Lesson 36
Land Application Equipment
By Ron Sheffield, North Carolina State University
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Disclaimer

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Intended Outcomes
The participants will
• Identify appropriate land application system(s) for their farm.
• Understand the importance of equipment calibration.
• Become familiar with the procedures to calibrate various pieces of application equipment.

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Activities
• Select appropriate application systems.
• Outline calibration procedures for land application equipment.
• Complete regulatory assessment.

PROJECT STATEMENT
This educational program, Livestock and Poultry Environmental Stewardship, consists of lessons arranged into the following six modules:
• Introduction
• Animal Dietary Strategies
• Manure Storage and Treatment
• Land Application and Nutrient Management
• Outdoor Air Quality
• Related Issues

Note: Page numbers highlighted in green are linked to corresponding text.
Selecting the Appropriate Land Application Method

The land application of livestock manure is facing growing scrutiny because of potential surface water and groundwater contamination as well as odor nuisances. As a result, when selecting and operating manure application equipment, producers must consider environmental issues along with materials handling and economic factors. When issues related to land application equipment are discussed in this lesson, producers are encouraged to evaluate their own sampling and record-keeping program. This can be done with the aid of the Regulatory Compliance Assessment (see Appendix A).

In the following pages, we will consider those (1) features of manure application systems that enhance a producer’s ability to use the nutrients in manure and (2) methods of calibrating manure application rates. Key considerations for minimizing the nuisances that neighbors experience during manure application will also be discussed.

Environmental considerations

Manure spreader as a fertilizer applicator. The fundamental principle underlying both best management practices and future regulatory requirements for manure application will be efficient crop use of applied nutrients. Manure spreaders will need to be managed like any other fertilizer or chemical applicator. Spreaders and irrigation equipment will need to apply manure uniformly, provide a consistent application rate between loads, and offer a simple means of calibration. Appropriate equipment selection and careful operator management will contribute to the efficient use of manure nutrients.

Nitrogen conservation. The availability of the nitrogen and phosphorus in applied manure is usually out of balance with crop needs. Typically, high soil phosphorus levels result from long-term applications of manure. The ammonium fraction, originally representing roughly half of the potentially available nitrogen, is lost by the long-term open lot storage of manure, anaerobic lagoons, and the surface spreading of manure. Systems that conserve ammonium nitrogen and provide nutrients more in balance with crop needs increase the manure’s economic value.

Odor nuisances. Odor nuisances are the primary driving factor behind more restrictive local zoning laws for agriculture. Better management of manure nutrients through increased reliance on manure storage and land application of manure in narrow windows of time may add to or reduce odor complaints due to weather conditions or the location and your relationship with neighbors. Manure application systems that minimize odor deserve consideration and preference when neighbors live near application sites.

Soil compaction. Manure spreaders are heavy. In a 3,000-gallon liquid manure tank, the manure alone weighs more than 12 tons. In addition, manure is often applied during the year, late fall and early spring, when high soil moisture levels and the potential for compaction are common. The impact of manure application on potential soil compaction requires consideration.

Timeliness of manure nutrient applications. The ability to move large quantities of manure during short periods of time is critical. Limited opportunities exist for the application of manure to meet crop nutrient needs and minimize nutrient loss. Investments and planning decisions that enhance the farm’s capacity to move manure or to store manure in closer proximity application sites will facilitate the improved timing of manure applications.
**Table 36-1. Environmental rating of various manure application systems.**

<table>
<thead>
<tr>
<th>Type of System</th>
<th>Uniformity of Application</th>
<th>Nitrogen (Ammonium) Conservation (no incorporation)</th>
<th>Odor Nuisances</th>
<th>Soil Compaction</th>
<th>Timeliness of Manure Application</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Solid Systems</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Box spreader: tractor pulled</td>
<td>poor</td>
<td>very poor</td>
<td>fair</td>
<td>fair</td>
<td>poor</td>
</tr>
<tr>
<td>Box spreader: truck mounted</td>
<td>poor</td>
<td>very poor</td>
<td>fair</td>
<td>fair</td>
<td>fair</td>
</tr>
<tr>
<td>Flail-type spreader</td>
<td>fair</td>
<td>very poor</td>
<td>fair</td>
<td>fair</td>
<td>poor</td>
</tr>
<tr>
<td>Side discharge spreader</td>
<td>fair</td>
<td>very poor</td>
<td>fair</td>
<td>fair</td>
<td>poor</td>
</tr>
<tr>
<td>Spinner spreader</td>
<td>fair</td>
<td>very poor</td>
<td>fair</td>
<td>fair</td>
<td>fair</td>
</tr>
<tr>
<td>Dump truck</td>
<td>very poor</td>
<td>very poor</td>
<td>fair</td>
<td>poor</td>
<td>fair</td>
</tr>
<tr>
<td><strong>Liquid Systems: Surface Spread</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Liquid tanker with splash plate</td>
<td>poor</td>
<td>poor</td>
<td>poor</td>
<td>poor</td>
<td>fair</td>
</tr>
<tr>
<td>Liquid tanker with drop hoses</td>
<td>fair</td>
<td>fair</td>
<td>good</td>
<td>poor</td>
<td>fair</td>
</tr>
<tr>
<td>Big gun irrigation system</td>
<td>good</td>
<td>very poor</td>
<td>very poor</td>
<td>excellent</td>
<td>excellent</td>
</tr>
<tr>
<td>Center pivot irrigation system</td>
<td>excellent</td>
<td>very poor</td>
<td>very poor</td>
<td>excellent</td>
<td>excellent</td>
</tr>
<tr>
<td><strong>Liquid Systems: Incorporation</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tanker with knife injectors</td>
<td>good</td>
<td>excellent</td>
<td>excellent</td>
<td>poor</td>
<td>fair</td>
</tr>
<tr>
<td>Tanker with shallow incorporation</td>
<td>good</td>
<td>excellent</td>
<td>excellent</td>
<td>poor</td>
<td>fair</td>
</tr>
<tr>
<td>Drag hose with shallow incorporation</td>
<td>good</td>
<td>excellent</td>
<td>excellent</td>
<td>good</td>
<td>good</td>
</tr>
</tbody>
</table>

