

Eye Injury in Migrant Farm Workers and Suggested Hazard Controls

S. E. Lacey, L. S. Forst, R. E. Petrea, L. M. Conroy

ABSTRACT. *The eyes are a common site of injury in agricultural operations. Identification of the cause of injury is important to inform preventive interventions. The objective of this study was to describe the hazards and mechanisms of acute traumatic injury to the eyes of agricultural workers who are hired in farming operations on a seasonal basis. A review of the literature was performed to summarize the mechanisms of eye injuries in agriculture. Field observations and informal interviews were performed to verify the literature and to determine whether there are eye hazards for farm workers that have not been reported in the literature. Additional mechanisms of injury were elicited, and suggested methods of injury prevention are presented here.*

Keywords. *Eye injury, Migrant farm workers.*

In 2002, there were 42,286 occupational injuries or illnesses involving the eye that resulted in days away from work, with an eye injury/illness rate of approximately 5.3/100 FTE workers (USDOL, 2006). A total of 1,556 eye injuries were reported to the USBLIS in the Agriculture sector, a number that is likely to be low due to underreporting in agricultural operations and for hired seasonal and migrant farm workers (Azaroff, 2002). Data from the Traumatic Injury Surveillance of Farmers indicated that 6.7% of all agricultural injuries were eye injuries, giving an estimated 13,512 lost-time eye injuries on US farms and ranches in 1993, compared to the BLS estimate of 2,906 lost-time eye injuries/illnesses in that same year (NIOSH, 1997).

Eye injuries are largely preventable, but understanding the mechanism of injury is key to implementing preventive interventions. This is particularly important for hired seasonal and migrant farm workers, who suffer a greater frequency and severity of health problems due to being employed in hazardous industries, receiving low wages, confronting disincentives to reporting injuries, not having access to health care, and a number of other social and economic barriers to good health outcomes (Villarejo and Barron, 1999; Rust, 1990; Coye, 1985; Meister, 1991; Mobed et al., 1992; Isaacs and Bean, 1995; Berger, 1993).

Nearly all specialty and field crop workers in the U.S. are hired seasonally, while livestock, dairy, and poultry workers tend to be hired year-round (USDA, 2006; Villarejo and Barron, 1999; IMCFW, 2007; USDOL, 2002). Primary industries of employment include

Submitted for review in May 2006 as manuscript number JASH 6477; approved for publication by the Journal of Agricultural Safety and Health of ASABE in April 2007.

The authors are **Steven E. Lacey**, PhD, CIH, Assistant Research Professor, and **Linda S. Forst**, MD, MPH, Associate Professor, Division of Environmental and Occupational Health Sciences, School of Public Health, University of Illinois, Chicago, Illinois; **Robert E. Petrea**, ASABE Member, PhD, Principal Research Specialist in Agriculture, Department of Agricultural Engineering, University of Illinois, Urbana, Illinois; and **Lorraine M. Conroy**, ScD, CIH, Associate Professor, Division of Environmental and Occupational Health Sciences, School of Public Health, University of Illinois, Chicago, Illinois. **Corresponding author:** Steven E. Lacey, Division of Environmental and Occupational Health Sciences, School of Public Health, University of Illinois at Chicago, 2121 West Taylor St., M/C 922, Chicago, IL 60612; e-mail: slacey@uic.edu.

fruit, nut, vegetables, sod, and horticultural products (USDA, 2006; IMCFW; 2007; US-DOL, 2002). Tasks performed include planting, harvesting, hoeing, detassling, weeding, sowing, cultivating, bunching, picking, thinning, packing, and loading (IMCFW, 2007).

Objectives

This research was undertaken to inform an injury intervention study with the goal of reducing eye injuries in Latino migrant and seasonal farm workers (LFWs) (Forst et al., 2004; Forst et al., 2006). The first step was to identify hazards by performing a review of the literature and observing the work performed in the field. The objective of this study was to describe the hazards and mechanisms of acute traumatic injury to the eyes of agricultural workers who are hired in farming operations on a seasonal basis. Specific aims were to review the published literature on occupational eye injuries in agriculture, and to undertake field observations to verify the literature and to determine whether there are eye hazards for farm workers that have not been reported in the literature.

Materials and Methods

Literature Review

A literature review was conducted to determine types of eye injuries, workplace hazards, and mechanisms of injury for the eyes of workers in agriculture. The PubMed database was searched using the following keyword combinations: eye/ocular injury, eye/ocular illness, and agriculture/farming. The literature review was restricted to injuries defined as traumatic events of acute occurrence, and specifically excluded chronic illness such as pterygium and cataracts. The references sections of the initially identified publications were examined to find additional relevant articles to help ensure completeness of the search.

Field Study

Following the literature review, information regarding workplace hazards and mechanisms of injuries to the eyes was gathered through a series of activities. An industrial hygienist supervised and participated in walk-through surveys of each farming operation, which included individual informal interviews of farm owners, supervisors, and farm workers, and observations of LFWs during work in the fields. Informal interviews typically included discussions with 2 to 4 persons per site. A walk-through survey instrument was developed and used to identify, record, and characterize potential eye hazards. Since the overarching objective was to develop an injury intervention strategy for LFWs, the observations were focused on this population.

Farming Operations

Thirty-six farms that employ more than five LFWs per season in the catchment area of two LFW service organizations were approached to participate in the intervention study (Forst et al., 2004). Thirty-four agreed, and 28 that represented all the types of farming operations were assessed. Their agreement led to personal interviews with the owners, implementation of an eye injury intervention project among the LFWs they employed, and access to their farms. The farms that participated included one produce-packing facility, greenhouses and outdoor operations for ornamental plants, sod farms, an apple orchard, a tree nursery, a dried-food processing facility, and specialty vegetable crop operations. These farms employed upward of 1000 LFWs per season. The seasonal farm worker population in Illinois and Michigan is predominantly Latino; thus, this population's work conditions are applicable to most seasonal farm workers in this region.

