Current Health Effects of Agricultural Work: Respiratory Disease, Cancer, Reproductive Effects, Musculoskeletal Injuries, and Pesticide–Related Illnesses

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Abstract

Agriculture has experienced major bio–technological advances and economic and socio–cultural disruptions since the publication of "Agriculture at Risk" in 1988. At that time, it was recognized that there were acute needs in the prevention of musculoskeletal syndromes and injuries, agricultural respiratory disease, noise–induced hearing loss, pesticide–related illnesses, and concerns regarding the excesses of cancers noted in epidemiological studies of farmers. In this article, we discuss the progress made in identification of new respiratory syndromes related to confined animal feeding operations, pesticide–related illnesses, cancers implicating agricultural exposures, and ergonomics in agriculture. The focus is on the current state of knowledge in these areas, the author's recommendations for further improvement in research techniques, and the potential application of this information to improve human health in production agriculture nationwide.

Keywords. *Agriculture, Agricultural health, Occupational health, Agricultural respiratory disease, Respiratory disease, Pesticides, Endotoxin, Organic dusts, Pesticide–related illnesses, Confined animal feeding operations, Animal confinement, Cancer, Ergonomics, Noise–induced hearing loss, Exposure levels.*

The agricultural sector has undergone immense change since the publication of "Agriculture at Risk" in 1988. In some respects, there has been improvement in the health and safety of those working in agriculture due to improved technology, personal protection, and awareness of hazards. The establishment of the National Institute for Occupational Safety and Health (NIOSH) Agricultural Health and Safety Centers as a result of that effort has provided a network for the collaboration of academic health center researchers, agricultural safety educators, and agricultural engineers to institute a multi–disciplinary approach to research, outreach, and

Article was submitted for review in August 2001; approved for publication by the Journal of Agricultural Safety and Health of ASAE in November 2001.

Presented, in part, at the *Agricultural Safety and Health Conference: Using Past and Present to Map Future Actions* held March 2–3, 2001, in Baltimore, Maryland.

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  ISSN 1074-7583

education in agricultural health and safety. The regional centers appropriately reflect the geographic variation in farming conditions and practices. Regulatory approaches to improving occupational and environmental health in agricultural practices have included the passage of the Worker Protection Standard in 1992 and the Food Quality Protection Act in 1996, both dealing exclusively with pesticides.

There is still much to be done, however, to prevent injuries and improve the health status of those working in agriculture. Even with the consolidation of agricultural operations and the increased complexity and size of farms and other agricultural operations, there is a lack of knowledge of how many people are adversely affected by their exposures, particularly long–term, low–level exposures. The majority of production operations are exempted from direct OSHA regulation, and as a result, the medical surveillance that occurs in other industries often does not occur, or at best occurs sporadically, in agriculture. The reporting system for occupational illnesses is still woefully inadequate, which makes it almost impossible to accurately track trends, determine accurate numbers of those with illnesses that are a consequence of agricultural occupational exposures, and determine long–term adverse health effects from agricultural exposures. Farmers have an increased prevalence of many acute and chronic health conditions including cardiovascular and respiratory disease, arthritis, skin cancer, hearing loss, and amputations. Other health outcomes have been little studied in the agricultural workplace, such as stress and adverse reproductive outcomes (Brackbill et al., 1994). Mental health conditions, primarily stress and depression, have increasingly become recognized as significant health issues and a contributor to injuries (Kidd et al., 1996).

Three prospective cohort studies have been launched in the U.S. that will help answer some of the questions: The Agricultural Health Study in North Carolina and Iowa, the Keokuk Study in Iowa, and the California Farmer Cohort Study (Alvanaja et al., 1996). In this article, we describe the progress that has been made since 1988 in addressing respiratory exposures and illnesses, cancers related to agricultural chemical exposures, pesticide–related illnesses, and ergonomic issues. A recent conference sponsored by the Agricultural Health and Safety Network (ASH–NET) was held in Baltimore to address the progress made in responding to the health issues raised by the 1988 Agriculture at Risk Conference at the University of Iowa. This article is an expansion of an invited white paper that addresses the human health effects of agricultural practices. The topics chosen were our evaluation of the issues that have been the primary focus of current research, primarily in North America. We also considered the potential for maximum health benefit of the changes that are occurring.