**Solid manure application systems**

Manure of 20% solids or more is typically handled by box-, side discharge, or spinner-type spreaders. Box-type spreaders range in size from under three tons (100 cubic ft) to 20 tons (725 cubic ft). Box spreaders provide either a feed apron or a moving gate for delivering manure to the rear of the spreader. A spreader mechanism at the rear of the spreader (paddles, flails, or augers) distributes the manure. Both truck-mounted and tractor-towed spreaders are common.

Flail-type spreaders provide an alternative for handling drier manure. They have a partially open top tank with chain flails for throwing manure out the spreader’s side. Flail units have the capability of handling a wider range of manure moisture levels ranging from dry to thick slurries.

Side-discharge spreaders are open-top spreaders that use augers within the hopper to move wet manure toward a discharge gate. Manure is then discharged from the spreader by either a rotating paddle or set of spinning hammers. Side-discharge spreaders provide a uniform application of manure for many types of manure with the exception of dry poultry litter.

Spinner-type spreaders, used to apply dry poultry litter, are similar to the hopper-style spreaders used to apply dry commercial fertilizer or lime. Manure placed in the storage hopper is moved toward an adjustable gate via a chain drive. Manure then falls out of the spreader onto two spinning discs that propel the litter away from the spreader. Uniform application can easily be achieved with spinner spreaders by either varying the spinner speed or angle.
Application rates can be adjusted by changing the travel speed and opening or closing the opening on the spreader gate.

With the growing concern about the manure contamination of water and air resources, spreaders must be capable of performing as fertilizer spreaders. Typically, such equipment has been designed as disposal equipment with limited ability to calibrate application rates or maintain uniform, consistent application rates. Several considerations specific to solids application equipment follow:

- The operator must control the application rate. Feed aprons or moving push gates, hydraulically driven or power takeoff (PTO) powered, impact the application rate. Does the equipment allow the operator to adjust the application rate and return to the same setting with succeeding loads?

- Uniformity of manure application is critical for fertilizer applicators. Variations in application rate are common both perpendicular and parallel to the direction of travel. Uniformity can be checked by laying out several equal-sized plastic sheets and weighing the manure falling on each sheet (Figure 36-1). The variation in net manure weights represents a similar variation in crop-available nutrients.

- Transport speed and box or tank capacity impact timely delivery of manure. Often 50% or more of the time spent hauling manure is for transit between the feedlot or animal housing and field. Truck-mounted spreaders can provide substantial time savings over tractor-pulled units for medium and long-distance hauls. Trucks used for manure application must also be designed to travel in agriculture fields. Available four-wheel drive and duel or flotation-type tires should be considered for trucks that will apply manure. Increased box or tank capacities speed delivery. Spreaders must be selected to move and apply manure quickly.

- Substantial ammonia is lost from solid manure that is not incorporated. Most of the ammonia nitrogen, representing between 20% and 65% of the total available nitrogen in manure, will be lost if not incorporated within a few days. Practices that encourage the incorporation of manure into the soil on the same day that it is applied will reduce ammonia losses but may increase soil erosion.

Figure 36-1. The strategic location of several equal-sized plastic sheets can indicate solid manure’s uniformity of application.
Alternative delivery systems that speed the movement of manure, offer options for incorporating manure, and minimize the mixing of manure and air enhance the liquid application of manure.

Flexible hose systems distribute manure at rates up to 1,000 gallons per minute.

