AGRABILITY PLOWSHARES TECHNICAL REPORT

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Lighting for Farmsteads and Self-propelled Agricultural Machinery

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INTRODUCTION

When it comes to agricultural production, lighting is an important consideration in nearly all sectors of the farmstead: the shop, livestock buildings, storage areas, machine shed, walkways, entryways, transitional spaces and out in the field. Adequate lighting levels allow surroundings to be seen sooner, more clearly, and in greater detail whether it be at the workbench, when handling animals, or during operation of machinery.

This article is intended to serve as a guide for farmers (especially those with vision loss/impairment) in selecting and applying appropriate lighting that contributes to a safer and more effective working environment. It details relevant aspects in a practical framework, with examples, where applicable, details of lighting types, their advantages and disadvantages, the importance of understanding illumination levels and appropriate light placement. In addition, it assists in determining how much light is needed and how the light should be located or focused for various farming activities.

One of the most pronounced influences on the characteristics of the human eye is aging. As the eye ages, the pupil becomes smaller and the lens gets thicker, both of which reduce the amount of light received by the retina. In fact, at around age 60, the retina captures only about one-third of the light that it captured at age 20 (LRC, 2017). With the mean age of U.S. farmers being 58.3 years versus 42.2 years of age for the general working population (USDA, 2014; BLS, 2014), the issue of sufficient lighting for the performance of everyday tasks may well be key to an aging farmer's safety, efficiency, and well-being.

Vision-related issues are apt to occur when a particular task and/or the design of a working environment exceeds the visual capacity of the individual worker who may be impaired due to injury or disease. It follows, then, that such impairments may be addressed by increasing the visual capacity of the worker via medical treatment, corrective eyewear, vision aids (e.g., magnification) and/or reducing the visual demands of the task via adjusting its environment. Applying corrective measures to increase one's visual capacity does not fall within the scope of this article, but this should be the first avenue explored with the appropriate medical provider to ensure the highest visual capabilities possible. Next in the process are steps taken to adjust the environment to optimize visual tasks, with light levels perhaps being the key adjustment. As Brawley (2009) notes: "Well-designed lighting is one of the most important design elements that will support an individual's ability to perform normal daily activities and decreased level of disability associated with these impairments." Impaired vision makes task performance not only more challenging, but also more dangerous, especially in agricultural workplaces that contain many potential hazards.

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TYPES OF LIGHTING COMPARED

In achieving the best lighting conditions possible, the choice between ambient (or natural) lighting versus artificial lighting needs to be considered. Until the invention of the electrical light, most of agriculture was operated on a sunup to sundown basis. When it got too dark to see, work in the field was stopped, except for some tasks that would be done under moonlight. The incorporation of windows and skylights were instrumental for not only keeping out the rain, but also letting the sunlight in because it provided better lighting than any other source. The appropriate placement of windows over workbenches, for example, has long been used to enhance the work environment. With the introduction of artificial lighting, beginning with flame-based lamps, extension of the workday, has been made possible.

*Table 1. Light Types, Advantages/Disadvantages, Efficiency, and Lifespan.**

Type	Advantages	Disadvantages	Efficiency (lumens/ Watt)	Lifespan (hours)
Incandescent	Low initial cost, small size, excellent color rendering, dimmable, simple circuitry, variety of sizes/ shapes.	Inefficient, high operating cost, short service life, excessive heat output, glare potential, sensitive to vibrations, uses filament.	12-18	750-1,500
Xenon	Dimmable, warm light.	Low efficiency, excessive heat output, uses filament.	30-50	2,000
Halogen	Medium service life, excellent color rendering, bright white, dimmable, small size.	Excessive heat output, high operating cost, sensitive if touched, glare potential, uses filament.	16-29	2,000-4,000
Compact Fluorescent Lamps (CFLs)	Low operating cost, long service life, low/medium initial cost, medium/high color rendering, low operating temperature.	Temperature sensitive, difficult to dim, contains mercury.	60-70	6,000-10,000
Metal Halide (HID)	Low operating cost, highly efficient, long service life, good color rendering, reasonable optical control.	High initial cost, requires ballast, long start-up/re-strike period, high starting current, glare potential, contains mercury.	65-115	10,000-15,000
Linear Fluorescent	Low initial and operating cost, highly efficient, long service life, medium/high color rendering, low heat output, diffuse light source. (*T5 recommend*)	Temperature sensitive, requires ballast, limited optical pattern control, difficult to dim, T12 being phased out, contains mercury.	80-100+	20,000
High-Pressure Sodium (HID)	Very low operating cost, exceptionally efficient, long service life, high lumen maintenance, reasonable optical control.	High initial cost, requires ballast, poor color rendering, long start-up/re-strike period, high starting current, glare potential, contains mercury.	85-150	24,000
Light Emitting Diode (LED)	Low operating cost, exceptionally efficient, longest service life, low heat output, choice of color, applicable in harsh conditions.	Medium/high initial cost, low/ medium color rendering, not for high-heat environments.	70-120	Up to 100,000