Articles in English were searched through the National Library of Medicine Medline from 1988 through 2000, focusing on agricultural health and occupational health categories. Further input was gathered from attending and participating in the NIOSH co–sponsored Agricultural Health and Safety conferences in Morgantown, West Virginia (1997); Saskatoon, Saskatchewan (1999); and Cooperstown, New York (2000). Because other articles address agricultural injuries, mental health, and environmental issues, the focus here is on occupational exposures that have the potential to cause physical illnesses from occupational exposures. We also recommend future courses of action to improve the health of those who work in agriculture, with a focus on production agriculture. Space limitations preclude a full discussion of the topics covered.

Demographic Issues

Health studies must consider several modifying factors in agricultural exposures that result in physical illnesses, including work force age and ethnicity, gender, type of commodity, work practices, engineering controls, and use of personal protective equipment. The work force has significantly changed and varies greatly by region. Principal operators tend to be white and older, while hired farmworkers are predominately foreign born, younger males. There has been a slight increase in women principal operators, both in crop and animal production. According to the 1997 U.S. Census of Agriculture, there has also been an increase in principal operators who work off the farm, which adds additional exposure. It is thought that agriculture is now at a low point in agricultural labor, and as the number of farms decreases, there will be an increase in the size of the agricultural labor force (Gunderson and Olenchock, 2000).

According to the 1997 USDA Census of Agricultural, the average age of principal operators is 54.3 years. The increasing age of the farm population may lead to increased susceptibility to the adverse effects of occupational exposures and to an increase in chronic diseases including respiratory and musculoskeletal illnesses. Many hired farmworkers no longer have an agricultural background and use employment in the agricultural sector as an entry–level job. Language barriers may exist that can impede following safety information on labels and training in proper work practices. Farm labor contractors instead of farm owners now hire large numbers of farmworkers, raising new health and safety concerns. All of these changes may increase health and safety hazards in the agricultural workplace.

The ethnic variation in the agricultural workforce compounds the potential health hazards. Multi–state and multi–center studies, such as the Agricultural Health Study in Iowa and North Carolina, can be a model for standardizing study design, increasing the number of study subjects to improve the power of the findings, and comparing similar exposure models and ethnic groups. In addition to the changing work force, other modifying factors, including advances in biotechnology, genetically modified organisms (GMOs), agrochemicals, and animal production methods, will need to be considered in terms of how they effect the health of farmers and farmworkers.

Respiratory Illnesses and Exposures

Respiratory illnesses and agricultural exposures have recently been reviewed in detail (Schenker, 1998). Agriculture involves potential exposure to a wide range of respiratory toxins, many in concentrations higher than in other industries. Despite low rates of cigarette smoking, farmers have an increased prevalence of several acute and chronic respiratory diseases, although widespread population measurements are lacking (Schenker, 1998; Zejda et al., 1993).

Organic Dust Exposure and Associated Respiratory Syndromes

The oldest known and best studied agricultural respiratory diseases are from exposures to organic dusts, such occurs in grain processing and confined animal feeding operations (CAFOs). CAFOs are defined as facilities that confine and feed animals for over 45 days in a 12–month period and do not grow or store grain. Density is expressed in animal units, which vary depending upon the species. For example, one animal unit (AU) is equal to one feeder or slaughter cattle, 0.7 dairy cow, or 2.5 swine over 55 pounds. A concentrated feeding operation contains over

1000 animal units. These are typically production units such as feedlots, swine confinement facilities, and poultry production facilities.

