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# Accessing and operating agricultural machinery: Advancements in assistive technology for users with impaired mobility

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**ABSTRACT**

This research focused on the advancements made in enabling agricultural workers with impaired mobility to access and operate off-road agricultural machinery. Although not a new concept, technological advancements in remote-controlled lifts, electronic actuators, electric over hydraulic controllers, and various modes of hand controls have advanced significantly, allowing operators with limited mobility to resume a high level of productivity in agricultural-related enterprises. In the United States, approximately 1.7% of the population is living with some form of paralysis or significant mobility impairment. When paired with the 2012 USDA Agriculture Census of 3.2 million farmers, it can be extrapolated that these technologies could impact 54,000 agricultural workers who have encountered disabling injuries or disease, which inhibit their ability to access and operate tractors, combines, and other self-propelled agricultural machines. Advancements in agricultural-specific technologies can allow for many of these individuals to regain the ability to effectively operate machinery once more.

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accessibility; controls; disability; ergonomics; impairment; safety

## Introduction

Since 1979, Purdue University's Breaking New Ground (BNG) Resource Center has been involved in helping agricultural producers with physical disabilities safely and effectively access and operate their machinery through the application of assistive technology (AT). This has included conducting basic research, design, and concept recommendations. Although some of the early designs and concepts have changed little over time, the arena of AT continues to develop through such advances as user-control interfaces, electronic valves, universal designs, and more reliable, robust AT components.

When it comes to their machinery, farmers and ranchers with impaired mobility must rely heavily on AT, or the assistance from others, in order to access the operator's station and to manipulate the controls. The specific technologies this paper focuses on are the safe, independent, and efficient operation of self-propelled equipment.

There are numerous types of physical impairments that require AT intervention if one is to regain the ability to operate agricultural machinery. The most common are spinal cord-related (resulting in paraplegia or quadriplegia), back-related, arthritis/neuromuscular-related, and amputation-related disabilities. (Field, 1992) According to Yoder, Stoller, and Field (2000), an estimated 250–300 farm and ranch operators in the United States experience a permanent spinal cord injury each year. Currently, approximately 1.7% of the total US population lives with some form of paralysis (Armour et al., 2016). Applying that percentage to this nation's approximately 3.2 million farmers/ranchers puts the number of individuals who would benefit from agricultural equipment modifications at around 54,000 (USDA, 2014).

## Barriers to accessing agricultural equipment

The evolving trends in production agriculture lend to designs of machinery and implements capable of efficiently covering vast areas of land. Associated with this capability is often the increased size of machinery and implements. The large stature of such machinery introduces barriers, or at minimum difficulties, for some users to gain access to the operator's station due to the numerous steps or ladder rungs, height of the initial step, narrow door openings, or lack of sufficient handholds for adequate stability. Some of these barriers can be corrected with low-cost interventions such as an additional step and/or the addition of a handrail both outside and inside the operator's station.

For operators with severe mobility impairments, more extensive intervention measures must be taken to ensure the safe transfer of the user from ground level to the operator's seat. The recommended method, encouraged by Assistive Technology Professionals (ATPs), Rural Rehabilitation Specialists, and numerous studies conducted by BNG, is through the use of machine-accessing lifts.

### *About machine-accessing lifts*

A lift specifically designed to transport one up and into the operator station is, by far, the safest machine-accessing method for both the user and/or the assistant in avoiding secondary injury. Among the less-conventional—and most

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risky—options include the operator being carried by an assistant, the operator being lifted via front-end loader or forklift on another machine, and the operator being somehow conveyed up a stationary ramp to the cab entry level.

This section will cover the most common styles and types of lifts driven by consumer demand, as well as the benefits/ideal scenarios and limitations for each, technological advancements in both design and operation of lifts, and finally, recommendations and safety considerations for selecting the appropriate lift to best fit user intent.

## Styles and types of lifts

There are three different lift styles (i.e., ways of transporting one up to the operator station) and two different lift types (i.e., lifting system structures and components) commonly used in industry. The three styles are the *sling lift*, the *platform lift*, and the *chair lift*; over the years, these have changed little from the early models. However, the types of lifts (and their attendant technologies) have changed considerably, with the two distinctly different ones being the *dedicated-machine lift*, which is mounted directly to a particular piece of equipment, and the *independent* or *mobile lift*, which is mounted to a pickup truck or trailer that is pulled alongside of the machine to be accessed. The next sections provide a discussion of, first, the three styles and, then, the two types.

