

**Ergonomics and Musculoskeletal Injuries in Agriculture: Recognizing and
Preventing the Industry's Most Widespread Health and Safety Problem**

Larry Chapman

University of Wisconsin-Madison, Wisconsin, USA 53706

James Meyers

University of California-Berkeley, California, USA 94720

Abstract

Emerging data suggest that agriculture faces a near epidemic of musculoskeletal disorders. While there is not good national data on the extent of these injuries and illnesses either within agriculture or relative to other industries, there is growing evidence that this problem likely exceeds all other types of injury and disease in the agricultural industry.

The 1988 National Health Interview Survey reported that workers in production agriculture were the most likely to report daily exposures to a variety of musculoskeletal injury hazards. Re-analysis of this data (Guo et al., 1999) shows that the reported one year period prevalence rate of back pain among individuals working in production agriculture was about one and one-half times higher than the average for all US industries. Data from another NHIS follow-up study (Leigh and Fries, 1992) reports that farming was the occupation most often associated with disability in females and the second most often in males.

Studies on agricultural workers in California (Meyers, et al, 1998, 2000) report rates of musculoskeletal disorder (MSD) incidence ranking among the highest risk industries and 100 times greater than rates suggested as industrial targets by NIOSH (Healthy People, 2000). These authors report incidence rates of 40 per 1000 workers in nursery and floriculture and 80 per 1000 workers in vineyard operations. For comparison, the nonagricultural industry sectors with the highest 1997 rates for repeated trauma disorder were meat packing plants (922 disorders per 10,000), knit underwear mills (910 disorders per 10,000), and motor vehicles and car bodies (711 disorders per 10,000).

At the same time, researchers have demonstrated that these potentially permanently disabling injuries are readily prevented using ergonomics approaches.

Farmers and farm workers face some of the highest risks of work-related musculoskeletal injury and disease in the nation. However, the problem is little recognized within or without agriculture and is not currently given high prevention and research priority by most farm safety groups or organizations. The information presented here should result in: 1) reprioritization of agricultural health and safety research and prevention priorities with musculoskeletal disorders at or near the top; 2) expanded funding and support for developmental engineering research on new technologies for critical field problems such as hand cutting of plant materials, stooped posture, and lifting and carrying of heavy materials; 3) development of an organized system of surveillance for musculoskeletal disorders in agriculture; and 4) funding and support for expanded field intervention and prevention programs in cooperation with farmers organizations and the Cooperative Extension Services.

The authors acknowledge the support of NIOSH in multiple funded agricultural studies in preparing this paper including RO1 CCR914508.

Ergonomics and Musculoskeletal Injuries in Agriculture: Recognizing and Preventing the Industry's Most Widespread Health and Safety Problem

More production agriculture workers suffer musculoskeletal disorders than any other type of injury or illness. Musculoskeletal disorders can also disable individuals at rates near or above those of traumatic injury, respiratory injury, pesticide intoxication, dermatological injury or other types of injuries and illnesses. Efforts to prevent musculoskeletal injuries must recognize that agricultural work is diverse and so agricultural ergonomics must bridge many specific problems with a flexible, generic approach. The rewards for careful attention to ergonomics include a more efficient production process, lower labor costs, reduced injury absences and turnover, and reduced expenditures for medical care and worker compensation as well as a reduced toll attributable to musculoskeletal injuries. With sufficient attention to the larger goals of whatever work is underway, investments in ergonomics can often pay for themselves many times over (Oxenburgh, 1997; 1991).

I. Introduction

In March 2001, agricultural health leaders should be easily able to recognize that the prevalence and human and economic costs of musculoskeletal disorders make them one of the highest agricultural safety and health priorities. Instead, musculoskeletal disorders in agricultural workplaces remain largely unremarked. Currently, they are overlooked in most surveillance and prevention programs.