* Source: ASAE, 2004; EnergyStar, 2017; DOE, 2010).

There are many types of artificial lights available for farmstead applications, all with individual advantages, disadvantages, corresponding efficiencies, and usable life. Table 1 highlights eight common lighting types, ranging from the 150-year-old technology of incandescent bulbs to today's state of the art, light-emitting diode (LED), in ascending order of operating lifespan and power efficiency.

The lifespan of the different types of lights often depend on such factors as the environment in which they are placed, length of continued use, and quality of its component parts. For instance:

- Lights that have filaments (e.g., incandescent, xenon, halogen) are susceptible to vibrations, which will likely decrease their lifespan. That's why non-filament LEDs and high-intensity-discharge lights (HIDs) are better for mobile applications, such as on machinery.
- Fluorescent lights are susceptible to a cold environment, thus may require longer start-up times. Their life expectancy is not as long nor do they perform as well as LEDs or HIDs in certain environments.
- Lights left on for long durations are likely to last longer than those turned on and off frequently.
- Lights that operate at lower temperatures (e.g., LEDs) and/or are positioned in an area that allows for good air circulation will also likely last longer.
- Lights that produce an abundance of wasted energy in the form of heat (e.g., 88-94% for an incandescent bulb) are likely to have a shorter lifespan (ASAE, 2004).
- Lights that generate intense heat when they're on (e.g., halogens) should not be used in potentially flammable areas, such as hay mows, where combustible fumes/dust/etc. are present, or where birds might place nesting materials upon the light's housing.

CHARACTERISTICS OF LIGHTS

There are at least six issues in assessing the effectiveness of lighting for various areas of the farmstead and/or for the performance of farming tasks— (1) intensity, (2) glare, (3) contrast, (4) balance, (5) color perception, and (6) limitations (LRC, 2017). Following is a brief discussion of each.

Intensity

As already noted, older persons need two or three times more light to see comfortably than do younger persons. Thus, in choosing appropriate lighting it's important to understand the standard U.S. vs. metric measures of intensity—candlepower (cd) and footcandles (fc) vs. lumens (lm) and lux (lx). *Candlepower* or *lumens* is the rating of output at the light source, whereas footcandles or lux is the measurement of light at its intended destination—e.g., workbench surface, drill press table, shop floor (ASAE, 2004). The higher the value of cd, fc, lm, and lx, the brighter the light. It's also important to understand the relationship between light-source to object distance and level of intensity. As distance increases, intensity of the light decreases (ASAE, 2004). Table 2 presents the range of recommended luminance most appropriate for carrying out visually simple, visually moderate, and visually demanding agricultural tasks.

Table 2. Luminance and Light Types Recommended for Simple, Moderate, and Demanding Farm-Related Tasks.*

Task by level of visual challenge (with examples)	Range of luminance
Simple—Cleaning barn, feeding animals, loading/unloading material, refueling, hay mows, storage areas	30-100 lumens (2.8-9.3 footcandles)
Moderate— 'Rough' shop work, farm office work, cleaning	300-1,000 lumens (28-93 footcandles)
Demanding— 'Detailed' shop work, machinery repair / maintenance, operating power tools, sorting, inspecting, milking, care of animals	3,000-10,000 lumen (279-929 footcandles)

* Sources: ASAE Standards, 2003; Kaufman et al., 1984)

Figure 1 shows a digital light meter measuring the level of light at the work surface. Often used by professional photographers and design engineers to determine optimal lighting for their various tasks, such an instrument can also assist in evaluating light levels for agricultural activities. When conducting a worksite assessment for an older farmer or a person with a recognized visual impairment, determining light levels should be considered. In some cases, simple changes to increase the lighting levels can result in significant changes in productivity.

