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Agricultural Injury

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Background *Agriculture is one of the most hazardous industries in the US.*
Methods *We reviewed MEDLINE and NIOSHTIC to identify English-language studies addressing occupational injury among agricultural populations, focusing on North America. Additional references were identified from the reference lists of identified studies and from contacts with experts in the field.*
Results *U.S. data indicate up to approximately 780 deaths and 140,000 cases of nonfatal disabling injuries in 1998. Risk of agricultural injuries is approximately 5–10/100 persons per year, but is higher in certain risk groups, such as males and cattle workers. Falls, machinery, and animals are among the most common causes. Unique features of the agricultural workplace and exposed population combine to increase risk and hinder accurate measurement. These features include a wide range of activities, hazards, and dispersed work places in agriculture; a seasonal hired work force that often has brief tenure, poor English skills, and a distrust of officialdom; and a history of exemption regarding occupational health and safety regulations.*
Conclusions *Research in agricultural injury should include epidemiologic study of risk factors and evaluation of interventions. Although only limited data are available documenting efficacy of specific preventive approaches, prevention should focus on engineering controls, regulatory approaches, and education.* Am. J. Ind. Med. 38:463–480, 2000.

KEY WORDS: farmer; farm worker; agricultural worker; injury

INTRODUCTION

Agriculture is one of humankind's oldest and worthiest endeavors. The shift from hunter–gatherer to agrarian society approximately 10 millennia ago allowed humans to settle in numbers sufficient to support development of a culture of art and science. This shift, or ''first wave'' of civilization, set the stage for our future as a species [Toffler, 1980]. The fruits of civilization have not been won without cost, however. Agriculture is among the most hazardous industries, and its burdens are not equally borne across the population. For agricultural workers, injury is an important contributor to mortality and morbidity.

Injury is defined as physical damage occurring to an individual due to an acute exposure to energy levels outside the normal tolerance bands for human tissue [Robertson, 1992]. Epidemiologists generally limit consideration to injuries meeting certain severity criteria, such as requirement for medical care, loss or restriction of work or school time, or loss of consciousness.

Injury has historically been an important occupational risk in American industry and has been decreasing over the past six decades. For example, the occupational mortality rate for all industries combined decreased from 37 per 10^5 workers in 1933 to 3.8 per 10^5 workers in 1998 [National

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Safety Council, 1999]. Much of this decrease may be attributed to advances in design of industrial machinery and work places and to an increased emphasis on regulation heralded by the passage of the Occupational Safety and Health Act in 1970. Although agriculture has also progressed in reducing injury death, it remains one of the most dangerous industries in the US [Zwerling et al., 1995]. The National Safety Council (NSC) estimated approximately 780 occupational fatalities in agriculture for 1998, yielding an occupational mortality rate of 22.1 per 10^5 workers, second only to mining and quarrying, with 24.3 per 10^5 workers (Table I) [NSC, 1999]. The NSC estimated approximately 140,000 nonfatal occupational injuries in agriculture in 1998 [NSC, 1999]. The annual cost of occupational conditions (injury and illness) in farming, forestry, and fishing occupations in the US has been estimated at $209 million (excluding costs of lost productivity) with an average per-case cost of $368 [Leigh and Miller, 1997]. However, these figures are based on Workers' Compensation system data and underestimate true costs.

Statistics from other sources confirm the high toll of mortality and morbidity. The National Census of Fatal Occupational Injuries for 1998 reported 719 occupational injury deaths for agriculture (exclusive of forestry and fishing), yielding a rate of 21.4 per 100,000 persons per year vs. 4.8 per 100,000 persons per year in the private sector [U.S. Department of Labor, 1999a]. The U.S. Department of Commerce Census of Agriculture for 1997 noted 705 farm-related deaths and 50,544 nonfatal injuries [U.S. Department of Commerce, 1999a]. These figures include only farm operators and direct-hire employees; persons working for farm labor contractors are excluded. A recent Canadian study utilizing a national farm injury registry showed an occupational injury mortality rate of $11.6/10^5$ persons, placing agriculture as the fourth most dangerous industry in Canada [Pickett et al., 1999].

Occupational health statistics for California, the nation's most productive agricultural state, paint a similar picture. The Workers' Compensation Insurance Rating Bureau of California documented 34,214 cases (including 47 deaths) among agricultural–industry class codes in 1994, leading to a combined medical and indemnity loss of more than $176 million, or a per-case cost of $5,144 (unpublished data). Although rates and absolute numbers of occupational deaths and injuries vary by source, higher morbidity and mortality in agriculture compared with general private industry are a consistent finding.

THE AGRICULTURAL POPULATION

Epidemiologic investigation of health status among agricultural populations is frustrated by inadequate data for the number of persons at risk and the number of persons suffering injury. The 1997 Census of Agriculture notes 3,352,028 employment positions on the nation's 1,911,859 farms (Table I) [U.S. Department of Commerce, 1999].

Basic sociodemographic differences exist between family farmers and hired farm workers. Family farmers tend to be White, U.S.-born, well educated, and economically well-off [Schenker, 1995]. The median age among farm operators is between 50 and 55 years [U.S. Department of Commerce, 1999]. In contrast, hired farm workers are

TABLE I. Estimated Population at Risk and Burden of Injury for U.S. Agricultural Workers

Population	Estimated size of population at risk	Annual injury risk	Annual total number injured
U.S. agricultural workers, 1998	3,450,000	Mortality $22.1/10^5$	780 deaths
[National Safety Council, 1999]		Disabling injury 4.1/100 workers	140,000 disabling injuries
U.S. principal operators and family members, 1997			511 deaths
[U.S. Department of Commerce, 1999]			21,793 nonfatal injuries
U.S. direct-hire agricultural workers, 1997	3,352,028 (includes part-time workers)	Mortality $5.8/10^5$	194 deaths
[U.S. Department of Commerce, 1999]		Nonfatal injury 0.9/100 workers	28,751 nonfatal injuries
U.S. farm workers in crop production (SIC 01), livestock production (SIC 02), and agricultural services (SIC 07), 1998	1,777,500	Nonfatal injuries 7.7/100 workers	105,000 nonfatal injuries (38% associated with lost work days)
[U.S. Department of Labor, 1999b]	(excludes farms with $<$ 11 employees)		
U.S. farm workers in crop production (SIC 01), livestock production (SIC 02), and agricultural services (SIC 07), 1998	3,363,000	Mortality $21.4/10^5$	719 deaths
[U.S. Department of Labor, 1999a, 1999b]	(based on Current Population Survey, 1998)		

predominantly Hispanic, foreign-born, have low education and economic status, and a median age between 25 and 34 years [Mines et al., 1991, 1997].

Hired farm workers pose special problems for enumeration because of the transient nature of agricultural employment and the social, economic, and linguistic marginalization characteristic of this population [McCurdy, 1995]. The Bureau of Labor Statistics annual survey of workplace injuries and illnesses reports an average annual employment in 1998 of 772,600 persons in production agriculture [U.S. Department of Labor, 1999b]. This figure excludes contract laborers and farms with fewer than 11 employees. The decennial Census is also inadequate for enumerating farm workers because the count does not coincide in time with the main labor demand in agriculture and undercounts nonEnglish-speaking immigrant groups. Thus, many farm workers, especially migrants, are excluded. For example, the 1990 Census indicates 182,235 migrant and seasonal farm workers in California, yet figures based on employment, average crop-specific labor demand, and crop volume statistics suggest a population between 563,000 and 720,000—an undercount by the Census of approximately 60–70% [Gabbard et al., 1993].

