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ORIGINAL RESEARCH

Assessing Self-reported Occupational Hazards of Manure Applicators in the Upper Midwest

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ABSTRACT

Manure management on farms presents potential risks to human health and safety, including infectious, chemical, and physical exposures that may result in injury or fatality. Toxic gases and confined spaces are among the most common hazards. These hazards are especially salient for the Upper Midwest of the United States. This study characterizes the occupational health and safety practices and experiences of manure applicators in Minnesota. This cross-sectional study surveyed 162 commercial manure applicators about their work characteristics, safety practices, and health and safety experiences. Respondents reported an average of 17 hours per day applying manure during the busy season, which typically occurs several weeks each year. One hundred and thirty-one (90%) of 145 respondents did not regularly use gas monitors during application. Thirty-three (37%) of 90 respondents reported at least one symptom of gas exposure during manure application work. Those that worked with swine manure were more likely to report symptoms of gas exposure than those who did not work with swine (OR 9.5; CI: 2.0, 89.0). Those that had entered confined spaces were more likely to report symptoms of gas exposure than those who had not entered confined spaces (OR 4.4; CI: 0.1, 1.1). Fourteen (9%) of 150 respondents reported being injured when applying manure. Manure work can be hazardous and may be associated with injury and gas exposure. These findings offer a starting point for future research and intervention to protect and improve the health and safety of applicators.

KEYWORDS

Manure management; occupational safety; occupational health; animal agriculture; manure applicators

Introduction

Manure from animal production systems is a beneficial resource that contains nutrients for crops and plants. As such, manure applicators provide a valued service to agricultural operations in the transfer of manure from storage to land application. Environmental hazards, like contamination of waterways and spills, are mitigated through responsible management and application practices.[1]

Agriculture is a hazardous occupation, and manure work comes with potential human health and safety risks, including pathogenic, chemical, and physical exposures that may result in injury, illness, or fatality.[2] These hazards occur along "the path of manure," from the animal, barn cleaning, short-term storage, initial transfer, long-term storage, agitation, final transfer, and application.[3]

Agricultural workers, in general, experience an increased incidence of zoonotic enteric infections compared to the general public.[4] Livestock manure contains zoonotic pathogenic microorganisms, such as *Salmonella enterica, Escherichia coli, Campylobacter* sp., and *Cryptosporidium parvum*, among others, that can be transmitted to humans directly, during manure handling or processing, and indirectly, through routes such as contaminated food products and water.[5–7] Further, manure storage and agitation involve hazardous gases, including ammonia, carbon dioxide, carbon monoxide, hydrogen sulfide, and methane.[8–10] In confined manure storage spaces, such gases can reach unsafe concentrations, resulting in respiratory problems or fatality due to asphyxiation, poisoning, and explosions.[9–12] The American Society of Agricultural and Biological Engineers offers a standard for

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ventilating manure storages to reduce toxic gas inhalation risk.[13] Liquid manure storage also presents the risk of falling and drowning.[9] Equipment utilized during manure handling and transportation may also be associated with entanglement and other injury.[9] Many factors influence the health and safety hazards associated with this occupation, like temperature, humidity, and time in storage.[8,10,14–16] Park et al. [15, p.116] noted that, ultimately, a "manure-handling facility is particularly one of the most dangerous workplaces in a livestock farm."

Nour et al.[9] found a higher frequency of fatal and non-fatal manure-related incidents in Upper Midwest states that are highly productive in animal agriculture, such as Iowa and Minnesota. In the Upper Midwest, manure application occurs at variable intervals during the spring, summer, and fall, as each presents benefits and challenges for manure management.[17] During the fall season (approximately August through November), a large amount of manure is typically applied, as there is more time for optimal conditions between harvest and the first freeze.[9,18] The spring season (approximately late March through April) is often shorter due to cold temperatures and planting responsibilities.[18] Manure application timing is very dependent on environmental conditions like precipitation and temperature.[17] This can create particularly "busy" seasons where there are short windows of time (approximately two to four weeks) where the conditions are appropriate to apply manure.