Work-related musculoskeletal disorders are so common among experienced farmers and farm workers that many perceive them as no more than normal and inevitable consequences of farm labor. However, even when limited to the poor sources of data currently available on the extent of these injuries in agricultural workplaces, there is reason for new, high priority concern. We believe that the overall incidence of these injuries in the nation's agricultural workplaces likely exceeds 60 per 1000 workers, placing agriculture squarely among those industries with the highest recorded rates. This estimated incidence rate yields a total of over twenty times as many musculoskeletal injuries and illnesses as estimated pesticide injuries and illnesses in US

agriculture annually (Blondell, 1997). Musculoskeletal injuries and diseases likely affect the production agriculture workforce more frequently during their working years than any other safety and health problem. Disability due to musculoskeletal injuries and diseases incurred during their working years affect the production agriculture workforce more frequently and more severely than any other safety and health problem during the remainder of their working years and, for many, for the balance of their lives.

The direct health care costs alone of the estimated number of reported injuries are very conservatively estimated to exceed \$167,250,000 (6.69m workforce with an incidence rate of 5 per thousand and average cost of \$5,000). This figure does not include costs of lost productivity or the economic and human costs to the employers, workers, and families afflicted. Their true economic costs likely exceed those of any other category of agricultural injury or illness.

Finally, work-related musculoskeletal disorders are largely preventable, often with relatively simple and inexpensive modifications to work methods, tools, or tasks. In other instances, effective prevention may require rethinking work processes or arrangements. In either case, the payoff for improved prevention can often be measured in both improved work health and performance and improved productivity if thinking about prevention is juxtaposed with thinking about improving production practices.

Why are musculoskeletal disorders not our number one prevention priority in agricultural workplaces? This is the question we pose for agricultural health and safety professionals. Once the true extent, incidence, severity, and cost of work-related musculoskeletal disorders in American agriculture become more widely recognized, we believe this problem will become our highest farm safety priority.

II. Reference Points Found in *Agriculture at Risk*

When *Agriculture At Risk* was developed, there was almost no information available about the severity or extent of chronic musculoskeletal injuries and disease in production agriculture. Work-related musculoskeletal disorders develop slowly over months and years of repeated stresses. The risk factors themselves are ubiquitous, found in most jobs. Left unaddressed, musculoskeletal disorders can result in lifelong pain and permanent disability. As understanding about them has grown, recognition and diagnosis have literally exploded to make them the most frequent and most costly of work-related injuries in most industries. However, despite their growing priority among occupational health professionals, they have largely escaped recognition, prevention and control in most agricultural safety programs. While these injuries were known in 1987, they escaped notice in *Agriculture at Risk*.

III. Post-1987 Activities

As our understanding of musculoskeletal disorders has grown, so has our recognition of their widespread incidence to the point that they are now considered the most prevalent and costly of all work-related injuries (NAS, 2001, Bernard, 1997). Musculoskeletal disorders have been definitively associated with repeated or continued exposure to well-identified risk factors including: highly repetitive tasks, awkward positions of body segments and awkward whole body postures, heavy loads and avoidable material handling, sustained vibration, and other musculoskeletal disorder hazards. All commonly found in agricultural work.

By far the majority of research about work-related musculoskeletal disorders, involved risk factors and preventive strategies in agricultural workplaces has taken place since 1987. With a few exceptions, the majority of this work has been undertaken and performed by a few

multidisciplinary research and extension teams depending on open, competitive funding programs. Regulatory action in the form of state initiatives to improve prevention of work-related musculoskeletal disorders has been taken, first in California and later in Washington State, which included agricultural workplaces. However, proposed federal regulations have, regrettably, exempted agricultural workplaces.