Liquid manure application systems

Tank wagons have traditionally performed the application of liquid or slurry manure. While this method has facilitated the disposal of manure at a relatively low capital cost, it has included some hidden costs including soil compaction, loss of ammonium nitrogen, and odor. Recently, many unique approaches to land application of liquid or slurry livestock manure have appeared. Alternative delivery systems that speed the movement of manure, offer unique options for incorporating manure, and minimize the mixing of manure and air enhance the liquid application of manure. A discussion follows of some potential features to be included in a manure application system.

Remote manure storages. Remote manure storage (or storages) is (are) an integral part of many unique delivery systems. Locating the manure storage near the fields that will receive the manure as opposed to near the animal housing has several potential advantages. Manure is transported via pump or tanker to the remote storage throughout the year, minimizing the labor required to move manure during field application. Remote sites may provide location options where odor or visual nuisances are less of a concern or reduce storage construction costs.

Weigh cells. The recent commercial application of weigh cells to manure tank wagons provides the equipment operator with information on the weight of manure applied. Weigh cells enhance the operator’s ability to accurately estimate application rates and thus more accurately predict the nutrients available from the manure application. The addition of weigh cells to a manure spreader demonstrates this equipment’s transition from waste disposal to fertilizer application.

Shuttle tankers. The standard 2,000- to 4,000-gallon tractor-pulled tanker cannot move manure fast enough for some livestock operations. In some regions, over-the-road tankers are being used to shuttle manure from storage areas to the edge of a field. Manure is then transferred to separate liquid application equipment or remote storage. Often, used semi-tractor milk or fuel tankers with capacities of 6,000 gallons or more are purchased for shuttle duty. Before implementing this approach, check licensing and inspection requirements and the carrying capacity of local bridges.

Flexible hose systems. Flexible hose delivery systems tied to a tractor-pulled field implement or injector unit move liquid manure quickly (Figure 36-2). A common approach begins with a high-volume, medium-pressure pump located at the liquid manure reservoir. Manure is delivered to the edge of the field (at the field’s midpoint) by standard 6- or 8-inch irrigation line. At this point, a connection is made to a 660 ft long, 4 inch in diameter soft irrigation hose. Often two lengths of hose are used. Manure is delivered to a tractor with toolbar-mounted injectors or splash plates immediately in front of a tillage implement.

Flexible hose systems distribute manure at rates up to 1,000 gallons per minute (gpm). Thus, a one million gallon storage can be emptied in a 24-hr pumping period. Comparatively, using 3,000 gallon or greater tankers increases soil compaction. However, the high cost of capital equipment makes it affordable only to larger livestock operations and custom applicators.

Pumping liquid manure from the manure storage to the field is becoming increasingly common. Manure of up to 8% solids is being pumped several miles to a remote storage or to field application equipment. Pipe friction is the primary limiting factor. Manure with a solids content below 4% can be treated
as water in estimating friction losses. However, an additional allowance for friction loss is required to pump manure with above 4% solids content. Manure-handling systems that involve the addition of significant dilution water or liquid-solids separation equipment provide a slurry that is most appropriate for this application.

To pump manure (> 4% solids) longer distances requires heavy-duty equipment. Aggressive chopper units are often installed just before the pump when solids separation equipment is not used. Industrial slurry pumps are selected to overcome the pipe friction losses and avoid potential wear problems. Buried PVC piping with a high pressure rating (e.g., 160 psi) is generally selected. Because manure leaks are far more hazardous than water leaks, joints must be carefully assembled and tested. Special care must also be given to piping crossing streams and public roads. If public roads will be crossed, appropriate local governments maintaining these roads should be contacted early in the planning process.

Surface broadcast of liquid manure. Surface application of liquid slurries provides a low-cost means of handling the manure stream from many modern confinement systems. Tank wagons equipped with splash plates are commonly used to spread manure. However, surface application suffers from several disadvantages including ammonia loss, odor, and poor uniformity.

- Ammonia losses. Surface application of slurries results in losses of 10% to 25% of the available nitrogen due to ammonia volatilization (Table 36-2).
- Odor. Aerosol sprays produced by mixing manure and air carry odors considerable distances (Table 36-3).
- Uniformity. Splash plates and nozzles provide poor distribution of manure nutrients. Wind can add to this challenge.
A few recent developments attempt to address these concerns. For the first time, boom-style application units for attachment to tank wagons or towed irrigation systems are appearing commercially. These systems use nozzles or drop hoses to distribute slurry. They tend to reduce odor concerns and improve uniformity of distribution. Other systems are under development.

**Direct incorporation of liquid manure.** The options for direct incorporation of liquid manure are increasing (Figure 36-3). Injector knives have been the traditional option. Knives, often placed on 20- to 25-inch centers, cut 6- to 8-inch deep grooves in the soil into which the manure is placed. High power requirements and limited mixing of soil and manure are commonly reported concerns.

Injector knives with sweeps that run four to six inches below the soil surface facilitate manure placement in a wider band at a shallower depth. Manure is placed immediately beneath a sweep (up to 18 inches wide), which improves the mixing of soil and manure. Locating the manure higher in the soil profile minimizes potential leaching, decreases the number of hot spots that affect plant growth, and reduces power requirements.