Results

Literature Review

Thirty-five articles were identified that described mechanisms of eye injury in agriculture. These are described in the Appendix. Many of these articles reported the severity and mechanism of eye injury cases, as described by the treating physician, that occurred in agricultural settings over the past 50 years. The majority of cases came from visits to health care providers following workplace injuries in agricultural settings; injury sources and mechanisms came from work histories taken from injured agricultural workers.

Field Study

The field portion of this study was undertaken to verify the literature and to identify current hazards that have not been described previously because of limitations in study design, because described operations did not include or specify those that employ LFWs, or because these hazards have simply been overlooked.

The current hazards not previously described are reported below, along with possible preventive measures. In practically every situation noted below, risk may be further reduced by use of protective eyewear (Fong and Taouk, 1995; Vasu et al., 2001; Xiang et al., 2005); in the U.S., protective eyewear should meet the ANSI Z87 Standard (ANSI, 2003). The occupational hygiene hierarchy (i.e., substitution, engineering controls, administrative controls, and personal protective equipment) tells us that protective eyewear is the least desirable control method due to issues including worker acceptance and use of PPE, and the fact that the hazard still exists in the workplace. Control measures outside of protective eyewear are suggested. A control strategy utilizing a multiple control approach (engineering controls, administrative controls, and personal protective equipment) is likely to be more effective than one approach alone (Goldenhar and Schulte, 1996).

Physical and Mechanical Hazards

Hydraulic Equipment Lines

Failure of hydraulic lines in the proximity of workers is a hazard across all industries that utilize such equipment. This is of particular concern in agriculture, where aging equipment often no longer has (or never had) an enclosure that serves as a physical barrier between the hydraulic line and the worker. It was reported that the failure of a hydraulic line on a small tractor at a nursery resulted in a worker being sprayed in the eyes and face with hydraulic fluid.

Though it is not a substitute for appropriate maintenance and inspection, we encountered an improvised guarding system implemented by the grower at the nursery. When the employee returned to work after time off due to his injury, the grower and employee sought to decrease the probability of another incident by sheathing the hydraulic lines with lengths of webbed fire hose to contain the fluid should a leak occur. Without proper inspection and maintenance, however, this may provide a false sense of safety, so judgment must be exercised cautiously. Fire hose is not rated for either the chemical composition of hydraulic fluid or the pressure generally associated with agricultural equipment hydraulic systems, which can reach 2200 pounds per square inch. Other types of barriers, enclosures, or partial enclosures may be engineered. Hydraulic lines need to be periodically inspected and replaced when they show signs of wear; these lines could feasibly be inspected on a daily basis.

Forklifts

One of the study facilities that utilized forklifts to move and load their product noted multiple occasions where workers were sent to the emergency room to have small metal-

lic slivers removed from their eyes. The injury was reportedly caused by metal slivers shearing off of the forklift skid risers and being thrown back at the operator's face.

Again, this is an issue of proper maintenance and inspection. After multiple emergency room visits, this facility installed Plexiglas shields to partially enclose the forklift cab. This effectively addressed the problem, and at last inquiry, there had been no additional injuries of this type.

Shop Hazards

We observed that much of the machine maintenance necessary to operate the farm is performed by the grower. The typical hazards of working with power tools, hand tools, and welding equipment are encountered on a regular basis. By our observations, the LFWs are not likely to be charged with such tasks, as welding and mechanics are the work of a skilled laborer. However, in order to prepare for more typical LFW duties such as hoeing for weeds and to loosen soil, we observed LFWs using a grinding wheel to sharpen the hoes. The grinding wheel was guarded, but the worker lacked appropriate eye and face protection.

Proper maintenance and inspection of equipment and its guarding are the basis of mechanical hazard prevention. Shop hazards are nearly universal for any mechanized industry, and account for a large number of injuries across industries. Hazard control utilizes nearly all the same techniques. Proper shielding is essential for such machinery. Eye and face protection must be made available in the shop, and use of personal protective equipment must be enforced by the grower or foreman.

Building Materials

High winds cause more problems than simply creating airborne dirt and particulates. The evening before one of the project site visits, one of our study greenhouse operations lost multiple glass panels, resulting in shattered glass on the floors, on horizontal surfaces of rafters, and in potted plants; all of this glass needed to be cleaned up.

Depending on the specific needs of the growing operation, several alternatives to glass exist. Substitution of glass with an alternative material eliminates the resulting hazard of shattered glass. Alternative materials include polyethylene film, double-layer structured panels, and fiberglass-reinforced panels (ACES, 1998). Polyethylene is cheaper and requires less structural support, but it may be unattractive for larger operations since its lifespan is approximately two years. Double-layer structured panels are strong and have high heat retention, but they have decreased light transmission and are at a cost comparable to glass. Fiberglass-reinforced panels are typically made of acrylic or polycarbonate, and are cheaper, lighter, and more insulating than glass. Fiberglass-reinforced panels have a lifespan range of 5 to 20 years, which is reflected in the expense of the material (ACES, 1998). Substitution of materials is directed by horticulture needs, but there exist safer alternatives where feasible.

Airborne Soil and Particulates

Plastic sheeting is often used during growing of ground crops. Plastic sheeting is laid along the length of the crop rows to keep the product (e.g., watermelons) off the soil to prevent rotting of the crop and for weed control (fig. 1). Over the course of the growing season, the plastic settles and becomes caked with dirt, and to varying degrees, partially buried. Plastic mulch may be buried along the edges to hold the sheeting down. At the end of the season, this plastic is pulled up from this layer of earth (fig. 2), creating a very dusty environment. Workers from several ground crop farms complained that this particular job was very irritating to the eyes.



