

1.0 INTRODUCTION

1.1 Background

Substantial efforts have been made in the study of occupational induced airway diseases. A strong link has been found between worker exposure to organic dust and resulting acute pulmonary spasms. The supporting studies behind this link are primarily in the industries of cotton, animal and swine farming; however, some studies have been related to landscaping type tasks (i.e. mowing, leaf blowing). The relationship between organic dust and pulmonary response is associated with respiratory irritants that are found in materials such as soil, grain, and compost, especially when these materials have become moist. Some of the culprits that have been identified as causative agents of respiratory spasms are endotoxin, fungal spores, and fungal mycotoxin.

Although the majority of the studies involving organic dust exposure have been conducted in agricultural settings, the current study focuses on this respiratory hazard in the landscaping industry. During the early spring, landscapers work heavily with wood mulch, which contains many organic materials that potentially harbor the aforementioned irritants. This study will measure the exposure levels of endotoxin and fungal spores in the landscaper workers' breathable space. Pulmonary function testing will be conducted to identify any acute respiratory changes that may occur across the work shift. Also, the efficacy of respiratory protective devices as a means of protecting the workers from these bioaerosol hazards will be determined.

1.2 Justification

Industrial and Systems Engineering (ISE) encompasses many different areas of practice. Over the years, the ISE discipline has evolved from its classical focus on manufacturing and operations research, to include safety, human factors, transportation, and management. Safety Engineering is a branch that has been gaining in popularity recently, since industries are now being held liable for the safety of their employees.

Engineering controls are the first line of defense in an industrial setting to protect workers. This type of control consists of first removing the hazard, if possible, via work re-design (Kohn et al., 1996).

As a secondary approach, administrative controls can be implemented to protect the worker from impending danger. Administrative controls are developed by management to help alleviate the hazard; for example job rotation is a type of administrative control. This control does not eliminate the hazard but lessens the exposure (Kohn et al., 1996).

Personal protective equipment (PPE) is used as an intervention as a last resort. If the nature of the occupational setting is such that the hazard can not be eliminated and administrative controls are not effective or just not enough, the PPE implementation should be considered. PPE is the barrier between the worker and the hazard, if for some reason the barrier is compromised then the worker is exposed to the hazard. This control places the responsibility of the individual's safety on the individual themselves instead of the company. Proper use, maintenance, and risk education are all vital to making the PPE control effective (Kohn et al., 1996).

In this study, PPE will be studied as a possible control to minimize the effects of respiratory irritants in wood mulch. This intervention method is being used instead of an engineering of administrative control because of the variability in the environment and tasks being performed by the workers in the landscaping industry. In addition to the quality of PPE implementation, the air in the employees' breathable space will be tested for exposure levels. The employees' lung function and capacity will also be studied from pre to post shift.

1.3 Problem Statement

The focus of this cross-sectional field study is two-fold; first, to determine whether, or not, landscaper workers working with wood mulch are exposed to significantly high levels of certain respiratory irritants such as endotoxin and fungal spores,. High levels are defined by enough exposure to cause a ten percent or more shift in pulmonary function in exposed employees from pre shift to post shift analysis.

The second purpose is to observe whether respirators minimize or eliminate any shift in pulmonary function in exposed workers, and to evaluate equipment design and the need for design improvements.

1.4 Research Question

1. To what extent are landscape workers that are exposed to respiratory irritants via wood mulch experiencing a shift in pulmonary function?
2. Is there a need for occupational exposure limits for non-infectious microorganisms and on what basis?
3. How can the respirator's design be improved in order to make it a more practical and effective intervention for workers?

1.5 Hypothesis

The hypothesis is that there will be an acute respiratory response to the organic hazards associated with wood mulch used by landscaper workers without respirators and no significant response in workers wearing the provided respirator. The response in those not wearing any personal protective equipment is hypothesized to be greater than ten percent. This level of response would be considered a significant shift from pre shift to post shift according to the National Institute for Occupational Safety and Health (NIOSH). The shift will be measured with a spirometer. The specific value that is expected to decrease is "forced expiratory volume in one second" observed in the lung function.