Martin and others have estimated there are approximately 2.5 million hired farm workers in the US; 2.0 million of these are engaged in crop production [Gabbard et al., 1993; Martin and Martin, 1994]. Of these, approximately 900,000 are migrant and seasonal workers. Approximately two-thirds of these shuttle from a fixed location outside the US and stay for the season (''shuttle migrants''), and one-third travel to follow crop employment [Martin and Martin, 1994].

Migrant farm workers tend to follow three main migration streams: the Eastern stream comprising Florida to the North Atlantic states, the Midwestern stream comprising Texas through the midwestern states, and the Western stream based in California and Arizona ranging up to Oregon and Washington [Meister 1991]. The Eastern stream is the most ethnically diverse, including African Americans, Caribbean peoples, and Hispanics. The Midwestern and Western stream are approximately 90% Hispanic [Meister, 1991].

The National Agricultural Workers Survey (NAWS) provides useful demographic information on the farmworker population (Table II) [Mines et al., 1991; Rosenberg et al., 1993, 1998; Mehta et al., 2000]. The survey is conducted three times a year among a national sample of crop farm workers. The population is predominantly young males and overwhelmingly Hispanic, Spanish-speaking and foreign-born. Mexico is the most common place of birth. Farm workers typically have a 7th grade education and have spent 10–12 years in agriculture. Farm workers are employed an average of 24 weeks per year in agriculture and five additional weeks per year in nonagricultural jobs. The median family income is between $7,500 and $9,999. Individual incomes are approximately half this figure and lowest among unauthorized workers. Over 60% of farm workers live in poverty [Mehta et al., 2000]. In spite of these extreme circumstances, farm workers infrequently utilize social support programs. Increased utilization is seen among authorized workers and families with children [Mines et al., 1997].

In the 1990–91 national survey, approximately 12% of farm workers were unauthorized to work in the US. More recent national NAWS data show 52% of agricultural workers were unauthorized [Mehta et al., 2000]. The most likely reason for this marked increase in unauthorized workers is the Immigration Reform and Control Act of 1986 (PL 99-603), which allowed undocumented workers to become legal permanent residents. After receiving this status, many subsequently left agricultural employment. This created a demand for workers and drew illegal immigrants, primarily from Mexico. Economic instability and poverty in Mexico have also contributed to such immigration [Taylor et al., 1997].

EPIDEMIOLOGIC STUDIES OF INJURY IN AGRICULTURE

Although several recent and valuable epidemiologic studies of farm injury have been performed (Tables III, IV), they have focused on agricultural populations consisting predominantly of family farmers. Population-based studies (Table III) have shown an overall injury risk of approximately 10% per year, ranging from 0.5/100 person-years [Layde et al., 1993] to 16.6/100 person-years [Pratt et al., 1992].

Host and farm-environment characteristics affect risk (Table IV). Most studies have shown increased risk for persons younger than 19 or older than 65 years of age [Hoskin et al., 1988; Pratt et al., 1992; Gerberich et al., 1993; Zhou and Roseman, 1994; Nordstrom et al., 1995; Nordstrom et al., 1996; Lewis et al., 1998]. Older persons are at particular increased risk for mortality [Crawford et al., 1998]. Men are at up to 4.5-fold increased risk compared to women [Crandall et al., 1997]; this increase is reduced when accounting for the number of hours worked [Pratt et al., 1992; Gerberich et al., 1993; Nordstrom et al., 1996]. Among women, total hours worked is associated with injury risk [Stueland et al., 1997]. It is likely that the observed increased risk for men is due to both greater total hours worked and engagement in more hazardous jobs compared to women.

Few data address the effect of race or ethnicity. National data show higher mortality from agricultural injury rates among Blacks compared to Whites [Myers and Hard, 1995]. Age-adjusted agricultural fatality rates were 2.5-fold higher for North Carolina African American farmers

TABLE II. Selected Demographic and Socioeconomic Characteristics of U.S. and California Hired Crop Farm Workers: National Agricultural Workers Survey

	U.S. farm workers		California farm workers	
Characteristic	**1990–1991 [Mines et al., 1991]**	**1997–1998 [Mehta et al., 2000]**	**1990–1991 [Rosenberg et al., 1993]**	**1994–1997 [Rosenberg et al., 1998]**
Demographics				
Age	Median 31 years	Median 29 years	Median 32 years	Median 30 years
Gender	71% male	80% male	74% male (81% of unauthorized workers are male)	82% male
Place of Birth	62% foreign-born (57% from Mexico)	81% foreign-born (77% from Mexico)	92% foreign-born (82% from Mexico)	95% foreign-born (91% from Mexico)
Education	Median sixth grade education	Median sixth grade education	Median sixth grade education	Median sixth grade education
Accompanied by family		52% married; 45% of persons with spouse and offspring resided apart from family	60%	45%
Spanish as primary language	65%	84%	88%	95%
English-language fluency	36% report can read English well	12% speak or read	11% speak, 14% read	Fewer than 10%
Employment characteristics				
Weeks of work per year	Average 26 weeks in agriculture, 8 in non-farm work	Average 24 weeks in agriculture, 5 in non-farm work	Average 33 weeks in agriculture, 2 in non-farm work	Average 23 weeks in agriculture, 3 in non-farm work
Hired through farm labor contractor	23%	19%	31% (86% of jobs in fruit, nut, vegetable crops)	30%
Payment scheme	71% hourly, 28% piece-rate, 1% mixed	77% hourly, 20% piece-rate, 2% mixed	69% hourly, 22% piece rate, 9% mixed	73% hourly, 24% piece rate, 3% mixed
Average hourly wage	$4.85; $5.25 for fruits and nuts work	$5.94 ($5.80 when employed by farm labor contractor) 12% earned less than minimum wage. Purchasing power decreased 10% 1989-1998.	$5.41, ($4.45 when employed by farm labor contractor)	$5.69 ($5.27 when employed by farm labor contractor)
Work authorization	12% unauthorized	52% unauthorized	9% unauthorized	42% unauthorized
Economic status				
Median annual income	Individual: $5,000–$7,500 ($2,500–$5,000 for unauthorized workers) Family: $7,500–$10,000	Individual: $5,000–$7,499 Family: $7,500–$9,999	Individual: $5,000–$7,499 ($2,500–$4,999 for unauthorized workers) Family: $10,000–$12,499	Individual: $5,000–$7,499 ($2,500–$4,999 for unauthorized workers) Family: $7,500–$10,000
Poverty rate (based on U.S. Census definition)	50% (Poverty increases with family size.)	61% (65% for foreign-born)	48% (Poverty increases with family size.)	61% (Poverty increases with family size.)
Social services utilization	18% (primarily food stamps)	Unemployment insurance 20% 13% used Medicaid	13% (primarily food stamps)	18% received needs-based assistance during preceding 2 years. Unauthorized worker families were less likely to use needs-based social services.