Figure 1. Plastic ground sheeting during the growing season.



Figure 2. Plastic ground sheeting being removed by workers at end of season.

Some growers attempted, when possible, to defer this task to another time if the wind was too high, in an attempt to minimize exposure. Wetting is a simple method for minimizing airborne dust. This is the same principle employed to control dust levels at construction or demolition sites, where water is sprayed over the dry, loose material in an effort to keep airborne levels low. Where feasible, the area should be lightly wetted with any reasonable irrigation system to control dust. Biodegradable, plant-based, plastic-like materials (bioplastics) are approaching a state of durability for agricultural use at a competitive price. An Australian company is working to commercialize cornstarch-based biodegradable ground sheets for agriculture that dissolve when plowed under the soil. The product reportedly breaks down into carbon dioxide and sugar. Substitution of materials that can be simply and safely tilled into the ground would eliminate the sheeting-associated eye hazard altogether.

Outdoor Exposure

The outdoor agricultural work environment provides nearly constant opportunity for eye irritation from the sun, wind, and airborne particulates. Chronic irritation due to sun, wind, and particulates is significant and demands control.

In some instances, it may be possible to minimize bare land by planting in order to help reduce dust levels. Trees planted along property lines are effective screens that help interrupt winds that may otherwise travel unabated at high speeds, picking up dirt and debris along their path. Planting ordinary lawn grass on the otherwise bare ground of an orchard would aid in stabilizing the soil between the crop rows and could minimize the likelihood of loose earth becoming airborne; this would also help reduce erosion of soil.

Soil Handling

Airborne dust/soil exposure may also exist in partially enclosed environments. Bulk potting soil rooms are often found in greenhouse operations. The soil is manipulated from bulk to small apportionments via small front-end loaders. Movement of soil within a small space often creates a significantly dusty environment. The potting of plants may occur in a potting shed, an area often located within a warehouse-type structure or a semi-permanent structure. Soil may be delivered to the individual workers potting the plants via conveyor, and this material transfer provides ample opportunity to create a dusty environment. It is important to recognize the type of soil used for particular operations; for example, it was reported to us that certain mixtures of potting soil containing high percentages of vermiculite readily became airborne, causing eye irritation.

In addition to protective eyewear, wetting may be appropriate in these types of environments to control dust levels. Judgment must be exercised in determining the feasibility of wetting for an individual facility. Local exhaust ventilation may be utilized to reduce dust exposures, particularly in high-production operations that take place in permanent facilities, such as some potting operations. Attention should be given to the type of soil being used in a given operation and appropriate controls. The soil selection process is of course a function of horticulture requirements, but recognition of the propensity of a particular soil type to become airborne will help workers anticipate and identify possible hazards.

Soil, dust, and other particulates causing eye irritation are a nearly ubiquitous hazard in the agricultural environment, making it exceedingly difficult to control. Personal protective equipment in the form of protective eyewear seems to be the most effective control measure for work in generally dusty environments.

Other Impact Hazards

The following eye hazards have been reported to varying extents in the literature, but were commonly encountered in the field and are worth reviewing. Perhaps the most likely source of eye injuries to farm workers, particularly in the case of LFWs, is penetrating and non-penetrating injuries from vegetable substances. Figure 3 shows a worker bent at the waist with his face in and among the gladiolas that he is harvesting. The same type of hazard exists with pruning and harvesting of orchard crops, such as apples, where the worker's eyes are at nearly constant risk of being poked by a branch or leaf. The same risk is also present when workers extract shrubs from the ground and wrap their roots in burlap before sale or shipping (fig. 4). These types of tasks involve work in very close proximity to plant material, increasing the likelihood of contact and injury. Other sources of airborne particulates from tasks observed to be commonly performed by LFWs include tossing bales of hay from a tractor trailer bed, and following in close proximity to a tractor to pick up product missed or accidentally discarded by a harvesting machine.

Corn is largely harvested by machine in the U.S., but as the first ears of corn become available, they are often hand picked by LFWs. Corn is pulled off the stalk toward the



Figure 3. Worker harvesting gladiolas.



Figure 4. Worker wraps a shrub with burlap after extraction from ground.

worker's face, and it was reported that the tassels of the corn might impact the face. Several workers we encountered made note that this is a source of eye injuries.

A mixed array of possible environmental factors is involved in the pathology of pterygium, and the relationship between ultraviolet light exposure and cataracts is well documented, so methods to minimize such mechanisms of chronic irritation are needed. Controlling exposure to dust, wind, glare, and sunlight are all aided by consistent use of protective eyewear and a brimmed hat.

Chemical Hazards

Pesticides

Direct preparation and application of pesticides is a task that often appears to be performed by the grower or by a few selected individuals, usually not seasonally hired

LFWs. This is a generalized observation and is likely dependent on the size of the operation, the relationship between grower and worker, and the employer's resources. By observation, the primary source of pesticide exposure for LFWs appears to be exposure upon re-entry to a recently treated field. An often-reported complaint was handling produce with pesticide residue that is left on its surface, even after USEPA time-to-entry requirements have been met. Eye irritation comes with workers handling product and then touching their faces. We observed that workers commonly used bandanas tied over their nose and mouth to decrease the likelihood of accidentally touching their face with contaminated hands.

Proper pesticide management by the grower is of primary importance in controlling this exposure. Further, promotion of proper hygiene is necessary, as directed by the USEPA Worker Protection Standard and Restricted Entry Intervals (REIs), which call for field washing facilities (USGPO, 2000). Hand washing is a simple but critical intervention to reduce exposure.