2.0 LITERATURE REVIEW

2.1 Respiratory Changes Associated with Organic Dust

2.1.1 Airway Disease-General

Airway disease is a recognized serious ailment in society today. The human body can maintain for days without food and water, but not more than minutes without the proper amount of oxygen(NIOSH, 2001). Airway disease inhibits the body from easily receiving and exchanging the gases needed to sustain human life. There are many reasons for airway disease: genetics, individual's lifestyle (i.e. smoking), and occupational exposure.

Currently only three types of industries have Occupational Safety and Health Administration (OSHA) mandatory spirometer screening. Any industry that exposes employees to coal, asbestos, or cotton is regulated under OSHA to perform pulmonary function screenings. OSHA respiratory standards were originally derived from the cotton industry. Spirometry, even though it is not mandatory in all industries, is a common tool used by many industries to regulate their employees' lung capabilities and monitor exposure risks. Spirometry is used as a preliminary scan of the performance of the worker's respiratory ability. From the employee's performance on the pulmonary function test (PFT), the presence of obstructive, restrictive, or a combination disease can be determined. These diseases cause abnormalities in lung performance that are detected by the spirometer.

2.1.2 Obstructive Disease

Obstructive diseases are those that result in an interference of airway flow. Obstructive disease is classified by NIOSH as any physical obstruction of the airway passage or any ailment that affects the airway diameter or in any other way reduces the amount of airflow in and/or out of the respiratory system. The PFT is a conclusive test for obstructive diseases. Examples of obstructive diseases include emphysema, asthma, and chronic bronchitis.

2.1.3 Restrictive Disease

Spirometry is not a conclusive test for restrictive diseases, but it will show a need for further testing by identifying lung function abnormality. Besides inhibiting air flow, restrictive diseases can also cause a decrease in the lungs' ability to expand. The capacity is compromised, but the lungs at that capacity may still function "properly" deceiving the spirometer. Capacity dysfunction tends to be more tissue related disease pathology versus the existence of physical obstruction common to obstructive diseases. Examples of restrictive diseases include asbestosis and silicosis (NIOSH, 2001).

Airway disease can also have detrimental effects on other vital organs. If oxygen and carbon dioxide are not exchanged properly via the lungs, then other organs may be deprived or exposed to toxic conditions that cause the organs to deteriorate and/or fail. Since the respiratory system regulates the gas exchange in the circulatory system, there is a direct link between lung disease and heart disease. However, numerous indirect links between the respiratory system and all other bodily systems exist. The respiratory system is the life support of the body and when it fails to perform properly, the rest of the body is compromised.

2.1.4 Occupational Asthma

Occupational asthma is a condition found in workers that are exposed to respiratory irritants. The name *occupational asthma* refers to work-related respiratory spasm symptoms. The symptoms are much like those of clinical asthma. They include wheezing, chest tightness, and coughing. In addition to these symptoms, some workers may also experience runny nose, sneezing, and watery eyes. Symptoms and the severity of the symptoms will vary among workers and may be as minor as temporary inconvenience (Lane et al., 1997).

This condition can be as minor as temporary inconvenience that may last only during the shift, or may continue for several hours to even a week after exposure is eliminated. Or this condition can be fatal. Occupational asthma varies in severity depending on the person's respiratory system, the amount of irritant being inhaled, duration of exposure, and the type of irritant (Lane et al., 1997).

2.1.5 Organic Dust Toxic Syndrome

Organic Dust Toxic Syndrome (ODTS), which is also referred to as Humidifier Fever, Atypical Farmer's Lung Disease, Silo Unloader's Disease, Pulmonary Mycotoxicosis, among several other names, is an ailment caused by the inhalation of certain organic dusts. Pulmonary mycotoxicosis is a misleading name; research has found that more so than mycotoxin, endotoxins are to blame for ailments commonly associated with ODTS.

Occupational asthma and ODTS are both caused by biological agents, primarily endotoxin. The foreign particles are inhaled and either penetrate the lung tissue or stimulate the body's natural defenses. Both of these reactions can prove to be detrimental to pulmonary ability.

Ragnar Rylander has accumulated a general list of symptoms that are associated with worker exposure to organic dust; "cough with and without sputum, chest tightness, wheezing, and dyspnea" (Rylander et al., 1990).