TABLE III. Population-based Studies of Agricultural Injury

Reference	Population and study design	Observed injury risk	Other findings
Hoskin et al. [1988]	Interviewer-administered survey of agricultural workers in 31 states	4/100 FTE for work-related injuries 4,105 work-related injuries and 1,648 nonoccupational injuries from 37,293 farms comprising 184,650 persons	Machinery: 17.6% Animals: 16.9% 65.4% required medical attention Increased risk for beef, dairy, fruit farms, hired workers, small farms ($\leq$ 49 acres)
Brison and Pickett [1992]	1-year prospective survey of 547 subjects (personal interview and telephone follow-up) of nonfatal injuries in 117 beef and dairy in Eastern Ontario. Participation rate 33%	7/100 person-years 44 injuries (3 of which were nonwork-related) among 40 individuals on 33 farms	Equipment 34% Livestock 24% Falls 10% 46% of cases treated in hospital emergency department Increased risk for beef farm (RR = 2.5), increased work experience, full-time work (RR = 2.5) and prescription drug use in farm owners (RR 2.7).
Pratt et al. [1992]	Mail questionnaire survey with telephone follow-up over 2 years of 600 dairy farmers in NY selected from U.S. Department of Agriculture farm list. Participation rate for completion of study was 37%	16.6/100 person-years 200 injuries among 151 persons workers on 201 farms during 1984–1986	Machinery: 35% Animals: 32% 70% of cases sought medical attention Increased risk for men (19.5 vs. 6.9/100 person-years), large farms, owner–operators, older age
Gerberich et al. [1993] Regional Rural Injury Study	Telephone survey of 3,939 farm households with 13,132 persons in Minnesota, Wisconsin, North and South Dakota, and Nebraska (Participation rate 62%)	5.8/100 person-years, or 5 per 10^5 hours worked (equivalent to 10/100 FTE) for farming operation-related injuries. Nonfarming related injury rate was 5.3/100 peson-years	Livestock: 30% Machinery: 29% 81% of farming operation-related injury cases sought medical care. Increased risk for persons $\leq$ 19 years of age Risk for men and women approximately equal when accounting for hours worked
Layde et al. [1993]	2-year population-based prospective nested case–control study of injury in 12 rural zip code areas in Wisconsin Participation rate 90.4% for cases (n = 510) and 82.8% for controls (n = 183)	0.52/100 person-years for total population 3.3/100 person-years for farm residents 510 agricultural injuries among 506 subjects	Animals: 26% Machinery: 18.6% Falls: 16.8% Highest risk among males (4.6/100 person-years), farm residents, dairy farms
Zhou and Roseman [1994]	Mail and telephone survey of 718 rural Alabama farmers (participation rate 86.2%)	9.9/100 person-years for agricultural injuries 71 agricultural injuries in 56 farmers	Machinery: 28.6% Falls: 23.2% Animals: 12.5% Increased risk for dairy, forestry, younger age, farm ownership, alcohol consumption, and prior injury
Nordstrom et al. [1995]	Cohort study of 510 cases occurring between 5/90 and 4/92 in defined rural area (Marshfield Epidemiologic Survey Area, MESA)	3.5/100 person-years for dairy farm residents vs. 1.4/100 person-years for nondairy farm residents	Animals: 26% Machinery: 18.6% Increased per-hour risk for part-time workers For adult males: 5.6/100 person-years or 4.3/200,000 hours worked

TABLE III. (Continued)

Reference	Population and study design	Observed injury risk	Other findings
Pickett et al. [1995b]	Mail survey of 4,110 farm persons on 1,364 farms in Ontario (participation rate 74%)	5.8/100 person-years 238 farm-related injuries	Machinery: 29% Lifting: 20% Farm animals: 16% Falls: 16% 68% of cases received medical care. Increased risk for males (7.5/100 person-years), owner–operators
Myers [1998]	Mail survey of 11,630 farms (participation rate 55.3%) drawn from National Agricultural Statistics Service listing	4.7/100 FTE for lost-work-time injuries 121,937 lost-work-time injuries	Livestock: 20.0% Machinery excluding tractor: 19.3% Medical attention sought in 82.5% of cases Highest rates among nursery workers (19.4/100 FTE) Hired workers at greater risk than operator family members (4.9 vs. 4.6/100 FTE)
Browning et al. [1998]	Telephone survey of 998 farmers $\geq$ 55 years of age in 60 Kentucky counties over a 1-year period. Participation rate 71%	9.03/100 person-years 98 farm-related injuries among 88 farmers	Falls: 24.9% Machinery: 22.5% Wood-cutting: 14.6% Animals: 14.3% 80% of cases consulted physician. Increased risk for previous injury (OR 2.40), hearing difficulty (OR 1.59), and vision difficulty (OR 1.42), and annual income $>$ \$40,000
Lewis et al. [1998]	Cross-sectional mail and telephone survey of population-based sample of 390 principal operators from USDA listing of Iowa farmers in 18 Iowa counties (two counties from each of 9 crop-reporting districts). Participation rate 39.4%	10.3/100 person-years 48 injuries involving 40 principal operators among 390 principal operators at risk.	Livestock 33% Equipment 29% 90% received medical treatment. Increased risk among workers born after 1940 (OR 3.12), workers with work-limiting health impairment (OR 2.38).
Crawford et al. [1998]	Cross-sectional mail and telephone survey of population-based sample of 2,571 principal operators from USDA listing of Ohio cash-grain farmers. Participation rate 43.6–71.4%	5/100 person-years 235 injuries; case–control analysis restricted to 90 white male farmers with at least one injury involving agricultural work vs. 1475 controls	Farm machinery 22% Overexertion 20% Increased risk among persons younger than 30 years of age (OR 6.8), higher neurological symptoms score (OR 2.61), and divorced operators (OR 3.01)
Hard et al. [1999]	U.S. farm production workers $<$ 25 years of age based on the National Traumatic Occupational Fatality Survey (NTOF) 1990–1993 (workers $\geq$ 16 years of age) and the Census of Fatal Occupational Injuries (CFOI) 1992–1995 (workers of all ages). Denominator based on Current Population Survey (includes workers age $\geq$ 15 years).	Approximate three-fold increased mortality for agricultural production workers $<$ 25 years of age compared to workers of all ages in U.S. private industry. NTOF: $12/10^5$ vs. $4.4/10^5$ CFOI: $16/10^5$ vs. $5/10^5$	Males represented over 96% of deaths. Tractors were leading source of injury (NTOF: 18.4%, CFOI: 23.2%), followed by trucks and agricultural machinery. Over 60% of tractor deaths related to overturn.

TABLE III. (Continued)

Reference	Population and study design	Observed injury risk	Other findings
Myers et al. [1999]	U.S. farm production workers $\geq$ 55 years of age based on the National Traumatic Occupational Fatality Survey (NTOF) 1990–1993 and the Census of Fatal Occupational Injuries (CFOI) 1992–1995	Greater than two-fold increased mortality for agricultural production workers $\geq$ 55 years of age compared to $<$ 55 years of age. NTOF: $33/10^5$ vs. $14.2/10^5$ CFOI: $46.4/10^5$ vs. $17.4/10^5$	Males represented approximately 98% of deaths. Tractors were leading source of injury (NTOF: 300 deaths, CFOI: 593 deaths) followed by trucks, agricultural machinery, and animals. Approximately 53% of tractor deaths related to overturn.
Lyman et al. [1999]	Mail/telephone/in-person survey of male farmers and farm workers in nine predominantly Black Alabama and Mississippi counties. Study sample included 1,310 participants (702 White owner/operators (WO), 348 Black owner/operators (BO), and 260 Black farm workers (BW)).	Overall cumulative incidence of any previous agricultural injury 23.4% ($83.7/10^5$ farming years) Compared to WO, BOs had approximately one-half the risk (injury/10^5 farming years) for any agricultural injury; risk for BOs was comparable to WOs.	Cuts/lacerations and bone fractures most common. Machinery WO: 32% of injuries BO: 38% of injuries BW: 23% of injuries Livestock WO: 20% of injuries BO: 8% of injuries BW: 0% of injuries
Pickett et al. [1999]	Canadian farm population, based on fatalities registered with the Canadian Agricultural Injury Surveillance Program 1991–1995	503 work-related fatalities ($11.6/10^5$ persons)	Tractors: 47.5% Other machinery: 24.3% Bimodal seasonal distributions of deaths, with increases in May and July–September. Death rates increased with age.

