agricultural-related injuries and fatalities, the high ratio of fatal to non-fatal incidents reported in this article suggests that a significant number of non-fatal or near-miss incidents go unreported preventing comprehensive documentation. The lack of any type of centralized or required reporting process will continue to result in under reporting of manure-related incidents, especially those that are non-fatal. There were multiple accounts identified during the discovery process in which workers were reported to have become overcome by a toxic environment during exposure to manure handling activities but were able to self-extricate or be removed from the site to recover without medical attention. In one case, a farmer shared about lowering his son on a rope sling into a manure storage structure and having the son pass out while suspended over liquid manure. The father was able to lift his son out, who recovered once reaching fresh air. In two other cases, workers who were checking the level of manure in a semi tanker were overcome and fell from the truck. None of these cases were included due to the wishes of the source and lack of adequate documentation. These types of "near misses", however, could provide valuable information to the development of injury prevention efforts. There were also issues with identifying the actual cause of death, especially in cases involving drowning, asphyxiation, and exposure to toxic gases, including hydrogen sulfide. Where there was access to autopsy reports, exposure to hydrogen sulfide was mentioned in some cases, but more frequently the official cause of death was identified as asphyxiation due to oxygen deficiency.

As with most farm-related fatalities, few autopsies are conducted. This lack of medical information also prevents a determination of the role placed by alcohol, drugs, or prior health conditions of the victim.

The data were also limited due to the inability to conduct additional on-site investigations involving interviews with victims and witnesses. It was found that only a few of these incidents were investigated by the Occupational Safety and Health Administration (OSHA) or the NIOSH FACE Program due to the agricultural workplace exemption or lack of resources. For example, it was believed that incidents, especially non-fatal or "near misses", at large swine production operations are under reported considering the large number of these facilities with on-site manure storage structures and the large number of employees. In general, a multisource surveillance system is needed to provide enough documentation for each case. These sources should not only include news media and on-line sources but also death certificates, workers' compensation reports, medical or hospital reports, coroner reports, police reports, and motor-vehicle incident reports. Such a system does not currently exist and is unlikely to be established in the foreseeable future.

1.6 Definitions

1. **Agricultural confined space:** Any space found in an agricultural workplace that was not designated or intended as a regular workstation, has limited or restricted means of entry or exit, associated with potential physical and/or toxic hazards to workers who intentionally or unintentionally enter the space. This includes:

- Manure storage structures
- Below floor storage pits
- Sump pits
- Above ground storage tanks
- Ponds, lagoons, and open pits
- Manure digesters
- Manure agricultural transport vehicles
- Grain transport (trucks, gravity bed wagons, and auger cart)
- Manure handling vehicles (tanks, applicators, and spreaders)

- Other

2. **Case:** A documented incident involving one victim
3. **Cause of injury:** In incident datasets indicates the specific reason of an injury such as suffocation, drowning, Trauma from falling, and entanglement in machinery.
4. **Coding and classification system method:** Is the most widely used system for classifying the nature and external causes of injury. It means transform the incident information that gathered from different sources into useable form for surveillance purposes (Bondy et al, 2005).
5. **Coding scheme tool:** A reliable tool to categorize detailed incident review that can process on the dataset.
6. **Hazard:** Any facility, location, equipment, tool, job, task, or action that presents a potential of serious injury or death to any individual.
7. **Incident summary:** the narration that can be used to record what happened through the event.
8. **Incident:** A drowning, falling, or suffocation event that may include multiple cases due to manure structure exposure.
9. **Lagoon**: is a man-made outdoor pond-like earthen basin that designed to receive and hold livestock waste as part of a system designed to manage manure slurry, which is washed out from underneath animal pens.
10. **Manure handling:** working and dealing with animal wastes and manure.
11. **Manure pit:** is a confinement man-made indoor/outdoor pond-like structure on livestock farms for the collection and storage of manure, in either open lots or enclosed.
12. **Seven central-state regions:** The seven states include in NE, IA, SD, ND, KA, MO, and MN and served by the Central States Center for Agricultural Safety and Health (CS-CASH).
13. **Surveillance:** The systematic and ongoing collection of morbidity and mortality data to monitor trends in specific areas of injury (Institute of Medicine (US), 1999).

1.7 Acronyms

ANSI – American National Standards Institute

ASABE – American Society of Agricultural and Biological Engineers

BLS - Bureau of Labor Statistics

CDC - Center for Disease Control and Prevention

CFOI - Census of Fatal Occupational Injuries

CS-CASH – Central States Center for Agricultural Safety and Health

FACE – Fatality Assessment and Control Evaluation

H_2S – Hydrogen Sulfide

ISASH – International Society for Agricultural Safety and Health

NASD – National Agricultural Safety Database

NIOSH - National Institute for Occupational Safety and Health

OSHA - Occupational Safety and Health Administration

PACSID – Purdue's Agricultural Confined Space Incidents Database

PPE – Personal Protective Equipment

PUASHP – Purdue University Agricultural Safety and Health Program

SOII - Survey of Occupational Injuries and Illnesses

USDOL – United States Department of Labor

USDA - United States Department of Agriculture

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2. DEVELOPMENT OF METHODOLOGY TO DOCUMENT AND CODE FARM-RELATED INJURIES AND FATALITIES INVOLVING MANURE STORAGE, HANDLING AND TRANSPORT - WITH SUMMARY OF 2017 INCIDENTS

A version of this chapter has been published with the following citation: Mahmoud M. Nour, William E. Field, Ji-Qin Ni & Charlene Cheng (2018). Development of methodology to document and code farm-related injuries and fatalities involving manure storage, handling and transport - with summary of 2017 incidents**.** Journal of Agromedicine, 24:1, 90-100, DOI: 10.1080/1059924X.2018.1539420

2.1 Abstract

As part of ongoing surveillance of fatalities and injuries involving agricultural confined spaces by Purdue University's Agricultural Safety and Health Program, nearly 300 cases involving manure storage, handling, and transport equipment and facilities have been documented over the past 30 years. With the exception of a summary of 77 fatalities published by Beaver and Field[1], these cases have not been previously analyzed or published due to a lack of resources and the limitations of the Purdue Agricultural Confined Spaces Incident Database (PACSID) which was designed primarily for analysis of grain-related cases. These limitations included differences in terminology used to code case information in the PACSID and dissimilar causative and contributing factors.

To develop a consistent and more useful approach to process and analyze data, 28 U.S. manure-related incidents involving 39 victims documented as having occurred in 2017 were examined for type of incident, victim characteristics, primary contributing factors, and nature of injuries. A review of literature was conducted to identify previously reported contributing factors, and a coding rubric was developed and reviewed by a panel of experts. It was determined that the rubric provided a consistent way to code and analyze descriptive information available on each case. A pilot analysis was completed of the 39 cases using the new tool, and results were summarized. The final methodology will be used to analyze all historically documented incidents, as well as future incidents. Findings presented include a review of relevant literature, discussion of the methods used in case documentation, classifications developed from sample data, and a summary of incidents in 2017. Anticipated outcomes include: 1) consistent strategy to document, code, and summarize manure-related incidents; 2) means of classification of key contributing

factors; 3) identification of new or emerging trends; and 4) completion of previously documented incidents.

2.2 Introduction

Over the past four decades, Purdue University's Agricultural Safety and Health Program (PUASHP) as documented incidents involving grain storage, handling and transport equipment, and facilities. Data gathered from these incidents, often involving multiple victims (cases), were entered in an electronic database developed by Kingman and Field (2005).1 The Purdue Agricultural Confined Spaces Incident Database (PACSID) now contains nearly 2000 individual cases representing persons injured or killed while exposed to agricultural confined spaces, primarily involving grain storage, handling or transport facilities, and equipment. Summaries of this data have been published by Field and Bailey (2)2; Kelley and Field (3)3; Kingman and Field. (2001)4; Kingman and Field (1)1; Roberts et al. (5)5; Riedel and Field (6)6; Cheng et al. (2016)7; and Cheng et al. (2018).8 During the surveillance process, cases involving other non-grain related types of agricultural confined spaces were also documented but not added to the database, due to its design limitations or the lack of relevant selection categories. These cases included injuries and fatalities involving tower silos, bunker silos, wells, storage tanks and manure storage, handling and transport equipment, and facilities. Cases involving manure comprised the second largest category of incidents following grain-related cases. These data could not be fully queried or summarized due, as noted, to the differences in agents involved, such as the type of structure, and causative factors identified in the various types of confined spaces-related incidents. The development of a more relevant classification system was undertaken utilizing cases documented during 2017 as a convenience sample. From these cases, individual coding fields were identified that could be used to classify and summarize previously identified and documented cases of injuries and fatalities in which manure storage, handling, or transport were involved. Findings from the eventual analysis of all related cases documented to date and future cases will be used to develop more effective, evidence-based injury prevention and mitigation strategies and to develop a representative baseline for future assessment of these efforts. This article focuses on the development of the data classification and coding tools and processes and provides a summary of 2017 incidents using the methods developed.

2.3 Review of Literature

A review of the published literature identified no attempt to consistently monitor over time injuries or fatalities associated with livestock manure storage, handling, or transport. In addition, no published work was identified that attempted to design an agricultural-based surveillance method or consistent data classification/coding system that could be used to assess the frequency or severity of these events.

Considerable research has been conducted and published on the chronic and acute health effects of exposure to the toxic environments often found in contained livestock production facilities including confined feeding operations and their associated manure storage facilities.[9–15] The most significant hazards identified in these studies related to the chronic respiratory hazards for workers exposed to gases and aerosols that are released from decomposing or agitated liquid anaerobic digested livestock manure, especially liquid manure slurry. However, none of the studies reviewed attempted to monitor on a continuing basis individual cases of injuries or fatalities, estimate the frequency or severity of these incidents, identify geographic distribution or primary farm type, or identify causative factors including those related to both respiratory and machinery hazards associated with manure storage handling or transport.

The National Institute for Occupational Safety and Health (NIOSH) published two reports on two incidents in 1989 involving seven workers who died due to exposure to oxygen deficient manure storage facilities on dairy farms. Five of the victims died attempting to rescue the initial victims.[16,17] There was, however, no evidence that NIOSH attempted to determine the frequency of these incidents.

In 1990, a NIOSH alert entitled “Request for Assistance in Preventing Deaths of Farm Workers in Manure Pits” was published to promote awareness of the risks of manure storage and the potential for multiple fatalities to occur.[18] The NIOSH alert described seven deaths from asphyxiation (suffocation) that occurred during two incidents involving entry into manure pits. This alert was developed to target injury-prevention efforts among farm workers who were at risk or may be unaware of the danger of entering manure pits.

Hallman reported on a NIOSH case study that illustrated the hazards of power take off operated manure pumps.[19] Though typically not identified as manure storage-related incidents, fatalities and injuries identified through the PACSID surveillance effort involving the transfer,

pumping, agitation, and transport of liquid manure appeared to be more common than reported in the literature.

Based upon a convenience sample of cases documented by PUASHP prior to 2005, Beaver and Field analyzed 77 fatal U.S. cases that were documented between 1975 and 2004.[20] In addition, 21 severe injuries and 14 international cases were documented during the same period. The findings showed a greater proportion of events occurring at dairy operations (54.5%) versus at swine operations (44%). All the fatal cases documented were male, and 27% of the cases involved workers 21-years-old or younger, and 21% involved youth under the age of 16. The largest portion of fatalities (34%) occurred to persons conducting repairs or maintenance activities on manure handling equipment such as liquid manure pumps and agitators. It was also found that 22% of those fatally injured had entered a manure storage or handling facility in an attempt to rescue another person. One of the recommendations from the study was to develop a centralized reporting system for these incidents and to conduct more in-depth investigations of incidents involving multiple victims. This summary represented one of the first attempts to obtain a more detailed understanding of the magnitude of the problem of manure related injuries and fatalities rather than a response to specific incidents. However, the authors recognized that the study was severely limited due to the small population size, the fact the cases analyzed were all fatal, and they were limited in geographic scope.

Four European incidents with 10 deceased victims involving manure pits, an outdoor open space beside a manure pit, and inside a biogas plant were reported.[21] Three of the four cases had multiple victims that all involved rescue attempts of unconscious co-workers or family members. The authors warned that in high concentrations, hydrogen sulfide, a gas identified in the reports cited, led to a loss of consciousness.

Hallam et al. summarized research on fatalities and injuries related to exposure to livestock manure with an emphasis on prevention strategies for decreasing mortality and improving facility design to reduce exposure to toxic gases.[9] The authors recommended that workers have access to self-contained breathing apparatus (SCBA), lifelines, external observers, and other confined space access precautions. No longitudinal study of these incidents or attempts to determine frequency were mentioned.

Park summarized 17 incidents related to manure storage and transport in which 30 workers died and 8 were injured between 1998 and 2013 on Korean farms.[22] Cases were identified through

newspapers and online searches, with the fatalities being primarily caused by asphyxiation. The authors recommended that additional surveillance efforts were needed, since there was no formal process in place to document and summarize these events.

Numerous extension/education publications and on-line sources were reviewed; however, none addressed attempts to assess the frequency of manure-related injuries and fatalities or conduct a risk assessment of all types of manure storage, handling, and transport practices to which workers are exposed. In numerous publications, the same high-profile incidents involving multiple victims were referenced. The primary focus of these educational resources was on exposure to toxic environments within manure storage structures.

2.4 Methods

The desired outcome of this research was to first develop a consistent method for documenting, coding, entering, and summarizing injuries and fatalities related to the storage, handling, and transport of livestock waste. A pool of nearly 300 unanalyzed cases already existed, but a method for organizing the data had not been developed as it had for cases involving grain storage and handling. The existing structure for the PACSID was used to develop a draft coding tool. This tool was then aligned with the work done by Murphy and Manbeck[23] to develop a safety assessment strategy for manure storage; the recommended safe practices found in the American Society of Agricultural and Biological Engineers (ASABE) Best Practice Standard ASAE EP[24]; and the relevant recommendations of the U.S. Department of Agriculture's National Institute of Food and Agriculture (USDA-NIFA) Committee on Agricultural Safety and Health.[25] The tool was reviewed by a panel of experts and then applied to the 28 incidents involving 39 individuals (cases) documented in 2017. Revisions were made to the tool to reflect feedback and to accommodate the scope of the data gathered from the 2017 cases. The resulting coding tool is attached as Appendix 1.

2.5 Documentation of Cases

As noted, the currently used database was designed primarily to document, consistently store, and analyze data related to grain-related injuries and fatalities. During the search and ongoing surveillance efforts for these cases, unrelated cases involving manure storage, handling,

and transport were documented. These overlaps occurred due to the similarities in the terminology found in the reports of both types of cases and used as key terms in on-line searches. These terms included: “asphyxiation”, “suffocations”, “confined space”, “fell into”, and “rescued from”. All documented “non-grain” cases were preserved but had not been entered into the database for reasons noted above. Also, as noted in the review of literature, a convenience set of 77 of these cases, all fatal, was analyzed and reported on separately by Beaver and Field,[20] but was not included in the PACSID. Between 2013 and 2016, additional more aggressive on-line searches for manure-related cases were conducted as part of a U.S. Department of Labor OSHA Susan Harwood grant to develop safety training resources on agricultural confined spaces. Again, due to the lack of adequate or relevant coding fields, the cases were not entered into the database or fully analyzed. However, findings did reaffirm the problem of secondary victims during rescue attempts and incidents involving manure handling equipment, which were addressed in the educational materials being developed. Findings led to a decision to expand surveillance efforts to include not only incidents related to drowning and toxic atmospheres related to manure storage, but also those involving auxiliary equipment, such as agitation equipment, liquid manure pumps, mechanical barn cleaners, and incidents occurring on public roadways during transport of solid or liquid manure. Associated with some of the data gathered was also information on manure spills that sometimes-accompanied personal injury incidents.

Newspaper clippings were a primary source, but literature reviews, online searches, personal interviews, obituaries, documents from prior civil litigation, and earlier catalogued death certificates were also used to capture incidents. Over 12,000 archived newspaper clippings, not available online, of farm-related injuries and fatalities were manually reviewed to identify relevant cases. Sources also included case studies published by the National Institute for Occupational Safety and Health and state reports summarized in the Census of Fatal Occupational Injuries. Ongoing daily Google alerts were incorporated into the search process using a variety of relevant key words and phrases and have been monitored for over 5 years. These aggressive surveillance efforts resulted in nearly 300 cases being identified, with 39 fatal and non-fatal cases being documented in 2017.

2.6 Classification of Cases

Upon completion of the pilot coding tool, the authors applied it to the cases identified in 2017 and collectively completed the coding as a means to test the applicability of the coding tool and develop a pilot summary of the data. This team approach led to additional revisions to the coding tool, especially in relationship to contributing factors and agents involved. Existing coding fields used to code grain-related cases were used as a basis for developing the new classification rubric. Comparable coding fields that were applicable to the revised coding tool, included:

- Date of incident (month, day, and year)
- Time of day
- State
- Address or county
- Type of farm (dairy, swine, beef, poultry, other)
- Fatal vs. non-fatal
- Number of victims
- Cause of injury or death
- Suffocation
- Drowning
- Asphyxiation
- Trauma from fire/explosion
- Trauma from fall
- Electrocution
- Entangled or caught in machine
- Trauma from roadway collision
- Trauma from equipment failure
- Access to uncovered manure pit
- Machine/vehicle related drowning
  - Victim
  - Name
  - Sex
  - Age
  - Relationship to farm

In addition, new categories for causative agents and contributing factors had to be developed to reflect the differences between grain storage, handling, and transport operations and

those associated with manure storage, handling, and transport facilities. The new descriptions of the agents involved are as follows:

- Underground or underfloor manure storage structures
- Above ground manure storage tank
- In ground manure storage (lagoon pit)
- Manure handling equipment (barn cleaner, skid steer, frontend loader)
- Manure transport vehicle (solid manure spreader, liquid transport vehicle)
- Manure agitation or pumping equipment
- Manure pumping pit or enclosure
- Electrical components
- Fire or explosion

A narrative section was also included to capture information such as the tasks being done by the victim at the time of the incident or extra ordinary circumstances. This section was, however, not searchable.

The final version of the coding tool was found to be applicable in most, but not all cases due primarily to insufficient data or unique circumstances in some cases requiring the use of "other" as a category.

2.7 Summary of 2017 Cases

The following pilot summary represents what the larger summary will look like if resources become available to enter the case information from the previously identified, approximately 300 cases, into the modified PACSID using the new coding tool. It is further hoped that publication of this preliminary summary will lead to the identification of additional cases and feedback on the need for other information that would be helpful in designing injury prevention efforts.

A total of 28 incidents involving 39 individual cases were documented in 2017. Of these 39 individuals, 21 cases (54%) were fatal. Out of the 28 incidents, there were 8 incidents involving multiple fatalities/injuries. Two victims were reported in six incidents, three victims in one incident, and four in another. As with confined spaces in general, the risk of multiple victims involved in manure-related incidents is higher than other types of workplace-related incidents.

The cases were primarily work related, but also included 10 cases that were classified as non-work related, including the death of a 3-year-old male who drowned after falling into an open

manure pit and a 5-year-old male who fell off a manure spreader and was run over. All of the victims in 2017 were male, with an average age of 36, which is substantially younger than the average for grain related injury victims, which is approximately 53.[26]

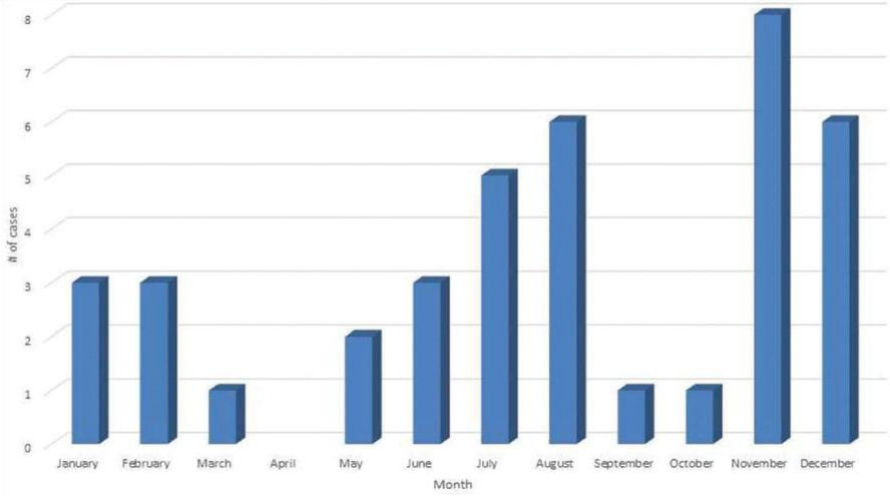

Figure 2-1: The distribution of cases by month (N = 39) for the 2017 summary.

The distribution of incidents by month is shown in Figure 2-1. November and December were peak months, with the majority of these cases involving handling, transporting, or field application of solid and liquid manure, especially on dairy farms. The second peak period of July-August reflected earlier findings that suggested there is greater risk of exposure to toxic manure gases, such as hydrogen sulfide, during hot weather when liquid manure is agitated and transferred by pumps for field application. (Figure 2-1)

Table 2-1: Distribution of cases by state (N = 39).

State	# Cases
PA	6
NY	6
MI	5
WI	5
MN	4
FL	3
ID	2
VA	2
CA	1
CO	1
IA	1
KY	1
TX	1

Table 2-1 provides the distribution by state in which the incident was reported. Michigan, New York, Pennsylvania, and Wisconsin, all strong dairy states, ranked at the top of the list. Figure 2-2 shows the distribution of agents involved in 2017. The agent was reported in 21 cases, with manure handling equipment the most frequently identified agent (8 cases) and followed by manure transport equipment (5 cases). The actual cause of death other than drowning or asphyxiation was rarely mentioned, even when official police and fire/rescue reports were available.