These symptoms have been observed throughout history as common ailments associated with acute respiratory injury due to inhaled toxins. Ramazzini wrote in his acclaimed book about these symptoms associated with grain sifters in the 1700's.

2.2 Physical – Spirometry

The main function of the respiratory system is gas exchange. Oxygen is brought into the system and then transferred into the circulatory system through the alveoli-capillary relationship after the release of carbon dioxide. Once air enters the body through the nose or mouth, it travels down the upper airway consisting of the tongue, larynx, and trachea. The oxygen then goes into the upper lobe of the lungs (bronchi), and continues on into the lower lobe (bronchioles and acinus). The acinus is where the transfer of oxygen from the respiratory system into the circulatory system occurs. Alveoli ducts terminate in alveolar sacs, these sacs' walls are one cell thick and are surrounded by capillaries that have walls that are also one cell thick. This thin boundary allows oxygen to travel through the alveolar membrane into the interstitial fluid and then oxygen diffuses into the capillaries and attaches to the hemoglobin of the red blood cells.

The oxygen is carried all over the body in exchange for carbon dioxide that is removed from the body.

Spirometry is the measure of the lung's ability to expire the gases that are exchanged with the circulatory system. Also, spirometry can determine the lung capacity of an individual. The lung capacity is relevant, because it is important to know the amount of gases removal that one experiences and the ability to inhale an appropriate volume to sustain the body's organs. The spirometer is a standard preliminary tool used for screening new employees and is also a follow-up tool to identify any possible respiratory problems that may have developed during the individual's term with the company.

2.2.1 Forced Expiratory Volume

The forced expiratory volume (FEV) is one of the most common measures of lung function or health. It is a measure of the amount, or volume, that an individual is capable of exhaling forcibly. The amount varies among individuals based on age, gender, stature, life style, amongst many other factors (WebMD Health, 2001).

It is also common to see a measure of FEV in one second, referred to as FEV₁. The volume of air that an individual is able to expire in one second can be used to help identify both obstructive and restrictive diseases.

2.2.2 Forced Vital Capacity

Another measure is the forced vital capacity (FVC). The capacity of the lungs can also be an indicator of pulmonary disease. A patient may be able to exhale a "normal" amount in one second, but the overall capacity can still be below normal, showing a need for further pulmonary testing. As a result, both measures are needed when testing for a pulmonary disease (acute and chronic).

2.3 Occupational Settings Studied

2.3.1 Grain Handlers

There is a considerable amount of literature on the role of endotoxin and other organic particles as respiratory health hazards associated with agriculture. Bernadino

Ramazzini, an Italian physician, was one of the first to document a relationship between agriculture and respiratory disease. Ramazzini lived from 1633 to 1714, and within his lifetime he made several important advancements in defining and establishing occupational medicine. Ramazzini noticed a connection between grain sifting and respiratory difficulty. It is believed that there were similar observations made by Olaus Magnus a hundred of years before Ramazzini. Those observations are not as well known, but do refer to grain threshing as the task of apprehension. Even though correlations were made between agriculture and respiratory distress, the research stayed hard to come by. Many, including Bernadino Ramazzini, argue that the lack of information is due to the fact that agriculture workers were considered subservient and their health was not of societal concern. Others argue that due to the rural location of agricultural settings, the 'city' researchers and physicians were not well aware of the severity of the problem nor easily immersed in the hazardous environment (May, 1993). Regardless of the truth behind the lack of information, there still was little documented about this field of industry.

Ramazzini's book "De Morbis Artificum" ("Diseases Of Workers") outlines his work in the forefront of what would come to be known as occupational medicine (Ramazzini, 1964). Some of the occupations that Ramazzini observed that resulted in pulmonary discomfort were starch-makers, grain sifters and measurers, and stone cutters. He also looked at many other occupations and ailments that were associated with those tasks. The most acclaimed respiratory "study" of Ramazzini is the one concerning grain sifters and measurers. He described their discomfort as "The throat, lungs, and eyes are keenly aware of serious damage; the throat is choked and dried up with dust, the pulmonary passages become coated with a crust formed by dust, and the result is a dry and obstinate cough..." (Ramazzini, 1964).