Abbreviations: RR: Relative risk; OR: Odds ratio; FTE: Full-time equivalent, or 200,000 hours worked.

compared to White farmers [Richardson et al., 1997]. A New Mexico death certificate study showed highest risk for farm injury deaths among American Indians (51.2 per 10^5), followed by Hispanics (17.2 per 10^5) and nonHispanic Whites (6.2 per 10^5) [Crandall et al., 1997]. Among rural Alabama farmers and farm workers, 23.4% reported an agricultural injury during their entire farming careers (Table III). Black owner/operators were less likely to report a previous injury than were White owner/operators (RR 0.48, 95% CI 0.33–0.63) [Lyman et al., 1999]. Black and White owner/operators differed in their farming activities and injury characteristics. Black owner operators were more likely than White owner/operators to farm field crops and less likely to work with livestock. For both Black and White owner/operators, cuts and fractures were the most common nature of injury. Farm machinery was the most common object involved with the injury (approximately one-third of cases). For both groups, carelessness was the most often cited contributing factor. Twenty-four percent of White owner/operators and 49% of Black owner/operators reported persistent problems related to their injury. Black farm workers were more likely to experience lost work, financial difficulty, and reduced activity than Black or White owner/operators [McGwin et al., 2000]. The higher severity among Black owner/operators and their observed lower injury rates may be consistent with underreporting of less severe injuries in this group.

Host characteristics relating to general fitness and alertness have been associated with agricultural injury risk. Persons with a previous history of injury or current work limitations are at up to four-fold increased risk [Cleary et al., 1961; Zhou and Roseman, 1994; Lewis et al., 1998]. Increased risk has also been found among hearing-and vision-impaired farmers, although the findings were not statistically significant [Browning et al., 1998]. Alcohol use [Zhou and Roseman, 1994; Pickett et al., 1996; Crandall et al., 1997] and prescription drug use [Brison and Pickett, 1992; Pickett et al., 1996] have also been associated with injury risk. Participation in safety courses has not been shown to reduce injury risk in North American agriculture [Cleary et al., 1961; Layde et al., 1993; Lewis et al., 1998]. An uncontrolled study of Finnish reindeer herders in which participants received personal and written safety instruction demonstrated a 43% reduction in injury risk [Pekkarinen et al., 1992].

Farm work-place characteristics are also associated with injury risk. A large survey of 31 states noted approximately 25% increased risk for persons working on farms $\leq$ 49 acres [Hoskin et al., 1988]. Risk increases with

TABLE IV. Risk Factors for Occupational Injury Among Agricultural Workers

Risk factor	Population	Results	Selected references
Host risk factors			
Age	Farmers; all agricultural workers	Mixed; increased risk of younger and older workers in large studies of all agricultural workers.	[Hoskin et al., 1988; Gerberich et al., 1993; Zhou and Roseman 1994; Nordstrom et al., 1995; Nordstrom et al., 1996; Pratt et al., 1992; Lewis et al., 1998; Crawford et al., 1998; Hard et al., 1999; Myers et al.,1999; Lyman et al., 1999; Pickett et al., 1999]
Gender	Farmers; all agricultural workers	Higher risk for males (4.4—8.7% per year) than females (1.3—2.7% per year); difference in risk decreased after accounting for hours worked.	[Hoskin et al., 1988; Gerberich et al., 1993; Nordstrom et al., 1995; Nordstrom et al., 1996; Pratt et al., 1992; Crandall et al., 1997; Pickett et al., 1999]
Race or ethnicity	Farmers and farm workers	New Mexico: Overall mortality 21.3/10^5 p-y (American Indian: 51.2/10^5 p-y; Hispanic: 17.2/10^5 p-y; Anglo: 6.2/10^5 p-y)	[Crandall et al., 1997]
		North Carolina: Fatalities at 2.5-fold increased risk among Black farmers compared to White farmers.	[Richardson et al., 1997]
		Rural South: Nonfatal injury among White owner/operators 100.2/10^5 farming years; Black owner/operators 47.9/10^5 farming years; Black farm workers 95.7/10^5 farming years.	[Lyman et al., 1999]
Education	Black and White farmers and farm workers in rural Alabama and Mississippi	Approximate two-fold increased risk of reporting prior injury among persons with some posthigh-school education	[Lyman et al., 1999]
History of previous injury or current work limited by impairment	Farmers; all agricultural workers	Previous injury associated with three-to four-fold increased risk; current impairment associated with 2.4-fold increased risk.	[Cleary et al., 1961; Zhou and Roseman, 1994; Lewis et al., 1998; Browning et al., 1998]
Hearing difficulty	Kentucky male farmers $\geq$ 55 years of age	Increased risk with hearing difficulty (OR 1.59, 95% CI 0.95—2.67)	[Browning et al., 1998]
Vision difficulty	Kentucky male farmers $\geq$ 55 years of age	Increased risk with vision difficulty (OR 1.42, 95% CI 0.76—2.63)	[Browning et al., 1998]
Prescription drug use	Ontario beef and dairy farmers	Increased risk (2.8-fold) for persons regularly using stomach remedies or laxatives; increased risk (4.2-fold) in men 45 years of age or older using heart or circulatory medications	[Brison and Pickett, 1992; Pickett et al., 1996]
Alcohol consumption	Farmers, farm-related deaths	Alcohol consumption of over 200 ml/day more than doubled risk; alcohol more likely involved in farm-related deaths than nonfarm-related deaths	[Zhou and Roseman, 1994; Pickett et al., 1996; Crandall et al., 1997]
Farm ownership	Farmers	Greater than three-fold increased risk for farm owners	[Zhou and Roseman, 1994; Pratt et al., 1992; Brison and Pickett, 1992]
Hired vs. family workers	All agricultural workers	Approximately 10% increased risk among hired workers	[Hoskin et al., 1988]
Participation in safety courses	All agricultural workers	No apparent effect of participation in safety courses	[Cleary et al., 1961; Layde et al., 1993; Lewis et al., 1998]

TABLE IV. (Continued)