IV. Accomplishments and Impacts

Accomplishments on this issue with respect to agricultural workplaces during 1987-2000 have been few. They have primarily focused on four areas: a) demonstration that agricultural workplaces feature high levels of exposure to known risk factors; b) initial evidence that persons working in agriculture exhibit high rates of musculoskeletal disorder incidence; and c) that an applied ergonomics approach working at the crop or commodity specific scale can have positive impact and be accepted by farmers and farmworkers, and d) that regionwide efforts to promote better labor aids and production methods can reduce exposures to musculoskeletal disorder hazards.

a. ergonomic hazards in agriculture

There is ample evidence of widespread exposure of those who work in agriculture to severe ergonomic risk factors on a daily basis. In many cases, risk factor exposures can exceed those found in some of the non-agricultural industries now commonly cited as among the most hazardous for musculoskeletal disorders. Meyers (1998b) in reviewing the work of the University of California Agricultural Ergonomics Research Center for the past decade has cited three general risk factors as both endemic and of highest priority throughout the agricultural industry. They are: lifting and carrying heavy loads (over 50 lb.); sustained or repeated full body

bending (stoop); and very highly repetitive hand work (clipping, cutting). Still, addressing them effectively will require treating each crop and commodity's tasks individually and developing interventions that are both acceptable to farmers and farmworkers and which have significant preventive impact.

Each type of production agriculture has its own unique ergonomic hazards and musculoskeletal injury problems, although some hazards are similar throughout production agriculture in general. It should be noted that while many of the types of hazards reported can be said to be of general industrial concern and for which some generic approaches to reduction have been developed, each agricultural commodity imposes unique and specific demands and conditions on the worker. This means that most interventions, even where patterned on proven existing strategies, must be individually addressed. As a result there simply are not now ready, off-the-shelf tools and technologies for addressing most workplace ergonomics hazards found in agricultural workplaces.

While by no means have all types of agricultural operations and workplaces been subject to risk exposure analysis, research in a number of differing types of crops and commodities clearly demonstrates the types of risk factors present and currently available controls in the form of work practices or labor aids (Chapman et al., 2001).

b. current information on the scope of musculoskeletal disorders in agriculture

While reliable information on injuries or even the size of the US agricultural industry's total workforce is very limited, there is reason to believe that the prevalence of musculoskeletal disorders among many of those who work in production agriculture tasks far exceeds those in many other industries.

According to the Census of Agriculture, there were 1,911,859 farms in the US in 1997 (US Department of Agriculture, 1999). Using 1987 USDA estimates of 3.5 employees per farm (admittedly low) we can estimate the population at risk as at least 6.7 million persons. The actual number is probably much higher.

The US Bureau of Labor Statistics collects annual data on musculoskeletal health problems but only from farms with eleven or more employees, and obviously only from those with diagnosed and reported disorders. A few other types of special studies are available but no comprehensive surveillance information exists. Farmers and farmworkers are not generally covered by worker's compensation insurance, so there is no incentive for reporting musculoskeletal injuries through insurance claims and little likelihood that this data can serve as a proxy for actual musculoskeletal problem incidence or prevalence rates. For a number of reasons, researchers suspect that any current estimate of musculoskeletal injury incidence rates for production agriculture is likely to be an underestimation. First, most information comes from larger farms while little is known about small operations where other injury problems have sometimes been found to be more prevalent than on larger operations. Second, researchers have documented cultural barriers (e.g. culturally inappropriate prompts and stoicism) to acknowledging the presence of injury and pain among both farmers and farmworkers. Finally, some researchers suspect a selection bias may be in operation in that workers who develop problems tend to leave agriculture for other work.

US Bureau of Labor reports (US Bureau of Labor Statistics, 1999) find a incidence of reported disorders of about half of that for private industry in general. However, it also an incidence of sprains and strains more than 20% higher the private industry average, a 12% higher incidence of back pain in agricultural work than that of the private industry average, and a

reported incidence of tendonitis equal to that for private industry. Combined with earlier noted concerns about these figures, we must suspect that real rates of musculoskeletal disorders for agriculture to be higher than estimated here.

In population-based studies that did not depend on employer reports, the agriculture forestry and fishing occupation group was the highest occupation group in reported exposures to musculoskeletal hazards (US DHHS, 1998). A 1988 National Health Interview Survey reported that the agriculture fishing and forestry occupation group was the most likely to report daily exposures to all of the types of musculoskeletal injury hazards asked about. When individuals working in production agriculture were separated from the agriculture forestry and fishing group, their back pain was in the top ten of all US industry subsectors (Guo et al., 1999). The reported one year period prevalence rate of back pain among individuals working in production agriculture was about one and one-half times higher than the average for all US industries.