Figure 1. Digital light meter used to measure available light in work area.

Glare

There are two types of glare that affect vision quality: direct and reflected, both of which may be the result of too much light, a poorly positioned light source, and/or the surrounding surface's reflectance (LRC, 2017). **Direct glare** is caused by the light source being in line with one's eyes and the intended task. To correct this problem, the light should be re-located or shading/frosting/diffusing added to prevent direct or intense eye-level contact. Simply putting a shade on a lamp may be all that's required. In the cab of a tractor and other self-propelled machine, dusty windshields and operating into the rising or setting sun can cause excessive glare. A mesh or tinted see-through visor can be used and/or the light source re-positioned (if the glare is caused by equipment-mounted lights). Tinted visors can absorb as much as 92% of visible light and reduce glare by more than 70% (Rosen, 2017). Most modern, cab-equipped tractors now come with tinted windows, which have greatly increased operator visibility and reduced eye strain.

Reflected glare results from light bouncing off surrounding surfaces. To reduce or eliminate this problem, choose workbench tops, flooring, wall paint/covering, etc. that don't have shiny surfaces or, again, relocate the light source. Halogen and full-spectrum lighting (simulates natural daylight) causes the least amount of glare and might be a good option (Warren & Barstow, 2011). If reading is required in the environment, such as the location where shop and service manuals are kept, softer desk lighting would be preferred. Avoiding glossy paper or choosing a different color of the paper for printed material could also reduce glare.

Contrast of both the color and the surroundings of objects is also an important visibility consideration. For example, words in black ink on white paper are easier to read than bright- or pastel-colored words on white paper. The same principle holds true for being able to see—or not see—objects in contrast to the surrounding surfaces (e.g., a metal washer on a concrete floor). For this reason, choose colors for work surfaces, tools and labeling that ensure optimal contrast with surrounding colors.

From a safety standpoint, using bright red or yellow for floor markings alerts one to a potential hazard, such as a changing of working surface level or a machinery operation zone.

Arrangement of work materials to highlight contrast can also be helpful (Warren & Barstow, 2011). For example, dark objects placed against lighter backgrounds, or vice versa, and bright colored tape or neon paint applied onto tool handles will make them more visible. Also, arranging tools by size in tool caddies or bins manufactured for that purpose can reduce what are known as "figure-ground issues," which are caused by overlapping tools that create a confusing pattern for people with low vision. Other organizing-related strategies include labeling drawers, bins, and cabinets plus putting tools back in their proper place after use, both of which help one find the right tools under lower light conditions. The simplest solution in many of those cases is bringing more light to the problem area.

Table 3. Common Recommendations for Persons with Impaired Vision Using Hand-tools.

Marking tools with colored tape to distinguish measurement designation (Example: Red for SAE and Blue for Metric).

Purchase laser-etched size labeled sockets and wrenches for easier reading.

Organize tools to identify proper placement and size identification.

Identify contents of storage cabinets/containers with plastic backed, high contrast labels.

Fill molded/stamped scales and lettering with a contrasting color.

Label parts, tools, machinery, etc. with high contrasting marker (Example: Sharpie® Metallic Silver for dark surfaces, or Industrial Black for high heat and light colored surfaces).

Balance

Sudden or drastic changes in light levels make it difficult for the eyes to adjust quickly and can lead to a brief period of limited visibility, even blindness (LRC, 2017); this could result in injury and/or work error. One example is the initial arc from a welder. Using an auto-darkening rather than merely a traditional tinted lens welding helmet would likely address this problem. Another example is entering and leaving a dark building on a bright, sunny day. As to the entering issue, a long-term 'solution' might be adding lights immediately inside the building entrance (or any area where there's a significant change in illumination level) to provide a more gradual change. As to exiting, one could put on UV-light-filtering sunglasses before opening the door. To reduce "searching" for lighting controls, motion activated switches are available to replace traditional switches for turning on lights when a person enters the room.