Risk factor	Population	Results	Selected references
Time spent in agricultural work	Farmers; all agricultural workers	Risk per hour worked higher among part-time workers; overall risk (not accounting for hours worked) higher for full-time workers	[Zhou and Roseman, 1994; Nordstrom et al., 1995; Nordstrom et al., 1996; Layde et al., 1993; Layde et al., 1995; Brison and Pickett, 1992; Pratt et al., 1992; Browning et al., 1998; Crawford et al., 1998; Lyman et al., 1999]
Carelessness or hurried	Black and White farmers and farm workers in rural Albama and Mississippi	Approximately 50% increased risk for reporting previous injury among owner/operators characterizing themselves as somewhat or not careful Approximate 50–100% increased risk among owner/operators characterizing themselves as sometimes or frequently hurried	[Lyman et al., 1999]
Work environment risk factors			
Farm size	All agricultural workers	Nearly 25% increased risk for persons working on farms $\leq$ 49 acres	[Hoskin et al., 1988]
Farm residence	All agricultural workers	Farm residents at 6.3-fold increased risk compared to nonfarm residents	[Nordstrom et al., 1995; Stueland et al., 1995]
Gross annual farm income	Farmers	Risk increases with income; OR 1.52 for income $>$ \$40,000	[Browning et al., 1998]
Presence of nonresident farm workers	All agricultural workers in three Wisconsin counties	Greater than two-fold increased risk for machinery-and animal-related injuries	[Layde et al., 1993; Layde et al., 1995]
Presence of farm machinery	Black and White farmers and farm workers in rural Alabama and Mississippi	Tractor use and presence of $>$ 15 pieces of farm machinery associated with up to 3.5-fold increased risk for reporting previous agricultural injury	[Lyman et al., 1999]
Crop or work activities	Farmers; all agricultural workers	Increased risk at fruit farms; beef and dairy workers at approximately 2-fold increased risk.	[Hoskin et al., 1988; Zhou and Roseman, 1994; Nordstrom et al., 1995; Nordstrom et al., 1996; Brison and Pickett, 1992; Browning et al., 1998]
Seasonal and temporal factors	Farmers, all agricultural workers	Injury risk increased during fall and spring and weekends	[Cleary et al., 1961; Hoskin et al., 1988; Zhou and Roseman, 1994; Pratt et al., 1992]

income [Browning et al., 1998] and the presence of nonresident farm workers [Layde et al., 1993, 1995]. Several studies have noted increased risk on beef, dairy, and fruit farms [Hoskin et al., 1988; Brison and Pickett, 1992; Nordstrom et al., 1995, 1996; Browning et al., 1998; Villarejo, 1998]. Risk increases during fall and spring, seasons in which high levels of labor input are required [Cleary et al., 1961; Hoskin et al., 1988; Pratt et al., 1992; Zhou and Roseman, 1994].

SPECIFIC CAUSES OF AGRICULTURAL INJURY

The farm work environment is characterized by a wide variety of hazards for injury, including machinery, work from heights, animals, water, poisonous gases and other chemicals, and electricity [McCurdy, 1995; Von Essen and McCurdy, 1998]. A study of Workers' Compensation claims in Washington state found that farm workers were at increased risk for fatal injury (RR 2.5), sprains and strains (RR 1.4), fractures (RR 2.3), dislocations (RR 1.9), concussions (RR 1.9), and amputations (RR 2.5) [Demers and Rosenstock, 1991]. The predominance of musculoskeletal injuries has also been shown using California surveillance data [Osorio et al., 1998a, 1998b] and Workers' Compensation data (Table V) [California Department of Industrial Relations, 1997]. National data show predominance of livestock, machinery, and falls as the most important sources of occupational injury on the farm [Myers, 1998].

TABLE V. Characteristics of Nonfatal Occupational Lost-Work-Time Workers' Compensation Cases California, 1995

Characteristic	Agriculture N (%)	All private industry N (%)
Total cases	11,830 (100)	219,085 (100)
Nature of injury		
Sprains, strains	5,151 (43.5)	87,938 (40.1)
Bruises, contusions	909 (7.7)	15,556 (7.1)
Cuts and lacerations	730 (6.2)	17,064 (7.8)
Multiple injuries	545 (4.6)	7,917 (3.6)
Fractures	467 (3.9)	10,194 (4.7)
Body part affected		
Trunk (including back)	4,797 (40.6)	77,707 (35.5)
Back	3,592 (30.4)	55,063 (25.1)
Upper extremities	2,226 (18.8)	53,138 (24.3)
Eye	789 (6.7)	7,024 (3.2)
Source of injury or illness		
Worker motion or position	3,344 (28.3)	51,959 (23.7)
Containers	1,742 (14.7)	27,400 (12.5)
Floor, walkway, ground surfaces	1,453 (12.3)	29,966 (13.7)
Vehicles	1,082 (9.1)	16,311 (7.4)
Chemicals	144 (1.2)	3,915 (1.8)
Events or exposure		
Contact with objects or equipment	3,128 (26.4)	55,904 (25.5)
Overexertion	2,168 (18.3)	45,589 (20.8)
Falls	1,546 (13.1)	29,854 (13.6)
Transportation accidents	711 (6.0)	9,563 (4.0)

Source: Based on data from California Department of Industrial Relations, Occupational Injuries and Illnesses Survey, California, 1995 [California Department of Industrial Relations, 1997].

Agricultural Machinery

Agricultural machinery is necessary for farm production and represents an important cause of injury on the farm, accounting for 18–35% of cases [Cleary et al., 1961; Hoskin et al., 1988; Brison and Pickett, 1992; Gerberich et al., 1993; Layde et al., 1993, 1995; Zhou and Roseman, 1994; Nordstrom et al., 1995; Pickett et al., 1995a, 1995b; Hartling et al., 1997; Crawford et al., 1998; Lewis et al., 1998; Myers, 1998]. There is a wide variety of machinery used on the farm, and each holds unique hazards. Injuries and fatalities have been associated with loading equipment [Centers for Disease Control and Prevention, 1996], power-takeoff devices [Centers for Disease Control and Prevention, 1995], augers [Beatty et al., 1982], corn pickers [Gorsche and Wood, 1988], hay balers [Centers for Disease Control, 1992], tractors [Karlson and Noren, 1979; Cogbill et al., 1985; Goodman et al., 1985; Etherton et al., 1991; Gerberich et al., 1993; Layde et al., 1995; Myers and Synder, 1995; Kelsey et al., 1996; Lee et al., 1996], and motor vehicles [Gerberich et al., 1996]. Common mechanisms of injury include entanglement and being run over or pinned [Hartling et al., 1997]. Death certificate data for 1980–85 indicate that an average of 369 occupational deaths per year in the US involved agricultural machinery as the external cause of death [Etherton et al., 1991]. The injury death rate per 100,000 total population (including nonfarmers) from agricultural machinery increased 44% from 1930 to 1980, while the death rate from nonagricultural machinery fell by 80% in this period [Baker, 1992]. Lyman, et al. [1999] demonstrated a dose-dependent risk (up to 3.5-fold increased risk for >15 pieces of agricultural machinery) for reporting previous lifetime agricultural injury among rural Southern White owner/operators.

Layde and coworkers [1995] performed a nested case–control study of machinery injury in Wisconsin. Eighty-eight adult agricultural machinery-related cases were found. Tractors constituted the largest portion (14.8%) of injuries. The most frequently injured body parts were the hand (26.1% of cases) and eye (12.5% of cases). Males had nearly a six-fold increase in risk compared to females. Persons working on farms with less than $1000 annual product sales had higher rates than persons on more productive farms. Hours worked per week was significantly associated with risk (odds ratio per hour 1.02, 95% CI 1.01–1.03). Residents on farms with nonresident workers had a 2.3-fold increased risk. Reduced risk was noted for persons on farms where cows were fed in the barn rather than allowed to graze freely (OR 0.28, 95% CI 0.12–0.64) and where the herd contained registered cows (OR 0.36, 95% CI 0.17–0.79).