The type of toxic gas or level of oxygen that fatality victims were exposed to was rarely confirmed, but in prior research it appears that oxygen deficiency and the presence of high concentration of hydrogen sulfide were significant contributors to these deaths (Figure 2-2).
Regarding the type of farm, for 15 cases the specific type could not be determined due to insufficient data at the time of analysis. In cases where farm type could be identified, dairy was the most common with six. Swine and poultry operations each reported 1 case. Eleven of the cases took place on public roadways during transport of liquid or solid manure and two were reported to have occurred in a manure pumping station, or pump pit or enclosure.

2.8 Limitations

As with many types of agricultural-related injuries and fatalities, the high ratio of fatal to non-fatal incidents reported in this article suggests that a significant number of non-fatal or near-miss incidents go unreported preventing adequate documentation. The lack of any type of central required reporting process will continue to ensure under reporting of manure-related incidents.

There were multiple accounts unveiled during the discovery process in which workers were reported to have become overcome by a toxic environment during exposure to manure handling activities but were able to be removed from the site to recover without medical attention. In one case, a farmer shared about lowering his son on a rope sling into a manure storage structure and having the son pass out while suspended over liquid manure. The father was able to lift his son out, who recovered once reaching fresh air. None of these cases were included due to the wishes of the source and lack of adequate documentation. These types of “near misses”, however, could provide valuable information.

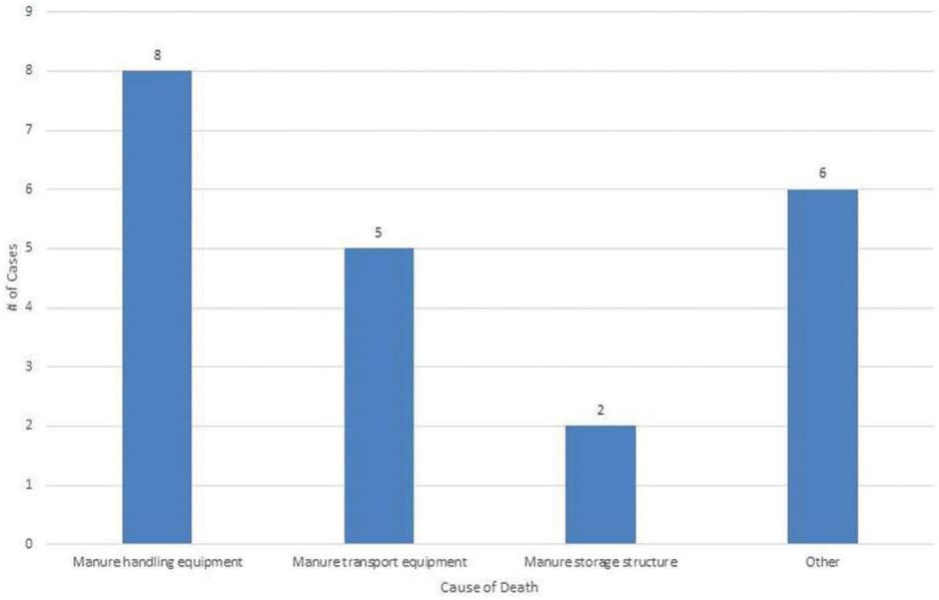

Figure 2-2: The distribution of agent involved in 2017 fatalities (N = 21).

There were also issues with identifying the actual cause of death, especially in cases involving drowning, asphyxiation, and exposure to toxic gases, including hydrogen sulfide. Where there was access to autopsy reports, exposure to hydrogen sulfide was mentioned in some cases, but more frequently the official cause of death was identified as asphyxiation due to oxygen deficiency. As with most farm-related fatalities, few autopsies are conducted. This lack of medical information also prevents a determination of the role of alcohol, drugs, or prior health conditions of the victim.

The data were also limited due to the inability to conduct additional on-site investigations involving interviews with victims and witnesses. It was found that few of these incidents are even investigated by the Occupational Safety and Health Administration (OSHA) due to the agricultural workplace exemption. For example, it was believed that incidents at large swine production operations are under reported considering the large number of these facilities with on-site manure storage structures and the large number of employees.

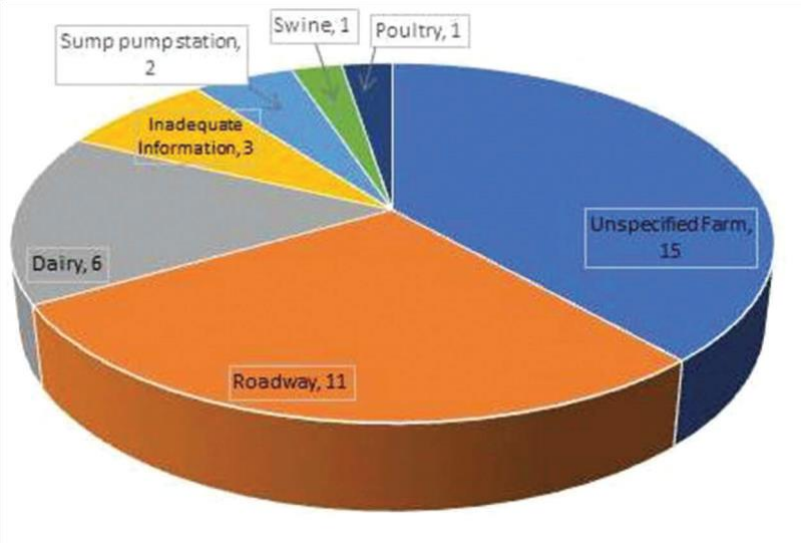

Figure 2-3: The distribution of cases by category for 2017.

In general, a multisource surveillance system is needed to provide sufficient documentation for each case. These sources should not only include news media and on-line sources but also death certificates, workers' compensation reports, medical or hospital reports, coroner reports, police reports, and motor-vehicle incident reports. Such a system does not currently exist but is unlikely to be established in the foreseeable future.

2.9 Discussion

Because of the surveillance efforts, the scope of cases now being documented is believed to be more representative of typical injuries and fatalities involving manure storage, handling, and transport operations. To date, nearly 300 cases have been documented between 1975 and 2017, but are yet to be fully summarized using the new coding process. This does not include a large number of cases documented outside the U.S., including 11 in 2017.It is anticipated that the total number of cases will increase as the surveillance efforts continue.

It remains premature to draw firm conclusions regarding what will be found when the balance of the 300 documented cases is summarized. There are, however, indications that the frequency of incidents involving manure storage and handling not related to toxic environments will be higher than originally believed or suggested by the current published research and educational resources. Past failure to document incidents involving manure handling equipment

such as barn cleaners, scrapers, and liquid pumps due to the focus on high profit, multi-victim incidents has caused a possible miss direction of prevention resources.

There is a need to continue the surveillance effort in order to provide an evidence-based response. This work, however, is not supported by any currently federally funded agricultural safety initiative.

2.10 Conclusion

The purpose of this preliminary effort was to develop a more consistent way to code injuries and fatalities that involve storage, handling, and transport of manure. This goal was achieved through the development of a standard documentation process and coding tool, and it is anticipated that the coding process will be used on the pool of cases that have been currently documented, along with future cases.

Regarding the frequency of these incidents, it appears they are relatively rare compared with other types of farm-related injuries and fatalities. However, this research clearly identified that there is a gap in the understanding of the problem, its scope and frequency, and the most effective strategies to prevent future incidents. It recommended that incidents involving all forms of agricultural confined spaces continue to be monitored and the findings used to promote regulatory, engineering, and educational efforts to reduce the frequency and severity of these incidents.

2.11 References

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3. FARM-RELATED INJURIES AND FATALITIES INVOLVING CHILDREN, YOUTH, AND YOUNG WORKERS DURING MANURE STORAGE, HANDLING, AND TRANSPORT

A version of this chapter has been published with the following citation: Mahmoud M. Nour, William E. Field, Ji-Qin Ni & Charlene Cheng (2020). Farm-Related Injuries and Fatalities Involving Children, Youth, and Young Workers during Manure Storage, Handling, and Transport. Journal of Agromedicine, DOI: 10.1080/1059924X.2020.1795034

3.1 Abstract

Objective: Manure storage, handling, and transport facilities and equipment have been associated with life threatening hazards on many livestock farms. These hazards have been documented in prior research as including 1) exposure to toxic manure gases or lack of adequate oxygen in enclosed structures, which can be fatal to both humans and livestock; 2) below and above ground liquid manure storage structures that have the potential risk for drowning and falling; and 3) mechanical hazards associated with manure handling and transport equipment, including entanglement, road collisions, runover, and equipment failure.

Methods: Over the past 40 years, Purdue University's Agricultural Safety and Health Program (PUASHP) has collected, documented, and maintained data regarding agricultural-related injuries and fatalities associated with agricultural confined spaces in the U.S. As part of ongoing surveillance, a total of 369 fatal and non-fatal cases relating to manure storage, handling and transport equipment, and facilities have been documented. Of these, 89 have involved children, youth, and young farm workers ages (birth–21) documented between 1975 and 2019. The purpose of this study was to summarize these 89 documented cases to better understand contributing factors and to develop recommendations for evidence-based strategies to reduce the frequency and severity of these incidents. Though recognized as not comprehensive for all incidents of this type, the data represent the largest data set known to exist, providing insight into previously unstudied hazards facing children and youth living and working on, and visiting farms as non-workers.

Results: Findings in this study include: there has been an increase in the documented frequency of these incidents, which may be due, at least partially, to enhanced or more aggressive surveillance efforts; 57% of the cases were fatal; incidents involving underground or inground manure storage facilities were the most frequent type; incidents involving manure transport

vehicles were higher than expected; 33% of the victims were five years of age and younger; and July was the month with the most documented incidents.

Conclusions: Recommendations for future injury prevention strategies include incorporation of information on manure-related hazards in curricula targeting children and youth, more aggressive enforcement of child labor laws that currently prohibit the employment of youth to work in manure storage structures or to be involved in their operations, and greater use of physical and administrative controls, including safety signage, fencing, gates, and covers to restrict access to manure storage structures.

3.2 Introduction

For over 40 years, Purdue University's Agricultural Safety and Health Program (PUASHP) has been documenting and maintaining data on fatalities and injuries involving grain storage, handling, and transport operations. This work has resulted in a large number of publications specifically related to agricultural confined spaces, including publications by Kelley et al. (1996);[1] Freeman et al. (1998);[2] Kingman and Field (2005);[3] Beaver and Field (2007);[4] Riedel and Field (2013);[5] and Nour et al. (2018);[6] As part of this on-going surveillance effort, incidents involving livestock manure storage sites, including manure pits, were also identified but were not included in the original PUASHP database. With support from a U. S. Department of Labor, Susan Harwood Training Grant, the database was expanded and renamed as the Purdue University Agricultural Confined Space Incident Database (PACSID). The reorganized database allowed for non-grain related incidents to be coded and included such as those involving tower silos, well pits, and manure storage and handling operations. Data from the PACSID were used to develop evidence-based curricula for emergency first responders and young and beginning workers exposed to agricultural confined spaces of all types in the U.S. The database continues to be expanded and currently contains over 2,400 incidents/cases documented primarily between 1975 and 2019. The distribution of these cases by agent category is shown in Figure 3-1. The second largest category of incidents were related to manure storage, handling, and transport operations, which represented 369 cases or just over 15% of all reported cases currently in the PACSID.

Based upon a preliminary review of the data analyzed by Issa et al.,[7] it was determined that as many as one in five documented incidents involved children and youth age 21 and younger. With support from the National Children's Center for Rural and Agricultural Safety and Health

(Marshfield, Wisconsin), a study was undertaken to conduct a search of the database and to investigate those incidents involving children and youth to gain a better understanding of how the problem impacted this age group. The search identified 89 individual cases that served as the basis for this article. The purpose of this investigation was to 1) enhance the understanding of the health and safety impact of agricultural manure storage and handling facilities and equipment on children and youth through analysis of incidents documented in the PACSID; 2) determine the causative and contributing factors related to children and youth injuries and fatalities associated with manure storage and handling facilities and equipment for preventing similar injuries in the future; and 3) develop evidence-based recommendations with the potential of reducing the frequency and severity of injuries involving children and youth exposed to agricultural manure storage and handling facilities and equipment found on livestock farms.

3.3 Literature Review and Background

Farming remains among the most dangerous occupations in the U.S., and farmworkers are at high risk for fatalities and injuries, with an annual death rate of 26.0/100,000 persons compared with 3.3/100,000 persons overall.[8,9] Farming and ranching operations are one of the few industries in which family members, especially children, (who often share the work and live on the premises) are also at risk for fatal and nonfatal injuries.[10] Youth employed in agriculture experience especially high rates of injury, and young migrant and seasonal farmworkers may be extremely vulnerable.[11] The National Institute for Occupational Safety and Health (NIOSH) estimated 893,000 youth under 20 years-of-age resided on farms in 2014, with about 454,000 youth performing farm work. In addition to the youth who live on farms, an estimated 266,000 off- farm youth were hired to work on US farms in 2014.[10] In the same report, NIOSH stated that in 2014 an estimated 12,000 youth were injured on farms; 4,000 of these injuries were due to farm work. According to U.S. Department of Labor's, Bureau of Labor Statistics (BLS),[12] between 1995 and 2002, an average of 113 youth less than 20 years-of-age died annually from farm work- related injuries. Half of these fatalities involved youth under age 15. For workers 15 to 17, the risk of fatal injury is four times the risk for young workers in other workplaces. Dogan and Demirci[13] reported that farming is one of the few industries in which entire families are at increased risk of injury, and that the injury rate is highest among children age 15 and under and adults over 65 years-of-age. In addition, DeWit et al.[14] stated that risks for agricultural injury among youth and young adults on

farms relate directly to the amounts and types of farm work exposures in which young people engage. Many children currently doing farm work would not be allowed to perform the same work in fast food restaurants, manufacturing plants, or coal mines, because the work would be considered unsafe. However, current regulations continue to exempt most farm youth, including those under the age of 16, from performing certain tasks recognized as hazardous such as operating machinery, harvesting tobacco, and working while exposed to the elements without consideration of these inherently unsafe conditions.[11]

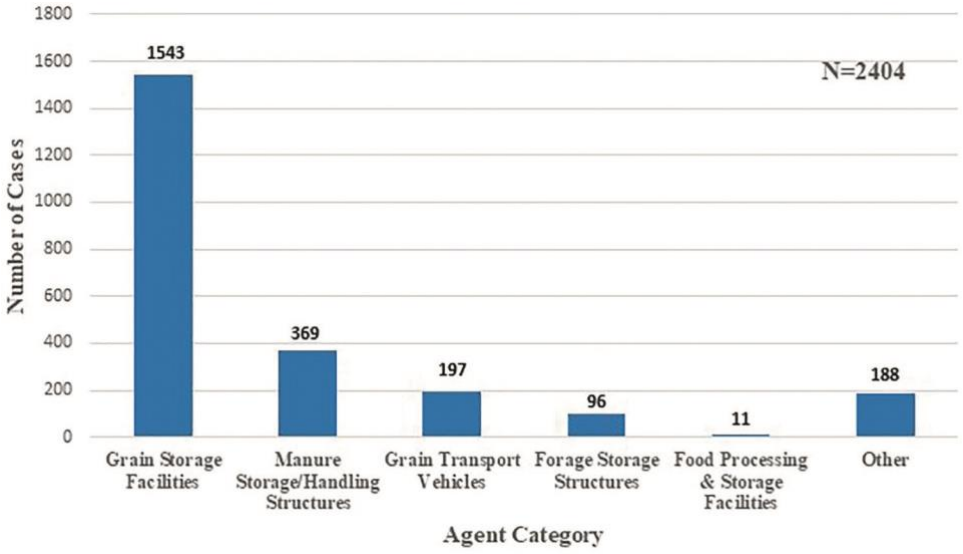

Figure 3-2: Documented injuries fatalities in PACSID database based on agent category between 1975 and 2019 (N = 2404).

Even though there is considerable literature documenting the frequency, severity, and occurrence of child and youth-related injuries on farms, very little research was found regarding children and youth injuries involving on-farm confined space incidents. Among those, Issa et al.[7] summarized 246 documented U.S. cases of children and youth under the age of 21 involved in grain storage and handling incidents in agricultural workplaces from 1964 to 2013. They reported "While the frequency of injuries and fatalities involving children and youth in agriculture has decreased in recent years, incidents related to agricultural confined spaces, especially grain storage and handling facilities, have remained largely unchanged during the same period."[7] Approximately 21% of all documented incidents summarized[7] involved children and youth (age 20 and younger), and more than 77% of all documented incidents for this age group were fatal, suggesting a

significant under-reporting of non-fatal incidents. Findings indicate that the majority of youth incidents occurred at "OSHA exempt agricultural worksites" where reporting of workplace injuries is not required.[7]

The National Children's Center for Rural and Agricultural Health and Safety (NCCRAHS) at the Marshfield Clinic's National Children's Center estimated in 2020[15] that about every 3 days a child dies in an agricultural-related incident, and every day about 33 children are injured on farms. About 60% of the nearly 8,000 injured youth were not working when the injury occurred, suggesting that over 3,000 youth were working for wages when they were injured. Drowning was identified as one of the primary causes of injuries and fatalities. There was no detailed information specifically on manure-related incidents in the NCCRAHS annual report. Likewise, of the leading sources of fatalities among all youth, 25% involved machinery, 17% involved motor vehicles (includes ATVs), and 16% were due to drownings.[16] Cross Currents[17] reported that although American farms are highly mechanized, they still require substantial human labor. Children who live on farms are generally expected to help with farm work, and they also sometimes earn money by helping other farmers in the area. Such work might include operating farm machinery, feeding farm animals and cleaning their living areas, milking cows, collecting eggs from chickens, putting up hay, and harvesting other crops.

There are federal and state child labor laws designed specifically to protect children who are employed to do farm work. However, the children of farm families are exempt from these regulations, and youth as young as 10 and 11 years-of-age may work on farms for other farmers with a parent's written consent. They have to work outside of school hours in non-hazardous jobs, and they do not have to be paid minimum wage. Children aged 12 and 13 years may work outside of school hours in non-hazardous jobs, either with a parent's written consent or on the same farm as the parents. Children aged 14 and 15 years may be employed to perform any non-hazardous farm job outside of school hours, but they are required to receive training to perform hazardous tasks such as operating tractors over 20 PTO horsepower. Youth, 16 years old and older may perform any farm job, whether hazardous or not, for unlimited hours.[11,17] Some states have more restrictive child labor laws than the current federal regulations.

With respect to exposure to agricultural confined spaces, current child labor workplace safety standards for agricultural occupations (Hazardous Occupation Order for Agriculture) state that, children under 16 are forbidden to be employed to work inside a fruit, forage, or grain storage

structure designed to retain an oxygen-deficient or toxic atmosphere, an upright silo for 2 weeks after silage has been added, or in a manure pit.[18] A review of on-line extension publications identified several that addressed the hazards associated with storage and handling of manure. Both the reading level and visual content of these extension efforts appeared to target adult farm operators. Relatively little attention was given to the risks to children and youth.

3.4 Methods

The PACSID was the primary source of data for conducting this research and for ongoing documentation of manure-related injuries and fatalities. The research attempted to replicate methodologies used in previous studies to better understand the impact that agricultural confined spaces, especially related to grain storage and handling, have on children. This included work done by Cheng, et al.[19] on utilizing secondary agricultural education programs for young and beginning workers in the grain industry and increasing awareness of youth- related incidents involving grain transport vehicles.[20] The data in the PACSID are derived from a variety of sources including death certificates, news clippings, web searches, obituaries, and post-incident information volunteered from family members, extension educators, first responders, and others associated with the incidents.[6] In addition, considerable information was derived from several well-documented cases that resulted in civil litigation.

The definition used to identify an agricultural confined space for inclusion into the PACSID and for use in this study was as follows: “Any space found in an agricultural workplace that was not designated or intended as a regular workstation, has limited or restricted means of entry or exit, associated with potential physical and/or toxic hazards to workers who intentionally or unintentionally enter the space”. These spaces included:

- Manure storage structures
- Under floor storage pits
- Sump pits
- Above ground storage tanks
- Ponds, lagoons, and open pits
- Manure digesters
- Manure agricultural transport vehicles
- Manure handling vehicles (tanks, applicators, and spreaders)
- Other

In addition to confined space-related incidents, the search was expanded to cover other manure storage and handling equipment such as barn cleaners, manure spreaders, and liquid manure agitating and pumping systems. Additional information on the manure-related incident classifying and coding process can be found in Nour et al., 2018.[6]

The current PACSID was mined for any term that would imply child, youth, young beginning worker, and livestock waste, such as manure or slurry. Additionally, two independent national searches were conducted beyond the contents of the database using Google alerts, on-line sources such as state farm fatality summaries, and other archival sources for identifying potentially missed cases that might be included in the database for analysis.

A coding system[6] was utilized for categorizing and coding all manure-related cases documented and entered in the PACSID database. The coding tool allowed for case information to be classified and analyzed in terms of the frequency, severity, demographics, geographic distribution, and certain contributing factors of these incidents. This process ensured a relatively high level of consistency in monitoring and coding injuries and fatalities over time. Types of information that were collected included: source of incident data, date of incident, age, sex, state, region, incident category, number of victims, injury agent/facility/equipment category, and nature of injuries (i.e., fatal or non- fatal).

3.5 Results

The search resulted in the documentation of 369 cases involving manure storage, handling, and transport equipment and facilities that were documented in the PACSID as having occurred in the U.S. between 1975 and 2019. Of the fatal and non-fatal incidents documented, no fewer than 76 incidents involving 89 individual cases (24%) were children, youth, and young workers 21 years-of-age or younger. Of a total of 89 cases, 57 (64%) were fatal. Out of the 76 incidents, there were 9 incidents involving multiple fatalities/injuries. Two victims were reported in six incidents, three victims in two incidents, and four in single incident.

The annual average number of documented cases was 2 over the 44-year study period. In the last decade, however, (2009–2019), the annual average number increased to 4.7 based on a 5-year moving average (Figure 3-2). The trend line was relatively consistent until 2012 when more aggressive efforts were made to document incidents involving manure storage and handling.