### Sling lift

The sling lift transports the operator to the desired location using a mesh, fabric, or woven strapping sling suspended from a specialized hanger overhead. This style of lift is ideal for situations where space is limited (e.g., skid-steer loader cab, horse mounting) or when transfer from one seat to another is physically difficult. In some situations, if the operator is not capable of transferring, the sling can be detached from the support structure and left on the seat during operation of the machine. With a sling lift, caution must be exercised and consideration be given to avoid burses, pressure sores, or other secondary injuries. One should look for a model that has added padding and weight-disbursement characteristics. A winch-powered vertical sling lift could be mounted (a) on a mast on the exterior of the operator platform, (b) on a telescoping beam on the interior of the platform or cab, (c) on a roller track of an overhead beam in the machinery shed, which would allow the user to be lowered into the operator seat from above, or (d) to a parallel linkage fixture mounted to the floor of a building.

### Platform lift

(Figure 1) Designed to accommodate a wheelchair or flip-down seat or the operator in standing position, this style lift allows one to be positioned on a platform and then be lifted to the level of the operator station. It is often used in situations where the user has the ability to walk on level surfaces but has difficulty in climbing the stairs or steps that are associated with accessing most machinery.

### Chair lift

(Figure 2) The chair lift is perhaps the most popular style of lift for individuals with significant mobility impairments. To use it effectively, the operator must be able to transfer him-/herself from one seated position to another, i.e., first at ground level from wheelchair or vehicle to lift chair and then at the operator station level from lift chair to operator seat. One exception occurs with some models of tractors where the lift seat of the dedicated lift is dual purposed as the driver's seat of the tractor.


**Figure 1.** Platform lift with fold away platform to allow for conventional ladder use.

## Lift types

### Dedicated-machinery lift

(Figure 3) A dedicated-machine lift is mounted directly onto and used to access just one piece of equipment. It's commonly found in either a chair or a platform configuration attached to a vertical mast and powered by the machine's electrical system. The main benefits of the dedicated lift are: (1) the operator being able to enter/exit the machine at any time, and (2) a design (often a universal design) that has but few limitations as to movement, which allows it to be mounted to several different machinery types—and often to preexisting mounting points on their frames. Both the chair lift and the platform lift can be used on tractors, combines, and other machines with or without cabs. Moreover, the lift assemblies can be transported high enough above the ground level so as to avoid field crop residue during equipment operation and yet can be lowered to a position that allows easy transfer to or from a wheelchair.


**Figure 2.** Vertical-mast chair lift with hanger bracket for walker storage.

**Figure 3.** Dedicated-machinery lift with wired controller.

### *Independent lift*

(Figure 4) Being mounted to the bed of a pickup truck or a trailer (vs. onto one specific machine), the independent- or mobile-type lift offers the advantage of allowing the user to access multiple pieces of equipment not only for entry, but also for fueling and other maintenance activities—and without having to make any alterations. Its lift arm features a telescoping section that extends into the operator station, which both makes for easier transition and allows the lift to be positioned at a greater distance from the machinery.

While independent/mobile and dedicated lifts offer various benefits to the user (in addition to those noted above), there are also limitations to be aware of. Table 1 lists some further pros and cons the potential user should consider in his/her decision-making process.

## *Technological advancements in lift design/operation*

Lift designs have undergone many renditions. A brief summary of the most important ones—drive mechanisms, power sources, control-user interface, and optional accessories—is provided next, all of which have led to increased mechanical reliability, safety, and precision placement of the user.

### *Drive mechanisms*

Early designs commonly utilized parallel linkages, incline rail drives, and ball-screw drives. The first two (parallel linkage and incline rail) were not compact, had limited linear travel (to best position the user in near proximity for easy transfer), and did not always allow for the range of vertical motion necessary. Ball-screw drives, on the other hand, delivered high torque with relatively low power demands and provided the fail-safe benefit of preventing free-fall if malfunction occurred (Yoder et al., 2000). However, issues developed with the collection of residue on the drive components and the speed of operation was slower than users desired; thus, ball-screw lifts are generally limited to light-duty designs (Figure 5).

Today, the drive mechanism of choice for vertical-mast lifts is a roller chain coupled with a slip clutch in the gearbox and powered by an electric motor. This design allows for a range of customizable heights in order to match the machine to which it is mounted. The roller-chain drive mechanism is also less expensive, relatively low maintenance, and very durable.