In addition to sudden change-related lighting imbalance, a stark difference in brightness levels can contribute to glare, such as if a workbench has a bright light directly overhead while the surrounding area is much dimmer; again, a simple solution would be to increase the light level of that surrounding area.

The use of UV-light filtering tinted eyeglasses being widely prescribed for those who spend considerable time outside can contribute to difficulties when working in low light conditions, such as in shaded or poorly-lit buildings or while working on certain areas of machines with low ambient light. It may be necessary for some individuals to carry two sets of glasses to achieve the ideal level of glasses tint.

Color Perception

The type of light affects one's ability to perceive colors. Some types cast a yellowish tint on the illuminated areas, while others are more natural. Thus, when selecting light bulbs or fixtures, it's important to pay attention to their 'color temperature' (measured by degrees of Kelvin [K]), which will affect the way objects look (Westinghouse, 2017). For work environments, a bulb's/fixture's color temperature should be in the 3,100-6,500K range, identified on the packaging label and often directly on the bulb. Values greater than 4,500K emit a bluish tint, which more closely mimics natural daylight and increases one's ability to see details. Figure 2 shows the effects of various color temperatures from a light source on an illuminated area, while Figure 3 shows the color temperatures generally emitted by three different types of lighting.

Figure 2. Changing color temperature of light affects the way objects appear in work environment. (Source: Westinghouse, 2017)

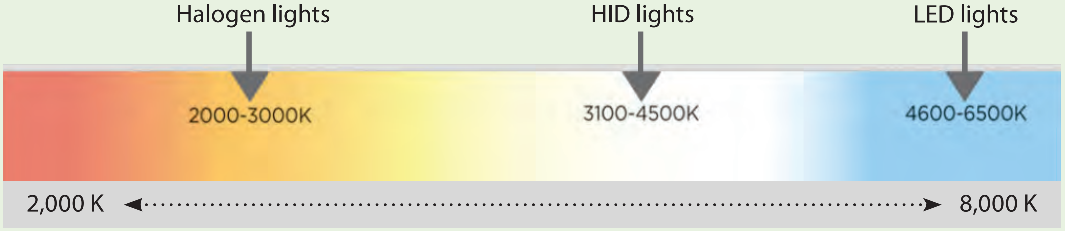

Figure 3. Color temperature (Kelvin) affects the light appearance on illuminated objects and varies by light type/source. (Source: Deere and Company, 2010)

LIMITATIONS

Lighting on both the farmstead and mobile machinery are limited by the capacity of the electrical system. All electrical circuits are limited by one or more of these parameters: components, power, or location.

Regarding Components. All components of an electrical circuit must work together to perform the intended task(s). Those components include the power supply, wires, breakers/fuses, light fixtures, and housings—all of which must be sized such as to support the demands of the task(s). Most lighting circuits for structures (e.g., barn, shop, machine shed, residence) in the U.S. operate at 120 or sometimes 240 volts (V) at 60 hertz (Hz). To protect from overloading the circuit, breakers or fuses are used to act as the 'weak link' (i.e., fail first) in case of an overload. They must be sized both to the size wire used when the circuit was installed and to the demands of the items being powered (e.g., welder, light, air-compressor, electric motor). For example, a 20-amp breaker should be sized to 12 AWG (American wire gauge) or larger wire and a 15-amp breaker sized with 14AWG or larger wire. Sizing regulations are available through the National Electric Code (NFPA, 2002). Understanding how the components of an electrical circuit are sized according to the components being used allows for appropriately powering a safe number of lights. Adding too many lights to the same circuit can result in excessive demands on the circuit, consequentially blown fuses or tripped breakers could occur. A simple way to determine if a circuit of lights is overloaded is to remove or disconnect one light. If the remaining lights brighten, it is a good indication that there are too many lights on the circuit.

Regarding Power. When purchasing a light bulb or fixture, its maximum power consumption, which is measured in watts (W), will be indicated on the bulb or package. A fixture equipped with a 100W bulb uses 100 Watts of power each hour. Knowing this value allows one to determine the energy efficiency of a particular light (often stated in lumens per W) and provides the information needed to calculate how many lights can be placed on a single circuit.