Increased risk for injury from farm machinery was also noted by Gerberich, et al., [1998] in a prospective study of injury conducted in Minnesota, Wisconsin, North Dakota, South Dakota, and Nebraska. Machinery (not including hand tools and tractors) was associated with 151 (19.7%) of 764 injuries observed in 13,144 persons during 1990. Risk factors for machinery-related injury included increased time spent working on the farm (RR 4.88, 95% CI 1.97–12.08 for 60–79 h/week compared to <20 h/week), auger use (RR 2.36, 95% CI 1.17–4.76), male sex (RR 3.79, 95% CI 1.81–7.92), separated/widowed/divorced status (RR 3.82, 95% CI 1.50–9.74 compared to <16 years of age and never married), and predominant work activity in field crops (RR 2.13, 95% CI 1.07–4.25). Lifting, pushing, and pulling were the most common injury-associated activities (20.5%). Injuries typically occurred in the farm yard (47.7%), in the months of May and October (corresponding to planting/cultivating and harvesting activities, respectively) and between noon and 6:00 p.m. Strains/sprains and lacerations/punctures each comprised 26% of injuries. The extremities were involved in 55% of cases and the back or

spine in 24%. Only 5% of injuries required hospitalization, yet 25% of injuries resulted in a persistent impairment. Approximately one-third of subjects had medical insurance covering at least half of the cost of injury; one-quarter had no insurance.

Farm Vehicle Injuries on Public Roads

Little information is available regarding public roadway injuries involving farm vehicles or machinery. A study of U.S. roadway fatalities involving nontruck farm vehicles using the National Highway and Transportation Safety Administration's Fatal Accident Reporting System (FARS) showed 655 fatal crashes on rural roads between 1988 and 1993 [Gerberich et al., 1996]. In comparison to crashes on rural roads not involving farm vehicles, drivers of farm vehicles were older (median 40.4 vs. 32.1 years), more likely male (92 vs. 82%), more likely to have at least one conviction for driving while intoxicated (12 vs. 8%), and less likely to have at least one speeding conviction (20 vs. 27%). Fatal crashes involving farm vehicles were more likely to involve being struck in the rear (36 vs. 4%), an overturn (21 vs. 9%), involve a fall from the vehicle (5 vs. 1%), or occur on roads with a speed limit of 55 mile per hour or greater. Only 8% of the nontruck farm vehicles were registered for road use.

This epidemiologic picture provides suggestions for preventive measures. Although only a small minority of farm vehicles in this study were registered for use on public roadways, virtually all farm operations require such travel [Gerberich et al., 1996]. The high proportion of rear-end crashes and increased likelihood of occurring on roads with speed limits of 55 miles per hour or greater suggests that differences in speed between regular traffic and farm vehicles is an important factor. Separate lanes for farm vehicles, although potentially expensive, may help prevent these crashes. The increased frequency of overturns and fall from the vehicles indicates that design features and use of safety belts should be examined.

Transportation accidents are also responsible for injury and fatalities, particularly among migrant farm workers. Farm labor contractors may provide transportation—sometimes as a condition of employment—and may utilize overloaded, unsafe vehicles and inexperienced drivers. Unfortunately no epidemiologic data are available on these injury events to our knowledge.

Tractor-Related Injury

Tractors are among the most common farm machines (4.8 million on U.S. farms in 1993) and are associated with the majority of farm machinery-related fatalities [Lee et al., 1996; Centers for Disease Control and Prevention, 1997; Reynolds and Groves, 2000]. Tractors accounted for 69% of agricultural machinery-related deaths between 1980 and 1985; over half of these were rollover incidents [Etherton et al., 1991]. Mortality data from the National Traumatic Occupational Fatality (NTOF) survey and the Census of Fatal Occupational Injuries (CFOI) indicate that tractors are the most common cause of occupational fatality in agriculture, comprising nearly one-fifth of fatalities (Table III) [Hard et al., 1999]. Agricultural production workers younger than 25 years of age were at approximately threefold increased risk for mortality compared to workers of all ages in private industry. Lee, et al. [1996] noted that over 40% of injuries occurred during mounting or dismounting of the tractor. Over 20% resulted in serious-to-life-threatening injury, and over a quarter of injuries led to persistent health problems. Tractor rollover incidents were more likely for skid-steer tractors.

Tractor rollover incidents claim the lives of approximately 200 U.S. farmers annually [Reynolds and Groves, 2000]. Tractor-related risk factors for rollover include high center of gravity, rear-wheel drive, narrow or ''tricycle'' front ends, improper hitching, and uneven terrain as risk factors for rollover [Reynolds and Groves, 2000]. Although the Occupational Safety and Health Administration (OSHA) requires the employer to provide rollover protection structures (ROPS) for all tractors manufactured since 1976 and operated by nonfamily employees (29 Code of Federal Regulations 1928.51), many farmers use tractors manufactured before this date. Approximately 60% of tractors on U.S. farms do not have ROPS [Myers and Synder, 1995; Centers for Disease Control and Prevention, 1997]. Tractor manufacturers agreed in 1985 to sell only tractors equipped with ROPS; approximately 87% of tractors manufactured after this date have ROPS, compared to 5% of tractors aged 30 years and older [Myers and Synder, 1995; Centers for Disease Control and Prevention, 1997]. In addition, federal OSHA requirements apply only to employees on farms with 11 or more employees, effectively exempting approximately 95% of U.S. farms and more than half of all agricultural workers from federal oversight [Aherin et al., 1992].

ROPS efficacy is reduced if the operator is not using a seat belt, especially in an open-cab tractor, because of the risk of being thrown and crushed under the ROPS [Reynolds and Groves, 2000]. A survey of New York farmers showed that seat belts were used for only 33% of operating hours [Kelsey et al., 1996]. Approximately 43% of operating hours occurred in tractors equipped with ROPS. The percentage of tractor-operating hours protected by both ROPS and seat belt use was between 8.2 and 32.5%.

Falls

Work at heights is required for harvesting tree fruit and in numerous other tasks on the farm. Falls represent up to one-quarter of injury cases on the farm [Brison and Pickett,

1992; Zhou and Roseman, 1994; Nordstrom et al., 1995; Pickett et al., 1995b]. Nordstrom and co-workers [1996] conducted a case–control study of 45 fall-related farm injury cases. Among farm residents, the risk for fall injury was 0.75 per 100 person-years. Men were at more than two-fold increased risk compared to women, but this effect disappeared when accounting for the number of hours worked. There was an approximate 2% increase in risk per hour worked, and nonresident workers were at over two-fold increased risk.

Animals

Animals-related injuries account for between 12 and 33% of injuries on the farm [Cleary et al., 1961; Cogbill et al., 1985; Hoskin et al., 1988; Brison and Pickett, 1992; Pratt et al., 1992; Gerberich et al., 1993; Layde et al., 1993; Zhou and Roseman, 1994; Nordstrom et al., 1995; Pickett et al., 1995b; Lewis et al., 1998; Myers, 1998; Von Essen and Donham, 1999]. Animal-related injuries are common on cattle and horse farms, where work with large numbers of heavy and powerful animals is required; in general, workers on these farms have high rates of injury [Hoskin et al., 1988; Brison and Pickett, 1992; Zhou and Roseman, 1994; Nordstrom et al., 1995; Browning et al., 1998].

Risk factors for animal-related injury include activities that increase exposure and proximity to the animals. For example, dairy cattle workers spending more than 30 h per week milking dairy cattle have up to 20-fold increased risk for injury; a four-fold increased risk was associated with trimming or treating hooves [Boyle et al., 1997]. Abrasions/contusions and sprains/strains/torn ligaments each represented slighly more than one-quarter of the reported injuries. Five percent of the injuries were life-threatening, and 28% led to persistent health problems.