**Figure 4.** Independent truck-mounted lift.

**Table 1.** Benefits and potential limitations of machinery-dedicated and independent lifts.

| Lift type | Benefits/ideal scenarios | Limitations |
|---|---|---|
| Machinery-dedicated lift | – With newer machinery, can pair operational life of lift to host machine; additional benefits are realized in the use of hand controls.<br>– Large operator station provides room to maneuver operator for easy transfer.<br>– Bracketry and mounting locations already exist on tractors that accommodate front-end loaders or saddle tanks.<br>– Tractors having observer/buddy seats provide additional space for easy transfer.<br>– Wide door openings allow for easier maneuverability. | – With short wheelbase tractors, it's difficult to fit components.<br>– 4WD tractors create pinch points from articulated steering.<br>– Dual front-wheel tractors have limited space when turn limits mast location.<br>– Open-station tractors with large fenders.<br>– Mechanical failure of the host machine limits operator to using only equipped machinery. |
| Independent/mobile lift | – Great range of motion—e.g., 12 foot up and 14 feet out.<br>– Allows access to all machines with the investment of a single unit.<br>– Access gained to other locations, in addition to ground level to the operator station.<br>– Reduces number of transfers.<br>– No obstructed visibility by mounted fixture.<br>– No modification of machinery needed.<br>– Operator not limited to 'equipped machinery.' | – Equipment must be located next to the lift for entry/exit.<br>– Difficult/dangerous emergency exit when out of range of lift.<br>– More expensive than vertical-mast units. |

### Power sources

Over the years, the two main sources of power for lift technology have been electric and hydraulic. Today, nearly all the newer lifts are electric powered; even where hydraulics are utilized, they are often powered by an independent electric pump. The electrical system is easily accessed on machinery without the engine running, which greatly improves the safety of lift-equipped machines. Early hydraulics-only lifts required the machine to be started from the ground *(with a secondary ignition switch)* to power the lift. Serious safety concerns with this design stemmed from the possibility of the machine being left in gear, thus increasing the potential for runovers.

With independent lifts, electric-powered hydraulic systems control their movement through the use of electronic valves and feature telescopic extension seats for closer transfers. It is now possible to automate their functions via use of electronically controlled hydraulic valves. A common request of independent-lift users is the ability to preprogram automatic destinations; development of this 'ability to preprogram' is well under way and should be available in the near future. The chief design engineer at Life Essentials, a leading manufacturer of agricultural mobility products, affirms that the exact-movement tracking capability of new model truck lifts will allow for preprogrammed buttons to automatically position the lift chair in a: (1) door-ready position (i.e., a location outside the driver-side door of a pickup truck for easy transfer onto the lift) and (2) return to the storage position Begley & Begley (2017).

### Controllers

All lifts mentioned here are controlled by some form of wired or wireless electrical device. On the newest models, only platform lifts are controlled by wired switches, while the chair and sling lifts are controlled by a wearable wireless controller fob (Figure 6). The wireless fob can operate the lift for some 30–35 hours on a single charge and will control the lift for 5 minutes on as little as a 1-minute charge. These controllers are industrial grade so they can withstand a punishing agricultural environment and use a micro USB port to recharge (as readily available as the charger type of many cell phones).

The range of wireless controllers is considerable. This offers users the ability to position independent lift seats either from another piece of machinery or from inside their vehicle. Being able to wireless-control the lift benefits both the dedicated-machine and independent models, since the operator is able to

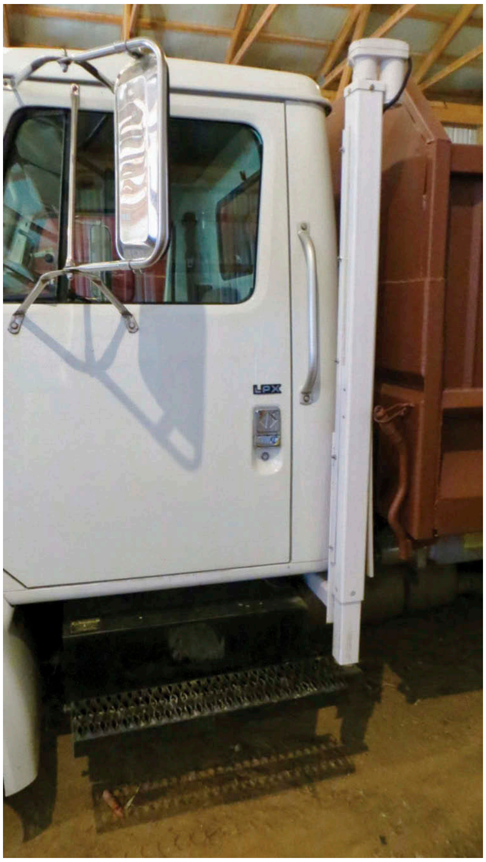

Figure 5. Ball-screw drive step lift.