Washing Harvested Product

After harvest, many crops are washed in some fashion to make them presentable for market. For a variety of crops, a diluted bleach solution is used for product washing to slow microbial growth. This washing is often performed in an assembly line type wash/sort work station, and it was reported that the chlorinated water periodically splashes the worker in the eyes and face.

A chlorinated system must be managed properly in order to maintain the appropriate concentration of free chlorine in the system. Too low a concentration compromises the desired disinfection effect, while too high a concentration leads to levels irritating or dangerous to workers. Working to maintain an acceptable chlorine concentration level is essential for protecting worker health. The risk of being splashed in the face by chlorinated wash water may be mitigated in part by partial enclosure of the washing system. Splash guards may be installed at low cost, with minimal distraction of the worker's line of sight.

Concern regarding the effectiveness of chlorine and potential chlorinated by-product residues has led food safety scientists to seek alternative process methods to disinfect minimally processed fruits and vegetables, including ozone and hydrogen peroxide (Sapers, 2001). The FDA and USDA have approved commercially available disinfectants, including chlorine dioxide, ozone, and ultraviolet radiation (MSU, 1998). Such advances in food safety may ultimately circumvent the need for chlorinated wash-water systems.

Greenhouse Irrigation

One method of irrigation within greenhouses is to use a system of hoses that spray the plants with water. The system is usually either stationary, hanging from the ceiling above the plants, or on a mechanical arm on an overhead track that sweeps over the plants. The watering system typically includes some type of nutrient solution dissolved in the water. Watering typically occurs at a time when workers are known to be out of the greenhouse area, i.e., after normal business hours. It was reported that on occasion a worker would find himself in the greenhouse at the moment that an automated timer would activate the irrigation system, subsequently spraying the worker with plant nutrient solution.

Infrared motion detection systems may be installed at a reasonable cost to help circumvent this problem. A system engineered to prevent activation of a scheduled irrigation or pesticide application if motion is detected is a primary means to protect workers who find themselves in the greenhouse at the wrong time. Prohibiting personnel access to areas to be sprayed is an issue that necessitates administrative control. Workers should be instructed, and reminded, of where and when their access is restricted; this type of reinforcement is easily transmitted in group safety meetings. Traditional lockout/tagout procedures to prohibit access during irrigation would greatly simplify this matter.

Field Irrigation

On hot days, it has been noted that workers are inclined to walk beneath overhead field irrigating apparatus in order to “cool off.” This irrigation system is also likely to contain a plant nutrient solution dissolved in the water to be delivered to the crop.

Workers should be instructed and reminded of the potential hazard, i.e., that the irrigation system does not necessarily contain potable water and may also contain dissolved plant nutrients; this is a specified education component of the Worker Protection Standard. Workers should be restricted from areas that are actively being irrigated. Workers that are kept at a distance from an active irrigation system are probably less likely to seek out its use as a shower. Providing ample potable water in the field for workers and reasonable work/rest schedules will also minimize this temptation.

Discussion

The purpose of this article is to identify the mechanisms of agriculture-related eye injuries reported in the literature and to report our experience of investigating those mechanisms of injury as observed in the field. Injury literature related explicitly to fishing, forestry, and food processing was excluded. Likewise, injury literature pertaining to farm-related recreational and domestic activities was excluded. The agricultural injury literature at large was not explicitly examined in order to narrow the scope of this article; these types of articles only occasionally address eye injuries, and when they do, it is almost always in the context of simple enumeration of eye injuries in agriculture with no regard to the mechanism of injury. Similarly, in order to narrow the scope of this article, the eye injury literature without regard to agriculture as occupation was not explicitly examined. Literature concerning eye conditions associated with chronic UV radiation exposure such as cataracts and pterygium were not addressed. Many articles reviewed in the preparation of this article highlighted traumatic agricultural injury (e.g. machinery, animals) that involved the head and face, but they lacked sufficient detail on the effect on the visual system, and they were consequently not included.

Since agricultural ocular hazards can vary greatly depending on several factors concerning the region, operation, and workforce, the observed hazards reported here are not necessarily applicable to all agricultural workforce populations. While focused on LFWs, there is no evidence that these hazards would be different for other farm worker populations. In the Midwestern U.S., most hired farm workers are Latino, and the study focused on this population. The hazards identified and described are not inherently specific to Latinos as an ethnic group, but rather they are hazards specific to seasonal farm workers in Illinois and Michigan. We do not anticipate ethnic differences that would make this population more susceptible to injury.

The farms that participated in this study were not randomly selected. The farms that participated reflect a convenience sample that utilized existing relationships with LFW service organizations and was not a systematic sampling of either commodities or of farms within commodities. The LFW service organizations provided contact information for farms where their Camp Health Aides (*Promotores de Salud*) had access to the farm worker population, which is generally, but not explicitly, reflective of a cooperative relationship with the service organizations.

The literature review in the Appendix provides insight regarding existing eye hazards in farming operations. A large portion of the literature addresses animal-related eye injuries. Latino seasonal farm workers in the Midwest have traditionally worked field operations, and this remains true for the Illinois and Michigan region, but there is a growing trend in other parts of the U.S. to utilize this workforce in animal operations. This trend

demands attention in order to ensure proper health and safety training as seasonal workers enter this market.