CHILDREN AND AGRICULTURAL INJURY

As for adults, obtaining accurate information on the number of persons at risk and the number of injuries occurring among children is fraught with difficulty. Approximately 1.3 million persons younger than 20 years of age live on U.S. farms according to the 1991 Census [Rivara, 1997]. Employment and earnings statistics from the Bureau of Labor Statistics indicate that approximately 132,000 children aged 16–17 years labored on U.S. farms in 1995 [Arroyo, 1997]. A recent report indicates approximately 123,000 children aged 14–17 years work on farms [Kruse, 1997]. Similar estimates have been provided by the National Agricultural Workers Survey and the Current Population Survey [General Accounting Office, 1998].

There are approximately 100 fatal and 32,800 nonfatal injuries annually among persons under 20 years of age on U.S. farms [Rivara, 1997; U.S. Department of Agriculture, 1999]. Approximately 14–24% of fatal farm injuries are among children younger than 16 years [Heyer et al., 1992]. Hoskin and coworkers [1988] observed that children aged 5–14 were at increased risk for injury, and fatalities were increased among children younger than 15. Up to 40% of nonfatally injured children are left with a permanent disability [Cogbill et al., 1985; Swanson et al., 1987; Zietlow and Swanson, 1999; Reed and Claunch, 2000]. Data from 1991–93 show a mortality of $8.0/10^5$ child farm residents and an overall injury rate of $1717/10^5$ [Rivara, 1997]. In comparison to 1979–81 [Rivara, 1985], these figures represent a 39% reduction in mortality in the presence of a 10.7% increase in overall injury risk. Although the causes for this pattern is uncertain, improved medical care may contribute.

Several factors contribute to agricultural labor and injury among children. There may be an economic need for children to work, especially among migrant farm worker families [Slesinger and Ofstead, 1993; Wilk, 1993]. Piece-rate pay systems may facilitate child labor because payment is based upon total production, which may represent the work of more than one individual, including children. Lack of adequate child care facilities may force parents to bring children to work sites, where supervision in a dangerous environment is inadequate [Slesinger and Ofstead, 1993; Wilk, 1993]. Finally, the writ and enforcement of child labor law have historically been weaker in agriculture than in other industries [Slesinger, 1992; Wilk, 1993]. Under the federal Fair Labor Standards Act (FLSA) of 1938, it is legal for children as young as 12 to work full-time in agriculture during school breaks; 14 is the minimum age in other industries. Dangerous machinery may not be operated by persons younger than 18 in other industries; in agriculture the minimum age is 16 [Wilk, 1993]. Finally, the FLSA does not apply to children working on their family farm; minors of any age may be employed by their parents in this setting.

Epidemiologic data indicate that gender is an important factor in childhood agricultural injury risk. Rivara calculated national mortality rates of $21.5/10^5$ rural children per year for boys compared with $3.8/10^5$ for girls [Rivara, 1985]. A similar pattern was observed in a death certificate study in Wisconsin and Illinois [Salmi et al., 1989]. A preponderance of boys has also been reported in case series from Wisconsin [Cogbill et al., 1985; Stueland et al., 1991] and Minnesota [Swanson et al., 1987]. Age may be an important modifying factor: Stueland's study of 246 pediatric agricultural trauma patients in Wisconsin found approximately equal risks for boys and girls below the age of 6 [Stueland et al., 1991]. Above this age, boys were at 3–4 fold increased risk. Studies from Wisconsin have noted a bimodal age distribution, with peaks around age 4 and 14–16 years [Cogbill et al., 1985; Stueland et al., 1991]. Season and temporal factors are also important factors for agricultural injuries. Injuries are more likely to occur during

the summer months [Cogbill et al., 1991; Stueland et al., 1991] and on weekends [Stueland et al., 1991].

Studies from Kentucky [Stallones, 1989], Wisconsin [Cogbill et al., 1985; Stueland et al., 1991; Stueland et at., 1996], and Minnesota [Swanson et al., 1987] indicate that the most important causes of childhood agricultural injury are machinery, animals, and falls. The relative importance of each varies with age and sex. Stueland's pediatric trauma study noted that boys between the ages of 6 and 18 years were most likely to suffer machinery-related injuries, whereas girls were more likely to be injured by animals [Stueland et al., 1991]. This likely reflects the different pattern of farm chores for boys and girls [Cohen et al., 1996; Schulman et al., 1997]. A prospective study of Ontario farms noted increased risk for boys compared to girls [Pickett et al., 1995a]. Farm machinery was the most common cause (one-third of cases), and entanglement, usually of clothing, was the most often cited mechanism of injury. National Center for Health Statistics (NCHS) mortality data for 1990–95 also show a preponderance (73%) of males among children younger than 6 years fatally injured by farm machinery [Centers for Disease Control and Prevention, 1999]. Deaths were more likely to occur in the spring and fall when machinery is in use and parents are distracted by farm chores. Factors associated with childhood farm injury on Wisconsin farms included hours worked per week (per-hour odds ratio 1.05) and presence of a disabled safety device (OR 2.64) [Stueland et al., 1996]. The father's attitude was the strongest predictor of intention to expose children younger than 14 years of age to work hazards [Lee et al., 1997].

As for adults, childhood agricultural injury data reflect primarily the experience on family farms, and there are few data for hired farm workers or ethnic minorities. Schenker and coworkers [1995] studied death certificates of childhood fatalities in California. The study reviewed 40 unintentional traumatic deaths of children younger than 15 years occurring on farms with an International Classification of Diseases (ICD) code for injury (E800-949) between 1980 and 1989. Deaths occurring in a farm residence and traffic accidents were excluded. Although the study did not focus on farm workers, it categorized subjects as Hispanic and nonHispanic. Boys were at several-fold increased mortality risk compared to girls (1.2 vs. $0.4/10^5$ rural population), an effect that was observed in all age groups and for both Hispanics and nonHispanics. The rate for Hispanic boys was 70% higher than for nonHispanic boys (1.7 vs. $1.0/10^5$). Machinery accounted for 30% of deaths, with the largest portion of these (67%) involving tractors.

Prevention of childhood injury revolves around eliminating or minimizing contact between children and farm hazards. Younger children should have a safe, fenced play area removed from work activities, the farm should be inspected regularly and hazards corrected, barns and shop areas should be locked against entry by children, machinery should be turned off in a safe condition (e.g., hydraulic arms lowered) and the keys removed, and children should not be allowed to ride agricultural machinery [Centers for Disease Control and Prevention, 1999]. Operation of machinery should be restricted to older adolescents who possess the knowledge, skills, and ability to operate the machinery safely. The National Committee for Childhood Agricultural Injury and Prevention (URL: www.nagcat.org) has presented additional recommendations, including educational measures, funding of further research, adoption of voluntary guidelines, end enforcement of health, safety, and labor laws to reduce childhood injury [National Committee for Childhood Agricultural Injury and Prevention, 1996].

REGULATORY ENVIRONMENT

The farm environment poses special problems for injury control and regulation because it is nearly unique in its broad and changing array of occupational hazards. Unlike other industries with defined production lines and processes that can be engineered to minimize risk, farms have production tasks spread across a wide geographic area under changing or dangerous weather, light, and other environmental conditions. Risk is increased if machinery is poorly designed, inadequately maintained, or improperly operated.