In a study conducted in Northeastern Colorado, similar procedures were used to evaluate the effects of endotoxin exposure on respiration. The main difference in this study and the one outlined in this paper besides the location is the task and population. The Northeastern Colorado study was conducted on 25 farms during wheat harvesting in the summer of 1994. In order to be eligible to participate in this experiment individuals needed to be at least eighteen years old, not on any medication for a recent surgery, cold,

lung disease, or heart problem, not experienced a collapsed lung in the last six months, and not using any form of bronchodilator. These qualifications will be very similar to those used for the experiment in this paper. A pre-shift spirometer reading was administered along with a post shift PFT. Measurements of interest included FVC and FEV₁ which is true of this landscaping study.

Another similarity in methods is the shift dust collector. In the Colorado study participants wore a dust monitor for the length of the shift (shifts were at least six hours long). At the termination of the shift, samples were sent to a lab for analysis. The only presence of PPE in this study is a note that four of the participants briefly wore dust mask during certain tasks, but no evaluation of the effectiveness or need for PPE was conducted in this Colorado study (Viet et al., 2001). In the 1980's a study by Von Essen, "Lower Respiratory Tract Inflammation in Grain Farmers", lower respiratory tract inflammation of grain farmers was observed (Von Essen et al., 1990). In this study both physical exams and spirometer readings were normal. The lower respiratory inflammation was identified in chest x-rays. The 23 participants in this study were non-smoking, and non-asthmatic grain farmers who had suspicious respiratory symptoms. A control group consisted of 13 students volunteers. The symptoms that the participating farmers were experiencing follow in line with those compiled in Rylanders general list. Farmers complained of coughing, dyspnea, and or chest tightness post exposure. It was determined that there is an acute response to grain dust exposure among farmers. There also appears to be a possible correlation between grain dust and chronic respiratory disease. The long term damage is due to acute affect with resulting macrophage engagement. The presence of macrophages and their ability to attack and destroy foreign bodies in the respiratory system may also cause some scarring of the tissue in the respiratory system. It is this scar tissue that may lead to future chronic problems for farmers. This macrophage reaction is normal, but if it is constantly engaged it can cause similar pathology to asbestosis.

2.3.2 Swine Management Workers

Swine farmers are also a common target of endotoxin exposure studies. Voelzang has delved into the chronic effects of endotoxin exposure in a recent study (1998). Over

a period of three years, there was an observed “accelerated decline in lung function” observed in the participating pig farmers (Flannigan et al., 2001). The amount of pulmonary debilitation that occurred related directly to the amount of exposure of the farmers. The dose-response curve for endotoxin exposure illustrates that the more that one is exposed to the toxic bacteria the worse the pulmonary effects ranging from a temporary spasm to permanent lung damage and respiratory difficulty (Flannigan et al., 2001)

2.3.3 Textile

Wang et. al. (2002) published the results to a follow-up study concerning female textile workers in China. The methods used in this three year study were similar to those being employed in this study, except that Wang’s study is longitudinal and the present study discussed here was cross-sectional. There is a difference in the execution of the PFTs between this study and the one that is being proposed. For three spirometers to be considered valid in Wang’s study, spirometers could not vary by more than five percent. However, this landscaping study is using a criterion of no more than ten percent variation was used as a valid reading. Also, the Chinese textile workers were stopped after seven attempts to produce three valid curves, in this landscaping study participants will be stopped after eight attempts. The differences in methods are contributed to the use of NIOSH established procedures being implemented in the study discussed in this paper (Wang et al., 2002).

2.4 Etiological Agents

2.4.1 Endotoxin - Bacteria

Bacteria are single cell microorganisms that are made up of nuclear material and a cell wall. They reproduce by binary fusion. Bacteria are omnipresent in the earth’s environments, and individuals are exposed to bacteria everyday, everywhere, continuously. Bacteria can be spread by numerous means including fomites, vectors, reservoirs, zoonosis, and carriers in almost every environment.