When possible, multiple control strategies were proposed for the identified hazards. In many cases, substitution and engineering controls are not feasible due to the nature of the work. The cost of suggested controls may be prohibitive. Technical feasibility and cost are certainly identified barriers to addressing many of the hazards identified, which are compounded by the general lack of health and safety enforcement in this industry. Protective eyewear is repeatedly recommended as part of the control strategy. While inexpensive and effective, protective eyewear suffers several limitations: poor fit with perspiration, fogging, and visual interference from tinted or poorly made lenses. The suggested hazard controls were developed by the authors based on occupational hygiene control experience with methods observed or applied in other occupational environments. The authors have not tested the effectiveness of the suggested hazard controls.

Finally, it is worth noting the impact of such injuries on the seasonal farm worker population. In most states, the time off work for recovery is uncompensated because of its brevity. The worker usually does not begin to collect time loss until a certain number of days after the injury, often two days to a week. Since a corneal abrasion is healed by the time that time loss begins, the worker's lost time is unpaid. For marginally subsisting farm workers, this is a major financial blow. These injuries are often lost and go unaccounted, but they have a substantial impact on individuals and the industry itself.

Conclusions

Agricultural workers are exposed to workplace hazards that can lead to eye injuries that range in severity from discomfort to partial or complete loss of vision. LFWs are particularly vulnerable to adverse outcomes from these injuries. This description of the well-known and newly identified hazards and mechanisms of injury should serve to inform interventions to prevent these potentially devastating injuries.

Acknowledgements

This work was supported by CDC/NIOSH Grant HHS CCU516863-02 as part of the NIOSH Community Partners for Healthy Farming Intervention projects. The lead author was supported by NIOSH Training Grant 731 CCT510424. Although they wish to remain anonymous, we greatly appreciate the assistance and participation provided by owners and employees.

References

- ACES. 1998. Hobby greenhouse construction. Alabama Cooperative Extension System. Available at: www.aces.edu/pubs/docs/A/ANR-1105/. Accessed 15 November 2002.
- ANSI. 2003. ANSI Z87.1-2003. Occupational and educational personal eye and face protection devices. Washington, D.C.: American National Standards Institute.
- Azaroff, L., C. Levenstein, and D. H. Wegman. 2002. Occupational injury and illness surveillance: Conceptual filters explain underreporting. *American J. Pub. Health* 92(9): 1421-1429.
- Berger, I. 1993. Characteristics of optometric practices that provide pro bono optometric care to migrant farm workers and other indigent groups. *J. American Optom. Assoc.* 64(2): 94-96.
- Blake, J. 1969. Ocular hazards in agriculture. *Ophthalmologica* 158(1): 125-135.
- Blake, J. 1971. Eye injuries in agriculture. *J. Irish Med. Assoc.* 64(418): 420-423.
- Blake, J. 1975. Eye hazards in rural communities. *Practitioner* 214(1283): 641-645.

- Brison, R. J., and C. W. L. Pickett. 1991. Nonfatal farm injuries in eastern Ontario: A retrospective survey. *Accid. Anal. Prev.* 23(6): 585-594.
- Browning, S. R., H. Truszczynska, D. Reed, and R. H. McKnight. 1998. Agricultural injuries among older Kentucky farmers: The farm family health and hazard surveillance study. *American J. Ind. Med.* 33(4): 341-353.
- CDC. 1995. Eye injuries to agricultural workers: Minnesota, 1992-1993. *MMWR* 44(18): 364-366.
- Cameron, L., N. Lalich, S. Bauer, V. Booker, H. Bogue, S. Samuels, and A. L. Steege. 2006. Occupational health survey of farm workers by camp health aides. *J. Agric. Safety and Health* 12(2): 139-153.
- Canavan, Y. M., M. J. O'Flaherty, D. B. Archer, and J. H. Elwood. 1980. A 10-year survey of eye injuries in Northern Ireland, 1967-76. *British J. Ophthalmol.* 64(8): 618-625.
- Cooper, D. K. C. 1971. Accidents in agriculture. *Injury* 3(1): 1-8.
- Coye, M. 1985. The health effects of agricultural production: The health of agricultural workers. *J. Pub. Health Policy* 6(3): 349-370.
- Dementi, B. 1994. Ocular effects of organophosphates: A historical perspective of Saku disease. *J. Appl. Tox.* 14(2): 119-129.
- Doshi, R. R. 1968. Ocular injuries in rural industries. *J. All-India Ophthalmol. Soc.* 16(4): 210-212.
- Earle-Richardson, G., P. L. Jenkins, D. T. Slingerland, C. Mason, M. Miles, and J. May. 2003. Occupational injury and illness among migrant and seasonal farmworkers in New York state and Pennsylvania, 1997-1999: Pilot study of a new surveillance method. *American J. Ind. Med.* 44(1): 37-45.
- Eduard, W., J. Douwes, R. Mehl, D. Heederik, and E. Melbostad. 2006. Short-term exposure to airborne microbial agents during farm work: Exposure-response relations with eye and respiratory symptoms. *Occup. Environ. Med.* 58(2): 113-118.
- Fong, L. P., and Y. Taouk. 1995. The role of eye protection in work-related eye injuries. *Aust. N.Z. J. Ophthalmol.* 23(2): 101-6.
- Forst, L., S. Lacey, H. Chen, R. Jimenez, S. Bauer, S. Skinner, R. Alvarado, L. Nickels, J. Zannoni, R. Petrea, and L. Conroy. 2004. Effectiveness of community health workers for promoting use of safety eyewear by Latino farm workers. *American J. Ind. Med.* 46(6): 607-613.
- Forst, L., I. Noth, S. Lacey, et al. 2006. Barriers and benefits of protective eyewear use by Latino farm workers. *J. Agromedicine* 11(2): 11-17.
- Goddey, N., O. Oladokun, E. Andy, and O. Emmanuel. 2001. Eye lesions and onchocerciasis in a rural farm settlement in Delta State, Nigeria. *J. Commun. Dis.* 33(3): 185-191.
- Goldenhar, L., and P. Schulte. 1996. Methodological issues for intervention research in occupational health and safety. *American J. Ind. Med.* 29(4): 289-294.
- Helmers, S., F. H. Top, and L. W. Knapp. 1971a. Ammonia injuries in agriculture. *J. Iowa Med. Soc.* 61(5): 271-280.
- Helmers, S., F. H. Top, and L. W. Knapp. 1971b. Ammonia and eye injuries in agriculture. *Sight-Saving Rev.* 41(7): 9-11.
- Horan, E. C. 1979. Perforating eye injuries in Cork: A review. *Trans. Ophthalmol. Soc. U.K.* 99(4): 511-514
- IMCFW. 2007. Available at: www.illinoismigrant.org/farmwrk1.html. Illinois Migrant Council Farm Workers. Accessed 23 February 2007.
- Isaacs, L., and T. Bean. 1995. An overview of the Ohio migrant farmworker safety needs assessment. *J. Agric. Safety Health* 1(4): 261-272.
- Johnston, S. 1971. Perforating eye injuries: A five-year survey. *Trans. Ophthalmol. Soc. U.K.* 91: 895-921.
- Levy, D. M., M. B. Divertie, T. J. Litzow, and J. W. Henderson. 1964. Ammonia burns of the face and respiratory tract. *JAMA* 190(10): 873-876.
- Levy, J., A. Kratz, and T. Lifshitz. 2005. Eye injuries due to tractor wheel explosion: Report of two cases. *Canadian J. Ophthalmol.* 40(6): 747-9.
- Lin, S., C. Lin, H. Wang, R. Tsai, and C. Ho. 1999. Fungal corneal ulcers of onion harvesters in southern Taiwan. *Occup. Environ. Med.* 56(6): 423-425.