With the loss of smaller operations and with facilities of over 2000 hogs becoming common, there has been a significant increase in the animal density found in animal production. It is estimated that there are as many as 700,000 workers in CAFOs, including owner/operators, family members, and employees, including 250,000 in hog confinement facilities (Von Essen and Donham, 1999). There has also been a significant increase in the exposure to organic dusts, bioaerosols, and toxic gases. Workers in larger hog operations can spend 40 or more hours per week inside the facilities. It has been suggested that long–term indoor exposure for 2 hours per day for 6 or more years in swine confinement facilities is associated with several respiratory conditions, including sinusitis, mucous membrane inflammation syndrome, non–immunogenic bronchospasm, and bronchitis (Thorne et al., 1995). Research involving inhalation of swine dust and bronchoalveolar lavage has shown increased neutrophil counts but not eosinophils, suggesting an irritant response rather than an allergic response (Von Essen et al., 1998).

There is increasing evidence that endotoxins, which are found in organic dusts from both grain storage and CAFOs, are a significant contributor to respiratory disease. A dose–response to endotoxin and pulmonary function deterioration has been established in numerous studies (Donham et al., 2000; Reynolds et al., 1996; Schwartz et al., 1995a; Schwartz et al., 1995b; Vogelzang et al., 1998; Zjeda and Hurst, 1994). Endotoxins are associated with the release of pro–inflammatory agents including tumor necrosis factor, interleukins, cytokines, and inflammatory cells (Jagielo et al., 1996). There are associated declines in pulmonary functions, primarily FEV_1 and symptoms including chest tightness, cough, dyspnea, and sputum production (Kennedy et al., 1995). Similar findings are seen in inhalational studies of swine confinement workers (Von Essen and McCurdy, 1998). Endotoxin is implicated to be the cause of the inflammatory reaction seen in byssinosis, which has clinical findings similar to grain fever (Schenker, 1998).

Most CAFO research has focused upon swine confinement operations, but recent studies have indicated similar dose–response findings in poultry operations. Significant dose–response relationships were also found to occur with exposures to total dust, respirable dust, endotoxin, and ammonia and cross–shift decrements in pulmonary function in both swine confinement and poultry operations (Donham, 1995; Donham, 2000; Reynolds et al., 1996). These include total dust concentrations of 2.4 to 2.5 mg/m^3, respirable dust of 0.16 to 0.23 mg/m^3, endotoxin of 640 to 1000 ng/m^3, and ammonia of 7 to 12 ppm. Recommendations have been made for the establishment of threshold limit values for organic dusts, respirable dusts, and endotoxins as a result of the dose–response relationship findings. The findings for ammonia occurred at levels well below the established TLV of 25 ppm.

"Asthma–like syndrome" is a non–allergic respiratory condition that is clinically identical to asthma but is not associated with persistent airway inflammation or airway hyperreactivity. Because the pulmonary deterioration can often be detected only by cross–shift testing, it can be difficult to document this condition in a typical clinic setting. The cross–shift decline in FEV_1 is generally less than 10% but can be between 10% and 15% (Schenker, 1998). It is most common in swine confinement workers, up to 10% acutely, but can also be seen in grain workers (Von Essen and Donham, 1999). A more chronic condition with similarities to byssinosis, including Monday morning response, has been identified in 11% of CAFO workers (Donham, 2000). A chronic form of non–allergic asthma, referred to as asthma–like syndrome, has been identified in as many as 25% of swine confinement workers (Von Essen and

Donham, 1999; Donham, 2000). It is uncertain what the long–term respiratory effects are and whether end–stage irreversible pulmonary disease will result. Acute bronchitis occurs in as many as 70% of CAFO workers, and 25% develop a chronic bronchitis (Donham, 2000).

Organic dust toxic syndrome (ODTS) is common and may be seen in up to 34% of CAFO workers (Von Essen and Donham, 1999). ODTS is an acute syndrome with clinical symptoms identical to acute farmer's hypersensitivity pneumonitis but lacking oxygen desaturation, pulmonary infiltrates, and a pattern of immunologic sensitization. It is considered an acute respiratory syndrome, but affected individuals report repeated symptoms with subsequent exposures. Donham (2000) has suggested that a chronic form of ODTS in swine workers may occur with chronic fatigue, dyspnea, and possibly mild pulmonary infiltrates.