A NIOSH Farm Family Health and Hazard Survey study of individuals working on small, family farms in Colorado, where over 90% of the operations had fewer than five employees, detected a one year period prevalence rate for back pain lasting a week or more of 26.2% (Xiang et al., 1999). This rate for Colorado farm employees was about two and one-half times higher than the National Health Interview Survey all industry average rate of back pain for males (10.7%).

Recent work by investigators in the University of California Agricultural Ergonomics Research Center using musculoskeletal pain and symptom surveys with hired farm workers in the plant nursery and wine grape vineyard industries suggested very high rates of musculoskeletal disorder incidence. Their work (UC AERC, 2000) indicated rates that placed these agricultural jobs among the nation's very highest risk jobs. Their survey of 1290 plant

nursery works suggested a rate of 400 per 10,000 workers. Their survey of 194 wine grape vineyard workers suggested a rate of 800 per 10,000 workers. While these results are limited because the surveys were not randomly taken across the populations at risk, they nonetheless point to rates that place these jobs squarely among the highest risk jobs recorded. For comparison, the nonagricultural industry sectors with the highest 1997 rates for repeated trauma disorders (not shown in the table) were meat packing plants (922 disorders per 10,000), knit underwear mills (910 disorders per 10,000), and motor vehicles and car bodies (711 disorders per 10,000) (US Bureau of Labor Statistics, 1999).

Data from a National Health Interview Survey follow-up study in 1982-1984 was used to estimate which occupations were associated with the greatest amount of musculoskeletal disability from the longest held jobs of individuals in a national probability sample (Leigh and Fries, 1992). Farming was the occupation most often associated with disability in females and the second most often in males. Farming was also associated with the second highest severity of disability of all occupations among women and the fifth highest for men.

Despite surveillance limitations the available evidence makes clear that musculoskeletal health and hazard problem rates for some types of agricultural work far exceed the average for all private industries and for some groups approaches the nation's highest rates. Certainly they appear to exceed the rates of other high priority farm safety issues such as pesticides and should be accorded a much higher prevention priority and level of research and development interest. Recently a few observers have begun to note that prevention of musculoskeletal disorders should be among the very highest of agricultural health and safety priorities (Villarejo and Baron, 1999). When asked, farmers and farmworkers with chronic back injuries readily agree.

c. successful intervention programs in agricultural workplaces

Ergonomics is the applied science of fitting tools and tasks to the persons performing them in such a way that the strengths of the human body and psychology are maximized and exposure of weaknesses to stressors is minimized. In the past decade a few small multidisciplinary teams of researchers and extension staff have undertaken efforts to develop organized intervention and prevention programs based on an ergonomics approach to the problems of specific tools and tasks encountered in agricultural workplaces. These programs have been largely successful in developing low-cost intervention strategies, which have proven acceptable to farmers and farmworkers, which have also proven effective at significantly reducing specific risk exposures. A forthcoming NIOSH publication entitled *Simple Solutions* highlights many of the most successful of these interventions (Baron et al., 2001).

Keys to success in this work have been: 1) cooperative partnership with involved farmers and farmworkers throughout intervention development and trial; 2) applied focus on commodity or crop specific tasks and tools; 3) intervention evaluation focused on health as well as ergonomics outcomes; and 4) fitting interventions to accepted production methods to encourage adoption and minimize worker displacement.

d. regional industry-wide interventions to encourage adoption of work methods and labor aids that can prevent musculoskeletal disorders

Well-designed interventions have successfully persuaded some farm managers of dairy operations in Wisconsin and managers of fresh market vegetable operations in Minnesota, Wisconsin, Illinois and Iowa to adopt production practices and labor aids that reduce exposures to musculoskeletal injury hazards (Chapman et al., 2000). These two regional efforts have fairly

convincingly demonstrated that once musculoskeletal problem solving solutions are identified, they can be successfully promoted to entire states or regions. The crucial factor was having a group of research scientists coupled with outreach specialists, pilot farmers and agricultural specialists all funded to work toward the same purpose: identification, control, and industry-wide prevention (and intervention evaluation) of musculoskeletal disorders in specific agricultural commodity areas. In addition, focusing on the promotion of production methods and labor aids that were not only safer but also sustained or improved production efficiencies insured popularity with farm managers.