Regardless of the contributing factors and data limitations, the research has provided a much clearer historical perspective of the problem than had been previously available.

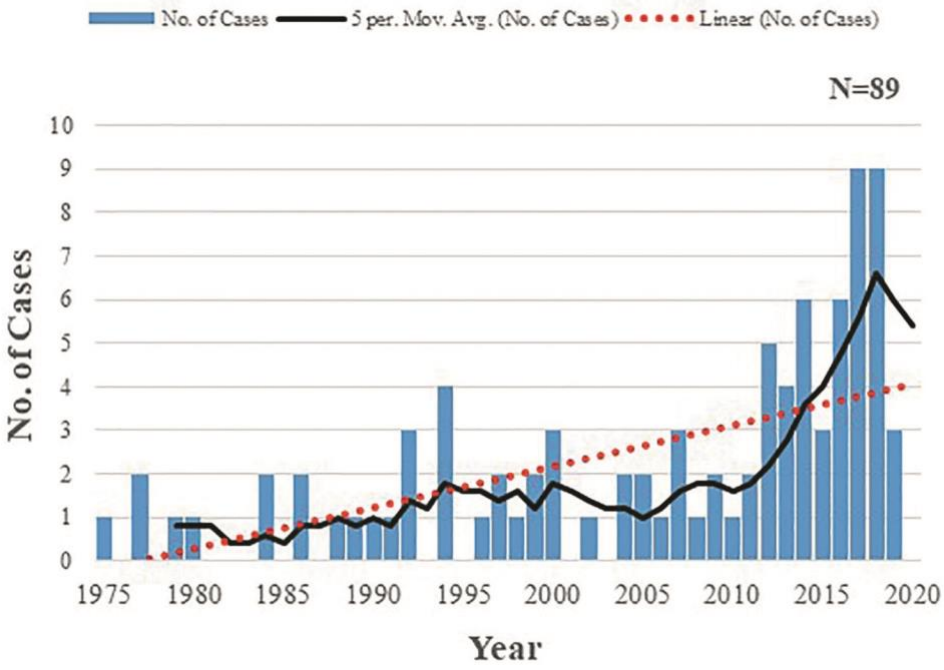

Figure 3-3: Distribution of children and youth fatal and non-fatal cases by year (N = 89).

Even though more attention has been given recently to child-related agricultural safety and health, data show an increasing number of documented cases over the past 10 years. This increase in the documented cases was influenced by several variables including limitations on reporting in the past, enhanced surveillance capabilities due to the Internet, increased use of agricultural confined spaces on livestock farms, and increases in child and youth exposure to confined spaces, including liquid manure storage sites. The current aggressive use of smartphone technologies, accessing the Internet or social media also makes the news of these incidents more accessible for broadcasting and searching.

Only 4 of the 89 cases lacked a specific age (Figure 3-3). There are two clear age groups most frequently involved in these incidents: 1–5 years-of -age and 16–21 years-of-age. From a developmental perspective, these two groups are very different, resulting in very different contributing factors. For example, younger victims were more likely to die from drowning, and older youth were more likely to have been involved with manure handling equipment. This distribution may require very different prevention strategies. Very noteworthy was the finding that 74% of the victims between ages 1 and 10 were fatal, reflecting both the severity of these incidents

and the under-reporting surveillance of non-fatal cases (Figure 3-3). For those victims ages 11–21, the percentage of fatalities was 62%. The average age of victims was 11 years, with nearly 83% of them being males; 11% of them were females, and 6% were an unknown gender.

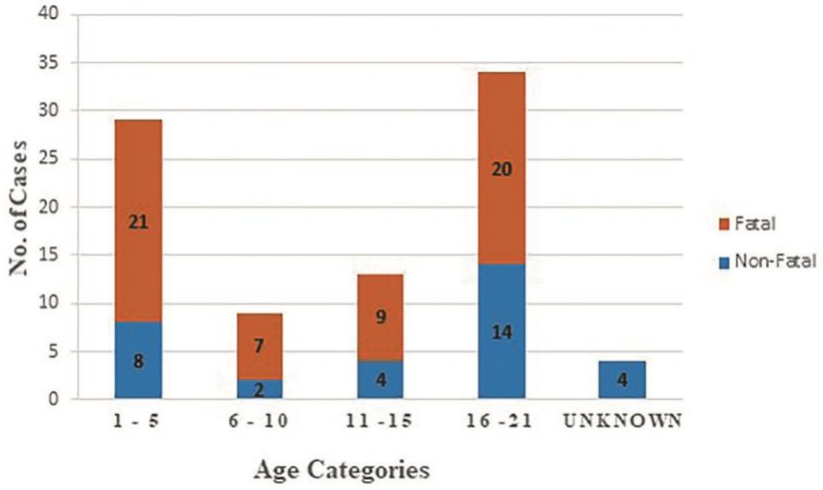

Figure 3-4: Distribution of children and youth cases by age category (N = 89).

Figure 3-4 provides a distribution of the type of agents involved in each incident. Among the 89 cases examined, 28 involved underground manure pits, and 26 involved manure transport vehicles (including trailers and tanks). These two categories accounted for more than 60% of documented cases.

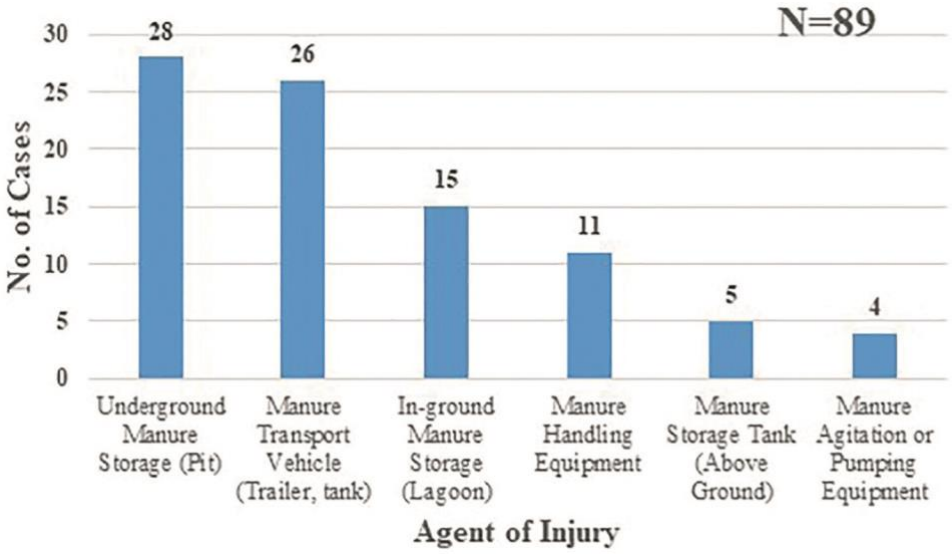

Figure 3-5: Distribution of children and youth cases by agent of injury (N = 89).

Some of the highest profile incidents recently reported in the media have involved multiple young victims who fell into a confined space, experienced trauma from equipment, or asphyxiated while being in close proximity to livestock manure storage structures. The primary causes of these events have been identified in media reports as the lack of awareness of the basic hazards associated with storage and handling of manure, lack of appropriate safety equipment, failure to comply with safe confined space practices, and lack of supervision and relevant training.

The three states with the largest number of documented cases of all types, including fatal and non-fatal, were Pennsylvania (13), Iowa (12), and Wisconsin (12) (Figure 3-5). The authors believe these three states were found to have a higher number of documented cases because they are all strong dairy production states. This confirms earlier work by Beaver and Field, who found that manure-related fatalities and injuries were more frequently documented on dairy operations. Another contributing factor may be that the three states with the highest frequency of incidents have had incidents in New York as compared to Pennsylvania, and the lack of cases documented in 29 other states, provide another indicator that the collected data are not comprehensive.

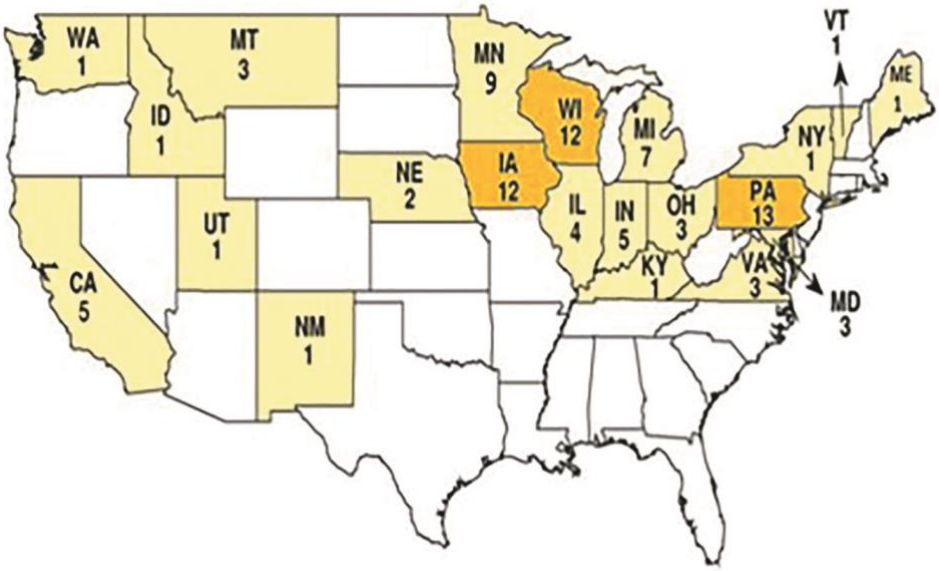

Figure 3-6: Distribution of children and youth cases by state (N = 89).

The three leading months for incidents were May, July, and October (Figure 3-6). Specific contributing factors associated with the month when the incidents occurred could not be

determined. One factor considered but not ascertained was the timing of manure application activities following wheat harvest in July and following corn and soybean harvest in October. Additional handling and transport of manure during these times in some regions of the U.S. may increase exposure to the hazards involved.

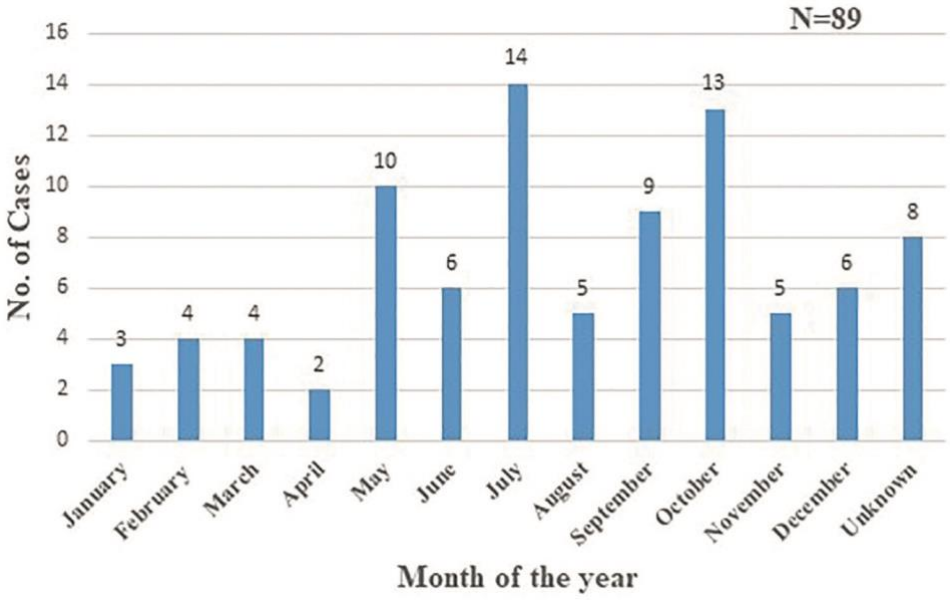

Figure 3-7: Distribution of children and youth cases by month of the year (N = 89).

Figure 3-7 provides a distribution of the cause of death or injury as reported by sources available. No effort was made to access official records to ascertain the medical cause of death for many of the cases in which the cause was not confirmed or incomplete. As noted from early studies, drowning was the most frequent cause of death identified. With respect to asphyxiation, hydrogen sulfide intoxication was noted earlier by Beaver and Field[4] as the most significant contributing agent.

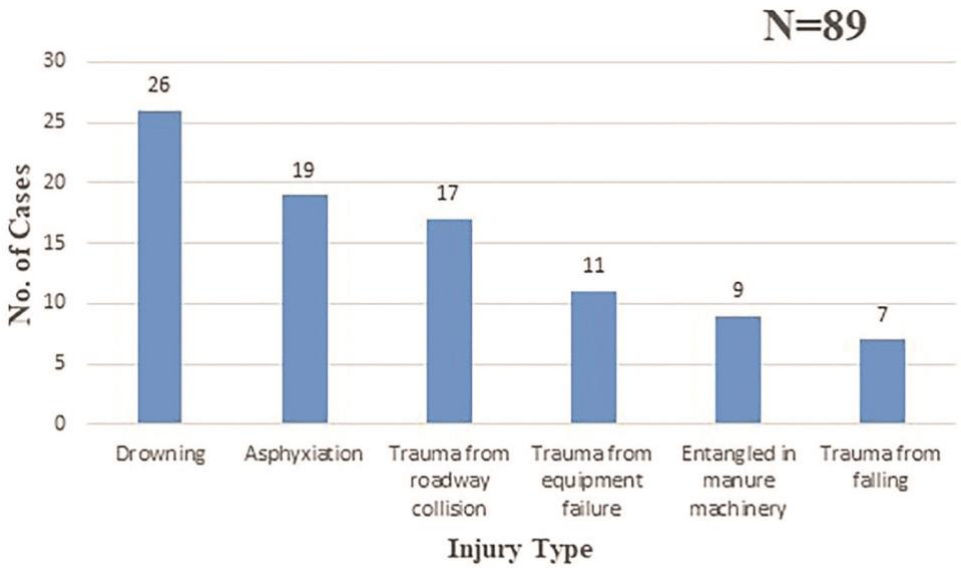

Figure 3-8: Distribution of children and youth cases by injury type (N = 89).

Data regarding the type of location of the incidents, for example, the type of farm, were not sufficient to determine the precise location in all cases. In some cases, there was confusion over where the injuries occurred, and where the victims were pronounced dead. It was clear, however, that the majority of incidents (over 66%) occurred on livestock farms, and the most frequently identified type was dairy farm (Figure 3-8). When combined, dairy and swine operations accounted for nearly 40% of all documented cases. There is high probability that the majority of unspecified farms were either dairy or swine.

Figure 3-9: Distribution of children and youth cases by location of injury (N = 89).

3.6 Discussion

This study demonstrated the first array of data on farm-related injuries and fatalities involving children, youth, and young workers exposed to livestock manure storage and handling operations in the U.S. The study examined 89 injuries and fatalities of manure-related cases involving children, youth, and beginning workers ages 21 years-old and younger through classifying and analyzing the documented cases in the PACSID from 1975 to 2019. Over the last 10 years, there has been an average of 4.7 children and youth injured or killed annually due to exposure to manure storage and handling facilities or related equipment. Though a relatively small proportion of all child and youth-related farm injuries, it is believed that these structures and equipment continue to be excessively dangerous, with a potentially high risk of injury and fatality for this population, as noted by the 64% fatality rate in the documented cases. The fact that 43% of the victims were 10 years-of-age and younger could prove significant in targeting prevention efforts. Regarding incident classification, it was estimated that due to the high percentage of victims under the age of 10, as much as 60% of the cases were non-work related.

As noted, due to the high percentage of fatalities, the authors believe that manure-related incidents have been significantly under-reported, especially for those resulting in non-fatal injuries such as unreported exposure to toxic gases found in manure storage and livestock housing facilities. One of the most often reported, but undocumented, incidents were falls into liquid manure storage

structures where the victims recovered without injury. This is supported by the high number of drownings reported.

There is an association between the type of livestock operation and the increased risk of manure- related incidents. Children and youth living and working on dairy and swine farms are at greater risk of experiencing an injury associated with storage and handling of manure. A major contributing factor at these farms is the storage and handling of liquid manure.

Another aspect of exposure to livestock manure not explored was the potential health risks due to biological agents, including infections due to exposure to livestock wastes. Cases were documented in which ingestion of liquid manure resulted in respiratory failure due to infection. Research on the health effects of exposure to manure toxic gases has been extensively published elsewhere.

Livestock manure structures such as manure pits, ponds, lagoons, and tanks and on-farm manure handling and transport operations were found to expose children, youth, and beginning workers to hazards with a high potential risk of causing injuries and fatalities due to suffocation, falls, entanglement, hydrogen sulfide intoxication, and drowning. The most significant cause of injury in manure structures among children and youth is most likely falling into above ground and underground manure storage facilities (liquid manure transport vehicles). These sites, especially on livestock farms should be considered high risk in need of targeted injury prevention efforts. Children and untrained youth should not have access to manure storage and handling facilities or any enclosed areas that contain livestock manure. These findings are only an initial step for providing significant evidence needed by decision makers to implement prevention strategies, regulations, and standards to prevent these incidents in the future.

3.7 Recommendations

The following recommendations are based upon the assessment of the findings and a review of the current relevant literature.

(1) Secondary agricultural education classes, farm safety training programs, and extension outreach efforts should be encouraged to provide and promote basic safety and health awareness about the hazards associated with all manure storage, handling, and transport operations in agricultural workplaces that pose a potential risk to children, youth, and young

workers. Parents should be included in the dissemination of safety resources. These efforts should target dairy and swine operations and high-risk activities such as exposure to liquid manure storage sites and confined spaces.

(2) There should be easy, on-line access to the needed safety information that improve farm workplace health and safety practices needed by farm children, youth, and young workers who are interested in farming or who work on family-operated farms and have exposure to agricultural manure storages and handling facilities and equipment.

(3) Training should be provided to all parents of youth and young workers on required personal protective equipment (PPE) and maintaining a safe workplace environment during manure storage, handling, and transport.

(4) Current structural and engineering standards for manure storage facilities and equipment, such as published by the American Society for Agricultural and Biological Engineering should be reviewed in light of these findings and enhanced to reduce risks in future facilities and equipment. Additional standards for signage, access covers, gates, fencing, and toxic gas monitoring equipment to reduce risks associated with these structures should be considered.

(5) Enforcement of existing workplace safety regulations, including the Hazardous Occupation Orders in Agriculture, can reduce the frequency and severity of child and youth exposure to agricultural confined spaces such as

   a. Since an expectedly high number of incidents involved manure transport equipment, special consideration is needed to further examine the cases of these incidents and how they can be prevented.
   b. Enforce existing child labor laws that prohibit children and youth under 16 years-of-age from working in or around agricultural confined spaces.
   c. Requirement that youth employed in agriculture under 16 years-of-age be provided instruction and training on tasks, such as exposure to confined spaces, considered especially hazardous.

(6) Continue to monitor confined space and manure-related injuries and fatalities to measure effectiveness of intervention efforts.

(7) Findings of this study can be a useful tool when adopting new design concepts for manure structures, to include monitoring atmospheric quality and fencing system on livestock farms.

3.8 Limitations

Agricultural injuries, especially those not fatal, of children are not well documented in standard occupational injury surveillance systems, and there is a lack of required injury reporting and documenting systems. Because of the unique characteristics of agricultural work, surveillance of and research into childhood agricultural injuries require unique methods, which are not comprehensive in nature. Most data on agricultural injuries of children were found to be out-of-date and limited in causative factors. This study relied very heavily on on-line searches of relevant cases. This method is recognized as having serious weaknesses in identifying non-fatal incidents. As noted, there is no central location or system or regulatory requirement to report confined space-related incidents, fatal or non-fatal. These limitations prevent, and will continue to prevent, comprehensive reporting of this type of incidents.

3.9 Acknowledgments

Documenting and summarizing the data used in this study was made possible by funding from Purdue's Agricultural Safety and Health Program and the National Children's Center for Rural and Agricultural Safety and Health (Marshfield, Wisconsin). This research was conducted as part of (NCCRAHS) mini grant. The authors wish to thank Marsha Salzwedel, the project manager of the National Farm Medicine Center and her team for their efforts and providing support for this effort.

3.10 Funding

This work was supported by Purdue's Agricultural Safety and Health Program and the National Children's Center for Rural and Agricultural Safety and Health (Marshfield, Wisconsin).

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4. SUMMARY OF SEVEN CENTRAL-STATE REGION INJURIES AND FATALITIES INVOLVING LIVESTOCK MANURE STORAGE, HANDLING, AND TRANSPORT OPERATIONS: 1976-2019

A version of this chapter has been submitted to the Journal of Agricultural Safety and Health (JASH) and is currently under review. Mahmoud M. Nour, Ed Sheldon, Charlene Cheng, Ji-Qin Ni & William E. Field. Summary of Seven Central-State Region Injuries and Fatalities Involving Livestock Manure Storage, Handling, and Transport Operations: 1976-2019

4.1 Highlights

- Historic under reporting of incidents, especially non-fatal, prevents a comprehensive understanding of the problem
- A total of 133 cases were documented in the 7-state region with Iowa reporting (43%) of those cases and asphyxiations accounted for 42% of all cases
- Most victims were male (>79%) with an average age of 38 and of 133 cases, 57% were fatal, and 16% of victims were children and youth under age of 21
- 13 incidents involved secondary victim cases, including (11 incidents involving 2, 1 incident involving 3, and 1 incident involving 4)

4.2 Abstract

Research was conducted to document, classify, analyze and summarize available injury and fatality data involving facilities and equipment for livestock manure storage, handling, and transport within the seven-state region served by the Central States Center for Agricultural Safety and Health (CS-CASH) in NE, IA, SD, ND, KA, MO, and MN. Data were initially drawn from the Purdue Agricultural Confined Spaces Incident Database (PACSID) that contained over 2,400 individual U.S. cases of agricultural confined space related entrapment, engulfment, entanglement, asphyxiation and falls that were documented between 1975 and 2019. Data from these cases have been partially summarized and published but findings did not include an indepth analysis of manure-related incidents. Approximately one in five, 460, of these 2,400+ cases involved storage, handling or transport of livestock wastes, including exposure to toxic gases that were documented in 44 years. Of these, 133 cases were documented as having occurred in the targeted seven central-

state region. Each case was identified and coded according to the protocol developed by Nour et al. (2018) to classify incidents related to livestock manure handling, storage, and transport. Iowa and Minnesota accounted for 79% of the total with swine operations accounting for 33% of cases when livestock type was known. Of the victims, Seventy-nine percent were male. Ages ranged from 1 to 85, with an average age of 38. Fifteen percent of the victims were age 21 and under. There were 13 incidents where two or more victims were identified, including one incident involving four victims. It is believed that historical underreporting of incidents, especially non-fatal incidents, continues to be a barrier to achieving a more comprehensive understanding of the scope and magnitude of the problem. Findings are, however, sufficient to be used in cooperation with stakeholders to enhance the contents and delivery of evidence-based agricultural safety and health programs, promote safer work practices, and contribute to the development of engineering design standards. The desired outcomes of this research included more effective strategies to protect farmers and farm workers who are at high risk of manure-related injuries. Findings also, provide a sufficient baseline to gauge the effectiveness of future injury prevention measures.