- Mackiewicz, J., E. Machowicz-Matejko, M. Salaga-Pylak, M. Piecyk-Sidor, and Z. Zagorski. 2005. Work-related, penetrating eye injuries in rural environments. *Ann. Agric. Environ. Med.* 12(1): 27-29.
- McKeag, D., R. Maini, and H. R. Taylor. 2002. The ocular surface toxicity of paraquat. *British J. Ophthalmol.* 86(3): 350-351.
- Meister, J. 1991. The health of migrant farm workers. *Occup. Med.* 6(3): 503-518.
- Melbostad, E., and W. Eduard. 2001. Organic dust-related respiratory and eye irritation in Norwegian farmers. *American J. Ind. Med.* 39(2): 209-217.
- Millea, T. P., J. O. Kucan, and E. C. Smoot. 1989. Anhydrous ammonia injuries. *J. Burn Care Rehabil.* 10(5): 448-453.
- Mobed, K., E. Gold, and M. Schenker. 1992. Occupational health problems among migrant and seasonal farm workers. *West J. Med.* 157(3): 367-373.
- MSU. 1998. Disinfection of produce washwater. East Lansing, Mich.: Michigan State University. Available at: www.msu.edu/~brook/publications/aeis/aeis652.htm. Accessed November 2002.
- NIOSH. 1997. Injuries among farm workers in the United States, 1993. NIOSH Publication No. 97-115. Cincinnati, Ohio: National Institute for Occupational Safety and Health.
- O'Malley, M., T. Barry, M. Verder-Carlos, and A. Rubin. 2004a. Modeling of methyl isothiocyanate air concentrations associated with community illnesses following a metam-sodium sprinkler application. *American J. Ind. Med.* 46(1): 1-15.
- O'Malley, M. A., S. Edmiston, D. Richmond, M. Ibarra, T. Barry, M. Smith, and G. M. Calvert. 2004b. Brief report: Illness associated with drift of chloropicrin soil fumigant into a residential area—Kern County, California, 2003. *MMWR* 53(32): 740-742.
- Rust, G. 1990. Health status of migrant farmworkers: A literature review and commentary. *American J. Pub. Health* 80(10): 1213-1217.
- Saari, K. M., and E. Aine. 1984. Eye injuries in agriculture. *Acta Ophthalmol.* 161: 42-51.
- Saari, K. M., J. Leinonen, and E. Aine. 1983. Management of chemical eye injuries with prolonged irrigation. *Acta Ophthalmol. Suppl.* 161: 52-59.
- Sapers, G. M. 2001. Efficacy of washing and sanitizing methods. *Food Tech. Biotech.* 39(4): 305-311.
- Schelp, L. 1992. The occurrence of farm-environmental injuries in a Swedish municipality. *Accid. Anal. Prev.* 24(2): 161-166.
- Smith, F. P. E. 1940. Eye injuries in agriculture. *Trans. Ophthalmol. Soc. U.K.* 60: 252-257.
- Strong, L. L., B. Thompson, G. D. Coronado, W. C. Griffith, E. M. Vigoren, and I. Islas. 2004. Health symptoms and exposure to organophosphate pesticides in farmworkers. *American J. Ind. Med.* 46(6): 599-606.
- USDA. 2006. Farm labor. Washington, D.C.: USDA National Agricultural Statistics Service. Available at: http://usda.mannlib.cornell.edu/usda/nass/FarmLabo//2000s/2006/FarmLabo-11-17-2006_revision.pdf. Accessed 23 February 2007.
- USDOL. 2002. National Agricultural Workers Survey. Washington, D.C.: U.S. Department of Labor. Available at: www.doleta.gov/agworker/report9/chapter5.cfm#t51. Accessed 23 February 2007.
- USDOL. 2006. Number of non-fatal occupational injuries and illnesses involving days away from work by industry division or selected characteristic by detailed part of body, 2002. Washington, D.C.: USDOL Bureau of Labor Statistics. Available at: www.bls.gov. Accessed 20 April 2006.
- USGPO. 2000. Worker protection standard, 40 CFR Part 170. Revised 1 July 2000. Washington, D.C.: U.S. Government Printing Office.
- Vasu, U., A. Vasnaik, R. R. Battu, M. Kurian, and S. George. 2001. Occupational open globe injuries. *Indian J. Ophthalmol.* 49(1): 3-7.
- Villarejo, D., and S. Barron. 1999. The occupational health status of hired farm workers. *Occup. Med.* 14(3): 613-635.
- Weinbaum, Z., M. B. Schenker, M. A. O'Malley, E. B. Gold, and S. J. Samuels. 1995a. Determinants of disability in illnesses related to agricultural use of organophosphates (OPs) in California. *American J. Ind. Med.* 28(2): 257-274.