Beaver and Field[19] gathered and analyzed mortality data related to on-farm manure storage and handling between 1975 to 2004.[19] Most deaths (34%) occurred while doing repair and maintenance on manure handling equipment, followed by attempting to rescue another person (22%).[19] Deaths often involved asphyxiation and occurred during the hottest part of the summer.[19] Many incidents were associated with the transfer of manure to the field.[19] Additionally, Choi et al.[10] accessed the Iowa FACE Program Database, reviewing occupational deaths occurring in Iowa between 1995 and 2003. Of the 272 deaths associated with agricultural operations, there were seven events and nine fatalities related to the handling of livestock manure, "accounting for approximately 1% of all reported occupational fatalities" in the state during that time [10,p.254]. The Iowa FACE Program was suspended in 2014; therefore, limited data and knowledge exist about ongoing fatal incidents related to manure work.[20]

There are often stringent licensing and education requirements to mitigate the occupational and environmental hazards of manure work, especially in agriculturally intensive areas such as Minnesota. Minnesota state law dictates that site managers and applicators that apply manure commercially must be appropriately licensed through the Commercial Animal Waste Technician (CAWT) program operated by the Minnesota Department of Agriculture.[21] Licenses are valid for one year. To be recertified, site managers and applicators must participate in continuing education workshops every other year; applicators may participate in a two-hour online training each year.[21] Workshops and online training opportunities focus on transportation regulations, nutrient availability, manure application, and storage safety. In Minnesota, there are an estimated 460 licensed commercial animal waste technicians, including site managers and applicators.[22]

While these licensing practices are established, there exists limited academic exploration into the health and safety risks presented by manure work, particularly as experienced by applicators. Murphy and Manbeck[23] conducted a mail survey in 2014 to identify characteristics of manure storage on farms and related safety behaviors. To our knowledge, there has been limited data characterizing the occupational hazards of manure applicators in the Upper Midwest of the United States. The objective of this exploratory study is to investigate the hazards associated with manure application work by characterizing the occupational health and safety practices and experiences of manure applicators in this region.

Methods

A cross-sectional survey of commercial manure applicators was administered by University of Minnesota Extension faculty at five Commercial Animal Waste Technician (CAWT) training sessions for recertification between January and March 2020. Survey items assessed practices and procedures for collecting, transporting, and applying manure to farm fields. Study investigators designed and pre-tested the survey

online with the Minnesota Custom Applicators Association personnel. The survey was distributed to participants via paper after in-person training sessions, alongside an evaluation form. Responses were anonymous, and participation was voluntary. Participants did not receive an incentive to complete the survey. Survey items using the terms "owners, operators, and employers," "the busy season," and "overexposure to manure gas" were intended to ascertain worker perspectives and therefore were individually interpreted by respondents (see Supplemental File A). The "busy season" that was most recently experienced by the surveyed applicators was fall 2019, a very wet year with early snow, which made for a particularly stressful season. As the study was anonymous and focused on practices and procedures of collecting, transporting, and applying manure to farm fields, the University of Minnesota Institutional Review Board determined that the study was exempt from human subjects review.

Survey data were entered into Qualtrics and analyzed using Stata/IC 16.1. Data describing the potential health and safety risks to the applicator were summarized with descriptive statistics. The percentage of respondents reported throughout this paper reflects the number of respondents to the variable or variables described rather than the total number of study participants. This includes variables accounting for specific aspects of manure handling and application, including transportation, manure type, and safety equipment utilized. Comparative analyses were performed to document the relationship between manure work practices with key health and safety outcomes, including injury and self-reported symptoms of gas exposure, such as dizziness, headache, shortness of breath, nausea, or vomiting, during manure work. To assess factors related to the history of injuries and symptoms of manure gas exposure, dichotomous outcome variables were created. Outcome variables of interest included self-reported symptoms of gas exposure during manure work (yes or no) and self-reported injuries when applying manure (yes or no). The associations between the outcomes and the exposures or demographic variables were characterized by odds ratios (OR), and 95% confidence intervals were estimated for exposure and demographic variables.