Mucous membrane inflammation syndrome is a complex of nasal, eye, and throat complaints commonly found in CAFO workers. Nasal symptoms occur in as many as 50% and sinusitis in up to 25% of swine confinement workers (Von Essen and Donham, 1999). Classic allergic asthma due to IgE and IgG antibodies and Type I occupational asthma is uncommon in CAFO workers. Generally, workers with pre–existing asthma do not tolerate working in swine confinement facilities for more than several months. These illnesses and syndromes result from exposure to the myriad of antigens and irritants found in CAFO organic dust, including pollens, animal and insect feces, animal dander, fungal spores, bacterial microorganisms, pesticides, and antibiotics. Engineering controls and personal respiratory protection can decrease symptoms and pulmonary decline from the exposure. Sprinkling canola oil in a swine room decreased dust and endotoxin levels as well as human respiratory effects (Senthilselvan et al., 1997; Zhang, 1997). Other interventions to decrease dust levels include adding fat to feeds, increasing mechanical ventilation, using wet methods to clean, and automated feeding.

Grain dusts also include a complex mixture of organic dusts as well as inorganic dusts. Many of the same symptoms occur in grain workers as well as in CAFO workers. In general, grain dust is thought to be pro–inflammatory by itself, particularly grain sorghum (Von Essen et al., 1995) and soybean dusts. A significant annual decline in FEV_1 was seen in grain workers, an indication of a dose–response relationship (Dosman et al., 1995; Jagielo et al. 1996). Grain sorghum appears to be the most strongly associated with respiratory symptoms (Von Essen et al., 1999).

Other exposures of concern in CAFOs include bacterial microbials, fungal organisms, and toxic gases. The primary gases of concern are ammonia and hydrogen sulfide (H_2S). Ammonia is also implicated in many of the irritant respiratory conditions and may be additive or synergistic with endotoxin. It is uncertain what role low–level H_2S plays in the role of respiratory disease. At lower concentrations, it is considered to be an upper respiratory and mucous membrane irritant, but it is a potentially fatal chemical asphyxiant at higher concentrations (Nelson, 1998).

Recommendations for Further Research

Medical surveillance continues to be lacking in CAFO workers. This appears to be an area where the agricultural workforce may increase in the future. Improved medical surveillance with baseline spirometry and ongoing screening for respiratory disease is important to decrease the high incidence of respiratory disease. Further research on the causes and prevention of irritant chronic asthma and asthma–like syndrome, ODTS, and end–stage irreversible pulmonary conditions is indicated. Larger numbers of participants are needed in prospective studies to determine dose–response relationships between respiratory illnesses, pulmonary measurements, and measurement of total and respirable dusts, endotoxins, and ammonia and other gases associated with CAFOs. Improved case definitions and diagnostic techniques to identify the more recently identified respiratory syndromes is crucial for accurately assessing the extent of respiratory disease resulting from organic dust exposure.

Recommendations for the establishment of exposure limits for organic dusts, endotoxins, and microbials have been made. There is also evidence that the exposure limits for ammonia are not protective and should be decreased. At a minimum, prospective pilot studies should compare facilities at the recommended levels to controls. Exposure limits should be actively pursued and encouraged (RLVs or TLVs) as an initial step toward developing regulatory limits.

Respiratory Effects of Inorganic Dust Exposure

Recent research has identified adverse respiratory effects of inorganic dust exposure in the agricultural workplace (Pinkerton et al., 2000; Schenker, 2000). This is particularly a hazard in regions with dry climate farming, such as California and the Southwest. Inorganic dusts come primarily from soil components and are dominated by silicates but may include significant concentrations of crystalline silica (Nieuwenhuijsen and Schenker, 1999). Exposures of agricultural workers to inorganic dusts, which are often mixed with organic dusts and other components, may result in macules, nodules, and interstitial fibrosis (Schenker, 2000). The prevalence and natural history of this disorder among agricultural workers is unknown.