Weinbaum, Z., S. J. Samuels, and M. B. Schenker. 1995b. Risk factors for occupational illnesses associated with the use of paraquat (1,1'-dimethyl-4,4'-bipyridylium dichloride) in California. *Arch. Environ. Health* 50(5): 341-348.

Xiang, H., L. Stallones, G. Chen, and G. A. Smith. 2005. Work-related eye injuries treated in hospital emergency departments in the U.S. *American J. Ind. Med.* 48(1): 57-62.

Appendix

Summary of the literature describing mechanisms of injury, source of hazard, and eye injury in agriculture.

| Source of Hazard | Study Design | Eye Injury Documented | Reference |
|---|--|---|-------------------------------|
| Mechanism of Injury: Strike to Eye | | | |
| Vegetation | Case series of agricultural eye injuries | Injuries from bushes (e.g. whitethorn), particularly while hedging; whin/gorse, briar, sticks, chips of wood. | Smith, 1940 |
| | Case series of rural occupational eye injuries | Injuries from small twigs, leaves, thorns, pieces of wood, and stone chips during the harvest season | Doshi, 1968 |
| | Case series of agricultural eye injuries | Injuries from contact with bushes, gathering/breaking sticks, chopping wood, and reaping corn by hand | Blake, 1969, 1971 |
| | Case series of eye injuries | Injuries while hedging, particularly whitethorn | Johnston, 1971 |
| | Review of agricultural eye injuries | Corneal injury from leaf/twig while clipping/pruning hedges and bushes; concussion cataract from impact from branch | Blake, 1975 |
| | Case series of eye injuries | Large proportion of agricultural eye injuries caused by vegetable substances | Canavan, 1980 |
| | Case series of agricultural eye injuries | Strike by wood or twig in forest while lumbering; strike by fragment while chopping wood | Saari and Aine, 1984 |
| | Case series of occupational eye injuries | Injury from contact with sticks; injury from fruit falling on the eye | Vasu et al., 2001 |
| | Case series of agricultural injury/illness | Strike injuries to the face, primarily the eye; most occurred in orchard setting while reaching up to pick fruit, working in a tree, working on or around a ladder, or riding a tractor | Earle Richardson et al., 2003 |
| Case series of agricultural eye injuries | Strike by fragment while chopping wood | Mackiewicz et al., 2005 | |
| Animal | Case series of agricultural eye injuries | Injuries by horses (unspecified); injuries from cow horn; injuries from flick of cow tail while milking | Smith, 1940 |
| | Case series of rural occupational eye injuries | Animal horn impact | Doshi, 1968 |
| Source of Hazard | Study Design | Eye Injury Documented | Reference |

| | | | |
|---------------------|--|--|-------------------------|
| | Case series of agricultural eye injuries | Contact with farm animals | Blake, 1969, 1971 |
| | Case series of eye injuries | Contact with farm animals, primarily cow horns | Johnston, 1971 |
| | Review of agricultural eye injuries | Contact with head, hoof, or tail of animal; integuments of animals/insects causing conjunctivitis and possibly keratitis; attack by birds, particularly children | Blake, 1975 |
| | Case series of agricultural eye injuries | Cow butting with horn | Saari and Aine, 1984 |
| | Case series of occupational eye injuries | Bull gore injury | Vasu et al., 2001 |
| | Case series of agricultural eye injuries | Cow butting with horn | Mackiewicz et al., 2005 |
| Machine or tool | Case series of agricultural eye injuries | Injuries from tools and machinery, usually in relation to repair work; injury from metal slivers; stone injury. | Smith, 1940 |
| | Review of agricultural eye injuries | Contact with spades, pitchforks, wire; fragments from rotary lawnmower | Blake, 1975 |
| | Case series of agricultural injuries | Eye injuries from combine harvester and grindstone | Cooper, 1971 |
| | Case series of eye injuries | Injury due to steel wire | Horan, 1979 |
| | Case series of agricultural eye injuries | Blunt eye trauma from a hayfork; fall of unidentified machine while in operation, striking the eye | Saari and Aine, 1984 |
| | Case series of agricultural injuries | Injury involving use of mowers | Browning et al., 1998 |
| | Case series of occupational eye injuries | Injury from sickle | Vasu et al., 2001 |
| | Case report of agricultural eye injury | Injury to eye from tractor wheel explosion while being inflated | Levy et al., 2005 |
| | Case series of agricultural eye injuries | Intraocular metallic foreign body from hammering; injury from simple instrument use (knife, reaping hook); injury from machine use (chaff-cutter, threshing-machine, grinding machine) | Mackiewicz et al., 2005 |
| Other strike injury | Case series of agricultural eye injuries | Fall from one level to another | Mackiewicz et al., 2005 |
| | Case series of agricultural eye injuries | Impact from stones, falls, explosions, and metal (including wire and vaccination needle) | Blake, 1969, 1971 |