Figure 6. Wireless control fob.

move the seat to a more appropriate storage position, to maximize visibility during field operation, and to close the cab door.

### Optional accessories

Lighting and cameras are available as optional accessories but potentially important ones. As the demands of agriculture often require farmer/ranchers to work into the evening or night, the proper positioning of lift components can be difficult—and potentially dangerous—in low-light situations. Modern lighting technology allows for lifts to be equipped with low-power LED lights, which add little burden to the host unit's electrical system while providing a well-lit work zone. Limited viewing angles can occur with users' truck-mounted and trailer-mounted independent lifts during operation and positioning. Properly located cameras allow users to better manipulate and view areas of near proximity when direct sight lines are not available.

## Recommendations for selecting a lift

Based on in-house designs, research, use of expert panels, and evaluation of homemade and commercial lifts, BNG has developed the following criteria for a machinery-access lift that meets both the safety and utility needs of the user: (Field, 1992; Yoder et al., 2000)

- A seat, platform, or sling to lift the user from ground level to the cab in a position that would facilitate easy transfer onto the operator's seat.
- Easy installation, with minimal alterations to the original equipment and minimal interference with user's vision. (An attached lift should not hinder the equipment's efficiency or function during operation.)
- A lift speed of approximately 3–4.8 meters (10–15 feet) per minute, and a load capacity of at least 136 kg (300 pounds).
- A fail-safe device that would protect the user in the event of power or drive-mechanism failure.
- An unobstructed path to the machine operating position. ('Unobstructed' includes guarding against pinch points, sharp edges, and protruding objects—all of which could cause injury or difficulty during use.)
- A power-limiting clutch or switch to minimize the chance of user injury or machine damage during operation.
- Safe exit alternatives in the event of an emergency.
- Flexibility, so that any able-bodied persons would not be significantly hindered when using the lift-equipped machine.
- Moderate cost such as to encourage the user to select a well-designed lift.

## Safety considerations in lift selection and operation

Operator safety is the utmost concern relative to the design and use of modern lifts. In the event of lift malfunction, a well-designed lift should possess both fail-safe devices to prevent free-fall and limiting switches to de-energize movement if the operator or lift comes into contact with another object.

If a machine malfunctions, a dedicated model offers a method of exit for the operator, *provided* the electrical system is still functional. An independent lift, of course, does not, requiring the operator to look for other means of vacating the machine. Thus, it's important that consideration be given to emergency use of the lift in the event of power failure or fire. If the lift is the only safe way to exit the machine, an action plan needs to be developed, along with, if possible, an alternative escape method. Regardless, every piece of machinery that requires a lift in order to access it should be 'equipped' with a two-way radio or cell phone and a fire extinguisher (Yoder et al., 2000).

In the event of power loss, many lift designs incorporate a backup method of exiting the machine. However, the use of a second person is often required unless a backup battery system is available. Vertical-mast lifts can be manually lowered with a ratchet, and swivel features can be 'unlocked' to allow for articulation of the seat carrier. On independent lifts, a hydraulic hand pump with release is triggered, along with a manual release of pivot points, to move the lift back to a transport position.

Slip clutches located in the lift's gearbox are intended to reduce the force of movement so as to prevent damage to the machine or injury to the operator. In the downward direction, some lift models will de-energize with approximately 6.8 kg (15 lbs) of down pressure. Those operated in cold climates may require the slip clutch to be adjusted to overcome increased resistance, especially with lateral articulation on uneven terrain (swinging uphill).

As noted earlier, vertical-mast lifts are often powered by an electric motor-driven roller chain. While such lifts' components are durable, the fail-safe measures incorporated into many designs cause 'safety dogs' to activate if the chain becomes slack in order to prevent free-fall of the user. Some homemade lifts are constructed using off-the-shelf cables or strap winches for powering. It is strongly recommended that all components be approved for the lifting of humans and that some sort of 'emergency-stop' is equipped to prevent a free-fall in the event of failure.