The National Electric Code specifies that a circuit used continuously (for periods greater than three hours at a time) should only be loaded to 80% of maximum capacity (NFPA, 2002). For example, on a 20-amp circuit, no more than 19 100-Watt bulbs/fixtures should be used, which is calculated using the formula: P = I x E, where "P" is the power in Watts, "I" is the current, rated in amps, of the circuit breaker or fuse, and "E" is the volts of the power supply. In our example, P = 20 amps x 120 volts = 2,400 Watts. Loading this circuit to 80% would yield 2,400 Watts x 0.80 = 1,920 Watts. So, if the light fixture installed on the circuit accepted a maximum of 100W bulb(s) per fixture, then 19 such light bulbs/fixtures could be installed on the circuit.

WHERE TO POSITION LIGHTS

Positioning of lighting depends on these three intended purposes: general, task-specific and/or supplemental, and safety and/or transitional.

General Lighting

Fixtures for general lighting needs are commonly positioned either on the ceiling or on the wall. Often, commercial-style ceiling light fixtures are categorized as 'high-bay' or 'low-bay.' High-bay fixtures are typically used when ceiling heights are greater than 15 feet. Low-bays are most appropriate for ceiling heights less than 15 feet, which generally would make them better suited to farm shops. A differentiating characteristic of the two types is the 'diffuser,' which is used to spread the light enough to illuminate the desired area. Diffusers on low-bay fixtures spread light wider than those on high-bays. Lighting mounted on the ceiling provides excellent top-down illumination of the area and is good for large spaces. One consequence, however, is the producing of shadows by tall objects, such as equipment stored in the area. For instance, a tractor or combine under a ceiling-mounted fixture can cast a shadow over a significant area of the floor.

An alternative (or compliment) to ceiling lights is wall-mounted lighting, especially for the farm shop and storage areas. One advantage is the decrease in shadowed floor space, potentially offering a safer working environment.

Also, those areas normally shadowed by overhead welding or ventilation hoods, cabinets and shields are better illuminated. Figure 4 shows wall-mounted fluorescent lighting in a shop that has a white metal ceiling, which allows the light to be distributed from multiple angles. Although this increases glare on the ceiling, the work surfaces below are suitably illuminated (without shadows) from multiple angles.

Figure 4. Wall-mounted lighting provides both top-down reflected light and side-angled light, resulting in less perceived shadows on work areas.

Task-Specific or Supplemental Lighting

This type of lighting is focused on an intended task or on a given area, such as that around a stationary tool, workbench, or where additional lighting is needed to efficiently perform the task. More and more tools, both stationary and hand-held, have built-in lights to illuminate the work surface or small targeted area (e.g., drill presses, table saws, drills, impact drivers) (Figure 5). Targeted-area lighting helps one make safer and more efficient use of the tool. Also, gooseneck lamps may be ideal for adjusting targeted light on the workbench. And lights can be added under cabinets to illuminate work surfaces.

Figure 5. Cordless 18V impact driver with integrated LED light.

Supplemental lighting is often needed for hallways, stairwells, and outside steps. It's also likely needed when working from the underside of vehicles, machinery, and other pieces of equipment. In these situations, 'wearable' light sources (e.g., head- or hat-lamps), corded or reel-type trouble-lights, or tools with build-in lights have proven invaluable. Among the recent innovations in supplemental lighting technology are small LED lights available as dedicated fixtures, hand-held or wearable flashlights/lamps, or continuous strips. Continuous strip LEDs, which are available in different colors, color temperatures, and configurations (e.g., 30, 60, or 120 lights per meter), can be sized to custom lengths and affixed in nearly any location; some have waterproof coverings and adhesive backing.

LED fixtures are quickly becoming the norm for efficient, long-lasting, and bright lighting applications on the farm. Figure 6 shows a farm shop that's been equipped with LED fixtures. Having a high lumen-to-watt ratio allowed 16 such fixtures to be connected to a single 20-amp circuit.