V. Gaps and Future Needs

While many generic strategies for the elimination or reduction of workplace ergonomics risk factor exposure have been demonstrated and published in other industries, such work in agriculture remains largely unaddressed (NIOSH, 2001). Further, because agricultural workplaces and tasks vary significantly by season, commodity, geography and production method, there are literally hundreds of distinct situations and work processes involved.

a. surveillance

As has been indicated in this report, organized surveillance of the musculoskeletal disorder problem in agriculture is virtually non-existent. Currently, annual Bureau of Labor Statistics data are inadequate for determining the extent and severity of musculoskeletal disorders and other work-related health problems. (e.g. Occupational Injuries and Illnesses: Counts, Rates and Characteristics, 1997. Washington DC:US Department of Labor Bureau of Labor Statistics.

1999). The data now available: 1) reflect only large farm experience (i.e. only employers with 11 or more employees are required to report) and 2) the numbers of even large employers reporting in agricultural sectors are so few that cell sizes are often too small to allow rate calculations.

Since the current BLS employer-based reporting system is inadequate, one option would be to try to fix it by trying to include small farm employers. This could be difficult and would undoubtedly encounter political resistance. A second option would be to address injury and illness reporting in the agricultural sector with a provisional system until some new BLS-based solution could be worked out. For instance, one suggestion is adding an occupational injury and illness reporting supplement to the annual National Health Interview Survey. This has been done before on a one-time basis for all occupations. We suggest that this method be used only for employees and managers in production agriculture. The technical aspects are workable. Additional costs should be shared by the Bureau of Labor Statistics and/or other agencies interested in agricultural occupational health.

b. identification and control

While it is logical and useful to apply general strategies to generally similar tasks, significant development and application work is usually required to result in effective intervention. For example, while use of air powered cutters has been clearly shown to be effective in meat cutting, transfer of that technology to a high priority agricultural task such as making cuttings for plant propagation cannot yet be made practically. One of the involved problems is that workers in making plant cuttings work much faster than any currently available air powered shears tested so far. So far no existing air powered shears tested have proven adequate for this task. This problem extends to a wide range of agricultural pruning, weeding, and harvesting tasks. There is

a priority need for developmental engineering work on alternative technologies for these and other tasks. To date there is no standing funding program for developmental engineering research in applied agricultural ergonomics.

While many other such examples might be cited, the important point is that we cannot count on the immediate transfer of even known preventive technologies to many agricultural tasks. Of the triumvirate of risk factor priorities cited earlier, the problem of addressing the many types of hand cutting tasks in agricultural operations stands near the top. Development and application of new cutting technologies are desperately needed. Portable power systems that can be readily used in the field, up trees, or in other awkward situations are needed. When one turns ones attention to the many situations of awkward postures involving extreme forward bending (stoop) found in agricultural work the need for developmental and applied research is similarly broad and urgent. For the worst tasks (e.g. hand strawberry harvest) there simply are no proven strategies to turn to. For others, the answers may lie in development of a new series of small machines and related work process reorganization. At this time, however, there are no sponsored research programs for small agricultural machinery development. The third type of risk factor cited is lifting and carrying of heavy loads. This is one priority that has been most successfully addressed in the field so far. Lightening loads and changing handling technologies are, by contrast with the other areas, fairly well researched areas. In most cases, what is needed here is field trial and application of proven concepts. However, what has been shown to work for winegrapes does not fit plant nurseries or dairies. Each crop and commodity presents distinctly different design demands that must be addressed if the intervention is to be both acceptable and effective.