Keywords: Livestock, confined space, fatality, manure pit, manure storage, manure spreader.

4.3 Introduction

Agriculture remains one of the most dangerous industries in the U.S., especially for the self-employed. According to the U.S. Bureau of Labor Statistics, the fatal occupational injury rate in agriculture, forestry, fishing, and hunting is (23.4 fatalities per 100,000 full-time equivalent workers) and also among the top 10 occupations with respect to the number of non-fatal workplace injuries (BLS, 2019). Fatalities and injuries involving agricultural workers constitute a significant public health challenge and have a major economic impact on farm and ranch families and their farm operations, including uncovered medical expenses, lost work time and reduced productivity (New-Aaron et al., 2019). For example, Landsteiner et al. (2016) estimated total costs of the economic impact for farm injury in Minnesota ranged between $21 and $31 million (in 2010 dollars) annually over the 7-year study period from 2004 to 2010. The majority of the costs were attributable to indirect costs, such as lost productivity at work and home. Fatal injuries accrued the largest proportion of the estimated costs followed by hospitalized and non-hospitalized injuries.

According to the 2019 Ag Census, the seven-state region has a combined population of over 20 million people and livestock-related agriculture remains vital to the economy of these states. Iowa, Nebraska, Minnesota, and Kansas, included in the seven-state region, are ranked among the top 10 states for the number of farms, farm sales, crop and livestock sales, and contributed to a large share of agricultural production in the U.S. (USDA, 2019). Also, the 2012 Ag Census indicated that the seven central-states region is a farming community with heavily diversified agricultural production, employing over 650,000 farm owners/operators on about 437,042 farms that are generally considered high-risk work sites. This work force is exposed to a wide range of farm-related hazards that are not found in most other settings. About, 20.4% of all U.S. farm operators lived and/or worked on farm/ranch operations in the seven-state region (USDA, 2012).

Leigh et al. (2001) stated that agricultural occupational injuries are an underappreciated contributor to the overall national burden of health and medical costs. Also, Leigh et al. (2014) estimated considerable undercounting of nonfatal injuries and illnesses in agriculture and they believed the undercounting is larger than any other industry, especially because agriculture employs many undocumented workers (Leigh et al., 2001; Leigh et al., 2014). This undercounting of nonfatal agricultural injuries has limited the ability to identify areas in which preventive measures should be focused. Rautiainen and Reynolds (2002), however, reported that agricultural fatalities were well documented, and it was important to continue existing surveillance in the future. They recommended that more effective surveillance systems should be developed to collect information on agriculture-related non-fatal injuries and illnesses. They also noted that further efforts were needed to better define the populations at risk, including farmers and ranchers, family members, workers, migrant and seasonal workers, and others exposed to farm hazards.

Several workplace occupational hazards found on agricultural operations, especially on those farms raising livestock, have been related to the storage, handling, and transport of livestock waste, or manure (Langley and Morrow, 2010). These hazards include exposure to confined spaces, entrapments, entanglements in material handling equipment, falls, and toxic gases (Issa et al., 2016). With support from the Central States Center for Agricultural Safety and Health (CS-CASH), a study was undertaken to identify, classify, and summarize incidents involving livestock wastes in seven Midwestern states (Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota).

The goals of this research were to track, categorize, and summarize incidents involving livestock manure storage, handling, and transport facilities and equipment found in agricultural settings within the seven-state region. Findings will be used to prepare recommendations for injury prevention strategies to reduce the frequency and severity of manure-related incidents for that region and other livestock-producing states.

4.4 Background

With over a billion tons of livestock manure produced annually in the U.S. (Zhang and Schroder, 2014), disposal of this valuable resource consumes a substantial amount of resources including both labor and equipment. Livestock manure is potentially hazardous to both humans and animals if not managed properly (Li and Ni, 2020). Farmworkers who are engaged with storage, handling, and transport of livestock wastes are exposed to occupational, health, and safety hazards. These hazards include: 1) toxic manure gases or asphyxiants such as hydrogen sulfide, methane, ammonia, carbon dioxide and carbon monoxide in enclosed structures which can be fatal to both human and livestock due to direct exposure and asphyxiation (suffocation); 2) below- and above-ground liquid manure storage structures that have the potential risk for drowning and falling; 3) mechanical hazards associated with manure handling machinery, including entanglement and equipment failure; 4) both toxic atmospheres and mechanical hazards associated with livestock manure transport; and 5) exposure to potential pathogenic agents or biologic aerosols that could cause infectious diseases such as *Escherichia coli* (O157:H7), *Salmonella entrica*, and different other human pathogens (Johannessen et al., 2005). These hazards have been recognized in the literature for many years, but it remains unknown why individuals continue to enter agricultural confined spaces or carry out other hazardous tasks despite a general recognition of the potential dangers (Pate and Merryweather, 2012). For example, it has been recommended that agricultural workers never enter livestock manure collection structures and facilities without proper training, equipment, and confined space entry procedures (Hallman et al., 2005). Deaths in these facilities, however, continue to occur.

The National Institute for Occupational Safety and Health (NIOSH) documented, over three decades ago incidents involving livestock manure storage, handling, and transport operations and has published widely disseminated reports on two separate incidents in 1989 involving seven workers who died due to exposure to oxygen deficient manure storage facilities on dairy farms.

Five of the victims died attempting to rescue the initial victims. There was, however, no known attempt by NIOSH or other organization to determine the frequency of these incidents nationally or to determine what factors contribute to these events. In 1990, NIOSH issued a follow-up alert entitled "Request for Assistance in Preventing Deaths of Farm Workers in Manure Pits" to promote awareness of the risks of manure storage and the potential for multiple fatalities to occur (NIOSH, 1990). This NIOSH alert described the same seven deaths from asphyxiation (suffocation) that occurred during the two incidents mentioned in the earlier reports. This second alert was released to enhance injury-prevention efforts among farm workers who were at risk or may be unaware of the danger of entering manure pits. In addition, Hallman et al. (2005) reported on a New York case study identified as part of the NIOSH Fatality Assessment and Control Evaluation (FACE) program that illustrated the hazards of power take off operated manure pumps and the risk of entanglement.

A review of the published literature identified no historical attempt to monitor on a continuing basis injuries or fatalities associated with livestock manure storage, handling, or transport facilities and equipment. Work done by Nour et al., addressed efforts to design a surveillance method for consistent data collection and classification that could be used to assess the frequency or severity of these events (Nour et al., 2018). Numerous extension and agricultural education publications included risk assessments of the various types of manure storage, handling, and transport practices, however, much of this literature was not evidence-based and often based upon a small number of specific cases. In addition, on-line sources including (extension.org), the National Agricultural Safety Database (NASD), Bureau of Labor Statistics (BLS), and NIOSH FACE Reports were reviewed. However, no references were found that were based on the actual frequency or severity of manure-related injuries and fatalities or practices currently being used by livestock farmers and their employees.

Manure toxic gas atmospheres, especially hydrogen sulfide (H_2S), associated with agricultural confined spaces have been generally recognized to be potentially fatal in a very short period of time. Extreme caution has long been recommended whenever manure in storage is disturbed (for example, agitated or pumped) as the manure may contain large quantities of small gas bubbles that will be rapidly released (Ni et al., 2009) and overcome operators. Therefore, personal gas monitoring and proper ventilation have been determined to be critical in keeping human workers and livestock safe (Murphy, 2012a; Michael L. Pate, 2020). Livestock waste not

only contain toxic gases but also, it is a potential source for human pathogenic agents that may result in infectious diseases and health risks. Luna et al. (2018) documented twelve cases of *E. coli* (STEC O157:H7) infection associated with exposure to livestock manure and secondary person-to-person transmission that occurred in an Arizona-Utah border community. No common source of this type of data was identified.

There have been several studies conducted on the contributing factors behind incidents involving grain storage, handling facilities, and related confined spaces which have some similar characteristics (Field and Bailey, 1977; Kingman et al., 2001; Kingman and Field, 2005; Riedel and Field, 2013, Issa, et al., 2016). These studies, however, have not attempted to examine incidents involving other confined spaces including facilities used to store manure. As noted by Beaver and Field (2007), there have been, however, few attempts to monitor over time injuries and fatalities associated with livestock manure storage, handling, or transport equipment and facilities.

Though not historically established to document manure storage-related incidents, fatalities and injuries, the Purdue Agricultural Confined Space Incident Database (PACSID) surveillance effort has historically identified cases involving the storage, transfer, pumping, agitation, and transport of liquid manure. These cases appeared to be more common than reported in the literature (Issa et al., 2016; Nour et al., 2020). Beaver and Field (2007) used the PACSID database to analyze 77 fatal U.S. cases that were documented between 1975 and 2004.

Nour et al. (2018) developed an evidence-based approach to consistently identify and classify injuries and fatalities that involved storage, handling, and transport of manure. This research helped shed light on how well the cases included in the PACSID represented the actual nature of manure-related injuries and fatalities, and the frequency of these incidents. It also provided a better understanding of biases reflected in cases in the existing literature and the PACSID due to the nature of reporting and sources of data. For example, it was found that a small number of high-profile incidents were repeatedly addressed in the literature with differing accounts of what occurred. This work attempted to address, for the first time, the problem of underreporting of manure-related incidents. Results were applicable to dairy, swine, beef, and poultry production operations based on their similarities in storage, handling and transport practices. This research also documented gaps in the understanding of the magnitude of the problem, its scope and frequency. For example, in 2020, Nour et al. (2020), reported on the problem of exposing children, youth, and beginning workers to the hazards of livestock manure facilities and equipment where

there is a high potential risk of injuries and fatalities due to suffocation, falls, entanglement, hydrogen sulfide intoxication, and drowning. Eighty-nine cases in the PACSID involving children, youth and young workers, 21 and younger were documented and summarized. Of these cases, 23 occurred in the seven-state region with Iowa among the states with the highest number of cases (Nour et al., 2020).

Livestock manure-related injuries and fatalities among livestock producers is not only an issue in the U.S., but it's a global problem. For example, Park, et al., summarized 17 incidents related to manure handling activities in which 30 workers died and eight were injured between 1998 to 2013 on Korean farms. These cases were due to asphyxiation and related to the high hydrogen sulfide concentrations and were identified through newspapers and online searches (Park et al., 2016).

New-Aaron et al. (2019) stated that between January 2012 and June 30, 2017, print and electronic media monitoring systems operated by the CS-CASH occupational fatality data identified 1046 fatal and nonfatal agricultural injury incidents in the seven-state region (New-Aaron et al., 2019). Forty-one of these cases were due to manure-related work activities. In other words, nearly 4% of all documented agricultural injury incidents in the seven-state region were related to manure storage, handling, and transport.

Publicly available media or newspaper accounts are a primary source of data used by nearly all of the agricultural injury and fatality surveillance efforts. The work done by AgInjuryNews.org, through the National Farm Medicine Center and its collaborators, has been expanded the regional efforts to track Agricultural injuries and fatalities in the USA. It has been found in repeated analyses that this surveillance strategy is not comprehensive, and the reports are not always complete or accurate (Weichelt and Gorucu, 2019). The incorrect use of agricultural terms for machines, equipment, and structures prevents an accurate analysis without follow-up investigations. Furthermore, because the media reports are not reviewed for medical accuracy, the nature and severity of the injuries being reported, including the cause of death, may not be correct.

The severity of manure storage and handling incidents has been recognized as so great that engineering and practice standards have previously been developed to enhance the safety of the facilities and equipment involved. The American Society of Agricultural and Biological Engineers (ASABE) has published engineering practice standards that recommend specific safety training

guidelines and safeguards for workers who work in or around manure storage facilities, and address specific ventilation strategies (Murphy, 2012b). The existing engineering practices and standards include ASAE Engineering Practice (EP)-470 on "Manure Storage Safety" first published in 1992 (ASABE, 2011), ASABE EP-270 "Recommendations for Ventilation System in Barns Above Manure Pits", and ASAE S317.1, R2020" Improving Safety on Enclosed Mobile Tanks for Transporting and Spreading Agricultural Liquids and Slurry" (ASABE, revised January 2020). Also, ANSI and ASABE published a consensus standard (ANSI/ASABE S607) for enhanced ventilation in 2010 on "Ventilating Manure Storages to Reduce Entry Risk" (ASABE, 2011)**.**

4.5 Methods and Data Collection

The PACSID was initially mined for cases that included any term that would imply a relationship with livestock waste. This search identified 241 documented cases. A secondary search was conducted utilizing additional waste handling-specific terms such as manure or slurry, spreader, trench, septic, tank, skid steer loader, dump truck, lagoon and pit. In addition, new incident data were obtained from external sources including news clippings, published articles, voluntary reporting, on-line detection and notification services and civil litigation cases. An independent investigator was employed to conduct additional on-line searches as part of this study. A review of data documented in the Census of Fatal Occupational Injuries (CFOI) identified few cases with very limited descriptive information. A search of the AgInjuryNews.org site identified no new cases. Special efforts were made to collect additional information for cases with limited background evidence in order to enhance the quality of the data. However, no personal interviews related to the cases were conducted. Only publicly available sources were used exempting the study from the Institutional Review Board (IRB) oversight. A search was also conducted using OSHA archival incident data to identify cases that were recorded in the OSHA database under different categories, such as incidents in poultry houses, poisoning in confined spaces, and amputations. A request was submitted to the CS-CASH for copies of relevant clippings and case studies from the region that have been collected as part of their ongoing surveillance of agricultural-related injuries and fatalities. Associated case studies from the NIOSH State Fatality Assessment and Control Evaluation (FACE) programs that occurred in the seven-state region were

also identified and summarized in this study. The research was designed to continue the surveillance effort throughout the study period.

The coding system developed by Nour et al. (2018) was utilized to categorize all manure documented cases that already existed in the PACSID dataset and all new data. The data mined included the frequency, severity, demographics, geographic distribution, and trends of these events. Types of information that was partially available included: age group, year, sex, state, region, season, farm type, incident category, injury agent/facility/equipment category, and nature of injuries (i.e., fatal or non-fatal) (Nour et al., 2018). It was recognized that the data set, even if expanded during the study period, could never be comprehensive, especially considering the lack of data from earlier years. However, with over 460 cases currently documented and cases being added on a regular basis, the database remains the largest currently available. There is no other known source of information regarding manure-related incidents that provides sufficient information to develop reliable recommendations for implementation of more effective prevention measures.

From this data set, all 133 cases that occurred in the seven-state region served by CS-CASH from 1976 through 2019 were mined for additional analysis. The findings from this analysis should be applicable to most livestock production operations based on the general consistencies of storage, handling and transport practices used on most of these farms.

4.6 Findings

From 1976 through 2019, a total of 133 manure-related cases from the 7-state region were identified and documented. Of these, 75 (56%) were fatal and 58 (44%) were non-fatal. Most of the victims died of asphyxiation or drowning after entering both enclosed and open manure storage structures. On the other hand, 45% of the non-fatal incidents were the result of roadway collisions involving manure transport vehicles. Overall, 79% of victims were male, 9% were female, and 12% had no gender specified in case reports. Over the 44-year study period, the annual average number of documented cases was 3. However, 2018 had the highest number of cases (18) for the entire region, likely reflecting the beginning of intensive efforts to identify both fatal and non-fatal cases, and the increasing case of assessing this type of data on the internet. As noted, many of these incidents have historically gone unreported and may never have been recorded, especially in earlier years.

The distribution of incidents by state is shown in Figure 4-1. Iowa and Minnesota, collectively, had the most reported incidents in the seven-state region (105 cases, 79% of the total). On the other hand, Kansas, Missouri, North Dakota, and South Dakota had the least number of reported incidents (13 cases, 10% of the total), accounting for an average of three cases per state over the entire 44-year period. This very low frequency suggests that the current agricultural injury reporting system may under-report cases in these states.

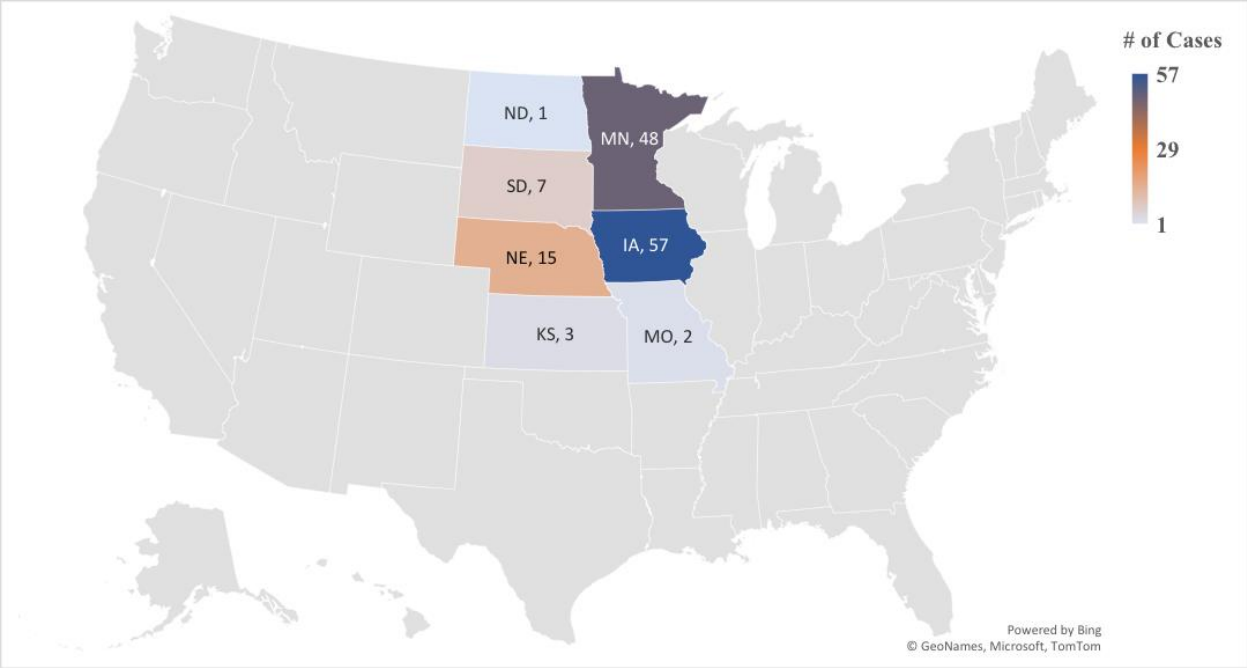

Figure 4-1: The distribution of manure-related cases by state within the seven-state region (N=133) from 1975 to 2019.

In 44 years, no fewer than 75 people, and most likely more, were killed in manure-related events and 58 people were injured in the seven-state region. While the region averaged 3 cases annually, the number of documented cases varied considerably from year-to-year. It is believed that the high numbers of livestock operations in Iowa and Minnesota were at least practically responsible for the higher frequency of incidents.

Eighteen cases were documented in 2018 and as low as one (in 11 years) or zero (in twelve years) regularly occurred. Yearly averages show a relatively slight increase in the average number of cases over the five decades (Figure 4-2).

Figure 4-2: The distribution of manure-related cases in the seven-state region by year (N=133).

A total of 20% of cases documented in the 7-state region did not have the victim's age identified. Sources indicated that 4 of the victims with no unknown age were children, but a specific age was not available. The average age of all victims in seven-state region, when the age was known, was 38 years (Figure 4-3).

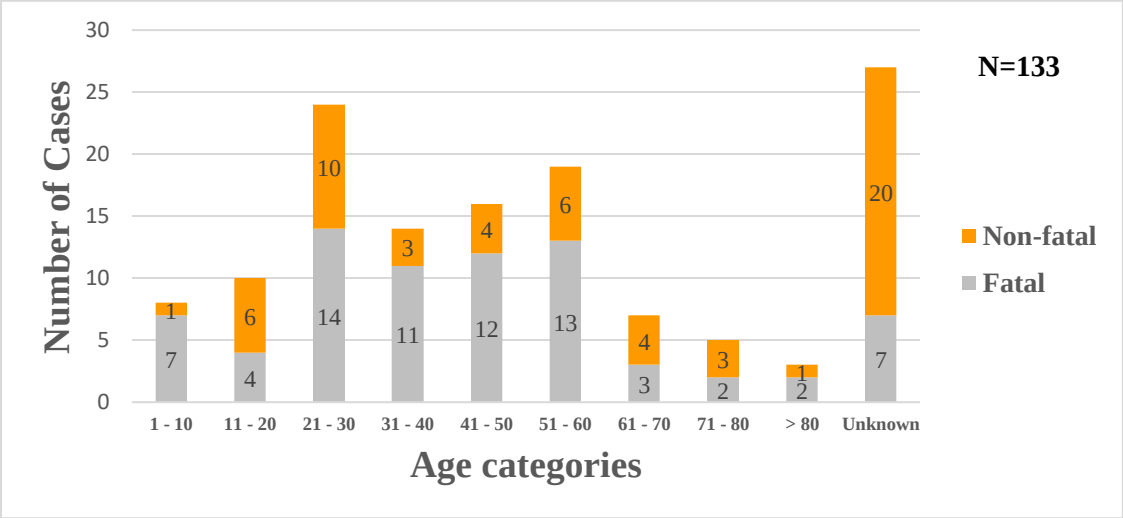

Figure 4-3: The distribution of manure-related cases in the seven-state region by age category

The majority of the victims were males (79%) with (9%) females, while the gender of 12% of the victims was unknown. Figure 4-4 shows the distribution of cases by gender with numbers of fatal and non-fatal under each category. Most cases that involved females were due to roadway collision with manure transport vehicles (manure spreaders, trucks, or tractors). One female case was a secondary victim killed while attempting to come to the aid of her husband who was overcome in a manure storage facility.