In many instances, switching to LED lighting on the farmstead may not require extensive modifications to existing light fixtures and will save money over time. Conversion bulbs are available to replace many standard incandescent light bulbs sizes, as well as fluorescent tube lighting. LED

Figure 6. High-bay LED lighting in new-construction high efficiency shop.

tubes are available in common T5, T8, and T12 sizes to work with both existing fixtures' ballast, or by removing the fixtures' ballast altogether (depending on selected model).

Personal Lighting

The diversity of tasks on most farms include many that could more easily be accomplished with additional lighting from a handheld light source or flashlight. Access to a charged, working flashlight can provide not only targeted light for poorly lit places on machines and a safe path after dark, but can also be a valuable personal safety/signaling device in some emergency situations. There are a wide assortment of flashlights on the market suitable for agricultural applications. Recommended features include: dust, moisture, and shock resistance; adjustable focus beam; rechargeable and/or common battery type; high lumen output; and magnetic mounting capabilities. Many older model flashlights can be updated by changing the bulb(s) to a modern technology, thus extending runtime, bulb life, different color temperature and lumen output. Every major piece of equipment and each farm vehicle should be equipped with a working flashlight.

Safety or Transitional Lighting

Lighting for safety involves the logical placement of emergency and transitional lights, such as to ensure the clear illumination of pathways and building exits. These lights can be equipped with an auxiliary power source that can be drawn upon in event of a power outage.

Low-wattage/high-efficiency dusk-to-dawn lights should be placed at the entrance of every building, both inside and out. Such lights are relatively inexpensive in both initial investment and operational costs. For example, the cost to operate one 7-watt dusk-to-dawn, waterproof entry light is about $2.25 per year (assuming $0.11/kWh and 8 hours of darkness per day)—a small investment, indeed, for the benefits of being able to better recognize hazards and avoiding falls, trips, and slips.

The use of farmstead security lighting adds at least two types of benefits. First, the lighting allows for greater visibility in moving around the farmstead after dark and second, these added lights discourage crime due to the increased likelihood of being caught.

LIGHTING FOR FIELD EQUIPMENT

Lighting found on newer agricultural machines has allowed farmers to capitalize on good conditions to accomplish field work regardless of time of day. This added lighting has made machinery safer, more productive, and even more roadworthy during non-daylight hours. However, for some individuals with impaired vision, the long hours under less than ideal lighting conditions can be stressful.

Upgrading the lighting on older self-propelled and towed machinery could be a problem if doing so would overload the equipment's limited charging systems, one consequence being more frequent battery and/or battery charging system replacement. However, new lighting technology requires less current draw, thus allowing for more and brighter lights with greater output. In addition, such lights have no filaments to fail under the vibration-harsh conditions commonly encountered during equipment operation. Manufactures often recommend a natural-light color temperature, which reduces both eye and body fatigue (Deere, 2010).