Other shallow incorporation tillage implements (s-tine cultivators and concave disks) are increasingly available options on many liquid manure tank wagons. These systems are most commonly used for pre-plant application of manure. Manure is applied near the tillage tool, which immediately mixes the manure into the soil. Speed of application, low power requirements, and uniform mixing of soil and manure have contributed to the growing popularity of this approach. In addition, such systems are being used to

Table 36-2. Nitrogen losses during land application. Percent of total nitrogen lost within 4 days of application.

<table>
<thead>
<tr>
<th>Application Method</th>
<th>Type of Manure</th>
<th>Nitrogen Lost, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadcast</td>
<td>Solid</td>
<td>15-30</td>
</tr>
<tr>
<td></td>
<td>Liquid</td>
<td>10-25</td>
</tr>
<tr>
<td>Broadcast with immediate incorporation</td>
<td>Solid</td>
<td>1-5</td>
</tr>
<tr>
<td></td>
<td>Liquid</td>
<td>1-5</td>
</tr>
<tr>
<td>Knifing</td>
<td>Liquid</td>
<td>0-1</td>
</tr>
<tr>
<td>Sprinkler irrigation</td>
<td>Liquid</td>
<td>0-1</td>
</tr>
</tbody>
</table>


Table 36-3. Odor emission rates during land spreading of pig slurry from manure storage.

<table>
<thead>
<tr>
<th>Application Method</th>
<th>Total Odor Emissions¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation</td>
<td>6,250</td>
</tr>
<tr>
<td>Conventional tanker with splash plate</td>
<td>1,322</td>
</tr>
<tr>
<td>Deep injection</td>
<td>689</td>
</tr>
<tr>
<td>Shallow incorporation</td>
<td>503</td>
</tr>
<tr>
<td>Low-trajectory spreader with 15 trailing hoses</td>
<td>130</td>
</tr>
</tbody>
</table>

¹Odor units per 1,000 gallons of slurry applied as measured by olfactometer.

sidedress manure on row crops without foliage damage. Sidedressing expands the season during which manure can be applied and increases the use of manure nutrients. All soil incorporation systems also offer the advantage of ammonia conservation and minimal odors.

**Irrigation systems**

A properly designed irrigation system uniformly applies wastewater at agronomic rates without direct runoff from the site. However, a “good design” does not guarantee proper land application. Poor management can compromise the performance of a well-designed system; likewise, a poorly designed system can sometimes provide good performance with proper, intensive management. To keep your system in proper operating condition, you should be familiar with your system components, range of operating conditions, and maintenance procedures and schedules.

Various sprinkler systems are described and illustrated in the next few pages. Although the equipment required for pumping and distributing lagoon effluent may be similar to conventional irrigation equipment, the smaller volume of water handled in most livestock lagoons and holding basins generally facilitates the use of smaller, less costly systems. It also is possible to use an application system for both effluent and freshwater irrigation. The type of irrigation system chosen may depend on the particle size of the effluent solids, the amount of available capital, and how much time and labor is available for pumping. The system capacity selected may also depend on the amount of available capital and how much time and labor is available for pumping. Table 36-4 gives the labor requirement for irrigating with various systems.

<table>
<thead>
<tr>
<th>Row Crop Application Method</th>
<th>Placement of Manure (not to scale)</th>
<th>Application Implement (side views)</th>
</tr>
</thead>
<tbody>
<tr>
<td>a) Injection: vertical knife/chisel</td>
<td><img src="https://example.com/diagram1.png" alt="Diagram" /></td>
<td><img src="https://example.com/diagram2.png" alt="Diagram" /></td>
</tr>
<tr>
<td>b) Injection: horizontal sweep</td>
<td><img src="https://example.com/diagram3.png" alt="Diagram" /></td>
<td><img src="https://example.com/diagram4.png" alt="Diagram" /></td>
</tr>
<tr>
<td>c) Shallow incorporation: s-tine cultivator (staggered)</td>
<td><img src="https://example.com/diagram5.png" alt="Diagram" /></td>
<td><img src="https://example.com/diagram6.png" alt="Diagram" /></td>
</tr>
<tr>
<td>d) Shallow incorporation: concave disks</td>
<td><img src="https://example.com/diagram7.png" alt="Diagram" /></td>
<td><img src="https://example.com/diagram8.png" alt="Diagram" /></td>
</tr>
</tbody>
</table>

Figure 36-3. Options for manure incorporation into the soil. Adapted from Jokela and Cote 1994.
Caution: Irrigation equipment used to apply manure or lagoon effluent and also connected to a freshwater source must be fitted with a check valve assembly.