Other Respiratory Illnesses

Farmer's hypersensitivity pneumonitis (FHP), previously referred to as farmer's lung disease (Schenker, 1998), has been the focus of limited recent research. Changes in feeding and bedding methods and a decrease in traditional silos may have resulted in a decreased incidence of FHP. Current recommendations and guidelines for the diagnosis of FHP have recently been published (Richerson et al., 1989; Schenker, 1998). Adequate personal respiratory protection has been shown to be protective against recurrent attacks of FHP. Smoking is associated with a lower prevalence of FHP, but smoking may lead to a more insidious development of chronic FHP (Ohtsuka et al., 1995). Emphysema has also been identified as an important outcome of chronic FHP (Erkinjuntti–Pekkanen et al., 1998; Schenker, 1998).

Drought conditions have been associated with higher nitrate in corn and resultant higher levels of nitrogen oxides in silage. Forage bags, also known as "ag bags," are seen more commonly as a method to store silage and haylage. They will generally decrease exposure to the potentially toxic confined spaces that can exist in silos. However, toxic levels of nitrogen dioxide and other oxides can occur at the opening of the bags. These levels may be within the immediately dangerous to life and health (IDLH) ranges, leading to silo–filler's disease (Pavelchuk et al., 1999). The use of corticosteroids early in the course of silo–filler's disease has decreased the development of delayed bronchiolitis obliterans, which otherwise results in irreversible pulmonary fibrosis or scarring.

Recommendations

Continued efforts to decrease organic dust production and exposure to thermophilic organism overgrowth should continue. Ongoing monitoring of individuals for the development of asthma, asthma–like syndrome, and COPD should be a part of current research.

Further evaluation of N–95 respiratory protection should also continue, including evaluation of respirators with higher protection factors, such as helmets with powered air purifiers, to determine if they are a safe cost–effective method to prevent progression of FHP with continued agricultural exposures. Affordable control measures for reducing agricultural dusts and gases should also be developed.

Precautions need to be taken in dry growing conditions, even if there is no entry into a confined space such as a typical silo of either the concrete or oxygen–deficient models. Research is needed on the long–term effects of inorganic or mixed agricultural dusts. Monitoring of NO_2 and not opening forage bags should be considered within the first two weeks of filling forage bags, similar to recommended practices for silos.

Agriculture–Associated Cancers

Farmers have decreased tobacco– and alcohol–associated cancers (Blair and Zahm, 1995a; Cerhan et al., 1998). However, many cancers have been associated with farming in epidemiological studies, although the results are inconsistent and there is no consensus on causality. A meta–analysis of cancers and agricultural associations showed only lip cancer to be elevated (Acquavella et al., 1998; Brownson et al., 1989; Zahm et al., 1997), and another meta–analysis found a significant association of multiple myeloma and farming in men and women (Kruder and Mutgi, 1997). Other cancers showing an inconsistent association with farming include non–Hodgkins lymphoma (NHL), prostate, skin, melanoma, brain, and soft tissue sarcoma (Blair and Zahm, 1995b; Brownson et al., 1989; Cerhan et al., 1998; Khuder et al., 1998; Morrison et al., 1993). Some cancers have been associated with specific exposures and may be increased in subgroups of agricultural workers, including pesticide applicators. NHL and phenoxyacetic acid herbicides (e.g., 2,4–D) have shown the strongest association (Blair and Zahm, 1995a), but the finding has not been consistent (Asp et al., 1994; Perry and Layde, 1998). An increased OR was observed in one study for leukemia and dichlorvos, famphur, and natural pyrethrin but no significant increase occurred with herbicides (Brown et al., 1990). There has been recent concern about endocrine disrupters and cancer. Organochlorines are weak endocrine disrupters, but an association of DDE and PCBs with breast cancer has not been consistently observed (Hunter et al., 1997; Krieger et al., 1994; Van't Veer et al., 1997; Wolff et al., 1993).