Classification of the bacteria species can be determined by the strand of DNA or RNA contained within the cell structure. Several thousand bacterial DNA and RNA

strands have been discovered and documented to date. As for bacteria cellular morphology, there are three basic categories: cocci, bacilli, and spirilla (Wald and Stave, 2001).

Gram-Negative bacteria have a thin cellular wall made up of distinct layers. The name 'gram-negative' refers to the results of staining the samples in the lab, bacteria that are gram-negative microscopically show up reddish in color. Endotoxins are produced when the gram-negative bacteria cell wall is breached (MicroBioNet). These endotoxins are considered to be culprits in human disease and occupational asthma. The particular part of the bacteria cellular wall that results in the presence of an endotoxin is the lipopolysaccharide. The lipopolysaccharide factor in the cellular wall fragment is pyrogenic in nature. This pyrogenic property of endotoxin is the reason that exposed workers may experience a fever along with respiratory symptoms (Wald et al., 2001).

Numerous studies have shown that endotoxin causes a pulmonary response in most individuals. In a study performed in California by NieuwenHuijsen, Noderer, Schenker, Vallyathan, and Olenchock, there was some attention paid to the tasks of mowing, ground preparation, pruning, and brush collection. The article noted complications with the study and recommended that more epidemiological studies be performed in order to gain more knowledge. Specifically, a spirometer will be used to measure whether the present endotoxin, total fungal spores, and gram negative levels acutely effect the pulmonary function of employees in this field (Nieuwenhuijsen et al., 1999). A pretest and posttest will be administered before and after the shift, respectively. A survey will also be administered in order to determine whether the worker has any other respiratory health issues. If smoking needs to be considered, then the number of years the smoking worker have been in this industry, amongst other health and demographics questions. Also, the dust will be evaluated using a non-invasive dust monitor. This will measure the amount and size of the particles that each worker is being exposed to while performing a specific task. After the landscaper workers are observed, a control group will also be administered the same tests and survey. This will allow for not only a baseline comparison within subjects, but also allow for a comparison to be made between landscaper worker with and without personal protective equipment (PPE).

Wood mulch is a sustainable environment for gram negative bacteria, thus endotoxins are also able to be viable. Endotoxins are strongly associated with gram-negative bacteria and will act as an indicator in this study of the presence of gram-negative bacteria (Todar, 2002). Depending on the levels of endotoxins and the duration of the exposure, both acute and chronic pulmonary problems can develop. In this study, only the acute responses will be noted.

2.4.2 Mycotoxin - Fungi

The environment is teeming with fungi: organisms with a key role in the decomposition of organic material; though less than one hundred of fungal species have been proven to cause of human diseases. The diseases that result from exposure to fungi can be grouped into three disease categories: mycoses, mycotoxicoses, and allergies. The primary disease found in agriculture due to fungi is considered to be mycotoxicoses. Landscaper workers may suffer from mycosis, which is commonly associated with soil, but allergies can also be an ailment that landscaper workers experience. Mycotoxicoses is associated more with agriculture products, i.e. corn, grain, nuts, etc. Mycotoxicoses may be an issue for landscaper workers, since mulch, as a decomposing organic material, would be a likely reservoir for fungi (Wald et al., 2001).

Mycotoxicoses inhalation leads to Organic Dust Toxic Syndrome ODTS, which has been widely researched and is the most common pulmonary ailment found in agriculture workers to date. There are two primary fungi species that are commonly to blame for this syndrome: *Aspergillus* and *Penicillium*.

Organic Dust Toxic Syndrome is just one of many occupational diseases stemming from the presence of fungi. As of 2001, there were roughly 400 toxic fungi metabolites in the environment that have been identified and documented (Flannigan et al., 2001).

This “disease”, like the others related to the inhalation of mycotoxins and endotoxins, results from the body’s response to the foreign objects in the pulmonary system. Much like asbestosis, the body “hurts” itself by trying to defend the respiratory system from foreign objects. The body’s immune system tries to break down the endotoxin and fungal cell walls, but in doing so, causes inflammation in the pulmonary

tissue. This inflammation is the main factor contributing to the presence of symptoms such as wheezing and coughing. This is also believed to be true of occupational asthma induced by indoor and/or outdoor air.