### Table 36-4. Operating characteristics of some sprinkler irrigation systems.

<table>
<thead>
<tr>
<th>System Type</th>
<th>Labor Requirement, hr/acre/irrigation event</th>
<th>Sprinkler Pressure$^1$, psi</th>
<th>Field Shape$^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stationary</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hand move</td>
<td>0.6-1.0</td>
<td>40-60</td>
<td>Any shape</td>
</tr>
<tr>
<td>Solid set</td>
<td>0.1-0.5</td>
<td>40-90</td>
<td>Any shape</td>
</tr>
<tr>
<td><strong>Moving</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traveling gun</td>
<td>0.2-0.4</td>
<td>50-100</td>
<td>Any shape</td>
</tr>
<tr>
<td>Linear move</td>
<td>0.1-0.3</td>
<td>5-80</td>
<td>Rectangle, square</td>
</tr>
<tr>
<td>Center pivot</td>
<td>0.05-0.2</td>
<td>5-80</td>
<td>Circular, square, rectangle</td>
</tr>
</tbody>
</table>

$^1$Pressure supplied to the initial sprinkler/nozzle. Pressure at the inlet to the system must be higher to compensate for friction losses and elevation differences within the field.

$^2$A range of field shapes are possible; however, some shapes may limit the total acres that can be irrigated or the suitability of specific system types.

Source: MWPS-30.

Caution: Irrigation equipment used to apply manure or lagoon effluent and also connected to a freshwater source must be fitted with a check valve assembly. The check valve assembly should be located between the freshwater source and the point of manure entry into the irrigation system. The check valve prevents the backflow of manure into the freshwater source. Check valves are commonly placed on irrigation systems used for fertilizer or chemical application.

**Effluent irrigation systems**

As with water irrigation, no one system is superior to another system. The following systems can be used for effluent irrigation:

- Stationary volume gun
- Solid-set sprinkler
- Traveling gun
- Center pivot and linear move
- Hand-move sprinkler
- Side roll
- Furrow or gated pipe irrigation

**Stationary volume gun.** This system can be used in many small effluent application systems (Figure 36-4). The system includes a pump and a main line similar to the hand-move system but with a single or multiple large-volume gun sprinklers. Advantages of the volume gun system include larger flow rates and a larger wetted area so less labor is required to move the sprinkler. Some volume guns are wheel mounted to facilitate moving the unit. Stationary volume guns typically have nozzle sizes that range from 0.5 to 2 inches and operate best at pressures of 50 to 120 psi. Coverage areas of 1 to 4 acres can be obtained with the proper selection of nozzle size and operating pressure. Gun sprinklers typically have relatively high application rates; therefore, adjacent guns should not be operated at the same time (referred to as “head to head”). Although stationary volume guns cost more than smaller hand-carry systems, the reduced labor cost and higher flow rates may offset the higher cost.
A typical volume gun that discharges 330 gpm at 90 psi of pressure wets a 350 ft in diameter circle (2.2 acres) with an application rate of 0.33 inches per hr. The power requirement is about 30 horsepower (hp). This system must be manually moved from one set or location to another, ensuring that the soil does not become saturated, which results in runoff.

**Advantages:**
- Few mechanical parts to malfunction
- Few plugging problems with large nozzle
- Flexible with respect to land area
- Pipe requirements are slightly less than with small sprinklers.
- Moderate labor requirement

**Limitations:**
- Moderate to high initial investment
- Water application pattern is easily distorted by wind.
- Significant odor source
- Tendency to over-apply effluents with high nutrient concentrations such as livestock lagoon effluent

**Solid-set sprinkler.** Stationary systems for land application of lagoon liquid are usually permanent installations (lateral lines are PVC pipes permanently installed below ground). One of the main advantages of solid-set sprinkler systems is that they are well suited to irregularly shaped fields. Thus, it is difficult to give a standard layout, but there are some common features between systems. To provide proper overlap, sprinkler spacings are normally 50% to 65% of the sprinkler wetted diameter. Sprinkler spacing, typically in the range of 80 ft by 80 ft using single-nozzle sprinklers, is based on nozzle flow rate and desired application rate. A typical layout for a permanent irrigation system is shown in Figure 36-4. Most permanent systems use Class 160 PVC plastic pipe for mains, submains, and laterals and either 1-inch galvanized steel or Schedule 40 or 80 PVC risers near the ground surface where an aluminum quick coupling riser valve is installed. In grazing conditions, all risers must be protected (stabilized) if left in the field with animals.

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**Figure 36-4. Schematic layout of a permanent irrigation system used to apply liquid manure.**
The minimum recommended nozzle size for wastewater is 1/4 inch, and the typical operating pressure at the sprinkler is 50 to 60 psi. While sprinklers can operate full or partial circle, the system should be zoned (all sprinklers operated at the same time constitute one zone) so that all sprinklers are operating on about the same amount of rotation and thus achieve uniform application.