Results

Study demographics, work characteristics, and safety practices

Of the 173 commercial manure applicators who participated in training events during 2020, 162 (94.0%) participants completed the survey. Table 1 presents the demographic and work characteristics of the surveyed manure applicators. The majority of respondents identified as male (88.3%) and white (94.4%). Respondents were fairly evenly distributed in age, with a slightly larger proportion (35.2%) in the 31–40-year-old age group.

Most respondents (88.9%) had prior Commercial Animal Waste Technician (CAWT) applicator training. In terms of manure work, most reported working in a team (82.7%) and going home after their shift rather than utilizing sleeping accommodations (58.0%). Respondents worked with a variety of application methods and species, especially swine (61.7%) and dairy (58.6%), during their manure work. Most respondents (84.0%) reported that they never enter confined spaces during their work. Those who entered confined spaces did so rarely, and a small portion (11.1%) used a gas monitor sometimes or always when entering. Four respondents reported wearing a self-contained breathing apparatus when entering confined spaces. Others indicated using ventilation (e.g., a fan) (n = 2), working as a team ("someone watching before start pumping") (n = 1), and wearing a five-point harness (n = 1) when entering confined spaces.

During manure application, most respondents (80.9%) did not use a gas monitor. Figure 1 lists the reported safety equipment used by 130 respondents during manure application. Most reported using protective boots (93.9%) and chemical resistant gloves (70.0%). Few reported using a hearing protection device (34.6%), goggles (33.85%), two-strap respirator ("dust masks") (11.5%), gas monitor (8.5%), cartridge-style respirator (2.3%), and self-contained breathing apparatus (1.5%).

Table 2 presents quantitative indicators of respondents' manure application work, including the number of farms, acres, and hours worked. A large portion of respondents (58.6%) reported transporting manure. Respondents reported applying manure on an average of 27.2 farms (Standard Deviation

Table 1. Demographics and work characteristics of surveyed manure applicators (n = 162).

Characteristic		N (%)
Sex		
	Male	143 (88.3)
	Female	5 (3.1)
	Prefer not to identify	1 (0.6)
	Missing	13 (8.0)
Age		
	Under 18 years	1 (0.6)
	18–30	30 (18.5)
	31–40	57 (35.2)
	41–50	28 (17.3)
	51–60	24 (14.8)
	Over 60 years	17 (10.5)
	Missing	5 (3.1)
Race		
	White	153 (94.4)
	Asian/Pacific Islander	0
	Hispanic	1 (0.6)
	Black/African American	1 (0.6)
	Native American	1 (0.6)
	Missing	6 (3.7)
Prior Completed Training		
	Commercial Animal Waste Technician Applicator	144 (88.9)
	Private Pesticide Applicator Certification	26 (16.1)
	Manure Management Plan	43 (26.5)
	Nutrient Management	15 (9.3)
	Confined Space Entry Training	13 (8.0)
	Missing	10 (6.2)
Role		
	Employee only	54 (33.3)
	Owner only	52 (32.1)
	Operator only	17 (10.5)
	Employee and operator	4 (2.5)
	Owner and operator	12 (7.4)
	Missing	23 (14.2)
Sleeping accommodations		
	Go home after shift	94 (58.0)
	Sleeping accommodations at work	25 (15.4)
	Both home and sleeping accommodations	15 (9.3)
	Missing	28 (17.3)
Working alone or in a team		
	Works alone	11 (6.8)
	Works in a team	134 (82.7)
	Works both alone and in a team	4 (2.5)
	Missing	13 (8.0)
Transport manure?		
	Yes	95 (58.6)
	No	56 (34.6)
	Missing	11 (6.8)
Species		
	Beef	64 (39.5)
	Dairy	95 (58.6)
	Swine	100 (61.7)
	Poultry	35 (21.6)
	Missing	11 (6.8)
Application method		
	Immediate Incorporation	63 (38.9)
	Drag hose	79 (48.8)
	Knife injection	87 (53.7)
	Broadcast	30 (18.5)
	Tanker	51 (31.5)
	Missing	32 (19.8)
Enter confined spaces?		
	Yes, 1 or more times per season	22 (13.6)
	Never	136 (84.0)
	Missing	4 (2.5)

(*Continued*)

Table 1. (Continued).