| Source of Hazard | Study Design | Eye Injury Documented | Reference |
|--|--|---|--|
| | Case series of agricultural eye injuries | Impact while performing repair work, including hammering, contact with instrument (in operation), flying objects (unidentified), contact with wire, exploding car battery | Saari and Aine, 1984 |
| Mechanism of Injury: Foreign Body | | | |
| Vegetation | Review of agricultural eye injuries | Irritation of conjunctiva and abrasion/ulceration of the cornea by plant hairs, seeds, burs, and other organic particulates | Blake, 1975 |
| | Agricultural injury survey | Corneal abrasions from foreign bodies; most injuries were associated with dusty conditions in spring and summer | Brisson and Pickett, 1991 |
| | Case report of agricultural eye injuries | Corneal trauma from pieces of onion skin or plant leaves | Lin et al., 1999 |
| Machine or tool | Case series of eye injuries | Injuries due to hammering | Johnston, 1971 |
| | Case series of agricultural injury | Foreign bodies in eyes; most eye injuries occurred while sharpening or drilling | Schelp, 1992 |
| | Agricultural injury survey | Foreign bodies resulting from hand and power tools, welding, grinding, cutting metal, and auguring grain | CDC, 1995 |
| Mechanism of Injury: Chemical Agent | | | |
| | Case series of agricultural eye injuries | Chemical injury due to lime; sulfate of ammonia | Smith, 1940 |
| | Case report of occupational ammonia injuries | Spray to eyes/face during ammonia application to crops | Levy et al., 1964 |
| | Case series of rural occupational eye injuries | Eye exposure to laboratory chemicals used for testing quality of milk | Doshi, 1968 |
| | Case series of agricultural eye injuries | Chemical injury due to lime | Blake, 1969, 1971 |
| | Case report agricultural injuries | Eye/face exposure during material transfer accidents | Helmerts et al., 1971a, 1971b |
| | Review of agricultural eye injuries | Noted hazards and identified specific fertilizers, weed killers, fungicides, and insecticides | Blake, 1975 |
| | Case series of eye injuries | Corrosive eye injuries due to chemical splash of formic acid-based livestock feed preservative | Saari et al., 1983; Saari and Aine, 1984 |
| | Case report of ammonia agricultural injuries | Periorbital edema following loose tubing on anhydrous ammonia applicator; corneal burn following trip on hose causing connector valve to open at farm supply store | Millea et al., 1989 |
| | Literature review | Effects of organophosphates on the eye | Dementi, 1994 |

| Source of Hazard | Study Design | Eye Injury Documented | Reference |
|------------------|---|--|------------------------|
| | Agricultural injury survey | Eye exposure to liquid agricultural chemicals (unidentified); eye exposure to fungicidal dust; child gaining access to chemical storage shed (unspecified agent) | CDC, 1995 |
| | Assessment of risk | Factors related to disability in organophosphate exposure; skin/eye illnesses examined | Weinbaum et al., 1995a |
| | Assessment of risk | Factors related to mechanism/circumstances of exposure are examined; symptoms of eye irritation noted | Weinbaum et al., 1995b |
| | Case report of agricultural eye injury | Eye exposure to paraquat by splashing | McKeag et al., 2002 |
| | Community exposure case | Eye irritation from byproducts of metam-sodium sprinkler application | O'Malley et al., 2004a |
| | Community exposure case | Eye irritation from drift of chloropicrin soil fumigant into surrounding community after field application | O'Malley et al., 2004b |
| | Exposure assessment and symptoms survey | Burning eyes associated with detectable levels of certain pesticide residues in home and vehicle dust | Strong et al., 2004 |
| | Agricultural occupational health survey | Itchy, irritated eyes from tasks associated with packing crops, applying fertilizer, working in fields during spraying, and early re-entry into sprayed fields | Cameron et al., 2006 |

Mechanism of Injury: Biological Agent

| | | |
|--|--|----------------------------|
| Case series of agricultural eye injuries | Myotic infection secondary to traumatic injury; corneal ulcer gave positive culture for <i>Aspergillus fumigatus</i> ; internal ophthalmomyiasis from second-stage larva of warble-fly occupying anterior chamber of eye | Blake, 1969, 1971 |
| Review of agricultural eye injuries | Tetanus secondary to perforating injury from horse-whips or from soil contaminated by animal feces | Blake, 1975 |
| Case series of agricultural eye injuries | Fungal corneal ulcers in onion harvesters; cultures grew <i>Candida</i> , <i>Cephalosporium</i> , <i>Cryptococcus</i> ; causes were <i>Aspergillus</i> , <i>Fusarium</i> , <i>Candida</i> , and <i>Cephalosporium</i> | Lin et al., 1999 |
| Screening survey | Eye lesions (cataract, glaucoma, optic atrophy, uveitis), impaired vision, and loss of vision secondary to onchocerciasis infection | Goddey et al., 2001 |
| Agricultural hygiene assessment | Eye irritation (red, dry, swollen, watery) in dusty farm work; symptom prevalence noted relative to total dust, fungal spore, and endotoxin exposure | Melbostad and Eduard, 2001 |
| Agricultural hygiene assessment | Red and irritated eyes significantly associated with exposure to 20 to 500 × 10 ³ fungal spores m ⁻³ | Eduard et al., 2006 |

Mechanism of Injury: Allergic Reaction

| | | |
|-------------------------------------|--|-------------|
| Review of agricultural eye injuries | Allergic inflammation of the conjunctiva from flowers, fruits, or hops | Blake, 1975 |
|-------------------------------------|--|-------------|