Preventative maintenance is the best 'insurance' against mechanical malfunctions. Modern lift designs, which are both simple and robust, require the operator to maintain only a few key components, the most crucial of which is the battery. Maintaining the machine's charging systems and proper maintenance of its battery (e.g., keeping it clear of dirt/residue/corrosion, checking the water level, insuring tight cable connections) will prevent many potential problems. For vertical-mast lifts, the drive chain should be lubricated and proper tension maintained. Lastly, although many lift components now are sealed and permanently lubricated, the operator should still be vigilant in identifying and replacing damaged or worn parts.

## About machine-operating hand controls

Adaptive hand controls are nonstandard hand-operated control devices that have been added to a vehicle or piece of equipment to replace or supplement those designed to be operated by other parts of one's body. They allow farmers/ranchers with physical disabilities to operate their machinery in a safe and efficient manner. Hand controls are not just limited to converting foot-operated controls (e.g., brakes, clutch, foot throttle) to hand-operated ones, but also to modifying hard-to-reach controls (e.g., differential lock, MFWD, PTO, throttle, steering column tilt) when the level of mobility and/or reach is likewise impaired. As an interface between the operator and the machine's function, they may be entirely mechanical and actuated using only the force applied by the operator, or they may involve components (e.g., pneumatic, electrical, hydraulic) that reduce the amount of force needed to actuate. Adaptive hand control devices include levers, push-buttons, joysticks, wheels, and rotary or linear switches.

Covered in this section will be common types of hand controls used by agricultural operators, technological advancements that have made tractor and self-propelled machine operation easier (for users with and without hand controls), and recommendations for selecting appropriate hand controls to best fit the needs of the operator.

### *Types of hand controls*

Most existing control alternatives for brakes, clutch, foot throttle, and differential lock are mechanical lever assemblies, which primarily consist of lever extensions or mechanical linkages (including cable-pulley assemblies). Lever extensions are usually constructed of flat-bar steel, steel tubing, or steel rods that are clamped, bolted, or welded to the factory control (Figure 7). Mechanical linkages can range from simple, relatively low-cost actuation systems to more complex ones. Hand controls sometimes incorporate electric, pneumatic, or hydraulic actuators that act upon the pedal linkages and require relatively low force to move toggle switches or other control devices. It is recommended that all actuators be installed with the default or neutral position for the disengaged clutch so that, in the event of malfunction, the machine defaults to a stopped position.

For a person having little or no lower-limb impairments, the amount of force sufficient for pushing and pulling controls is often derived from bracing the body with the legs and feet (Chaffin, Anderson, & Martin, 2006). However, if such bracing is not possible, some or all of the push-pull force exerted by the lowered limbs may transfer to the upper body and require other forms of bracing (e.g., the seat's backrest when pushing or a seatbelt/harness when pulling). The lack of reaction force from those limbs during pulling and pushing may also create instability in the torso, thus increasing the risk for falls and secondary injury.

### *Technological advancements in hand controls*

One of the first considerations to be made prior to installing adaptive hand controls is selection of the machine that provides the greatest potential for use and for successful modification. For example, some tractors lend themselves well to easier or less-costly modifications. Attempting to make modifications on older machines both reduces the usable life of the adaptation and fails to capitalize on newer design features that might better accommodate the operator's needs.

Some machinery, such as skid-steer loaders, allows the operator to manipulate the function/movement of an attachment using foot controls. If these controls are not accommodating to the user, an electronic valve assemble may be preferred so that the operator can control all movements of the machine and attachment via joystick assembly.

Transmission options (e.g., hydrostatic, shift-on-the-go, hydraulic high-low, shuttle shift, constant velocity, and infinitely variable) require less—and in some cases even no—clutching. Shuttle shifters allow the operator to shift from forward to reverse without use of the clutch while maintaining the same gear. In addition, hydrostatic, constant velocity, and infinitely variable transmissions, which are offered on many tractors and nearly all newer combines, have greatly reduced the need for extensive control modifications by allowing the operator the full speed


**Figure 7.** Removable hand controls attached to the clutch and brake pedals.

range of the vehicle with no or minimal use of a floor-mounted pedal. Care should be taken when using the transmission repeatedly for breaking in order to avoid damage to the transmission.

### *Recommendations for selecting modern hand controls*

Based on years of evaluating homemade hand controls at BNG as well as in-depth reviews of government- and professional society-developed standards relative to vehicular adaptive equipment, the following guidelines are recommended for the design and construction of adaptive hand controls (Ehlers et al., 2017). (Note: Each case must be examined individually, based on the operator's capabilities and specific piece of equipment being modified.)