Recent studies raise questions about other cancers, but more research is needed to establish causality. Childhood brain tumors were associated with exposure of mothers to pigs and horses during pregnancy, with working on a livestock farm, and with the child's living on a farm for over one year beginning when under 6 months of age (Holly et al., 1998). Atrazine is the most extensively used herbicide in the U.S., but there is no demonstrated evidence for an associated increased risk of colon cancer, soft–tissue sarcoma, Hodgkin's, multiple myeloma, or leukemia (Neuberger, 1995). Another study found no association of atrazine and ovarian cancer (Stump et al., 2000).

Recommendations

The meta–analyses suffer from heterogeneity of studies, type of farming, geographic area, and time period and limitations in exposure assessment (Acquavella et al., 1998). Farmers and farmworkers are exposed to multiple hazardous exposures including pesticides, fertilizers, paints, solvents, welding fumes, dusts, infectious microorganisms, and endotoxins. Generally, the studies have been done on white farmers and, to a much lesser degree, spouses. Very little research has been done on hired farmworkers, who may have a greater exposure, (Blair and Zahm, 1995b). The focus of the various studies has generally been on crop production farmers, who are exposed to each pesticide only a few times each year (Kruder and Mutgi, 1997). Research needs include more information on inert ingredients. Studies focusing on agricultural workers with more intense exposure to pesticides, such as small vegetable and fruit workers, are needed. The development of improved biomarkers and increased use of biological monitoring to establish dose–response relationships are needed. Improved homogeneity of the studies and standardization of the endpoints will also improve the reliability of the studies.

Non–Cancer Pesticide–Related Illnesses

Pesticide fatality rates in the U.S. have been steadily decreasing each year (Blondell, 1997; Caldwell et al., 1997; Klein–Schwartz et al., 1997; Litovitz et al., 1999). Hospitalizations and acute poisonings have decreased due to improved worker education, better technology of application and mixing methods, new formulations, better labeling and regulation, more IPM, and stricter registration including de–registration of the most toxic agents (Schuman and Simpson, 1997; Woodruff et al., 1994). There are considerable unreported exposures, with 29% to 44% of farmers reporting dermal or respiratory exposures with associated symptoms (Packgill et al., 1995; Perry and Layde, 1998; Reynolds et al., 1998). There is also less use of personal protective clothing during pesticide use for farmers who are unlicensed pesticide applicators, even though licensed applicators do not routinely use appropriate protection (Garry et al., 1995; Lexau and Heims, 1994; Mandel et al., 1996). Skin reactions are generally the most common adverse reaction (O’Malley, 1997).

Symptoms of pesticide exposure include headache, skin irritation, eye irritation, and fatigue. Over one–half of private applicators with a high pesticide exposure event had symptoms. Of these, only one–half sought medical treatment from a healthcare provider (Alavanja et al. 2000). Respiratory and flu–like symptoms were associated with pesticide exposures in Iowa farmers when applying livestock insecticides and with hand or arm exposures (Sprince et al., 2000).

There is recent concern regarding chronic pesticide exposure and adverse reproductive effects. Miscarriages have been associated with thiocarbamates, carbaryl, and unclassified pesticides and chemical activity, and preterm delivery has been associated with mixing or applying yard herbicides (Savitz et al., 1997). There was no strong or consistent pattern of association with pesticide exposure and time to pregnancy (Curtis et al., 1999). However, women working in agriculture–related industries and women residing on farms had an association with infertility (Fuortes et al., 1997).