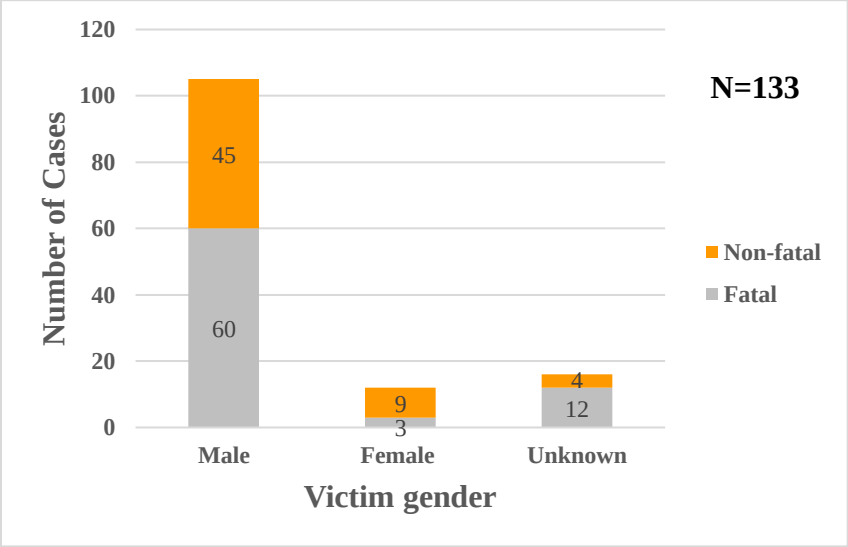

Figure 4-4: The distribution of manure-related cases in the seven-state region by gender.

Swine farms were identified as the most frequent type of farms involved in these incidents, representing 33% of all cases, while 14% occurred on dairy farms. Two-thirds of all fatalities occurred on swine and dairy operations. Of all cases, 22% reported trauma due to roadway collisions, but only 3 fatalities were attributed to roadway incidents (Figure 4-5). It is important to note, that 75% of incidents documented on swine operations were fatal versus 83% on dairy farms.

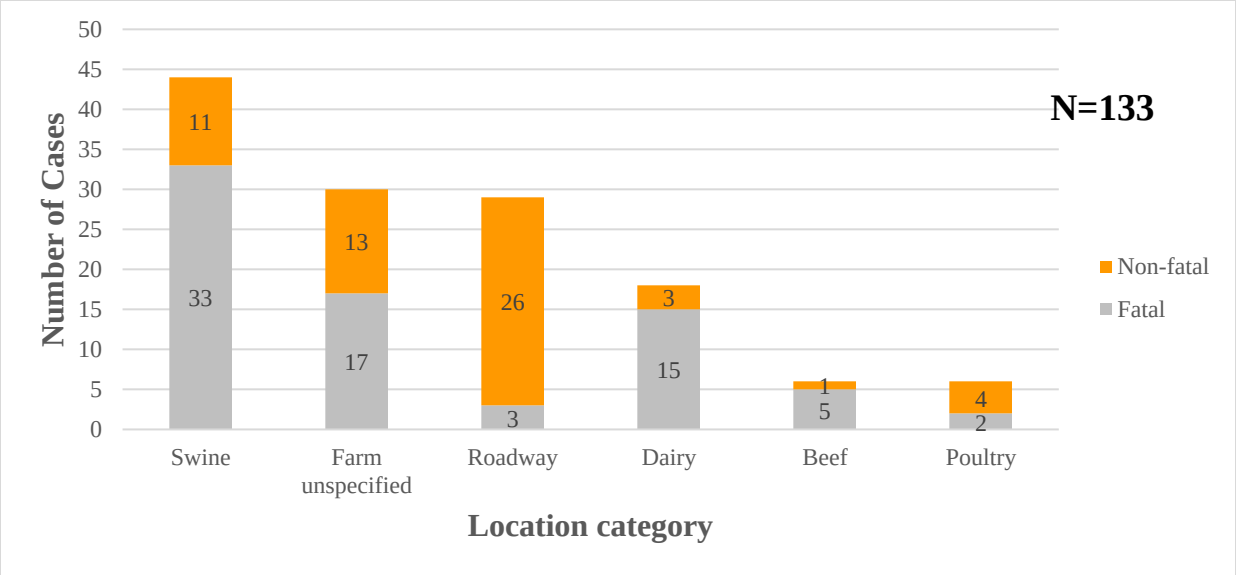

Figure 4-5: The distribution of manure-related cases in the seven-state region by incident location.

The distribution of incidents by month is shown in Figure 4-6. The peak month for total cases was October. This month is normally associated with substantial manure utilizing operations conducted after crop harvest and before soil freezes in the region. Most fatalities occurred in summer months of June, July, and August where according to Beaver and Field, the warmer weather contributes to a higher level of toxic gases production in manure storage structures. Of note was the finding that all incidents documented in August were fatal, and if fatalities for July and August were combined, these 22 cases would account for nearly 30% of all fatalities. Five cases had an unknown date of occurrence.

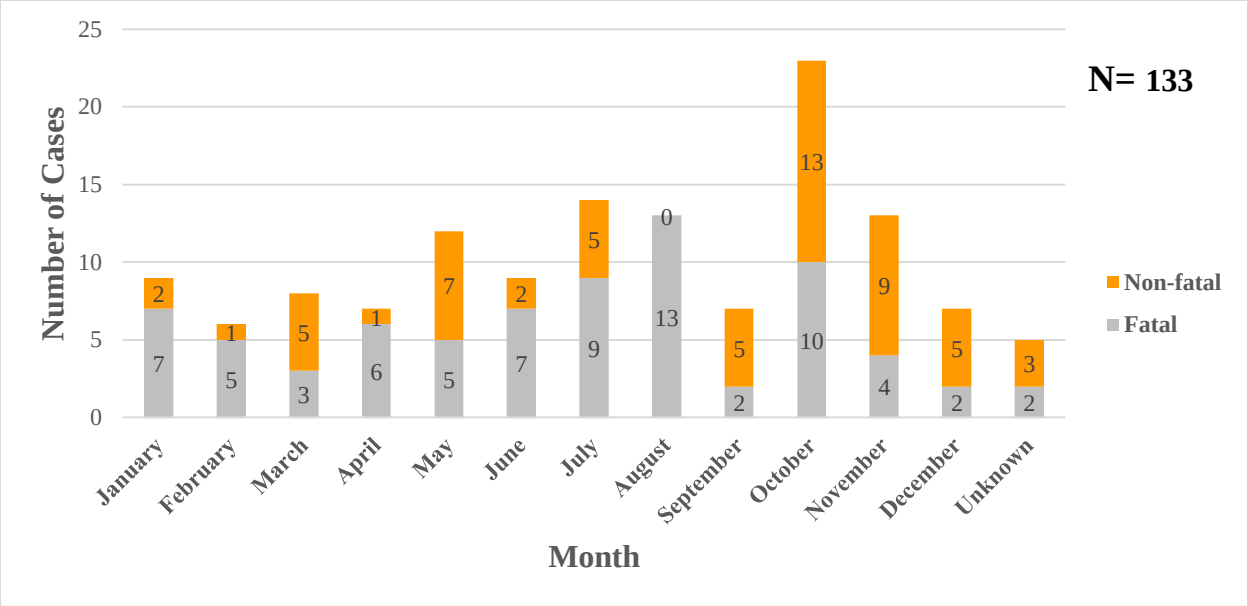

Figure 4-6: The distribution of manure-related cases in the seven-state region by month.

Most victims (57%) within the seven-state region died as a result of suffocation or asphyxiation with an overall 77% mortality rate due to exposure to toxic gases inhalation and losing consciousness within seconds to minutes depending on the gas concentration. Methane (CH_4) and Carbon Dioxide (CO_2) act as physical asphyxiants, producing anoxia by displacing Oxygen (O_2) in an enclosed space. In contrast, Hydrogen Sulfide (H_2S) acts as a chemical asphyxiant, interfering with cytochrome oxidase and aerobic metabolism (Hallam et al., 2012). It should be noted that a lack of access to death certificates and the confusion over the general use of the term asphyxiation and suffocation, a documentation of what actually caused the death in most cases was not possible. Incidents due to roadway collision involving manure transport vehicles was the second most overall frequent cause of injury identified, while drowning accounted for 15 deaths. Of these drowning cases, five victims were children who drowned while playing, and two cases occurred while the victims were trapped inside the cab of skid steer loaders that ended up in a manure lagoon. It is believed, however, that there are often unreported incidents involving successful rescues, or self-extrication from liquid manure storage structures, such as open lagoons. The third leading cause of fatality, and second leading cause of nonfatal injury, was entanglement in energized components of manure handling machinery, such as power take-off (PTO) drive lines on spreaders, barn cleaners, conveyors, and augers (Figure 4-7).

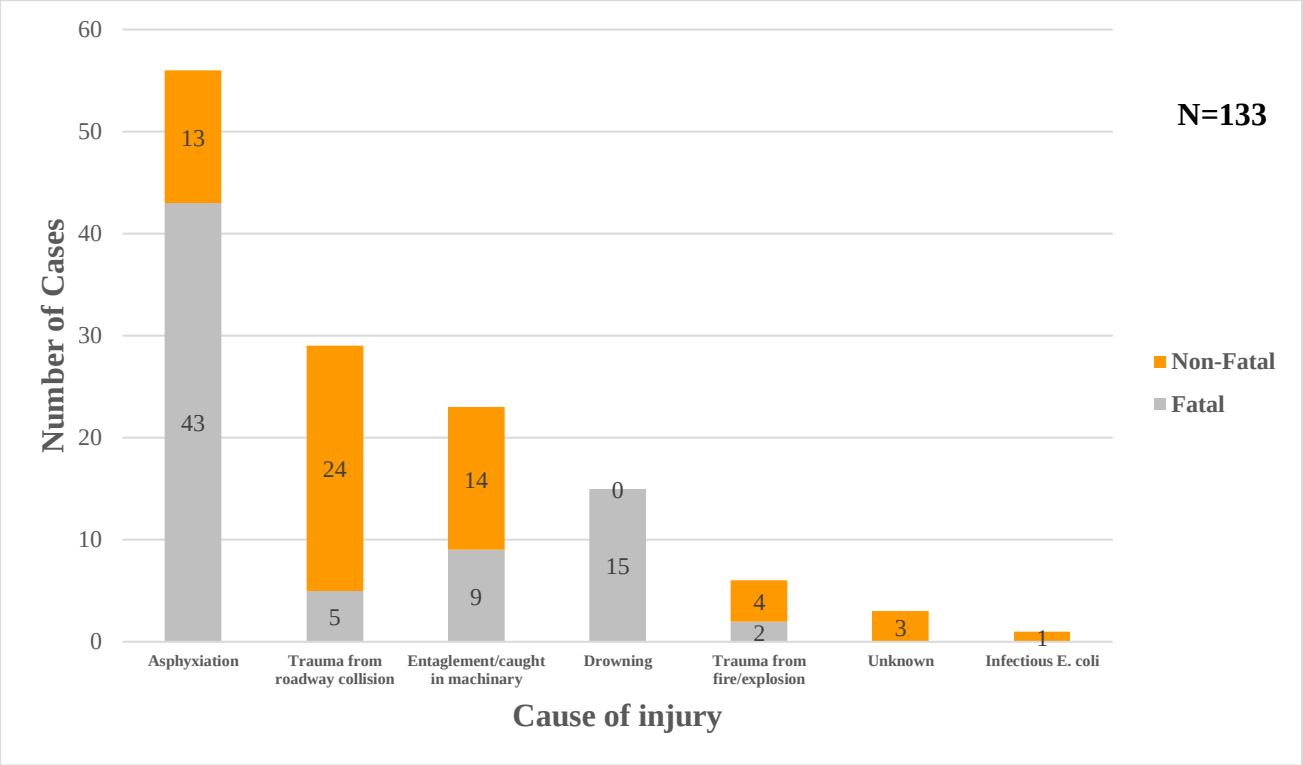

Figure 4-7: The distribution of manure-related cases in the seven-state region by cause of injury.

4.6.1 Case studies of manure-related injuries that occurred within the seven-state region:

From the 133 documented incidents, six case studies were selected to represent the types and severity of livestock manure-related incidents examined in this research. They are as follows:

Case study 1: Construction worker breaks through ice and drowns in manure pit.

Minnesota, Fatality, Asphyxiation.

On February 28, 2017, a construction worker was operating a skid loader preparing an outside area for a concrete foundation for a new building. The worker broke through the ice that was covering an abandoned manure pit and was submerged for approximately 20 minutes before rescue personnel pulled the employee from the skid loader. The victim was transported to the medical center where he was later pronounced dead (OSHA, 2020).

Case study 2: Farm contractor worker injures head and neck in fall from liquid manure tanker trailer.

Minnesota, Fatality, Trauma from fall.

At 12:00 a.m. on October 5, 2016, an outside contractor and a coworker were pumping liquid manure from a manure pit into a tanker trailer at a client's farm. There was a problem with a device located on the top of the trailer that indicated the liquid level within the tank. The victim had climbed to the top of the tanker trailer to conduct a visible check on the liquid level. He slipped off the trailer and fell to the ground at the rear of the trailer. His coworker found the worker on the ground when he came around the trailer. The victim suffered head and neck injuries and later died from his injuries (OSHA, 2020).

Case study 3: Farmer's finger amputated in manure spreader incident.

Iowa, Injury, Entangled/Caught in Machinery.

On October 14, 1998, a farm worker was operating a tractor-pulled manure spreader when he left the tractor with the PTO still engaged. He came into contact with an unguarded chain driven by the power take-off (PTO) shaft, catching his glove, amputating part of his left ring finger (OSHA, 2020).

Case study 4: Farm worker decapitated by manure spreader.

Kansas, Injury, Entangled/Caught in Manure Machinery.

On January 17, 1996, a worker at a beef farm had entered the truck bed of a manure spreader to perform a cleaning operation. The truck's PTO was left engaged, allowing the spreader to continue to operate. The victim became entangled in the rear portion of the manure spreader, where beater bars (propeller-type blades) chop and throw manure. The victim was decapitated. Although the owner's manual warned against entering the bed of the spreader when operating, safety decals, it was reported to be a common practice for employees cleaning the spreader at this location to enter the truck bed while the equipment was running (OSHA, 2020).

Case study 5: Swine farm worker dies of hydrogen sulfide inhalation in confined manure structure.

Kansas, Fatality, Asphyxiation.

This incident occurred at approximately 2:30 p.m. on February 17, 2010, on a hog farm. The facility consisted of two confinement buildings, (east and west) separated by the utility hallway. A worker was assigned to checking the health of the hogs, which included providing them with food and water and administering needed medications. Chores for each building took approximately 30 to 40 minutes. At the time of the incident, a coworker was pumping the manure holding tank from beneath the west confinement room. The coworker stated that he saw the victim arrive on site, but he didn't know when the victim entered the building. The coworker started pumping around 8:45 a.m. and was almost finished. Manure was being pumped from the south side of the building into a tank wagon that was pulled by a tractor to an offsite concrete pit and unloaded. According to two other coworkers, one of the two manure pit fans was ordinarily disconnected while the pumping took place, because the pump pipe was placed into the fan hole. The coworker pumping manure did not notice anything unusual during the process. The victim was working alone and was found unconscious at the north end of the utility hallway that separates the west and east confinement rooms. According to the final coroner's report, the immediate cause of death was acute respiratory failure due to hydrogen sulfide poisoning. When the fire department responded to the incident at 3:17 p.m., air measurements were collected inside the building using a four-gas meter. Hydrogen sulfide was measured at 42 to 44 ppm near the north service door, and carbon monoxide was measured at 30 ppm in the east building. According to the sheriff's report, the north and south service doors had been open for an unknown amount of time, which most likely ventilated the hallway prior to the fire department's air measurements (OSHA, 2020).

Case study 6: Farmer and his employee died after collapse and attempted rescue in manure storage pit

Iowa, Fatality, Multiple Victims, Asphyxiation.

On a spring afternoon in 2005, a 52-year-old farmer and his 23-year-old hired hand were emptying manure from the pit beneath a cattle confinement shed at the farmer’s homestead. After the job was finished, the farmer “climbed down” the vertical manure transfer pump that was in the pit, presumably to retrieve a chain that had fallen in the pit earlier that week. While in the pit, he

collapsed and fell backward, laying face-up. His employee either witnessed the collapse or discovered the farmer in the pit. He ran 150 yards to the farmer's house and told the wife to call 911 because her husband had fallen in the pit. The employee hurried back to assist the farmer. He was followed by the farmer's daughter. The employee then entered the pit in an attempted rescue. He, too, collapsed and fell face down in four to six inches of manure that remained in the pit. The farmer's father-in-law (who had come to the site by chance) and daughter witnessed the employee's collapse. After completing the 911 call, the farmer's wife rushed to the shed with a ladder to attempt rescue, but her father prevented her from entering. Within five to seven minutes of the 911 call, local firefighters and emergency responders arrived from the nearby town. Medical assistance was requested from a regional hospital 12 miles away. An initial rescue attempt was made by an emergency responder wearing only an air-purifying respirator. On his way into the pit, he had difficulty breathing and nearly passed out, but he managed to get back out of the pit. Firefighters then donned self-contained breathing apparatus (SCBA) respirators, entered the pit, and retrieved the unconscious victims. Medics took over care of the victims and transported them to the nearest hospital. From there, they were air-lifted to a tertiary-level hospital 70 miles away. Medical evaluation of both victims revealed anoxic brain injury. Neither regained consciousness. Over the course of several days, their conditions deteriorated, and do-not-resuscitate orders were made for each individual. The farmer died four days after the incident, and his employee died ten days later. Autopsies were performed. The cause of death for both individuals was anoxic-hypoxic encephalopathy due to inhalation of manure gases (Iowa, 2014).

4.7 Discussion

Efforts were made to analyze the injuries and fatalities involving livestock manure storage, handling and transport operations within the seven-state region served by CS-CASH. This study identified 133 cases that were mined from the PACSID database from 1975 to 2019, Occupational Safety and Health Administration (OSHA) incident search results from 1984 to 2019 and (CS-CASH) dataset from 2012 to 2019. These cases were classified and coded in accordance with a standard protocol (Nour et al., 2018). Causative factors were catalogued and summarized involving livestock waste mortality and morbidity among livestock producers, farm workers, and agricultural contract laborers. One of the interesting findings of this study was that the trend line is consistent with the continuing increase in the documented cases of children and youth manure-related injuries

and fatalities, as reported by Nour et al. (2020). It most likely reflects more effective surveillance efforts rather than an increase in actual frequency of incidents. The ratio between fatal and non-fatal incidents is also evidence of under reporting of non-fatal cases.

Findings from this research highlighted the magnitude of fatal and non-fatal livestock manure-related injuries among the farm population in that region. The findings also, provide a means to conduct more consistent future analysis of manure-related cases documented within the seven-states. All forms of agricultural confined spaces should continue to be monitored and the findings used to promote regulatory, engineering, and educational efforts to reduce the frequency and severity of these incidents.

The results of this study should be useful to a variety of stakeholders in the region, including Extension educators, producer groups, and occupational safety and health advocacy groups in better understanding the problem of livestock manure-related injuries and fatalities, including primary contributing factors. Finding could also help to estimate the economic impact of these incidents in the region. Results should also be helpful to other states that may not have a strong farm injury and/or fatality surveillance system in place.

4.8 Limitations

Occupational injuries and fatalities across all hazard categories of agricultural confined space facilities, especially those relating to manure storage, handling and transport have received little attention in the published literature. One reason for this is the lack of a centralized source of data to quantify the incidents and the lack of resources to conduct more in-depth investigations (Nour et al., 2018; Ramaswamy and Mosher, 2017). Limitations of this study include both the underreporting of farm-related injuries in general and more specifically the historical undercounting of manure-related cases, especially those that are non-fatal within the seven states served by CS-CASH. According to Leigh et al. (2014), there has been an estimated underreporting of incidents by as much as 40% due to the failure of current surveillance systems to adequately include production agriculture. Some sensitivity analyses suggested that the percentage of uncounted fatalities ranged from 61.5% to 88.3% due to underreporting (Leigh et al., 2014).

Gorucu et al. (2015), reported that newspaper accounts of injury incidents are not always completely accurate in their use of agricultural terms for machines, equipment, structures, buildings, and the like, nor in their descriptions of what actually occurred. This may result in some

inaccuracies in case characterization. The use of multiple sources for all cases entered into farm and agricultural injury databases helps to minimize this error (Gorucu et al., 2015).

There is currently no requirement to report most farm-related injuries or fatalities to a central location, as is mandated for most other industry classifications by Occupational Safety and Health Administration (OSHA) regulations (Cheng et al., 2020). In the seven-state region, the CS-CASH is actually the only entity that acknowledges data-gathering in those states and collects data specifically on agricultural related injuries and fatalities. This collection is accomplished through media monitoring and press clipping services. Some issues with collecting data on manure-related incidents in the seven-state region include:

1. Many times, deaths are mis-coded, and the death may be listed as some other cause. Limited data exists even on death certificates. There may not be enough specific information to determine the actual cause of death by only examining death certificates.
2. There is a clear lack of medical determination concerning the actual cause of death. This is generally due to lack of autopsies and the inconsistent use of the terms such as toxic gases poisoning, asphyxiation and suffocation.
3. Emergency Medical Service (EMS) personnel or attending physicians may not even code manure-related injuries as agriculturally related, making the cases difficult to ascertain as involving manure operations.
4. There are considerably fewer livestock confinement facilities in North and South Dakota than found in other states in the region, so numbers could be very low in these states.
5. Media monitoring systems are generally designed for all types agricultural injuries and manure-related incidents may not be identified by these searches.