**Advantages:**
- Good for small or irregularly shaped fields
- Do not have to move equipment.

**Limitations:**
- Higher initial cost
- Must protect from animals in fields
- Small-bore nozzles likely to get plugged or broken
- No flexibility to move to other (new) field

**Traveling gun.** Traveling gun sprinkler systems are either cable-tow or hard-hose drag travelers. The cable-tow traveler consists of a single gun sprinkler mounted on a trailer with water supplied through a flexible, synthetic fabric, rubber-coated, or PVC-coated hose. The pressure rating on the hose is normally 160 psi. A steel cable is used to guide the gun cart, a wheel or sled-type cart.

The hose drag traveler consists of a hose drum, a high-density polyethylene hose, and a gun-type sprinkler. The hose drum is mounted on a multi-wheel trailer or wagon and rotated by a water turbine, water piston, water bellows, or by an internal combustion engine. Regardless of the drive mechanism, travelers should be equipped with speed compensation so that the gun cart travels at a uniform speed from the beginning of the pull until the hose is fully wound onto the hose reel. If the solids content of the wastewater exceeds 1%, an engine drive should be used.

The hose supplies wastewater to the gun sprinkler and also pulls the gun cart toward the drum. The distance between adjacent pulls is referred to as the lane spacing. To provide proper overlap, the lane spacing is normally between 70% to 80% of the gun’s wetted diameter.

The gun sprinkler is mounted on the gun cart. Normally, only one gun is mounted on the gun cart. A typical layout for a hard-hose drag traveler irrigation system is shown in Figure 36-5.

For uniform distribution, nozzle sizes on gun-type travelers are 1/2 to 2 inches in diameter and require operating pressures of 50 to 100 psi at the gun. Gun sprinklers have a ring, taper ring, or taper bore nozzle. The ring nozzle provides better breakup of the wastewater stream, which results in smaller droplets with less impact energy (less soil compaction). But, for the same operating pressure and flow rate, the taper bore nozzle throws water about 5% further than the ring nozzle, i.e., the wetted diameter of a taper bore nozzle is 5% wider than the wetted diameter of a ring nozzle. Taper bore nozzles also provide better application uniformity throughout the wetted radius, resulting in about a 10% larger wetted area than the ring nozzle. Thus, the precipitation rate of a taper bore nozzle is approximately 10% less than that of a ring nozzle.

A gun sprinkler with a taper bore nozzle is normally sold with only one size of nozzle. A ring nozzle, however, is often provided with a set of rings ranging in size from 1/2 to 2 inches in diameter, giving the operator the

Regardless of the drive mechanism, travelers should be equipped with speed compensation... .

Gun sprinklers have a ring, taper ring, or taper bore nozzle.
flexibility to adjust flow rate and throw diameter without sacrificing application uniformity. However, a misconception exists that using a smaller ring with a lower flow rate will reduce the precipitation rate. This is not normally the case. Rather, the precipitation rate remains about the same because a smaller nozzle results both in a lower flow and in a smaller wetted radius or diameter. The net effect, therefore, is little or no change in the precipitation rate. Furthermore, on water drive systems, the speed compensation mechanism is affected by flow rate, and a minimum threshold flow is required for proper operation of the mechanism. If the flow drops below the threshold, the travel speed becomes disproportionately slower, resulting in excessive application even though a smaller nozzle is being used. Thus, system operators should be knowledgeable of the relationships between ring nozzle size, flow rate, wetted diameter, and travel speed before interchanging different nozzle sizes. As a general rule, operators should consult with a technical specialist before changing nozzle size(s) to a size different than that specified by the system design.

Advantages:
- Moderate labor requirements
- Few or no plugging problems with the large nozzle
- Flexible with respect to land area

Limitations:
- Higher initial cost than the previous systems
- High power requirement
- More mechanical parts than the other systems, especially with an auxiliary engine
- High rate of application

Center pivot and linear move. The use of center pivot systems for wastewater irrigation is increasing. Center pivots are available in both fixed pivot point and towable machines. They range in size from single tower
machines that cover around 10 acres to multitower machines that can cover several hundred acres. Center pivot manufacturers offer almost completely automated systems that use rotary sprinklers, small guns, or spray nozzles. Their disadvantages include high cost, small sprinklers, and fixed land area covered. Drop-type spray nozzles offer the advantage of applying wastewater close to the ground at low pressure, which results in little wastewater drift due to wind.

Linear move systems are similar to center pivot systems, except that they travel in a straight line. Depending on the type of sprinkler used, operating pressure ranges from 10 to 50 psi. Low-pressure systems reduce drift at the expense of higher application rates and greater potential for runoff. Low-pressure systems in the 20-psi range with nozzles less than 1/4 inch in diameter are not recommended for livestock effluent because the effluent solids could plug the system.