Characteristic		N (%)
Frequency of confined space entry		
	Never	136 (84.0)
	1–2 times	19 (11.7)
	3–4 times	1 (0.6)
	5–6 times	1 (0.6)
	Missing	1 (0.6)
Gas monitor use when entering confined spaces?		
	Never	58 (29.6)
	Sometimes	6 (3.7)
	Always	12 (7.4)
	Missing	96 (59.3)
Gas monitor use when applying manure?		
	Yes	14 (8.6)
	No	131 (80.9)
	Missing	17 (10.5)

The denominator for reported percentages is the number of participants in the study (162).

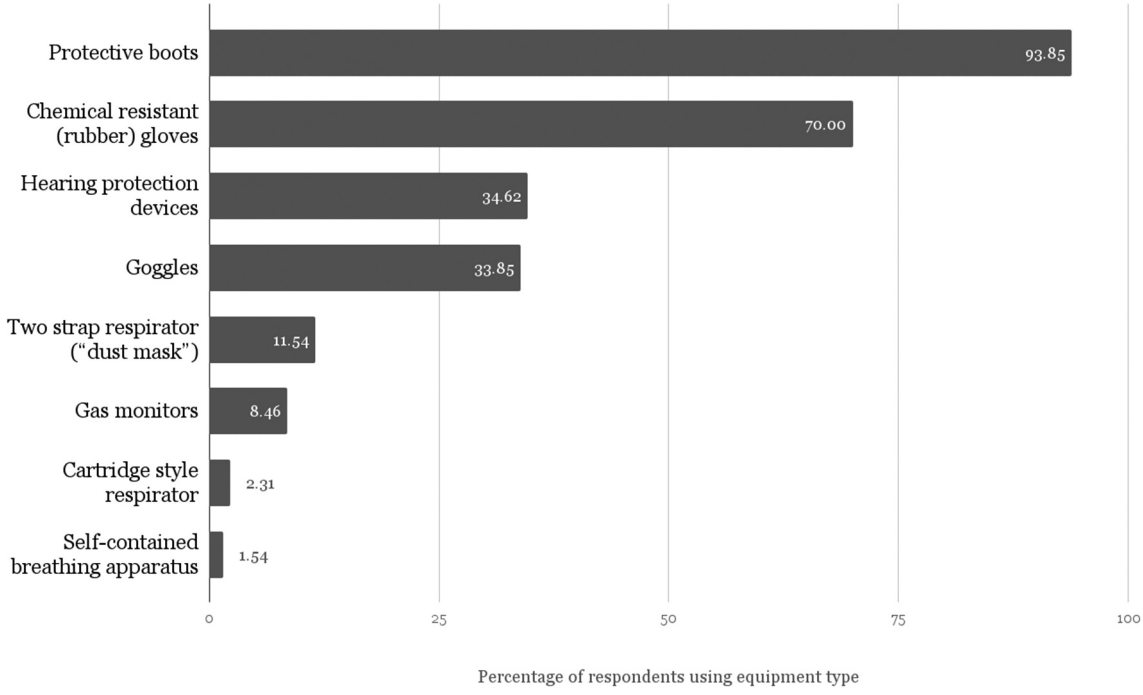

Figure 1. Personal protective equipment (PPE) and safety equipment used during manure application.

Table 2. Number of farms, acres, and hours of manure application work.

	n	Mean	Standard Deviation	Median	Minimum	Maximum
Number of farms applied in season	135	27.2	26.3	20.0	0	125.0
Number of acres applied in season	131	7,573.0	8,516.3	5,000.0	0	30,000.0
Number of hours per day applying manure during the busy season	143	17.0	5.4	17.0	0	24.0
Total work hours per day during the busy season	105	18.3	4.6	18.0	0	24.0
If transporting manure, furthest distance (miles) per trip	109	14.8	21.9	8.0	0	150.0

(SD) = 26.3) and 7,573 acres (SD = 8,516.3) in a season (spring or fall). During the self-determined busiest part of the season, respondents reported the number of hours engaged in both manure and other farm work. The mean total work hours reported during this time was 18.3 hours per day (SD = 4.6), and of this, respondents were applying manure for an average of 17 hours daily (SD = 5.4). As shown in Table 2, respondents reported transporting manure up to 150 miles and an average of 14.8 miles per trip (SD = 21.9).