- Materials used to construct adaptive hand controls should be strong and durable enough to withstand stress of normal operation (Prather, 2002; VA, 1978).
- All sharp and jagged edges should be eliminated to prevent injury or damage during operation and when entering/exiting.
- All components and parts should be resistant to corrosion, which weakens the structure or produces sharp edges.
- If possible, controls should be of an 'add-on' nature. Permanent alterations (e.g., welding, boring holes) could weaken a control's structural rigidity.
- Bolts should be graded bolts so as to withstand appropriate forces.
- Clutch hand controls should be designed to pull toward the operator to disengage (ASABE/ISO Standard 15077). However, in some cases where the operator is less stable or secure, being able to push may prove easier/safer.
- Push/pull forces should not exceed the operator's capabilities (Fathallah, Chang, Berg, Pickett, & Marlenga, 2008)
- Tractors with dual brake pedals should incorporate independent and equalized braking options with hand controls.
- Visual identification and labeling of adaptive controls should follow ASABE/ISO Standard 15077 and ANSI/ASABE AD11684 for color coding and identification, dependent upon control function. (ASABE, 2014; ASABE, 2011)

## Importance and sources of assistance

Many pieces of agricultural equipment can be successfully modified to meet the needs of farmers and ranchers with mobility impairments. Nevertheless, coordination with an ATP, an agricultural safety specialist, a rural rehabilitation specialist, or a specialized AT manufacturer, along with a strong peer-support group will increase the chances of successfully implementing appropriate assistive devices. Cooperative efforts between rehabilitation professionals and agricultural equipment manufacturers in addressing the needs of farmers with disabilities would also likely yield invaluable results by integrating designs and controls conducive to benefiting all agricultural machinery operators.

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## References

American Society of Agricultural and Biological Engineers [ASABE]. (2011). *Tractors, machinery for agricultural and forestry, powered lawn and garden equipment – safety signs and hazard pictorials – general principals*. St. Joseph, MI: ANSI/ASABE AD11684.

American Society of Agricultural and Biological Engineers [ASABE]. (2014). *Tractors and self propelled machinery for agriculture – operator* *controls – actuating forces, displacement, location and method of operation*. St. Joseph, MI: ASABE/ISO 15077.

Armour, B. S., Courtney-Long, E. A., Fox, M. H., Fredine, H., & Cahill, A. (2016). Prevalence and causes of paralysis – United States, 2013. *American Journal of Public Health*, *106*, 1855–1857. doi:10.2105/AJPH.2016.303270

Begley, J., & Begley, B. (2017). Life essentials mobility equipment. Personal Communication, unpublished.

Chaffin, D. B., Anderson, G. B. J., & Martin, B. J. (2006). *Occupational biomechanics*. Hoboken, NJ: John Wiley & Sons, Inc.

Ehlers, S. G., Field, W. E., Stuthridge, R. W., & Geng, Q. (2017). *AgrAbility plowshares technical report: Adaptive hand controls for agricultural machinery*. West Lafayette, IN: Purdue University, Breaking New Ground Resource Center.

Fathallah, F. A., Chang, J. H., Berg, R. L., Pickett, W., & Marlenga, B. (2008). Forces required to operate controls on farm tractors: Implications for young operators. *Ergonomics*, *51*(7), 1096–1108. doi:10.1080/00140130801961901

Field, W. E. (1992). *Assistive technology needs assessment of farmers and ranchers with spinal cord injuries*. West Lafayette, IN: Breaking New Ground Resource Center, Purdue University.

Prather, T. G. (2002). *Adaptive controls for tractors and machinery. AP-01-03. Biosystems engineering and environmental science info sheet, agricultural extension service*. Knoxville, TN: University of Tennessee.

U.S. Department of Agriculture [USDA]. (2014). *2012 census of agriculture, United States summary and state data*. Washington DC: U.S. Department of Agriculture.

Veterans Administration [VA]. (1978). *Add-on automotive adaptive equipment for passenger automobiles*. Washington DC: VA Prosthetics and Sensory Aids Service.

Yoder, A., Stoller, N., & Field, W. E. (2000). *Plowshares 8: New concepts in lift attachments for tractors and combines. AgrAbility plowshares technical report. BNG*. West Lafayette, IN: Purdue University.