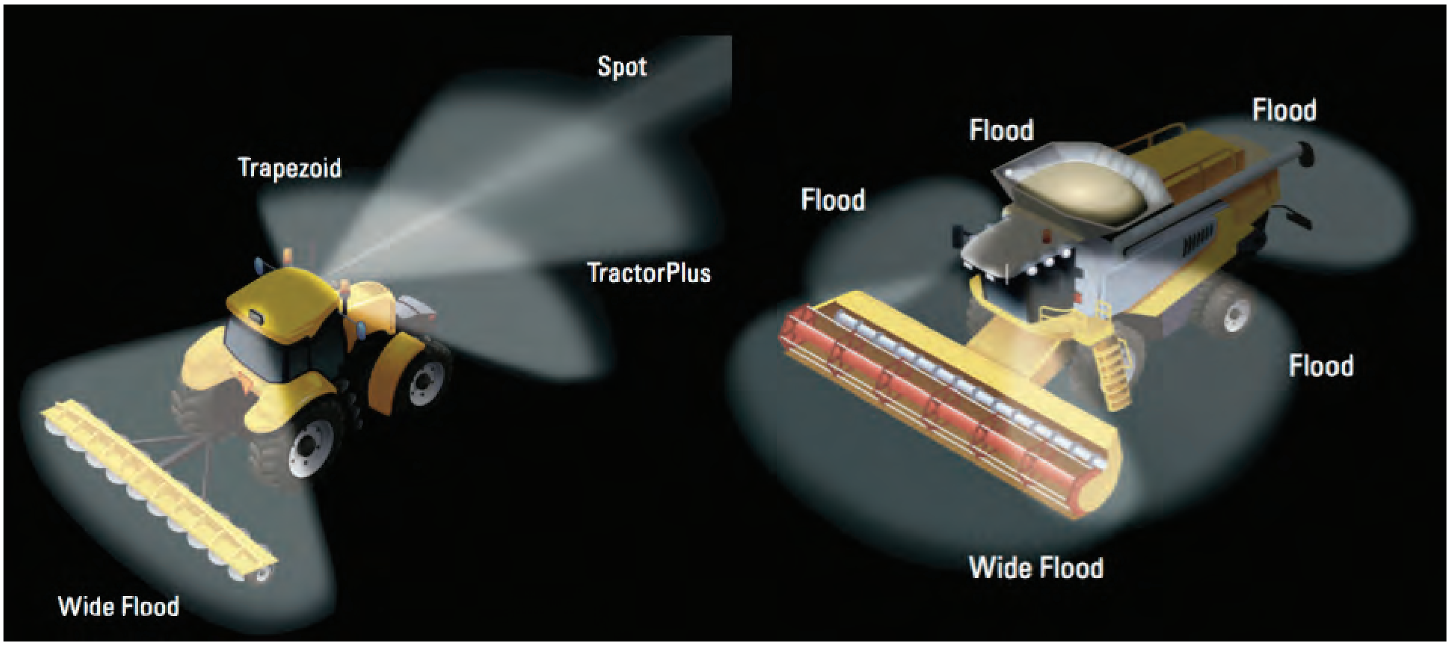

Figure 7. Light type and placement on self-propelled agricultural machinery. (Source: Modified from Grote 2016)

Light Type and Location Considerations

Equipment lighting requires various 'patterns' of light that work together to provide an optimal level of illumination of near and distant areas. These patterns are commonly referred to as spot, flood, and trapezoid (see Figure 7), the key features of each being as follows:

Spotlight. This type of light casts a long, narrow beam that permits long-distance viewing (Figure 8). Such a pattern is intended to view path-of-travel at the furthest point from the piece of equipment. Spotlights are not suitable for near proximity, as the beam is too narrow to effectively illuminate a wide area. However, they do allow the operator to see and follow rows and markers and to view distant obstacles, such as wood lines, fence rows, other equipment, and buildings. Spotslights are typically affixed atop the tractor cab or in the front grill, as elevated locations allow the light to be cast greater distances.

Figure 8: Spotlight Beam. (Source: Grote, 2016)

Floodlight. This type casts a very wide beam for viewing of areas in near proximity to the equipment (Figure 9). The wide beam is particularly useful for monitoring attachments to the front, rear, and side of the machinery. Lighting manufacturers produce several models that vary as to the degree of angle of illumination. Floodlights are usually located (1) behind the cab or on each rear fender to allow for illumination of objects/implements to the rear and (2) in the front of the cab but below the plane of the operator's eyes to illuminate areas forward and to each side of the machine.

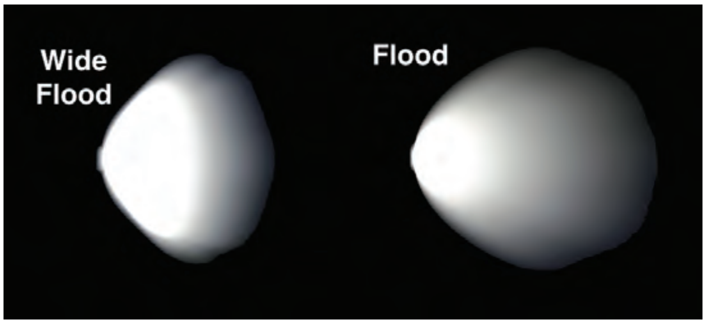

Figure 9. Floodlights. (Source: Grote, 2016)

Trapezoid Light. This is a mid-range light intended to illuminate the spaces between the flood and spot lights (Figure 10). Such lights are often positioned on the front grill of the machine to provide mid-range visibility.