Key health and safety outcomes

Of 149 respondents, 21 (14.0%) self-reported that they believed they had been overexposed to manure gases. Respondents reported this occurring particularly in situations where manure was being agitated (n = 5), stored (n = 3), or when there was little ventilation or air movement (n = 3).) Of 90 respondents, 33 (37.0%) recalled at least one symptom of gas exposure during manure application work.

Of 150 respondents, 14 (9.0%) reported being injured when applying manure, and 12 injuries were reported as minor; three required an emergency room visit, one required a healthcare provider visit, and one required both a healthcare provider and an emergency room visit. Respondents indicated a variety of causes for the injuries, including being struck by equipment (n = 5), cuts (n = 4), fatigue from long hours (n = 1), and poor ergonomics while applying manure (n = 1).

Respondents were also asked to qualitatively describe any safety or health concerns while applying manure. Responses included concerns about long hours and fatigue (n = 3) and gas exposure (n = 3). Others described concerns about road safety (n = 2) and the need for continued safety and health education (n = 1).

Factors related to illness and injuries

Demographic and work practice variables were compared to potential occupational hazards of manure applicators, including self-reported symptoms of gas exposure and injury during manure application work. Those working with swine manure had 9.5 times higher odds of reporting symptoms of gas exposure as compared to those who did not work with swine manure (95% CI: 2.0, 89.0). Those who had entered a confined space had 4.4 times greater odds of reporting symptoms of gas exposure as compared to those who did not enter confined spaces (95% CI: 1.2, 18.2). Finally, those who transported manure appeared to have lower odds of injury (OR = = 0.3; CI = 0.1, 1.1). There were no significant associations between symptoms of gas exposure or injuries and any other independent variables, such as demographics, role, other animal species, application methods, and safety practices and equipment.

Discussion

The results of this study suggest that occupational concerns, such as the hazard of gas exposure and injury, exist for manure applicators. Twenty percent of workers in our sample self-reported gas exposure symptoms related to their manure application work, and those who entered confined spaces during their work had increased odds of reporting these symptoms. While symptoms like dizziness, headache, shortness of breath, nausea, or vomiting may have other occupational causes, toxic gas inhalation is understood to be a major hazard related to manure work.[15,16] This is particularly true in confined spaces, where high concentrations of ammonia and hydrogen sulfide, can result in several negative health outcomes, including fatality.[15,16] This finding also aligns with the known risk of confined spaces in agriculture.[9,10,24–26]

Further, our study found that applicators in contact with swine manure had significantly higher odds of reporting gas exposure symptoms. This is consistent with findings from Park et al.,[15] where hydrogen sulfide and ammonia concentrations were dangerously high, particularly during the management of swine manure. Findings from Nour et al.[9] also indicated a higher percentage of manure-related fatal and nonfatal incidents on swine operations as compared to other livestock.

Personal protective equipment like self-contained breathing apparatuses or gas monitors may prevent exposure to hazardous gases and pathogens during manure management processes.[23] However, only a small percentage of

our sample reported using two-strap respirators ("dust masks"), gas monitors, cartridge-style respirators, or self-contained breathing apparatuses when applying manure. This is consistent with findings from Murphy and Manbeck [23, p.209], where "most farm operations with confined-space manure storages [did] not follow best safety practices," including the use of gas monitors, rescue lines, a developed safety plan, posted warning signs, and training for workers entering confined-space manure storages.