As noted, agricultural injury and fatality data have not been assembled and analyzed by any single agency or organization. Consequently, no analysis can ever be considered comprehensive as might be argued for other occupational fatalities or public health threats.

4.9 Conclusion

The study focused on injuries and fatalities that involved livestock manure storage, handling and transport documented in NE, IA, SD, ND, KA, MO, and MN. This study will generally impact livestock producers, their families, and farm workers who are at highest risk of

on-farm exposure to livestock manure storage, handling, and transport operations, with specific focus on farmers and farm workers served by the CS-CASH in the seven-state region. Key findings included:

1. Substantial underreporting of farm-related incidents, especially non-fatal injuries, presents several intimidating barriers for evaluating agricultural injury issues.

   In the last five years, Iowa and Minnesota averaged 21 occupational farm-related work injuries (of all types) per year as reported by Bureau of Labor Statistics in 2018 (BLS, 2019). During that same time period, the same two states reported an annual average of nearly 5 livestock waste-related injuries, indicating the BLS estimates for total number of agricultural injuries are probably low.
2. One finding documented by this study was the higher-than-expected number of "multiple victim events" and "secondary victims", who became victims while attempting to come to the aid of the initial victim. A total of 16 victims had placed themselves at risk in order to respond to the lifesaving needs of an initial victim.
3. Asphyxiation, trauma from roadway collision involving manure vehicles, or entanglement in energized components of manure machinery were the most common causes of injuries.
4. Swine operations has historically accounted for the most incidents related to livestock manure handling, storage and transport workplace injuries within the seven central-state region. However, this many reflect the nature of the livestock raised in the region, because Beaver and Field (2007) found that nationally, there were more fatal incidents at dairy operations. It was also noted that a greater percentage of incidents were fatal on dairy farms than swine operations.
5. Roadway collisions involving manure transport vehicles have received little to no attention in the research literature, even though, 22% of all documented cases were due to trauma from roadway collision.

4.10 Recommendations

It needs to be recognized that livestock manure-related injuries carry significant risk for farmers and farm workers. The following recommendations are based upon the findings of this effort and should allow for continued enhancement of the understanding of these incidents, and efforts to reduce their frequency and severity:

1. Efforts should continue to monitor the frequency and severity of livestock manure-related incidents that occur in CS-CASH service area. This should include fatalities, injuries, and “near-misses” (such as successful rescues that do not result in personal injury but reflect the nature of incidents occurring).
2. Additional investments should be made to conduct follow-up investigations of manure-related incidents in the region, in order to identify significant contributing factors and for use in promoting safe work practices, safer design features such as fencing of lagoons, more effective safety warning signage, and standard features that prevent equipment from being driven into open liquid manure storage sites.
3. Continue and improve the current surveillance and documentation press clipping initiative, and ensure a consistent incident coding and classifying system in order to identify potential trends and patterns, and to evaluate the efficacy of prevention initiatives.
4. Develop and disseminate new safety education resources that reflect the findings of this study, including the need to increase targeted prevention efforts during high risk times of the year.
5. Special attention should be given to educating Iowa and Minnesota livestock producers regarding the risks of manure-related activities, along with the benefits of complying with the existing provisions of current ASABE standards.

4.11 Acknowledgements

This work was made possible by funding from Purdue’s Agricultural Safety and Health Program and the Central States Center for Agricultural Safety and Health (CS-CASH) (Omaha, Nebraska). This research was conducted as part of CS-CASH pilot grants. The authors wish to thank Dr. Risto Rautiainen, the director of CS-CASH, Dr. Ellen Duysen, the coordinator of CS-CASH and their team for providing support for this effort.

4.12 Conflicts of Interest

The authors declare no potential conflict of interest was reported.

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5. SUMMARY OF KNOWN U.S. INJURIES AND FATALITIES INVOLVING LIVESTOCK MANURE STORAGE, HANDLING AND TRANSPORT OPERATIONS: 1975-2019

A version of this chapter will be submitted to the Journal of Agricultural Safety and Health (JASH) for publication. Mahmoud M. Nour , Yuan-Hsin Cheng, William E. Field, Ed Sheldon, and Ji-Qin Ni Summary of Known U.S. Injuries and Fatalities Involving Livestock Manure Storage, Handling and Transport Operations: 1975-2019

5.1 Highlights

- Under reporting of incidents, especially during early decades of the study, prevented a comprehensive assessment of the problem
- 48% of all cases were documented in the last decade and 28% documented during the last three years, primarily due to more aggressive surveillance.
- An average of approximately 10 cases were documented annually
- A total of 389 incidents involving 459 individual cases were documented, of which 59% were fatal and the overwhelming majority of victims were male (>85%) with an average age of 35
- 20% of all victims were children, youth and young workers 20 years old and younger
- 32% of the cases were due to asphyxiations or suffocation, while 27% were due to entanglement in manure handling, and transport machinery
- Incidents involving dairy farms represented 30% of all cases, while 16% occurred on swine farms
- Drowning incidents in manure storage structures and lagoons were the deadliest type of incidents with 97% being fatal
- 49 rescue incidents involving 119 victims, or “secondary victims” were documented.

5.2 Abstract

There is limited published research exploring livestock waste-related fatalities and injuries among farm operators and workers. While there has been ongoing surveillance of mortality and morbidity involving agricultural confined space-related incidents, few have attempted to achieve an understanding of manure-related incidents, often reported as involving confined spaces. Existing surveillance efforts have generally under reported fatal cases, undercounted injuries and 'near misses', and misclassified incidents as non-farm related. For over four decades, Purdue's Agricultural Confined Spaces Incident Database (PACSID) has been used to document farm-related incidents involving agricultural confined spaces. The two largest categories in the database have historically related to grain storage and handling (62% of documented cases) and manure storage and handling activities (22% of cases). The only prior summary of fatalities of manure-related cases in the database was done by (Beaver & Field, 2007). The specific goal of this research was to address the gaps in understanding the specific hazards associated with manure storage, handling, and transport by: 1) developing a consistent way to identify, document and code cases involving manure storage and handling; 2) summarizing all known U.S. manure-related cases, both fatal and non-fatal, documented in the PACSID; 3) identifying the most significant risks contributing to manure storage handling and transport-related incidents; and 4) providing evidence-based recommendations and mitigation strategies to enhance the effectiveness of current injury prevention measures. The PACSID database was searched and an aggressive effort was made to document additional cases through a variety of surveillance methods. The finalized coding system was applied to all documented cases to allow for consistent in-depth analyses.

A total of 459 U.S. individual cases and 83 international cases from the study period, 1975-2019 were coded with only the U.S. cases summarized. Overall, manure-related cases were documented in 43 states, 66% of them (302 cases) were reported in the traditionally heavily agricultural and dairy production states of CA, IA, MN, WI, NY, and PA. The large number of manure-related cases added to the PACSID database during the last decade was likely due to more aggressive surveillance efforts significantly employing multiple sources of data collection such as news clipping services and internet detection and notification system (Google Alert), and a general increased interest in farm-related hazards in the general media. The analyses of the 459 U.S. cases attempted to identify cause of injury, incident category, victim's gender, and age, distribution of cases by state, decade, year, and month. Of the cases reviewed, 59% were fatal, males ages 21-30

and dairy farm workers were identified as high-risk populations, and 49 incidents involved multiple victims. Farm injury data limitations and under reporting, especially during early years of the study, prevented a comprehensive assessment of the problem or identifying long-term trends. Findings of this study, however, provide a foundation for policymakers to develop more targeted workplace safety and health regulations and practices, evaluate existing standards, access impact of current injury prevention efforts, and redesign farm safety programs, especially those targeting livestock workers to mitigate and minimize the frequency and severity of manure-related injuries and fatalities.

Keywords: Livestock, confined space, fatality, manure pit, manure gas, manure storage.

5.3 Introduction

"Far better to prevent than to cure", this was considered the most essential sentence demonstrating the legacy of the founding father of occupational medicine: Ramazzini's expression included in the XIII oration (from the 1739 edition of the Opera Omnia) (Franco, 2020a).

According to the Hippocratic precept, Ramazzini always promoted the need to live a moderate lifestyle—an attitude which might appear somewhat outdated in the present society of excess, where people work more hours, more days, and more jobs. He was especially concerned when he identified risks and diagnosed health disorders related to a person's vocation or calling. Although understanding the association between environmental hazards and health and managing environmental or occupational diseases are skills that should be demonstrated by all current physicians, the concepts were novel in Ramazzini's time. He was an idealist when he suggested measures for preventing risks and protecting health in the workplace. Today's occupational safety and health standards and practices have built upon Ramazzini's legacy in providing evidence-based preventive measures against occupational illness and injury. He was a visionary health care provider who paid attention to the behavior of individuals, to whom he recommended following a balanced lifestyle—advice more valued because '*non est vivere, sed valere vita est*'15—life is not merely being alive but being well (Franco, 2020b).

5.3.1 Burden of Livestock Waste

Meeting the food needs of the growing world population which is estimated to be over 9 billion by 2050 is one of the greatest challenges facing agricultural livestock production. There are constraints such as land and water use, environmental impact of agriculture livestock production and regulations which may limit the ability of producers to simply add enough animals to meet future demand for foods of animal origin (Malomo, Madugu, & Bolu, 2018). In the U.S., there are an estimated number of 297,297 farms that applied manure to approximately 23,888,525 million acres. About 98,000 farm operations were estimated to have on-site manure storage, with approximately 13% of the 127,000 manure storage facilities being enclosed pits. Yearly, an estimated 19,000 operators acknowledged having entered an enclosed pit for variety of reasons (USDA, 2019). Working around manure holding structures can lead to potential fatalities and injuries among farm workers and considered as life-threatening exposures.

The decomposition of manure stored in lagoons, ponds, tanks, or pits produces carbon dioxide and methane, each greenhouse gases. It is estimated that this decomposition of manure accounts for about 13% of U.S. agricultural greenhouse gases. When manure is handled as a solid or deposited on fields, it tends to produce much lower greenhouse gas emissions due to incorporation into the soil. Lagoon and pit manure handling systems that emit relatively large amounts of methane, a potent greenhouse gas, are common on dairy and hog operations (Hellerstein, Vilorio, & Ribaudo, 2019).

5.3.2 Hazards of Manure Storage Systems

Wastes from livestock production are dominated by manure and other agricultural wastes including bedding, feed residuals, fluids, and soil. The anaerobic digested manure can produce a number of well-known toxic by-product gases, including hydrogen sulfide, methane, carbon dioxide, carbon monoxide, and ammonia. and therefore, human exposure can develop severely adverse health outcomes or even sudden death. Often livestock production facilities have slatted floors under the animals to collect the manure. This manure is typically collected in pits below the building or in a tank or lagoons outside of the building (Donham, Knapp, Monson, & Gustafson, 1982). Liquid manure storage is basically limited to lagoons, pits, ponds or tanks either below or above ground inside or outside the livestock building. Above ground storage, underground or

underfloor holding facilities in either open or enclosed livestock-structures can lead to injuries or fatalities from unprotected entry into the space and falls in or around structure. The most significant hazards identified, historically, with manure operations related to the chronic respiratory hazards for workers exposed to gases and aerosols that are released from decomposing or agitated liquid anaerobic digested livestock manure, especially liquid manure slurry. The typically slow generation of these gases during storage or handling is greatly increased in warmer weather or during the agitation or pumping of the liquid manure. Manure storage hazards include asphyxiation (suffocation), drowning, trauma from fall, infectious biohazard disease and trauma from equipment failure (Nour, Field, Ni, & Cheng, 2019; Stellman, 1998).

According to Sauvageau and Boghossian, 2010, asphyxiation or suffocation can be defined as the deprivation of oxygen supply to body tissues and can result from mechanical or non-mechanical constriction of the airway or from a decrease in breathable gas in the respired surrounding atmosphere (Sauvageau & Boghossian, 2010). They concluded all the definitions of asphyxia (suffocation) in confined spaces/entrapment/vitiated atmosphere in the following table:

Table 5-1: Definitions of asphyxia in confined spaces/entrapment/vitiated atmosphere.

Appellation	**Definition**
Drowning	Asphyxia by immersion in a liquid
Suffocation (General)	A broad term encompassing different types of asphyxia such as vitiated atmosphere and smothering, associated with deprivation of oxygen
Suffocation (Medical)	Death caused by reduction of the oxygen concentration in the respired atmosphere, formerly called vitiated atmosphere; reduction of the oxygen in the atmosphere by physical replacement by other gases or chemical changes such as combustion; by being confined in small airtight space
Confined spaces/entrapment/vitiated atmosphere	Asphyxia in an inadequate atmosphere by reduction of oxygen, displacement of oxygen by other gases or by gases causing chemical interference with the oxygen uptake and utilization
Traumatic asphyxia	A type of asphyxia caused by external chest compression by a heavy object
Positional or postural asphyxia	A type of asphyxia where the position of an individual compromises the ability to breathe

Table 5-1 continued

Entrapment / environmental suffocation	Inadequate oxygen in the environment Entrapment: individuals find themselves trapped in an air-tight or relatively air-tight enclosure; they exhaust the oxygen and asphyxiate Environmental suffocation: an individual inadvertently enters an area where there is gross deficiency of oxygen Excluded suffocating gases and chemical asphyxia
Exclusion of oxygen	Because of depletion and replacement by another gas or as a result of chemical interference with its uptake and utilization
Deaths associated with exposure to gases in the atmosphere	Oxygen may be reduced or absent from respired air or may be displace by the presence of other gases
Vitiated atmosphere	A vitiated atmosphere is deficient in oxygen, by displacement of oxygen from the atmosphere by inert gases or by gases generated by the atmosphere
Entrapment	A type of suffocation in which an individual is in an airtight or relatively airtight container and gradually consumes the available oxygen until there is no longer enough oxygen to sustain life; entrapment includes gaseous suffocation by gas displacing oxygen, leading to a hypoxic air mixture, and cases in which a substance prevents cells from utilizing oxygen

5.3.3 **Manure Handling, Transport, and Application-Related Hazards**

Handling, transport and utilization of both dry and liquid manure can be by hand or with mechanical aids like a front-end loader, skid-steer loader, barn cleaner and manure spreader, each of which presents safety hazards. Livestock manure is generally spread onto land as fertilizer with transport vehicles such as solid manure spreader and liquid transport tankers. Manure spreaders are generally pulled behind a tractor and powered by a power-take-off (PTO) from the tractor. They are classified into one of four types: box-type with rear beaters, flail, V-tank with side discharge and closed tank. The first two are used to apply solid manure; the V-tank spreader is used to apply liquid, slurry or solid manure; and the closed tank spreader is used to apply liquid manure. The spreaders throw the manure over large areas either to the rear or sides. Manure handling and transport hazards include entrapment in machine components, falling objects,

asphyxiation (suffocation), trauma from equipment failure, trauma from roadway collision, and dust and biohazard aerosols (Nour et al., 2019; Stellman, 1998).

According to Manbeck, and et al., 2016, manure storages should be considered confined spaces, but the agriculture sector was exempted from OSHA's 1910.146 standard when it first passed in 1993 and is still considered as the standard for atmospheric hazards associated with confined spaces including manure storages. On-farm manure storage pits contain both toxic and asphyxiating gases such as hydrogen sulfide, carbon dioxide, methane, and ammonia. Occasionally, farm workers must enter the manure storage pits for maintenance and repair. Most farms, however, do not have the necessary self-contained breathing devices or other confined space entry equipment; many also do not have toxic and asphyxiating gas detection devices. Consequently, it is been documented that farm workers enter manure storage structures unprotected, lose consciousness, and die. Tragically, such incidents often result in multiple deaths as an observing worker tries to assist the one originally overcome by the toxic and asphyxiating gases. The Occupational Safety and Health Administration (OSHA)-defined personal exposure levels (PELs) for hydrogen sulfide is 10 ppm and the American Conference of Governmental Industrial Hygienists (ACGIH)-defined threshold limit values (TLVs) for hydrogen sulfide is 1 ppm. Also, the ACGIH-defined TLVs for methane and ammonia are 1,000 and 25 ppm, respectively. The OSHA-defined personal exposure levels (PELs) for carbon dioxide is 5,000 ppm (Manbeck, Hofstetter, Murphy, & Puri, 2016).

Hydrogen sulfide (H_2S) is considered "knock down" agent and inhalation of H_2S causes rapid cellular asphyxia, collapse, and cardiac arrest. Because H_2S in gaseous form is heavier than air, the highest risk of exposure for workers is in enclosed spaces at, or just below, ground level. Favorable conditions for high H_2S production and accumulation — such as hot weather, confined spaces, and low wind — are likely better indicators for lethal acute exposure in agricultural occupational settings. Amongst livestock workers exposed in enclosed spaces below ground level, fatalities can be expected to be higher due to other factors such as falling, drowning, head injury during knockdown. Therefore, OSHA and the Bureau of Labor Statistics (BLS) considered H_2S as one of the most dangerous gases in the workplaces, second only among toxic gases to carbon monoxide. Generally, hydrogen sulfide represents a public health risk worthy of continued attention, as remains as a significant occupational hazard among livestock workers (Frame and Schandl, 2015 & Malone and King, 2018).

This study was designed to address a gap in current understanding of manure storage, handling, and transport related hazards by analyzing and summarizing known U.S. livestock manure-related data contained in the PACSID. It is the final step of a series targeted developing and implementing a surveillance system for all PACSID incidents (Nour et al., 2019; Nour, Field, Ni, & Cheng, 2020). This research has attempted to estimating the frequency or severity of these events, identify geographic distribution and primary farm type, victim characteristics, and identify causative factors including those related to both respiratory and machinery hazards associated with manure storage handling or transport. Though not typically or historically identified as manure storage-related incidents, fatalities and injuries identified through the (PACSID) surveillance effort involving the transfer, pumping, agitation, and transport of liquid manure appeared to be more common than reported in the literature. The goal was to disseminate new safety measures in order to support stakeholders and policy makers.

5.4 Background

Purdue University's Agricultural Safety and Health Program (PUASHP) has over a four-decade history of documenting and managing a database designed to identify, classify, and analyze fatalities and injuries involving agricultural confined spaces. The initial goal was to develop, as much as possible, a comprehensive database on U.S. agricultural confined space-related incidents including incidents involving grain storage and handling, manure storage and handling, and other types of confined spaces found at agricultural production sites. Over the past four decades 1975-2019, PUASHP has played a significant role in monitoring confined space-related incidents in the U.S. for the benefit of farmers' safety, health, and welfare. PUASHP has also published annual summaries of U.S. grain-related entrapments and engulfments for over 20 years. These contributions have been influential in the design and implementation of injury prevention efforts. Based upon a convenience sample of cases documented by (PUASHP), Beaver and Field analyzed manure-related 77 fatal U.S. cases that were documented between 1975 and 2004 (Beaver & Field, 2007).

According to a previous study to summarize prior research and evidence-based educational resources and to develop a consistent coding scheme tool for manure-related incidents, Nour, et al., 2019 reviewed extension/education publications and on-line sources (Nour et al., 2019). However, none addressed attempts to assess the frequency of manure-related injuries and fatalities

or conduct a risk assessment of all types of manure storage, handling, and transport practices to which workers are exposed. The literature supported that there is very little published information regarding the numbers, types, and characteristics of confined-space manure storages and facilities on farms across the U.S. (Murphy & Manbeck, 2014, Nour et al., 2019).

This study is the fourth one of a series targeted developing and implementing a surveillance system for all known PACSID manure-related incidents and the first one with wider scope of cases that has similar outcomes to Beaver and Field study in 2007. An international study has been summarized 17 incidents and 38 victims related to manure storage and transport during farm tasks and rescue attempts between 1998 and 2013 on Korean farms (Park et al., 2016).

In addition, insufficient amount of funds and resources were a historic problem to develop and manage a comprehensive farm-related injury surveillance system. The nonexistence of readily centralized reporting system or database hub for confined-space manure incidents, prevented a comprehensive assessment of the problem or identifying long-term trends.

5.5 Methodology

The first step of this research was to develop, test and evaluate a more consistent method of identifying, documenting, and classifying incidents involving livestock waste storage, handling, and transport facilities and equipment. The research targeted injuries and fatalities among farmers and farm workers who are at high risk of experiencing on-farm livestock manure structures and equipment injuries. The resulting coding tool was utilized categorizing all documented cases by using information about the work activity during the incident and surrounding conditions. This coding process was developed and tested with incidents documented in 2017. Data were summarized and results and other parameters were identified by (Nour et al., 2019).

Next, the PACSID database was reviewed for all cases that were identified as involving livestock waste-related storage, handling, and transport. The PACSID was found to include 238 cases that met the desired criteria. These cases were identified using key terminology that include manure, manure storage, manure spreader, manure gas, Hydrogen Sulfide exposure, etc.

A Boolean logic model was then used to select the specific search terms used and to identify key search factors and their relative significance. It also, has been used to conduct cyber searches of relevant research, and to validate the accuracy of incident through the coding and classifying process. A special effort was made to gather additional information on the identified 238 cases

from on-line sources. An aggressive search was also conducted to identify additional cases using Google alerts, on-line detection and notification services, news clippings, published articles and prior civil litigation cases. A search of data documented in both the Census of Fatal Occupational Injuries (CFOI) and the AgInjuryNews.org site identified no new cases. In many cases, very limited descriptive information presented inclusion of cases.

This effort resulted in an additional 221 cases or a total of 459 individual U.S. cases that were confirmed as occurring between 1975 and 2019. It also included 83 international cases which were not included in this summary. Utilizing the coding scheme system developed by Nour, et al., 2019, each new case was coded and entered to the statistical software SAS and Excel Spreadsheet for analysis and summarization (Nour et al., 2019).