2.5 Overview of Landscaping Occupation

2.5.1 Facts on Industry

According to the Bureau of Labor Statistics in the year of 2000, there were 28.4 per ten thousand full time landscaping workers that suffered from non-fatal occupational illnesses. That statistical value of 28.4 is compared to the less than 0.05 per ten thousand full time workers in general crop farming that experienced a non-fatal illness. This comparison stresses the importance of studying the landscaping industry. More specifically in 2000 there were an estimated 0.2 per ten thousand reported cases of a respiratory condition due to toxic agents in the landscaping field, and there were less than 0.05 per ten thousand full-time landscaper worker reported experiencing lung disease from exposure to dust. These labor statistics from the year 2000 are believed to be lower than the actual number of cases. This compilation of statistics includes full-time employees (like the ones being used in this study), even though many landscaping crews are made up of young part-time workers. Especially during the Spring and Summer months, landscape crews are companies mostly of high school and college students that need summer/temporary employment. Also, an acute respiratory reaction may be discarded by the worker as allergies or some other temporary unrelated illness. Many occupational illnesses go unreported by the affected employee. This hesitancy to report can be due to the work culture, lack of education of the present hazards, or an inability to properly identify the cause of the illness to the tasks involved in one's occupation. This study will help identify if there is a lack of reporting and if there is an acute pulmonary reaction to wood mulch.

The Occupational Safety and Health Administration (OSHA) have since 1983 had ten reported health related violations in the landscaping industry in the state of Virginia. Occupational illnesses are getting much needed attention with growing awareness of occupational hazards among society, the establishment of the Occupational Safety and

Health Administration (OSHA), and the establishment of the National Institute of Occupational Safety and Health (NIOSH). Unfortunately, landscaping has not currently caught the needed attention of public policy or societal concern.

Virginia regulates occupational illness at the state level instead of the federal government watching state industry. Virginia regulates state occupational industry through the Department of Labor and Industry (DOLI). The DOLI then reports to OSHA and posts their case reports on the OSHA website. Though these cases can be located on the OSHA website, the cases are limited in detail on the web.

Three of the ten health violation cases reported in Virginia occurred in southwest Virginia. Complete DOLI reports are public domain; however, the complete reports are destroyed after three years, compromising the ability to observe trends or see if any of these ten cases were respiratory in nature.

Respiratory hazards are vital to understand and protect against due to the importance of gas exchange to the body. A human can survive days without food and/or water, but only minutes without oxygen. If the employee's ability to breathe well is hindered by the presence of toxins in the environment from the wood mulch, then there is a need for an engineering control (i.e. requiring PPE) to improve the work environment. Humans respire about two percent oxygen through their skin, but the greatest oxygen exposure (relative to surface area) occurs in the lungs. Therefore, it is imperative that one's ability to breathe should not be restricted by irritants associated with one's occupational task (NIOSH).

2.5.2 Description of Mulching Task and Associated Risks

2.5.2.1 Mulching Hazards

Wood mulch is susceptible to the growth of innumerable species of bacteria and fungi. Bacteria are not visible in the mulch, but many fungi are visible due to their reproductive structures and color. Both can be microscopic allowing workers to be unaware of the microscopic organisms' presence. Employees are not only unaware of the fungi and bacteria existence in the wood mulch; the workers are also oblivious to the amount that they are inhaling into their respiratory system.

2.5.2.2 *Exposures to Fungi/Bacteria.*

Mulching is a task that requires workers to move and handle the wood mulch product. Wood mulch is the most common mulch used in the United States. The wood and bark products' decomposition allows bacteria and fungi to thrive. The breaking down of carbon compounds in the wood products "feed" the bacteria and fungi providing them with energy to grow and spread throughout the mulch. The carbon compounds found in wood mulch include cellulose, lignin, and simple sugars.

The four most common fungi that grow in wood mulch in the eastern United States are mushrooms, artillery fungus, bird's nest fungus, and slime molds. These fungi can become toxic to the respiratory system if the fungi are inhaled under certain circumstances and life cycle stages. This study will look at the circumstances surrounding the mulching task of landscaper workers (Brantley et al.).