There is urgent need for both developmental and field application and trial research on crop and commodity specific interventions. Such work must be performed in a cooperative manner with the targeted farmers and farmworkers as active participants. Without their participation, interventions are much less likely to prove field practical or acceptable, which means that they simply won't be widely used.

c. prevention, intervention, and intervention effectiveness evaluation

In addition to the desperate need for increased developmental and application research there is an equivalent need for increased extension of emerging interventions. The extension-related problems are at least two-fold in nature. First, and less obviously, there is need to interact on a continuing basis with the commercial companies that are expected to produce and market emerging interventions. This applies especially to those that are crop or commodity specific in focus. Such markets may be small in the scope of national marketing organizations. There are already examples of successful and proven interventions that are not being commercially produced or marketed because the markets are too small or because producers of conventional technologies and tools see little profit in retooling production lines. The answers may lie in developing partnerships with small, local technology producers. However, in any case, new and aggressive extension efforts aimed at involving tool and technology companies are needed.

Second, new extension funding and programs are needed to expand the focus of farm safety programs and existing production programs to recognize and address the problems presented by poor ergonomics in terms of both production inefficiencies and worker health and safety. Farmers and farmworkers are well aware that many tasks they must perform are awkward, difficult and even dangerous. However, they are generally not aware that the risk

factors involved in such tasks can be addressed with ergonomics, nor are they prepared to exercise an ergonomic vision of their work. On the positive side, these are not overly difficult things to teach. But, they are sufficiently new and different from the conventional view of commonly accepted tasks and tools that no one should long believe that simple pamphleteering by itself will accomplish the job. It will require knowledgeable and trusted agents interacting with farm owners, operators and workers on extended terms to change the farm community's perspective on both these common injuries and the necessary ways of analyzing and thinking about tools and tasks involved.

VI. Policy Implications

The challenges and demands to making nationally measurable progress in reducing the current epidemic of musculoskeletal injuries and diseases among farmers and farmworkers are significant. Still with what has already been learned about an ergonomics approach to prevention in other industries we know that much of the current burdens of human disability, lost productivity and income, and increased costs can be readily prevented with appropriate investment and effort. When you add the demonstrable fact that what is targeted is the group of most common and most costly work-related injuries and diseases in the industry, it seems inconceivable that we should continue to choose otherwise.

First, there is need for a reprioritization of current agricultural health and safety priorities, with musculoskeletal disorders at or very near the top of the list. It is important that NIOSH, USDA and other involved agencies make this recognition formal.

Second, there is urgent need for expanded engineering developmental research on alternate technologies for the critical field problems of materials cutting, repetitive and forceful tasks such as shoveling or weeding, stooped posture and lifting and carrying of heavy materials. In particular, the USDA should establish a National Research Priority Program in this area.

Third, there is urgent need for development of some organized system of surveillance for musculoskeletal disorders in agriculture. This surveillance will need to be able to identify and account for developing as well as diagnosed disorders.

Fourth, there is urgent need for new and expanded field intervention and prevention programs to be conducted at the specific crop or commodity task level. Such programs must take advantage of the national Land-Grant University system for agricultural research and extension and focus on cooperative partnership with farmers, farmworkers and the organizations that represent them. New levels of funding will be required for this effort. If new funding cannot be found in the near term, then funds and resources should be redirected to this work from lower priorities by major funding agencies. Funding in this area should be allocated on a regular competitive basis open to any public organization with demonstrated capability for conducting the work effectively.