An in-depth study of manure-related cases involving children, youth, and young workers was completed and published by (Nour, Field, Ni, & Cheng, 2020).

5.6 Findings

5.6.1 Distribution of Cases by Decade, Year, and Month

The distribution of documented manure-related incidents by year is shown in Figure 5-1 and by decade in Figure 5-2. It was recognized that there was a considerable lack of data from earlier decades that prevented a comprehensive longitudinal assessment. There was a dramatic change in the number of manure-documented cases in the decade of the 1970s (18 cases) as compared to the decade of 2010s (222 cases). Forty-eight percent of all cases were documented in the last decade and 28% of all cases were reported in the last three years of this study reflecting the intensive surveillance efforts. Overall, the average number of cases per year was 10 and there was a general increase trend in number of cases. The peak years for most reported cases were 2017 and 2018 which reflected the launching of intensive efforts to identify both fatal and non-fatal cases, increase the awareness regarding the potential risks of manure operations and the increasing case of accessing this type of data on the internet.

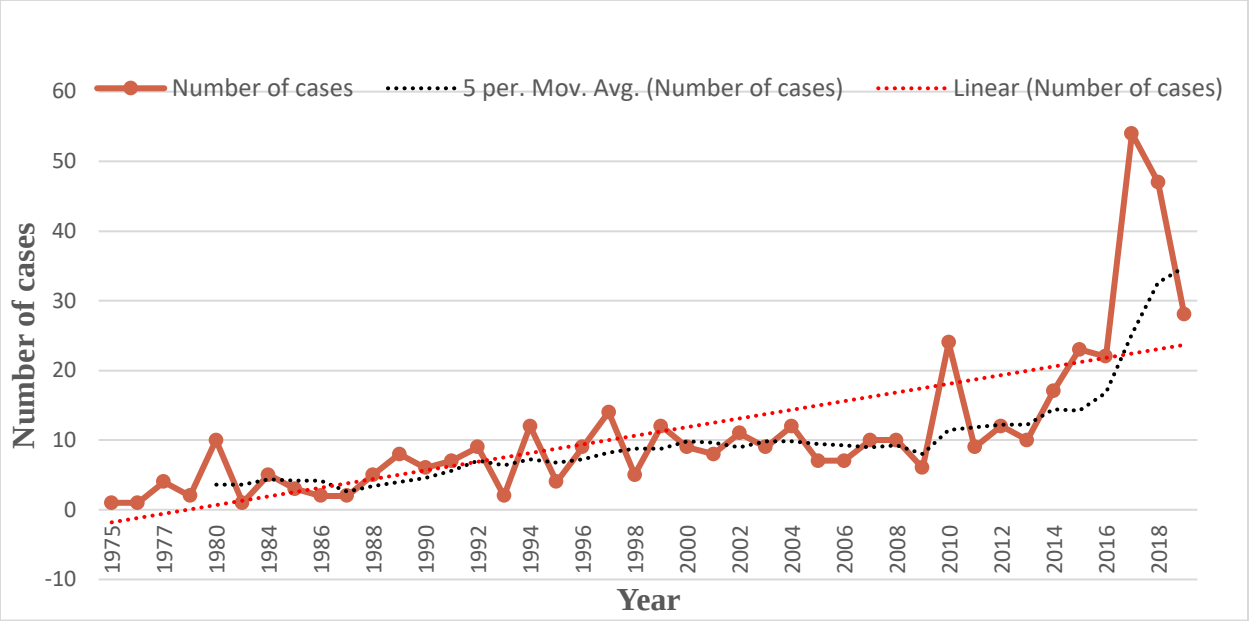

Figure 5-1: The distribution of manure-related cases in the U.S. by year from 1975 to 2019 (N=459).

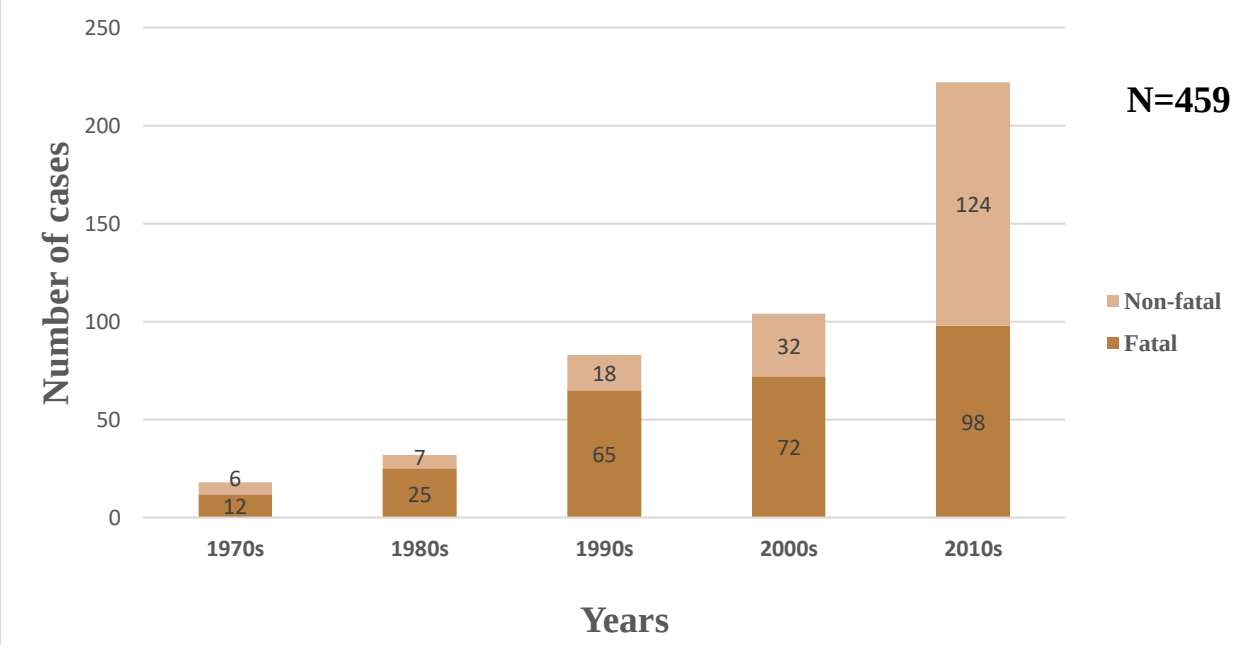

Figure 5-2: The distribution of manure-related cases by decade within the U.S. (N=459) from 1975 to 2019.

As noted from Figure 5-2 and from Beaver and Field (2007), the percentage of incidents involving fatalities has been unexpectedly high, ranging from 44 - 74%. With more aggressive surveillance, the number of documented cases has been increased and the ratio between fatal and non-fatal incidents was increased (Beaver & Field, 2007).

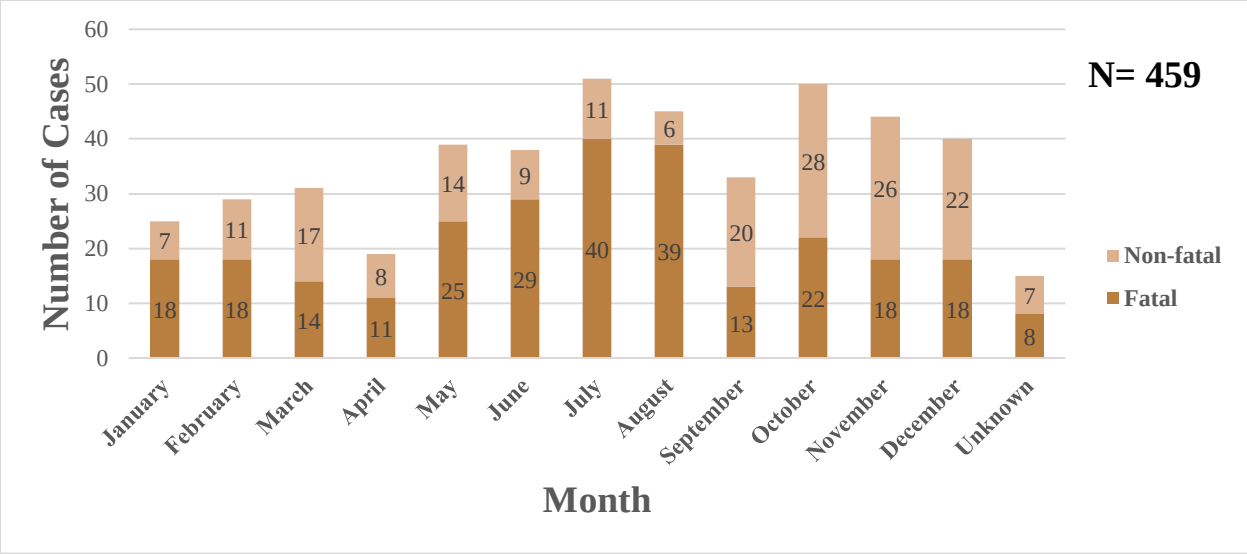

Figure 5-3: The monthly distribution of manure-related cases in the U.S.

The distribution of cases by month is shown in figure 5-3. The data over 44 years showed a bimodal distribution pattern, mode1: July, August, September; mode2: October, November, December with two distinct peaks in July and October. These two peaks, it is believed, reflected the warmer weather in July that contributes to higher levels of toxic gases being produced in manure storage structures and the more intensive application of liquid manure following wheat harvest in the June/July time period. The peak in October is more likely the result of manure application following corn and soybean harvest prior to the winter months when manure utilization is more difficult. Fifteen cases had an unknown date of occurrence.

5.6.2 Analysis of Fatal and Non-fatal and Secondary Victim Rescue Cases

Manure operations as other farm duties that required working in enclosed spaces have a greater probability of multiple victims' cases. A total of 389 incidents involving 459 individual cases were documented, of which 272 cases or 59% of all cases died during manure storage,

handling, and transport operations and 187 persons were injured. At least 49 rescue incidents involving 119 individuals or "secondary victims" was documented in this study and it was higher than expected. The "secondary victim" is the individual who became involved while responding or attempting to rescue the initial victim (Figure 5-4).

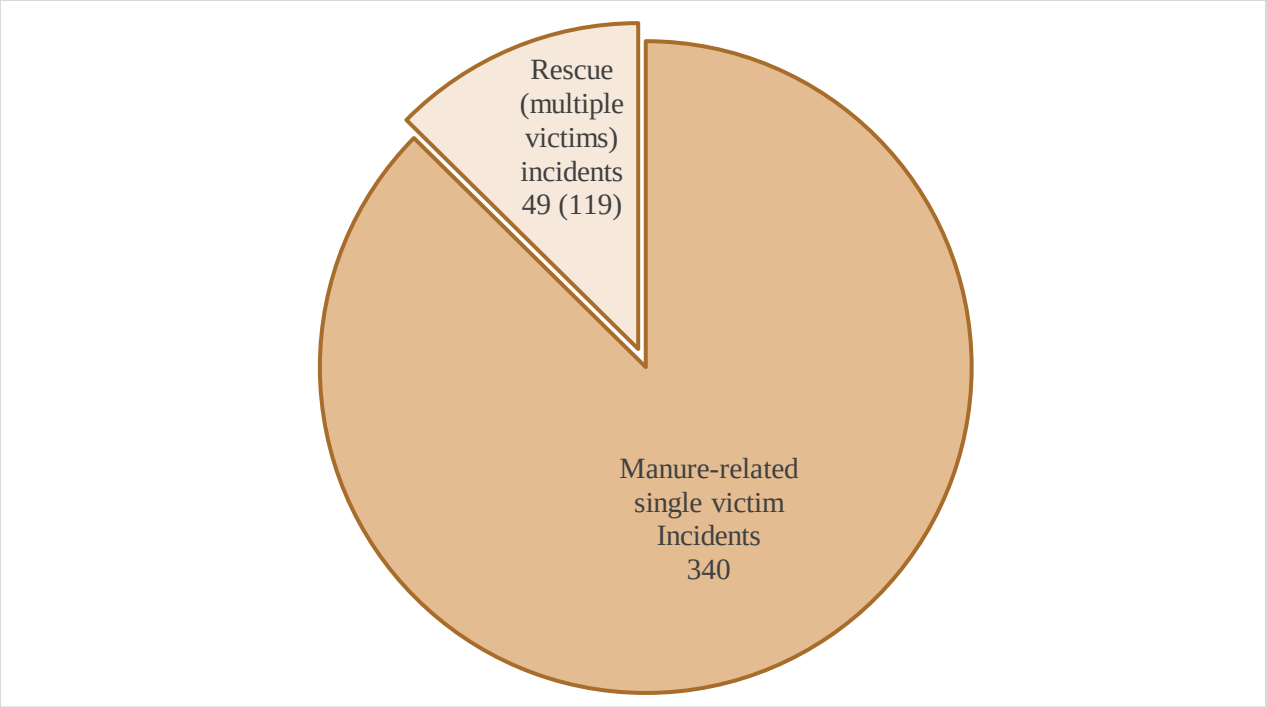

Figure 5-4: The percentage of "Secondary victims" cases in the U.S.

5.6.3 Distribution of Cases by Victim's Gender

The overwhelming majority of victims were male (>85%), as shown in Figure 5-5. Males were nearly more than ten times as likely to be involved in a fatal incident as females. The females who were involved in these incidents were more likely to be children and youth than adults or more probably involved in roadway collisions.

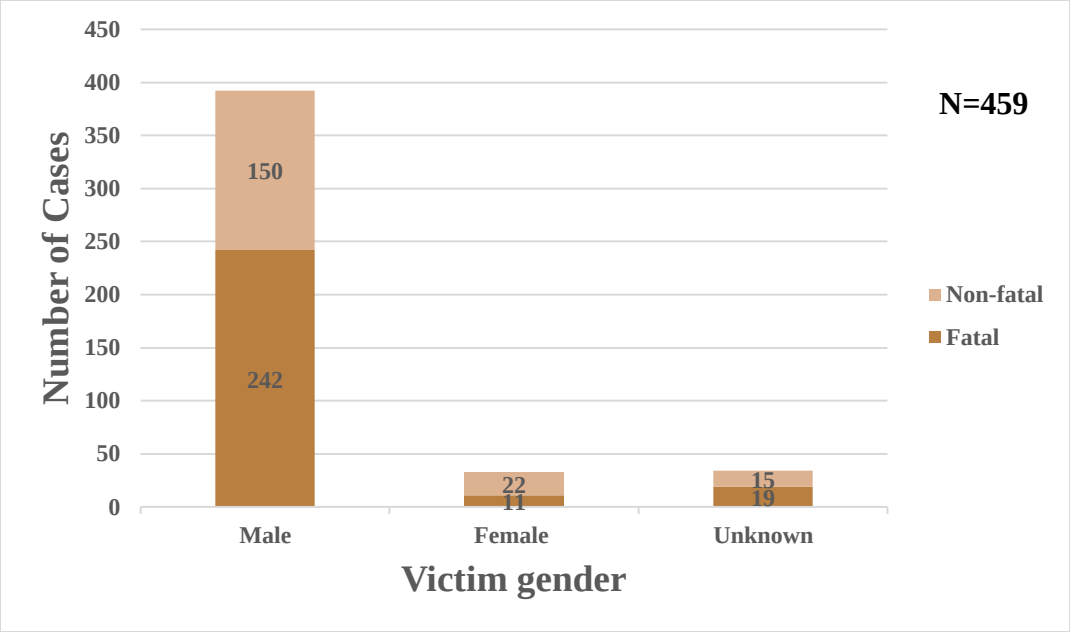

Figure 5-5: The distribution of manure-related cases in the US by victim's gender.

5.6.4 Distribution of Cases by State

Based on PACSID documented data, the largest proportions of cases 302 (66%) were reported in the traditionally heavily agricultural and dairy production states of CA, IA, MN, WI, NY, and PA. Figure 5-6 shows the distribution of cases by state except for two cases where the state was unknown. No cases were reported in seven states including Rhode Island, Hawaii, Alaska, West Virginia, Nevada, Louisiana, and Arkansas. Beaver & Field, 2007 reported that the 77 deaths documented in 56 separate incidents between 1975 and 2004 were documented in only 17 states and data was lack or missing in 33 states. Twenty-five states reported four cases or less and 12 states reported only one incident in 44 years. It is highly probable that more incidents, especially non-fatal occurred in some states, but could not be documented (Beaver & Field, 2007).

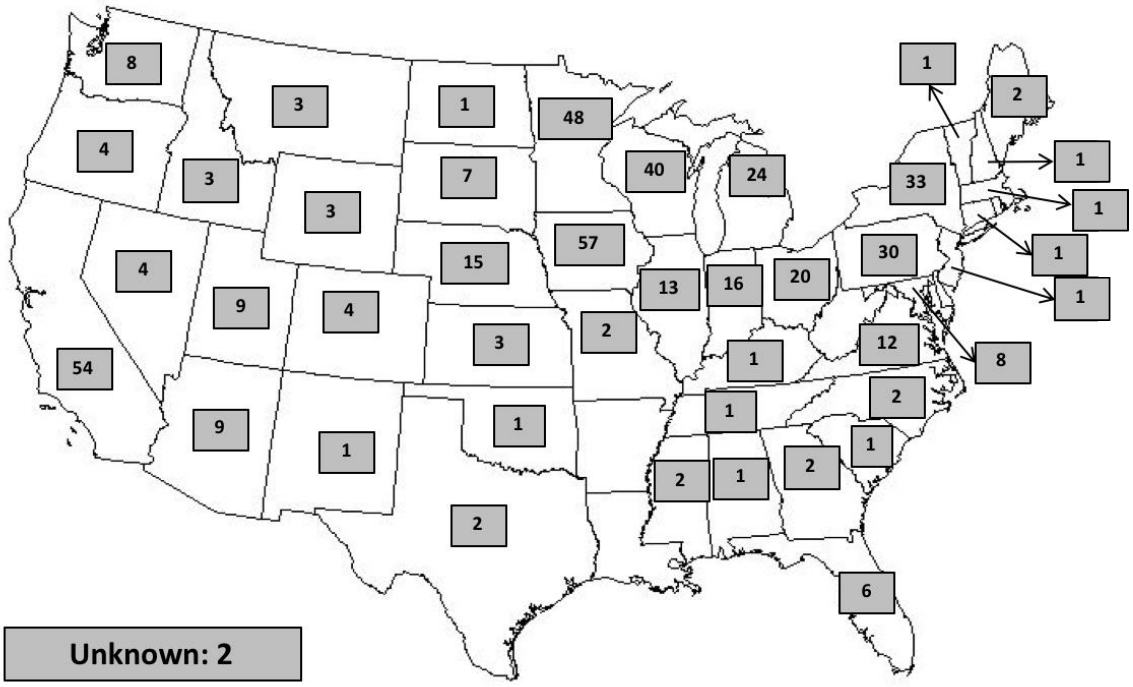

Figure 5-6: The distribution of manure-related cases by state (N=459) from 1975 to 2019.

5.6.5 Distribution of Cases by Victim's Age Category

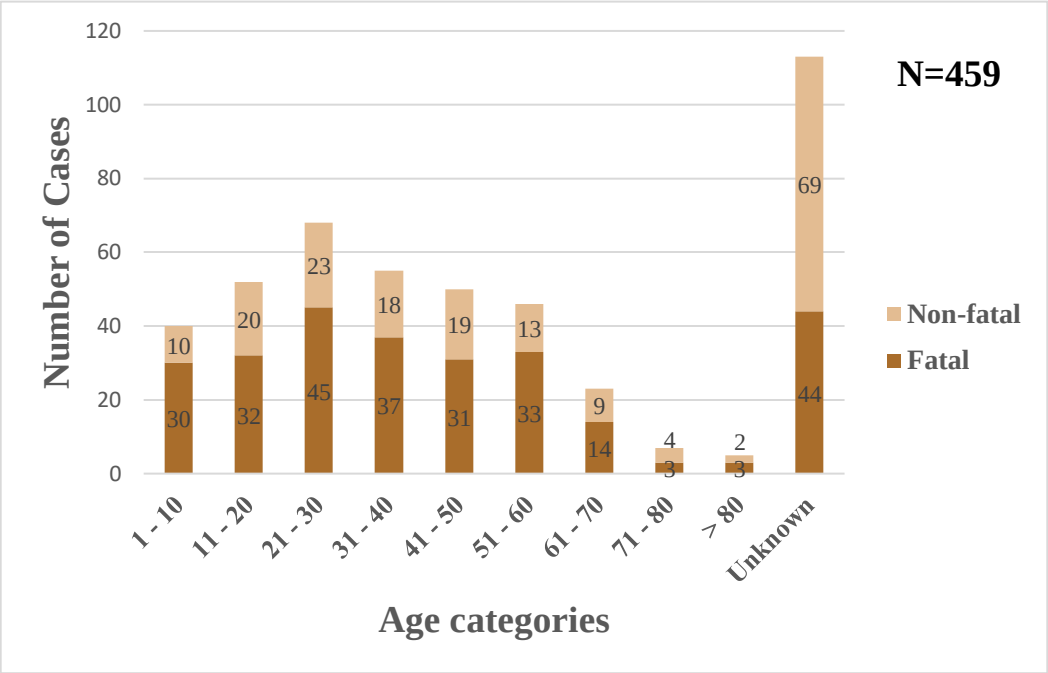

Figure 5-7: The distribution of manure-related cases in the U.S. by victim's age category.

About 22% of all documented cases were affirmed by the OSHA's archival incident data or the National Institute for Occupational Safety and Health (NIOSH) Fatality Assessment and Control Evaluation (FACE) reports. However, cases from these sources were lacking demographic information such as age of victim which is also often lacking in other reports. It was also unlikely that these data sources included children and youth since both sources focus only on work-related fatalities. Therefore, the data in Figure 5-7 showed variations regarding victim's ages over the 44-year period. Regardless, the age for about 24% of all cases was unknown. The peak age category was (21-30) with 68 victims. The average age of victims was 37 which is considerably younger than the average for grain-related injury victims, which has been reported to be approximately 53 and the average age of all farm operators was 58 (Nour et al., 2019). The fatality rate was high with children ten-year old and under and 20% of all victims were children, youth and young workers 20 years old and younger, which is comparable to the portion of children involved in grain-related incidents (Issa et al., 2016).