Several pesticides that are male reproductive toxicants are no longer registered in the U.S., including kepone, dibromochloropropane (DBCP), and ethylene dibromide (Sever et al., 1997). An ecologic study found increased prevalence of congenital birth defects in the children of pesticide applicators in the area of Minnesota with the highest fungicide and chlorphenoxy use. The findings included a more pronounced effect with infants conceived in the spring, an increased male:female ratio, and an association with trifluralin and 2,4–D but not atrazine (Garry et al., 1996). Cryptorchidism was significantly increased in male offspring of mothers employed in gardening, including greenhouse workers, orchards, and nurseries (Weedner et al., 1996). Other developmental defects associated with pesticide use include oral–facial clefts (Nurminen, 1995) and limb reduction defects associated with other organ system anomalies (Lin et al., 1994). As with most of these studies, these ecologic findings require further research before etiologic conclusions can be reached.

The acute findings of organophosphate poisonings have been well described, including organophosphate–induced polyneuropathy (OPIDP) and intermediate syndrome. The role of pesticide mixtures may be an important issue, as neuropathy can be induced in animals with a less–than–neuropathic dose when pesticide exposures occur in a specified order (Kiefer and Mahurin, 1997). Permanent neurological deficits have been reported as sequelae of organophosphate pesticide poisoning, including neuropsychiatric effects, peripheral neuropathy, poor performance on neuropsychiatric testing, and multiple chemical sensitivity (Meggs and Langley, 1997). A dose–response relationship is suggested because the severity of effects increases with more severe poisonings, as measured by length of hospitalization, lost workdays, and decreased cholinesterases (Rosenstock et al., 1991; Steenland et al., 1994). Chronic exposures also demonstrate subtle neuropsychiatric findings, such as lower reaction time of the dominant hand in higher OP exposure group (Fiedler et al., 1997). A subset of nine applicators had clinical evidence of peripheral neuropathic dysfunction out of 90 applicators with increased vibration sensitivity (Horowitz et al., 1999). Other studies have raised the issue of Parkinson’s disease and pesticide exposure (Battlefield et al., 1993; Fleming et al., 1994).

Recommendations

A significant issue that remains to be addressed is establishing causal linkages and dose–response relationship between chronic illnesses and pesticide exposure. The use of organochlorine pesticides and metabolites biomarkers, such as DDT and DDE, would help improve this, but the short half–life of OP biomarkers limits their usefulness for studies of chronic adverse health effects. The groups that have the highest exposures to pesticides (i.e., hired farmworkers, particularly those working in the vegetable and fruit commodities) should be targeted. A significant issue is the accurate evaluation of acute and chronic cholinesterase depression. Presently, comparing data from different clinical laboratories is difficult because of variable reporting units and normal value ranges, and different assay methods. Wilson et al. (1997) have called for the standardization of enzyme assays by the American College of Pathologists, development of standardized sampling and storage conditions to maintain activity and reduce reactivity, and consistent use of a portable, inexpensive field test to monitor cholinesterases (Wilson et al., 1997). Further research into the endocrine disrupter effects of pesticides is an area of critical importance. Prospective studies such as the Agricultural Health Study and the review of pesticides under the Food Quality Protection Act will help address this. Improved medical surveillance and reporting of pesticide–related illnesses will be important to further describe the epidemiology of pesticide illnesses. A nationwide effort to improve and standardize medical surveillance of pesticide applicators and others exposed to pesticides on a regular basis and reporting of pesticide–related illnesses is indicated.

Ergonomic Issues

Farming and other production agricultural activities are recognized as hard physical work. Musculoskeletal disorders (MSDs) are common in production agriculture and may increase as labor–intensive agricultural work has increased over the last 20 years (Villarejo and Baron, 1999). Chronic back pain was identified in 26% of farmers and ranchers in one survey, and increased with age and years worked (Xiang et al., 1999). As many as 71% of swine producers report chronic back pain (Von Essen and McCurdy, 1998). Arthritis of the hips and knees has been associated with dairy farming and driving tractors in New York dairy farmers (May, 1998). Studies of orchard fruit harvesting have identified ergonomic stressors such as working with raised arms, repetitively forceful lifting, and pressure on the shoulders from the straps of fruit bags (Fulmer et al., 2000). Evaluation of California nurseries identified 49% of injuries due to sprains and strains, with 46% of these affecting the back (Meyers et al., 1995). Ergonomic stressors identified include forceful exertions, pinching, stooping, prolonged static postures, awkward positions, and continual bending and twisting at the waist while handling excessive or asymmetrical weights (Meyers et al., 1997). It is difficult to apply standard ergonomic interventions throughout agricultural industries because agricultural operations involve varied duties at multiple locations (Meyers et al., 1995).