**Advantages:**
- High uniformity of coverage
- Low labor requirement
- Flexible with respect to land area

**Limitations:**
- Used for low solids and well-screened liquids only
- Not applicable for irregularly shaped fields
- High initial cost

**Hand move sprinkler.** The least expensive sprinkler systems for effluent irrigation are the hand move types that must be set up and moved by hand. Although considerable labor input is required, these systems may be preferable for small lagoons. Used hand move systems may be available, but their small sprinkler nozzles may not be suited for effluent irrigation. A screened inlet pipe, however, will reduce problems with small nozzles.

An example of such a system is a 1/4-mile lateral covering 1.8 acres with each 60-ft move. A total of 32 sprinklers would discharge 10 gpm each, for a total of 320 gpm pumped through a 5-inch pipe. The application rate would be 0.4 inches per hr.

Nozzle sizes used for moderately to heavily loaded lagoons are generally in the 1/2- to 1-inch range, and the nozzles typically cover 1/2 to 2 acres per sprinkler, depending on nozzle size and system operating pressure.

**Advantages:**
- Low initial investment, especially with a used system
- Few mechanical parts to malfunction
- Low power requirement (50 psi at the sprinkler)
- Adaptable to field shape. To get isolated corners, different lengths can be set and run almost any direction.

**Limitations:**
- High labor requirement; individual pipe sections are moved, which can be a very unpleasant task with effluent.
- Small sprinklers can plug.
- Tendency to overapply effluents with high nutrient concentrations, such as livestock lagoon effluent.
**Side roll.** This system rolls sideways across a rectangular field but is limited to low-growing crops. Crop clearance is slightly less than 1/2 of the wheel’s diameter. These systems use small sprinklers, require rectangular fields, and have several mechanical devices.

**Furrow or gated pipe irrigation.** These systems consist of a pump or gravity flow arrangement from a lagoon storage basin to a distribution pipe that has holes at regular intervals along its length. Effluent is discharged through the holes at a rate compatible with the land slope and soil infiltration rate. The gated distribution pipe usually is laid as level as possible across the upper end of a sloped soil-plant filter or manure receiving area. Gated pipe systems are suitable for land with 0.2 to 5.0 percent slope; they do not perform well on uneven or steeply sloped land. Flatter slopes result in ponding, or manure accumulating at the discharge point of the gated pipe, while steeper slopes cause effluent runoff with little opportunity for soil infiltration.

The advantages of gated pipe systems are relatively low cost, low operating pressures, and even effluent distribution if the pipe holes are properly located and sized. The disadvantages of these systems are high labor and management to ensure that they operate properly. Traditionally, gated pipe systems have been used to irrigate row crops. However, properly designed and managed gated pipe systems have also been successfully used to apply lagoon effluent to grassed areas.

**Issues when irrigating manure slurry.** The direct irrigation of manure slurry through a large-diameter sprinkler nozzle is an alternative for farms that produce large quantities of manure and have nearby pasture or cropland. The irrigation of liquid manure requires less labor, time, and operating expense than hauling and does not incur soil compaction problems.

Centrifugal pumps that can deliver at least 30 psi of pressure at the sprinkler nozzle are needed for irrigation. In addition, due to the slurry’s high solids content, a lift pump similar to the chopper-agitator pump already described is needed to maintain the centrifugal pump’s prime. Internal pump chopper mechanisms can help prevent clogging.

Slurries with more than 4 percent solids cause higher friction losses in pipes, requiring more pump pressure and hp. After pumping slurry, the irrigation lines must be flushed with clean water. With proper management, slurry manure up to 7 percent total solids can be irrigated.

The overapplication of nutrients is a concern with slurry irrigation systems. However, frequently moving sprinklers helps to minimize this concern. Thus, traveling irrigators are recommended. Hose drag travelers are less labor intensive and apply manure more uniformly than other traveling systems. Because the high solids content clogs other types of drives, the hose reel should be driven by an auxiliary engine. Gun sprinklers operate at higher pressures, resulting in greater potential for misting and wind drift.

**Land Application Equipment**

Developing an environmentally friendly land application system for manure requires proper management and careful review of application equipment. The producer’s willingness to consider manure and other livestock byproducts as a nutrient resource rather than as waste is critical. Manure application equipment must be selected and managed as fertilizer-spreading equipment rather than waste disposal equipment. A producer’s primary objective needs to be efficient use of manure nutrients.
The appropriate management of a manure application system determines if that type of application equipment will continue to be used after it has been purchased. The proper location and selection of application sites and of equipment is no assurance that problems will be eliminated. Manure spreading or spraying activities must be planned and managed to prevent nuisances and an adverse impact on groundwater, surface water, public health, and plants. The prevention of adverse impacts is accomplished by managing

- Application rates.
- Timing setbacks/isolation.
- Manure/effluent nutrients and other constituents.
- System performance.

Degradation of any aspect of the environment warrants re-evaluation of the use of a selected manure application system.