5.6.6 Distribution of Cases by incident location

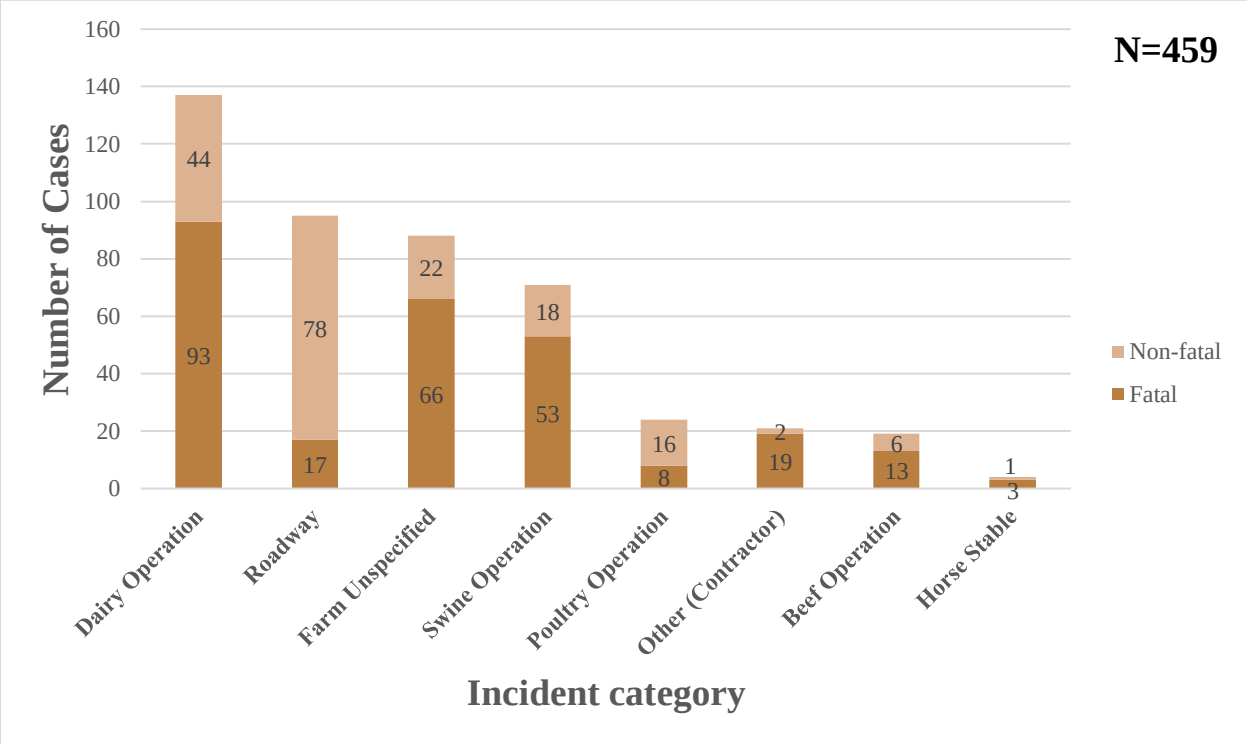

Figure 5-8: The distribution of manure-related cases in the US by incident location.

Dairy operations were identified as the most frequent type of farms involved in these incidents with an unexpectedly high fatality rate (68%), representing 30% of all cases. Roadway collision involving manure transport vehicles, with 21% reported cases, was identified in the second place and most cases were non-fatal (Figure 5-8).

5.6.7 Distribution of Cases by Cause of Injury

Asphyxiation or suffocation related incidents continue to be the leading cause of death. These cases along with entanglement in manure handling machinery represented about 59% of all cases. The use of the terms “asphyxiation” and “suffocation” appeared to be used interchangeably in some reports even though they are defined differently in the literature. Typically, the drowning fatality rate is still the highest among all causes of injury categories (Figure 5-9). In some cases, the victim appeared to be overcome by the toxic gases or lacking of oxygen in the space and collapsed in the residual liquid and drowning.

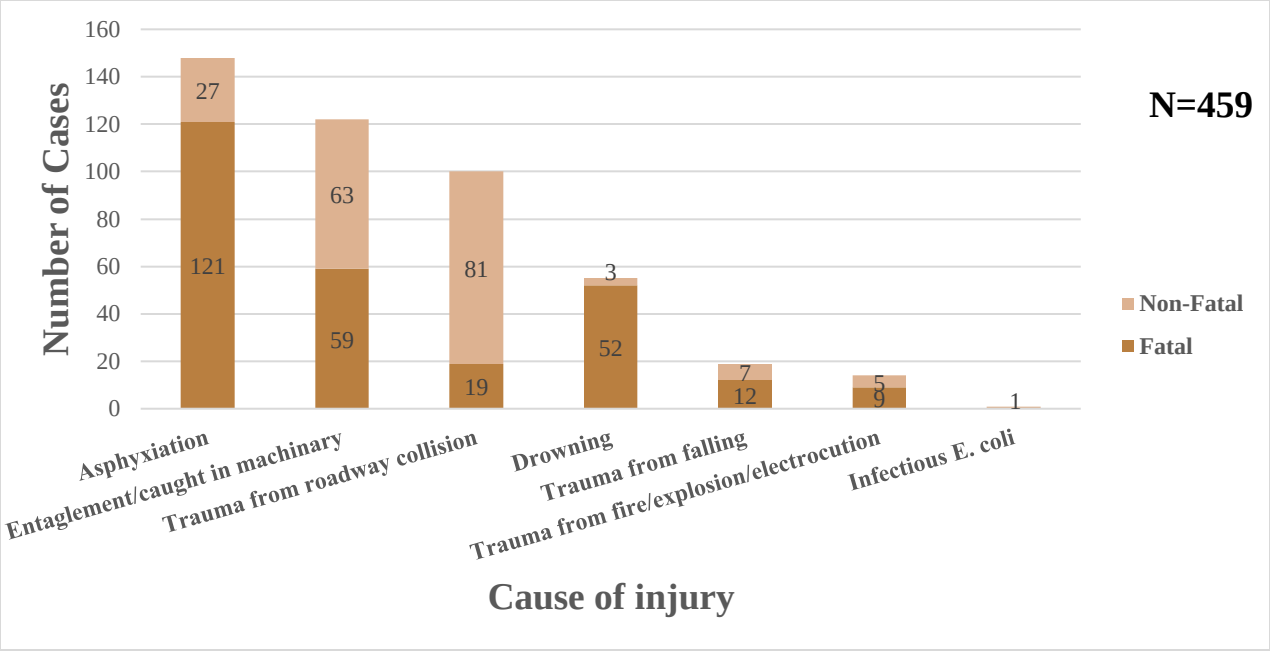

Figure 5-9: The distribution of manure-related cases in the US by cause of injury.

5.7 Limitations

As with many types of agricultural-related injuries and fatalities, the high ratio of fatal to non-fatal incidents reported in this article suggests that a significant number of non-fatal or near-miss incidents go unreported preventing comprehensive documentation. The lack of any type of centralized or required reporting process will continue to result in under reporting of manure-related incidents, especially those that are non-fatal. There were multiple accounts identified during the discovery process in which workers were reported to have become overcome by a toxic environment during exposure to manure handling activities but were able to self-extricate or be removed from the site to recover without medical attention. In one case, a farmer shared about lowering his son on a rope sling into a manure storage structure and having the son pass out while suspended over liquid manure. The father was able to lift his son out, who recovered once reaching fresh air. In two other cases, workers who were checking the level of manure in a semi tanker were overcome and fell from the trunk. None of these cases were included due to the wishes of the source and lack of adequate documentation. These types of "near misses", however, could provide valuable information to the development of injury prevention efforts. There were also issues with identifying the actual cause of death, especially in cases involving drowning, asphyxiation, and exposure to toxic gases, including hydrogen sulfide. Where there was access

to autopsy reports, exposure to hydrogen sulfide was mentioned in some cases, but more frequently the official cause of death was identified as asphyxiation due to oxygen deficiency. As with most farm-related fatalities, few autopsies are conducted. This lack of medical information also prevents a determination of the role played by alcohol, drugs, or prior health conditions of the victim.

The data were also limited due to the inability to conduct additional on-site investigations involving interviews with victims and witnesses. It was found that only a few of these incidents were investigated by the Occupational Safety and Health Administration (OSHA) or the NIOSH FACE Program due to the agricultural workplace exemption or lack of resources. For example, it was believed that incidents, especially non-fatal or "near misses" at large swine production operations are under reported considering the large number of these facilities with on-site manure storage structures and the large number of employees. In general, a multisource surveillance system is needed to provide enough documentation for each case. These sources should not only include news media and on-line sources but also death certificates, workers' compensation reports, medical or hospital reports, coroner reports, police reports, and motor-vehicle incident reports. Such a system does not currently exist and is unlikely to be established in the foreseeable future (Nour et al., 2019).

5.8 Summary and Conclusion

It is clear that the farm injury data limitations of under reporting manure-related incidents, especially during early decades of the study, prevented a comprehensive assessment of this problem or identifying the primary causative factors of injuries and fatalities. There is limited literature exploring livestock waste-related fatalities and injuries among farm operators and workers. While there has been ongoing surveillance of injuries and fatalities involving agricultural confined space-related incidents, few have attempted to better understanding of manure-related incidents in agricultural operations. Existing surveillance efforts have generally under reported fatal cases, undercounted injuries and 'near misses', and misclassified incidents as non-farm related.

Farmers/rancher who admitted entering or being around manure structures without respiratory protection is still a continuing and growing concern across the U.S. since Riedel and Field, 2013 reported that. This study provides additional evidence-based guidelines for safety and

health professionals regarding the challenge of entering into manure confined spaces on farms and ranches across the U.S. (Riedel & Field, 2013).

In the U.S. between 1975 through 2019, a significant number of fatalities and injuries have been occurred during manure operations especially in the traditionally heavily agricultural and dairy production states. Of the 459 individual cases, 271 (59%) were fatal, and 20% involved children under the age of 20 and younger. The most frequent activity (30%) was conducting in dairy farms. Drowning incidents in manure storage structures and lagoons were the deadliest type of incidents with 97% being fatal. Nearly all the cases, except roadway collisions involving manure transport vehicles, were occurred in close proximity to livestock manure storage structures and equipment or during maintenance activities.

This study used only documented incidents between 1975 – 2019 to gain a better understanding of manure-related injuries and fatalities in agricultural operations. It was designed to address gaps in the current national-level confined space injury data. Continued injury surveillance will not only contribute to maintaining a record of the frequency and severity of manure-related injuries but also improve lives of farmers and their families who are working in and around agricultural confined spaces, especially livestock manure operations. While the last decade has seen an elevated number of reported cases due to more aggressive surveillance system, unreported cases are still an inherited challenge for a comprehensive incident reporting system. The livestock manure-related injury and fatality data and assessing the incident mortality and morbidity trends should be used to guide prevention and intervention measures. The following main conclusions that can be drawn from the analysis of this review are:

1. Asphyxiation related incidents continue to be the leading cause of death during storage, handling, and transporting livestock waste.
2. Farm safety programs targeting dairy farms and manure transport vehicles should continue to be a top priority for intervention strategies, especially during peak manure handling periods, such as early summer and late fall.
3. Agricultural roadway collisions with manure transport vehicles remains a leading cause of the non-fatal injuries.

5.9 Recommendations

The following evidence-based interventions and recommendations provide an integrated solution that can reduce or prevent similar incidents during livestock manure operations.

- Develop new agricultural confined space-related hazards curricula which include waste-related hazards and injury prevention strategies through reducing or removing workplace hazards.
- According to the OSHA and ANSI regulations and standards, all confined spaces including livestock manure structures and operations must be considered dangerous, provided with the appropriate safety warnings, and entry forbidden except for qualified persons (farm security monitoring systems) with retrieval equipment (ANSI, 2009; OSHA).
- The employment of children and youth in agricultural operations involving hazardous tasks is a long-standing issue, therefore, there is a need for placing more emphasis on education of both parents and youth on the hazards associated with manure storage, handling, and transport and aggressive enforcement of current child and labor laws.
- Continuing training and public awareness measures are strongly recommended, especially targeting the six states with the highest number of documented incidents.
- While less attention has been given to hazards associated with the storage, handling, transport, and processing of agricultural wastes. Targeted training should be conducted for safety and health trainers and processing agricultural waste employees.
- emphasizing facilities that process agricultural waste to produce bio-gas; safe handling
- Safety programs should address the problem of asphyxiation/suffocation during manure operations and entanglement in manure machinery as a priority for the effective preventive measures.
- Agricultural livestock producers need to be better educated on the importance of warning and using toxic gases monitors (gas detection equipment) before entering manure structures or during manure handling operations, which will alert them to high manure gases concentrations.
- Secondary agricultural education classes, farm safety training programs, and extension outreach efforts should be encouraged to provide and promote basic safety and health awareness about the hazards associated with all manure storage, handling, and transport

operations in agricultural workplaces that pose a potential risk to children, youth, and young workers. Parents should be included in the dissemination of safety resources. These efforts should target dairy and swine operations and high-risk activities such as exposure to liquid manure storage sites and confined spaces (Nour et al., 2020).

- Current engineering standards (ASABE) should be reviewed in light of the findings of this research to determine whether or not enhanced engineering designs could be adopted which would reduce the risk of manure storage, handling, and transport.

5.10 Acknowledgements

The authors very much appreciate the support by the Purdue's Agricultural Safety and Health Program, Purdue University for funding this research.

5.11 Conflicts of Interest

The authors declare no potential conflict of interest.

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6. OVERALL SUMMARY OF FOUCS GROUP DISCUSSION AND RECOMMENDATIONS

6.1 Why Focus Group

Focus group discussion is a research methodology in which a small group of experts from different perspectives gather to discuss a specified topic or an issue for generating data or brainstorming a list of recommendations (Wong, 2007). The topic of this focus group was "strategies for preventing manure storage, handling, and transport-related injuries and fatalities". It was designed to help develop relevant evidence-based injury prevention and mitigation strategies. As part of this research plan of study, a focus group with a panel of experts in the occupational safety field convened to review the assessment findings of this efforts. In addition, the focus group collaborated on developing a specific list of evidence-based recommendations that would have a high probability of reducing the frequency and severity of the incidents if implemented.

6.2 Focus Group Members

- Professor Jiqin Ni, Department of Agricultural & Biological Engineering, Purdue University.
- Professor Michael Pate, Applied Sciences, Technology & Education Department, Utah State University.
- Professor William Field, Department of Agricultural & Biological Engineering, Purdue University.
- Ed Sheldon, MS., Department of Agricultural & Biological Engineering, Purdue University.
- Mahmoud Nour, MS., Department of Agricultural & Biological Engineering, Purdue University.
- Marty Huseman, Safety Director and Client Success Manager at Good Day's Work.
- Tracey Erickson, SDSU Extension Dairy Field Specialist, Watertown Regional Office.

6.3 Summary of Recommendations

The following recommendations are based upon the assessment of findings of this study and input from the focus group:

1. Develop, test, and disseminate a new agricultural confined space-related hazards curriculum for high-risk populations. Topics should include waste-related hazards, injury prevention strategies through reducing or removing workplace hazards, personal protective equipment (PPE), and emergency response procedures.
2. Targeted training should be conducted for safety and health trainers and supervisors of agricultural employees. This training should address the need to increase targeted prevention efforts during high-risk times of the year.
3. Secondary agricultural education classes, farm safety training programs, and extension outreach efforts to children, youth and young workers should be encouraged to provide and promote basic safety and health awareness about the hazards associated with all manure storage, handling, and transport operations in agricultural workplaces. Parents or guardians should be included in the dissemination of workplace safety resources during manure storage, handling, and transport operations. These efforts should target dairy and swine operations and high-risk activities such as exposure to liquid manure storage sites and confined spaces.
4. There should be easy, on-line access to the needed safety information that improve farm workplace health and safety practices needed by farm children, youth, and young workers who are interested in farming or who work on family-operated farms and have exposure to agricultural manure storages and handling facilities and equipment.
5. Current structural and engineering standards for manure storage facilities and equipment, such as published by the American Society for Agricultural and Biological Engineering should be reviewed in light of these findings and enhanced to reduce potential risks. Outcomes should be used to promote regulatory, engineering, and educational efforts to reduce the frequency and severity of these incidents. Additional standards for signage, access covers, gates, fencing, and toxic gas monitoring equipment to reduce risks associated with these structures should be considered. Adopting new design concepts for

manure structures can be a useful tool and also, include monitoring atmospheric quality and fencing system on livestock farms.

6. Enforcement of existing workplace safety regulations, including the Hazardous Occupation Orders in Agriculture, can reduce the frequency and severity of child and youth exposure to agricultural confined spaces.
    a. Enforce existing child labor laws that prohibit children and youth under 16 years-of-age from working in or around agricultural confined spaces.
    b. Requirement that youth employed in agriculture under 16 years-of-age be provided instruction and training on tasks, such as exposure to confined spaces, considered especially hazardous.
7. Continue a centralized reporting system for these incidents as found in PACSID and continue to conduct more in-depth investigations of incidents involving multiple victims.
8. Additional investments should be made to conduct follow-up investigations of manure transport-related incidents, in order to identify significant contributing factors regarding these high-profile incidents, special consideration is needed to further examine the cases of these incidents and how they can be prevented.
9. Social media, support groups, first person stories, YouTube videos, and blogs offer opportunities to promote behavior change for preventing workplace injuries.
10. Continue and improve the current surveillance and documentation press clipping initiative and ensure a consistent incident coding and classifying system in order to identify potential trends and patterns, and to evaluate the efficacy of prevention initiatives.
11. Special attention should be given to educating IA, CA, PA, NY, WI, and MN livestock producers regarding the risks of manure-related activities, along with the benefits of complying with the existing provisions of current ASABE standards.
12. Future research should consider the development of mobile applications (self-monitoring) that can interact with sensors to alert farmers and farm workers about the presence of toxic gases in workplace environments. Also, farmers are encouraged to adopt mobile video monitoring systems connected to their phones that will alert them to the presence of

individuals in hazardous locations such as manure facilities. These monitoring systems also allow individuals to interact and talk to each other to avoid hazardous environments.

6.4 References

1. Wong LP. Focus group discussion: a tool for health and medical research. Singapore Med J. 2008 Mar;49(3):256-60; quiz 261. PMID: 18363011.

APPENDIX

Appendix 1: Incident reporting coding tool form

Appendix

Agricultural Confined Space Incident Report Classification Form for Manure Storage, Handling and Transport Related Injuries & Fatalities

PACSID ID: _____

Source of Date for Incident Identification (Check all that apply):

- ☐ Published research article
- ☐ Phone/personal interview
- ☐ Electronic media (TV, Radio)
- ☐ News clippings
- ☐ Google alerts/on-line sources
- ☐ Other_____

1. General Incident Information

Date (Month/Day/Year) _____/_____/_____

Time of Injury _____ AM / PM **Weekday of Injury (circle):** S M T W T F S

Address _____

County _____ **State** _____

2. Number of Victims _____

3. Incident Classification

- ☐ Non-fatal
- ☐ Fatal
- ☐ Unknown

4. Type of Farm

- ☐ Dairy
- ☐ Swine
- ☐ Beef
- ☐ Poultry
- ☐ Other, specify_____
- ☐ Unknown

5. Victim Information

Name (Last, First): _____ ☐ Unknown

Age: _____ ☐ Unknown

Name (Last, First): _____ ☐ Unknown

Age: _____ ☐ Unknown

Name (Last, First): _____ ☐ Unknown

Age: _____ ☐ Unknown

Name (Last, First): _____ ☐ Unknown

Age: _____ ☐ Unknown

Sex:

- ☐ Male
- ☐ Female
- ☐ Unknown

6. Cause of Injury

- ☐ Suffocation
- ☐ Drowning
- ☐ Asphyxiation
- ☐ Trauma from fire/explosion
- ☐ Trauma from fall
- ☐ Electrocution
- ☐ Entangled/caught in machinery
- ☐ Trauma a from roadway collision
- ☐ Trauma from equipment failure
- ☐ Machine/vehicle related drowning
- ☐ Other, specify _____

7. Relationship to Farm

- ☐ Farm/ranch owner or farm operator
- ☐ Farm/ranch hired worker
- ☐ Farm/ranch family member
- ☐ Children at play
- ☐ Rescuers/first responders
- ☐ Visitor
- ☐ Contractor
- ☐ Other, specify _____
- ☐ Unknown

8. Agent / Facility / Equipment / Involved

- ☐ Underground or underfloor manure storage structure
- ☐ Above ground manure storage tank
- ☐ In-ground manure storage (lagoon/pit)
- ☐ Manure handling equipment (barn cleaner, skid steer, frontend loader)
- ☐ Manure transport vehicle (solid manure spreader, liquid manure tank)
- ☐ Manure agitation or pumping equipment
- ☐ Manure pumping pit or enclosure
- ☐ Electrical component
- ☐ Fire/explosion
- ☐ Other, specify _____
- ☐ Unknown

9. Contributing Toxic Gases Identified (Exposure to toxic substances/gases)

- ☐ Hydrogen Sulfied
- ☐ Carbon Monoxide
- ☐ Methane
- ☐ Carbon Dioxide
- ☐ Ammonia
- ☐ Non

10. Location of Incident

- ☐ Livestock building
- ☐ Farm yard
- ☐ Field
- ☐ Roadway/highway
- ☐ Farm unspecified
- ☐ Manure shed
- ☐ Farm road
- ☐ Manure pit/lagoon
- ☐ Pump septic systems
- ☐ Other, specify_____

11. Additional Narration (including task at time of incident):

_____
_____
_____
_____
_____
_____
_____

Completed By:_____ **Date:**_____

***Incidence references attached to this report**