From our sample, 9% reported injuries, some of which required a healthcare provider visit or a trip to the emergency room. While the literature about injuries and fatalities related specifically to manure management is quite sparse, studies by Nour et al.[9,24] summarized fatal and nonfatal incidents involving manure management from 1976 through 2019 using the Purdue Agricultural Confined Spaces Incident Database. Over this period, one in five confined space-related incidents involved manure management work.[9,24] There were 460 manure-related incidents documented.[9] Most victims were male and young, with a mean age of 38.[9] Nour et al. noted that this average age is much younger than the average age (53) for grain-related injuries.[24] In our study, injuries occurred only in male participants but were distributed relatively evenly across age groups.

Nour et al.[9] also found that fatal and nonfatal incidents were most frequent in October, a time when significant manure management occurs. Most deaths occurred in August when warmer temperatures can increase toxic gases in storage environments.[9] Additionally, many non-fatal incidents (45%) were due to collisions with manure transport vehicles on roadways.[9] However, in our study, those who transported manure appeared to have lower odds of injury, likely reflecting less direct manure handling among our study participants.

Possibly the most important finding of this analysis pertains to the extremely long working hours reported by manure applicators. Respondents worked a mean of over 18 total hours per day during the self-identified busy season, which could last between two and four weeks. Short time windows for manure application are necessitated by crop rotations, weather conditions, regulations, equipment availability, and the specialized nature of the services provided. Qualitative responses also highlighted the duration of work hours and the intensity of fatigue as top concerns among applicators. These concerns are further emphasized in the literature. For example, Williamson et al.[26] documented a link between reduced sleep and impairment at work. Dembe et al.[27] demonstrated a strong dose-response relationship where the rate of occupational injury increased as the number of hours worked per day increased, regardless of the worker's age, gender, occupation, industry, or region.

There are some limitations to note. This study characterizes manure application in the Upper Midwest; thus, the results may not apply to other regions, which may differ by the equipment used, animal species, season of application, work within different crop rotations, and government regulations. Further, our study population is a subset of applicators in the area. The study participants were licensed commercial animal waste technicians; therefore, the study excluded potentially important populations, particularly those exempt from licensure requirements like owners of smaller operations or youth workers who apply manure on family farms. Additionally, respondents self-identified their roles and activities. There is potential for recall bias. However, recall challenges may be less salient for variables capturing memorable events like an injury.[28,29] Finally, self-reported gas exposure symptoms (i.e., dizziness, headache, shortness of breath, nausea, or vomiting) may also occur due to fatigue and heat stress; therefore, these symptoms cannot be fully attributed to manure gases.

Future directions

This study adds to the knowledge about the occupational health and safety of manure applicators, but further research is needed. Many unknowns remain regarding the context in which manure applicators work. An exploration of manure work schedules may be of particular interest to determine strategies to manage worker fatigue. It may also be helpful to evaluate confined space ventilation and safety practices against standards set by the American Society

of Agricultural and Biological Engineers.[13] Further, future research would benefit from leveraging qualitative approaches like focus groups and interviews to gain deeper insight into the variables explored in this study. For example, it would be worthwhile to examine worker motivations for and barriers to using protective equipment and gas monitors during manure work, activities performed while working alone and in teams, and types of equipment and safety practices used while transporting manure.

In addition, future research should consider 1) characterizing the experiences of manure worker populations of more diverse geographical, racial, and cultural backgrounds, 2) examining the unique experiences and hazards of youth workers and farmers on small operations, and 3) identifying and evaluating various interventions to mitigate hazards. Most importantly, improved surveillance of injury, illness, and fatalities associated with manure-related occupations is required.

Interventions focusing on managing worker fatigue and increasing safety practices are needed at all levels of the hierarchy of controls to reduce the incidence of harm in manure work.[30] For example, workers could be trained to employ self-assessment strategies, particularly around identifying and mitigating fatigue. Administrative controls, such as providing training, ensuring adequate staffing, rotating shifts more frequently, and creating a workplace culture of safety and wellbeing, are likely to be more impactful than individual-level interventions.[31]

Conclusion

The findings of this exploratory study describe the complexity and variability of manure management work, which can be hazardous and may be associated with fatigue, injury, and symptoms of gas exposure. Manure management is an essential part of agricultural work; thus, there is a need to characterize and manage the attendant hazards, particularly those affecting workers.

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