References

- AERC, U. C. (2000). California Vineyard Ergonomics Partnership Project Final Report (NIOSH). Davis CA: University of California, Davis.
- Baron S, Estill. C., Steege A, Lulich N. (in press 2001). Simple solutions: ergonomics for farm workers. Cincinnati OH: US National Institute for Occupational Safety and Health.
- Bernard, B. (1997). Musculoskeletal Disorders and Workplace Factors. Cincinnati OH: National Institute for Occupational Safety and Health.
- Blondell, J. (1997). Epidemiology of pesticide poisonings in the United States, with special reference to occupational cases. Occup. Med., 12, 209-220.
- Chang S, Park. S, Freivalds A. (1999). Ergonomic evaluation of the effects of handle types on garden tools. International Journal of Industrial Ergonomics, 24, 99-105.
- Chapman LJ, Josefsson. K., Meyer RH, Newenhouse AC, Karsh B, Miquelon M. (2000). Intervention research to reduce injuries on dairy, berry, and fresh market vegetable farms. Cooperstown NY: NIOSH.
- Chapman LJ, Karsh. B., Meyers J, Newenhouse A, Meyer B, Miles J, Janowitz I. (in press 2001). Ergonomics and Musculoskeletal Injuries in Agriculture. In D. P. a. S. Reynolds (Ed.), Cooperative Agricultural Safety and Health: An Identification of Problem Areas in the Agricultural Environment. Cincinnati OH: American Conference of Governmental Industrial Hygienists.
- Duraj V, Miles. J., Meyers JM. (1999). Development of a conveyor-based loading system for reducing ergonomic risks in manual harvest of wine grapes. Paper presented at the 1999 Summer ASAE Meeting, Toronto, Ontario Canada.
- Fitzpatrick, J. (1979). Strawberry picking - an appropriate way. Appropriate Technology, 6(2), 4-5.
- Gite, L. (1990). Quality of work life of farm workers and ergonomics. Agricultural Engineering Today, 14, 5-17.
- Guo H, Tanaka. S., Halperin W, Cameron L. (1999). Back prevalence in US industry and estimates of lost workdays. American Journal of Public Health, 89, 1029-1035.
- Healthy people 2000. (1991). National health promotion and disease prevention objectives. Washington, D.C. : U.S. Department of Health and Human Services, Public Health Service.
- Hendrix, A. (1986). The pipe-rail system in glasshouse vegetable-cropping. Acta-Horticulturae, 187, 137-143.
- Hilton, W. (1997). Ergonomic job design in the hog industry. In J. Kohn (Ed.), The Ergonomic Casebook. NY: Lewis.
- Janowitz I, Miles. J., Tejada D, Miles, J, Duraj V, Faucett J, Kabashima J. (1998). Reducing risk factors for the development of work-related musculoskeletal problems in nursery work. Applied Occupational & Environmental Hygiene, 13(1).

Josefsson G, Miquelon. M., Chapman L. (1999a). Long day lighting for dairy housing: a work efficiency tip sheet. Madison WI: University of Wisconsin Biological Systems Engineering Department.

Kabala WP, Giacomelli. G. (1992). Transportation and elevation system for greenhouse crops. Applied Engineering in Agriculture, 8(2), 133-139.

Leigh J, Fries. J. (1992). Disability in a national sample. American Journal of Public Health, 82, 1517-1524.

Lundqvist P, Pinzke. S., Gustafsson B. (1992). Ergonomic factors in the work situation for AI-technicians on animal farms. In S. Kumar (Ed.), Advances in Industrial Ergonomics and Safety IV (pp. 129-134): Taylor and Francis.

Lundqvist P, Stal. M., Pinzke S. (1997). Ergonomics of cow milking in Sweden. Journal of Agromedicine, 4(1/2), 169-176.

Meyer RH, Newenhouse. A., Chapman LJ. (1999c). Work Efficiency Tip Sheet on Specialized Field Carts. Madison WI: University of Wisconsin Biological Systems Engineering Department.

Meyer RH, Newenhouse. A., Chapman LJ. (1999a). Mesh Produce Bags Easy Batch Processing: A Work Efficiency Tip Sheet. Madison WI: University of Wisconsin Biological Systems Engineering Department.

Meyers J, Bloomberg. L., Faucett J, Janowitz I, Miles JA. (1995). Using ergonomics in the prevention of musculoskeletal cumulative trauma injuries in agriculture: learning from the mistakes of others. Journal of Agromedicine, 2(3), 11-24.

Meyers J, Miles. J., Faucett, J, Janowitz, I, Tejada, D, Weber, E, Smith, R, Garcia, L. (1998). Ergonomics risk factors for musculoskeletal disorder in wine grape vineyard work. Paper presented at the National Institute for Farm Safety, Winnepeg, Canada.