Studies of nursery workers have been a model for ergonomic evaluation and intervention. Some of the interventions include use of handles on pots to decrease pinch grip; automatic washers; pallet trucks, tracks, and loading ramps to reduce forceful repetitive lifting; and smaller pots to decrease weights. Other interventions involve developing lighter equipment, more flexible protective clothing, new tools, and raised beds (Meyers et al., 1995). Research and ergonomic interventions are recommended for other commodities. The goal is to develop simple solutions that are inexpensive to produce and apply.

Other Health Issues

Hearing Loss

Numerous studies have found hearing loss to affect over 50% of the farming population (Beckett et al., 2000; Lexau and Heims, 1994; May, 1998). Noise levels are elevated, with mean noise levels of tractors, vacuum pumps, and feed unloading areas above the OSHA standard for hearing protection requirements (Holt et al., 1993; Marvel et al., 1991). Cabs on tractors and other equipment have greatly lowered the noise levels, but significant exposure still occurs. Increased use of personal hearing protection is recommended, as well as improved noise–reduction techniques that can be economically applied to all agricultural operations.

Tuberculosis

Hired farmworker (including migrant and seasonal worker) health problems remain an important issue (Mobed et al., 1992). *M. tuberculosis*, both latent tuberculosis infection and tuberculosis disease, is increasing in the migrant work force, predominately among Mexican and Central American workers, and is highest in U.S.–Mexican border communities (Lobala and Cegielski, 2001). Prevalence rates are significantly higher than U.S. rates. McCurdy et al. (1997) identified potential high–risk groups among California migrant farmworker housing residents consisting of young adults, former smokers, and persons born outside of the U.S. Recommendations include improved surveillance, diagnosis, and treatment, and ensuring completion of treatment to decrease multi–drug resistant strains of *M. tuberculosis*.

Conclusions

Technological advancement in agriculture has both improved working conditions and paradoxically increased some hazards such as indoor air exposure for confined animal workers. Engineering methods to decrease dust, endotoxin, and CAFO gas concentrations, and work practices to decrease prolonged personal exposure to the same respiratory toxins, should be extended to more CAFOs. Increased use of affordable gas monitors is an important method of protection against exposure to toxic levels of gases resulting from fermentation of grain and decomposition of manure. Further establishment of advisory threshold limit values (TLVs) and regulatory permissible exposure levels (PELs) to reflect the dose–response relationship of organic dusts and endotoxins and respiratory disease associated with work in confined animal feeding operations should be encouraged. Further attention is needed to the acute and chronic effects of inorganic dust in dry–climate agricultural regions.

The Food Quality Protection Act provides additional impetus for well–designed studies with similar study design to determine possible causal relationships between chronic pesticide exposures and adverse reproductive events and cancers, particularly lymphomas and reproductive organ tumors. Standardization and improvement of cholinesterase measurements and biomarker assessments will also significantly aid in establishing adequate means of exposure assessment.

Improved application of industry–wide, low–cost ergonomic interventions and commodity–specific standardization of the improved ergonomic tools is critical for decreasing the significant number of musculoskeletal disorders that exist in vegetable and fruit production. Mechanisms to improve the delivery of standard medical surveillance to agricultural workers, including improved reporting and tracking of occupational injuries and illnesses, in conjunction with improved safety engineering in the agricultural industry, are needed to bring the delivery of such services in line with other industries.

Acknowledgement

Appreciation is extended to the Agricultural Safety and Health Network (ASH–NET) for sponsoring the preparation of this article. This research was supported in part by the National Institute for Occupational Safety and Health, NIOSH Cooperative Agreement No. U07/CCU906162–08.

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