Figure 10. Trapezoid light. (Source: Grote, 2016)

Positioning and Mounting Considerations

To maximize quality of lighting for the operator, a primary consideration is where the lights are relative to his/her normal plain of sight. It's important that they be positioned above and/or below eye level. Those at or near the operator's eye level will likely illuminate suspended materials (e.g., dust), thus negatively affecting overall visibility (Templeton et al. 1998). A secondary issue involves the rigidity of the mounting location. Many light fixtures feature vibration-isolating gaskets to reduce unwanted interference, improving the overall visibility for the operator and extending the usable life of the light in instances where a filament style bulb is utilized. Lastly, operators should be aware that high output "field lighting" is not appropriate for highway transport, as the intense light can blind oncoming motorists. In these situations, it is necessary for the operator to have the ability to select the lighting configuration to best match the application.

SUMMARY

Advancements in lighting technology have made both farmsteads and mobile agricultural equipment more accommodating to the needs of operators by providing a better working environment. Increasing visual capacity of workers through a well-designed lighting system can indisputably have a positive impact on workplace safety and efficiency. Economic savings, due to the high-efficiency alternatives, allow for increased light output and/or added quantity of light fixtures with comparable or less energy demands.

Further assistance in selecting appropriate lighting is available through retailers that specialize in lighting, assistive technology professionals (ATPs), and agricultural equipment manufacturers and dealers. It is the consumers' responsibility to make a knowledgeable decision; therefore, it is paramount to network with others in pursuit of the best lighting technology for your farming operation.

Finally, even the best lighting cannot compensate for undiagnosed or untreated eye impairments. If there is any reason to suspect that visual limitations are contributing to workplace difficulties, the first step is to consult with a health care professional regarding eye-health-related issues. Failure to do so can lead to much more serious problems and possibly blindness.

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CITED REFERENCES

American Society of Agricultural Engineers (ASAE). 2004. Fundamentals of Electricity for Agriculture, 3rd edition, Chapter 11, pp. 301-340. ASAE, St. Joseph, MI

American Society of Agricultural Engineers (ASAE) Standards. 2003. ASAE EP344.2 Dec99: Lighting for Dairy Farms and the Poultry Industry. ASAE, St. Joseph, MI

Brawley, Elizabeth. 2009. Enriching lighting design. NeuroRehabilitation. 25. 189-199. 10.3233/NRE-2009-0515

Deere and Company. 2010. John Deere Tractor Wrork Lights Upgrade Guide. PowerPoint Guide. Moline, IL

Energy Star. 2017. Lighting Technologies: A Guide to Energy-Efficient Illumination. U.S. Environmental Protection Agency. https://www.energystar.gov/ia/partners/promotions/change_light/downloads/Fact%20Sheet_Lighting%20Technologies.pdf

Grote Industries. 2016. Agriculture Lighting and Visibility Products: Safety Solutions from Grote. Madison, IN

Kaufman, J. E., Christensen, J.F. 1984. IES Lighting Handbook, References Volume. Illuminating Engineering Society of North America New York, NY

Lighting Research Center [LRC]. 2017. Lighting the Way: A Key to Independence. Rensselaer Polytechnic Institute, Troy NY

National Fire Protection Association [NFPA]. 2002. National Electrical Code 2002. National Fire Protection Association. Boston, MA

Templeton, D. J., & Strong, R. W. 1998. Essential design considerations for today's tractor cab and a challenge for the future. ASABE Distinguished Lecture No. 22. St. Joseph, Mich.: ASAE.

U.S. Department of Agriculture [USDA]. 2014. 2012 Census of Agriculture. Vol. 1. Washington, D.C.

U.S. Department of Energy (DOE). 2010. Industrial Technologies Program: Common Industrial Lighting Upgrade Technologies. Washington, D.C.

U.S. Department of Labor [DOL]. 2017. Household Data Annual Averages 18b. Employed persons by detailed industry and age. Washington, D.C.

Warren, M. & Barstow, E. A. 2011. Occupational therapy interventions: For adults with low vision. Bethesda, MD: AOTA Press

Westinghouse. 2017. Understanding Color Temperature. http://www.westinghouselighting.com/color-temperature.aspx