Regulation of the agricultural work place is under the purview of several federal, state, and local agencies, making a coordinated approach to regulation difficult. The Fair Labor Standards Act of 1938 defines age limits for workers in agriculture and other industries and is under the auspices of the U.S. Department of Labor. Health and safety issues are addressed by federal or state OSHA agencies. Other governmental agencies may have jurisdiction in areas related to farm health and safety. For example, state Highway Patrol offices may be involved in regulating vehicles used to transport workers to jobs.

The regulatory challenge is compounded by the fact that the United States has a history of regulatory exemption for agriculture. For example, agriculture enjoys a de facto exception to federal regulation under the Occupational Safety and Health Act. Riders attached to funding bills for the federal OSHA have specifically prohibited the expenditure of funds to enforce workplace regulations on farms with fewer than 11 employees (the ''small-farm exemption'') [Aherin et al., 1992]. However, state OSHA agencies are not required to grant such exemptions and may regulate agriculture as they do other industries. Yet coverage for such a large and dispersed industry is daunting. For example, California comprises over 74,000 farms and retains only approximately 300 California state OSHA compliance officers, none of whom are dedicated to agriculture [McCurdy, 1997].

The increasing use of farm labor contractors as labor market intermediaries represents an additional regulatory challenge for health and safety among migrant farm workers. Approximately 30% of farm workers in California in 1994–97 were employed by farm labor contractors [Rosenberg et al., 1998]. Responsibility for health and safety, including Workers' Compensation insurance, has historically devolved to the contractor. However, recent regulatory developments make the employer jointly responsible [U.S. Department of Labor, 1997]. Farm workers' high degree of dependence on the contractor for employment, transportation, housing, and other amenities may hinder willingness to report work-related conditions.

PREVENTION

The agricultural work environment contains numerous sources of energy leading to injury risk in exposed populations. The ultimate aim of examining injury risk is to develop preventive approaches. A mechanistic model of injury epidemiology focusing on potential preventive interventions was pioneered by Gibson [Gibson, 1961] and refined by Haddon and others [Haddon and Baker, 1981]. According to this model, injury results when the agent, energy, carried by a vector, such as a machine, interacts with a host in an environment. Focusing on these factors furthers understanding of mechanisms and guides development of preventive approaches. The model recognizes preinjury, injury, and postinjury phases. Primary prevention focuses on the preinjury phase.

Primary prevention for the agent and vector revolve around engineering controls to reduce the amount of energy and likelihood that the human host will come in contact with it (Table VI). Examples include machinery shielding and ROPS on tractors. Engineering interventions can extremely effective in reducing injury risk. Sweden has nearly eliminated tractor rollover fatalities by requiring ROPS on tractors [Thelin, 1990; Reynolds and Groves, 2000]. Engineering controls must be carefully selected to assure their feasibility and ultimate adoption. Controls that are perceived to reduce production or hamper the work process are unlikely to be adopted and may be defeated [Miles and Steinke, 1996]. For example, ROPS may make it impossible to use a tractor in an orchard or in a barn with low door clearance, and power-takeoff shields may be removed by the operator because they interfere with necessary maintenance.

Measures aimed at the host population typically involve educational measures. Education may be emphasized over engineering control of hazards [Chapman et al., 1995], yet there are few data addressing its success in reducing injury incidence [Murphy et al., 1996; DeRoo and Rautiainen, 2000]. However, education may affect beliefs and attitudes, which have been correlated with injury risk in agriculture. Harrel [1995] conducted a survey of safety beliefs and

TABLE VI. Injury Risk and Prevention Among Agricultural Workers*

Agent (Energy: kinetic, mechanical, thermal, electrical, chemical) and Vector	Host population	Environment (Physical and social)
Factors contributing to injury risk		
Machinery and equipment ● Wide variety ● Potentially unsafe design ● Variable age and condition	Linguistic barriers Mistrust of officialdom and medical system	Dispersed and variable physical environment Wide variety of tasks and hazards
Farm animals	Economic barriers to care ● Lack of health insurance ● Inability to lose work time ● Transportation difficulties	Brief job tenure
Heights		Variable safety training
Chemicals		Time pressure
Electricity	Fear of jeopardizing employment and earnings	Difficulty in regulating 1.9 million widely dispersed U.S. farms
General preventive approaches		
Avoid or reduce use of high energy	Educate and train workers to utilize safety equipment and practices.	Prevent contact between host and energy source (e.g., improved engineering, protective guards, protective clothing)
Improve ergonomic design		
Develop engineering controls to prevent contact of human beings with energy		Proper maintenance of protective gear (e.g., seat belts, guards, power lockouts) Improve and enforce regulatory measures

*Based on the Haddon model [Haddon and Baker, 1981].

attitudes among 683 male Alberta farmers (participation rate: 53%). Attitudes characterized by risk-taking and belief in the inevitability of accidents were associated with farming-related injuries. Risk-reducing behaviors, such as use of protective clothing and operating machinery safely, were associated with lower injury risk.

Measures focused on the physical and social environment include engineering interventions, as described above, and regulatory efforts. Examples include proper use of farm equipment and child labor statutes and practices. Children should be kept away from moving or unguarded machinery, limited to tasks appropriate for age, and not allowed to accompany adults using machinery [Pickett et al., 1995a]. However, the regulatory framework for such practices is either absent or inadequate. Regulation and enforcement have been shown to reduce injury risk. For example, mandatory ROPS on tractors [Thelin, 1990] and lengthening of the period during which workers are not allowed contact with pesticide-treated crops in California [Mehler et al., 1992] have reduced occupational injury and illness rates. Regulatory efforts are currently limited by their practicality and acceptability among farmers and other agricultural groups.

Finally, research is of fundamental importance for injury reduction. Surveillance systems provide a rich source of information for hypotheses generation and testing. The National Institute for Occupational Safety and Health (NIOSH) has focused increasing attention to agricultural health through its programmatic support of regional agricultural safety and health centers (http://www.cdc.gov/niosh/agctrhom.html). In addition to supporting research and outreach for agricultural populations, including children, NIOSH maintains the National Agricultural Safety Database (URL:http://www.cdc.gov/niosh/nasd/nasdhome.html) of health and safety information resources in agriculture. The Canadian Agricultural Injury Surveillance Program (CAISP) also provides a useful model. Established in 1996, CAISP is a national registry of agricultural injury events [Hartling and Pickett, 1998]. The system provides for the ongoing monitoring and analysis of agricultural injuries in Canada. Investment in surveillance systems, descriptive and analytic epidemiological studies, and intervention trials to demonstrate effectiveness of safety interventions are critical to society's efforts to reduce the burden of injury in agriculture [Zwerling et al., 1997].

CONCLUSIONS

Agriculture is an important sector in the U.S. economy and has unique features relating to the work place and host population that contribute to injury risk. Existing data indicate that agricultural workers have an injury risk of approximately 5–10% per year. However, rates may differ significantly between certain subpopulations.

Engineering interventions to reduce the potential for contact between humans and excessive energy and to improve ergonomic conditions are most likely to be effective in injury reduction. Safety training should also play a role in preventive efforts, although further work is necessary to characterize and optimize its efficacy. Regulatory infrastructure, including enforcement of existing occupational health and labor regulations, is a critical component of prevention. Finally, continued research is essential to identify high-risk groups, examine risk factors, and develop and evaluate prevention strategies.

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