Meyers J, Miles. J., Faucett J, Janowitz I, Tejada D, Duraj V, Kabashima J, Smith, & R, W. E. (1998). High risk tasks for musculoskeletal disorders in agricultural field work. Paper presented at the American Public Health Association, Washington, DC.

Miles J, Meyers J, Faucett J, Janowitz I, Kabashima J, Tejada D, Duraj V. (1997). Tool design parameters for preventing musculoskeletal injury in nursery work. Paper presented at the ASAE Annual International Meeting, Minneapolis MN.

Miles J, Steinke. W. (1996). Citrus workers resist ergonomic modifications to picking ladder. Journal of Agricultural Safety and Health, 2(1), 7-15.

NAS. (2001). Musculoskeletal Disorders and the Workplace: Low Back and Upper Extremities. Washington DC: National Academy of Sciences, National Research Council.

Nevala Puranen N, Taatola. K., Venaelaenen-Juha M. (1993). Rail system decreases physical strain in milking. International Journal of Industrial Ergonomics, 12, 311-316.

Nevala-Puranen, N. (1995). Reduction of farmers' postural load during occupationally oriented medical rehabilitation. Applied Ergonomics, 26(6), 411-415.

Newenhouse AC, Meyer. R., Chapman LJ. (1999). Standard Containers: A Work Efficiency Tip Sheet. Madison WI: University of Wisconsin Biological Systems Engineering Department.

NIOSH. (2001). National Occupational Research Agenda for Musculoskeletal Disorders (Pub. No. 2001-117). Cincinnati OH: DHHS(NIOSH).

Oxenburgh, M. (1997). Cost-benefit analysis of ergonomics programs. American Industrial Hygiene Association Journal, 58, 150-156.

- Oxenburgh, M. (1991). Increasing Productivity and Profit Through Health and Safety. North Ryde NSW Australia: CCH International.
- Prussia, S. (1985). Ergonomics of manual harvesting. Applied Ergonomics, 16, 209-215.
- Scott GB, Lambe. N. (1996). Working practices in a percherysystem, using the OVAKO working posture analysing system (OWAS). Applied Ergonomics, 27(4), 281-284.
- Stal M, Moritz., U, Gustafsson B, Johnsson B. (1996). Milking is a high risk job for young females. Scand J Rehab Med, 28, 95-104.
- US Bureau of Labor Statistics. (1997). Occupational Injuries and Illnesses: Counts, Rates and Characteristics, 1997. Washington D.C.: US Department of Labor, BLS.
- Stoffert G, Wildt. U. (1987). Work physiological investigations of potplants handling on the ground. Acta Horticulturae, 203, 95-100.
- Therriault, R. (1988). Design of a harvesting-aid for strawberries. Paper presented at the American Society of Agricultural Engineers.
- Therriault R, Moueddeb. B., Trigui M. (1990). Power handling and self-steering for a strawberry harvesting-aid. Paper presented at the American Society of Agricultural Engineers.
- Univ. of Wisconsin,. (1999). University of Wisconsin Healthy Farmers, Healthy Profits Project. Madison WI: University of Wisconsin Biological Systems Engineering Department.
- USDA. (1999). 1997 Census of Agriculture. Washington D.C.: US Dept of Agriculture.
- USDA. (1990). Characteristics of Agricultural Workforce Households. Washington DC: US Dept of Agriculture.
- Villarejo D, Baron., SL. (1999). Occupational health status of hired farm workers. Occupational Medicine, 14, 613-635.
- Wick, J. (1992). Ergonomic analysis and evaluation of lemon picking. In K. S (Ed.), Advances in Industrial Ergonomics and Safety IV. Washington DC: Taylor and Francis.
- Xiang H, Stallones. L., Hariri S, Darragh A, Chui Y, Gibbs J. (1999). Back pain among persons working on small or family farms -- eight Colorado counties, 1993-1996. Morbidity and Mortality Weekly Reporter, 48(45), 301-304.