**Equipment calibration**

You can avoid the potentially adverse effects of overfertilization on ground and surface water by applying only the amount of manure, effluent, or wastewater necessary to maintain soil fertility for crop production. The calibration, or combination of settings and travel speed needed to uniformly apply manure, bedding, or wastewater at a desired rate, of manure-spreading equipment is important because it tells you the amount of manure and wastewater that you are applying to an area. Knowledge of the application rate and nutrient concentration of manure nutrients lets you apply manure at agronomic rates.

**Why calibrate?**

- Verify actual application rates
- Troubleshoot equipment operation
- Determine appropriate overlaps
- Evaluate application uniformity
- Identify “hot spots” or areas of deficient application
- Monitor changes in equipment operations, such as usage and “wear and tear”
- Determine changes in manure consistency or “thickness”

Simply put, calibration enables producers to know how much manure they are applying. Knowing the actual application rate allows them to apply manure and nutrients at specific rates that meet the needs of growing crops. Calibration also ensures that rates do not exceed state or local regulatory limits or the conditions expressed in a livestock facility’s operating permit.

Regular calibration can be used to troubleshoot problems that may be occurring in an application system. Application rates, uniformity coefficients, spread widths, and application patterns can be compared to previous calibration results, highlighting specific operational conditions that may require maintenance, repair, or replacement. At a minimum, equipment that applies manure, litter, or lagoon effluent should be calibrated annually. For larger operations, producers should consider a more frequent schedule.

During calibration, the required or appropriate overlap can be determined. Overlap distances and travel lane widths are best determined by measuring the distribution of applied material across the spread pattern. Rain
gauges, tarps, or disposable baking pans can be used to collect the applied manure before it is weighed or measured. Many times, visual estimates of desired overlap can be misleading. Due to variations in spreader volume and changes in manure moisture content and density, this is especially true when calibrating litter or solid manure spreaders. Sprinkler overlaps, typically calculated to be the points where an area is receiving less than half of the average catch across the spread width, generally vary between 50 to 80, depending on sprinkler type and wind conditions.

Ensuring application uniformity is extremely important to meeting a crop’s nutrient requirements while protecting the environment. Application equipment should be maintained and operated so it applies a given application rate as evenly as possible across a field. “Hot spots” or areas of overapplication due to operator error and noncalibrated or worn equipment may increase the occurrence of runoff or ponding, an accumulation of nutrients or metals, crop lodging, or excessive nutrients moving into shallow groundwater. Areas of low application will not produce the realistic yield that could be achieved on the site, leaving unused nutrients that accumulate or are lost to the environment.

As equipment is used and gets older, it loses efficiency, increasing the need for calibration. The loss of efficiency or performance may result in poorer application uniformity or changes in application rate. These factors are compounded due to the solids, acidity, and salts found in manure, litter, and wastewater. To monitor system performance, irrigation systems that pump liquids with high solids or with significant crystal buildup should be calibrated on a regular basis.

Lastly, equipment should be calibrated in response to changes in manure “thickness.” When a manure storage is emptied, a higher amount of solids will be removed and applied to fields. As the manure density increases, re-calibrate the equipment to ensure that the application rate is within acceptable limits. Spreaders should also be re-calibrated when a material is applied that is wetter or drier than the litter or manure spread during the previous calibration.

Calibrating Manure Application Equipment

Calibrating your spreader...is a simple, effective way to use the nutrients in manure more effectively.

Calibrating Manure Application Equipment

Calibrating Manure Application Equipment

If you do not know how much manure is being spread over a given area, you are probably not using the manure most effectively. Calibrating your spreader, however, is a simple, effective way to use the nutrients in manure more effectively. Only by knowing your spreader’s application rate can you apply the amount of manure that your crop needs and prevent water quality problems resulting from the overapplication of animal manure.

Applicators can apply manure, bedding, and wastewater at varying rates and patterns, depending on forward travel and/or power takeoff (PTO) speed, gear box settings, gate openings, operating pressures, spread widths, and overlaps.

Solid and semi-solid manure spreaders

To calibrate a spreader for solid manure (20% or more solids), the following materials are needed:

1. Bucket
2. Plastic sheet, tarp, or old bed sheet. An even size—8 ft by 8 ft, 10 ft by 10 ft, or 12 ft by 12 ft—makes calculations easier. A 56-inch by 56-inch sheet, equaling 1/2,000 of an acre, can be used to simplify calculations...
but exercise caution when determining application rates using a small collection area (1 lb collected equals 1 ton/acre).

3. Scales

Spreader manufacturers rate solid and semisolid spreaders either in bushels or cubic feet (to get cubic ft, multiply bushels by 1.25). Most spreaders have two rating capacities: (1) struck or level full and (2) heaped. It is difficult to accurately estimate the calibration of solid manure spreaders based on their capacity (volume) because the density of solid and semisolid manures, or their weight per volume of manure (in lbs per cubic ft), varies widely, depending on the type and amount of bedding used as well as its storage method. Therefore, if you estimate spreader application rates as the volume of the manure that the spreader holds, you are overlooking the fact that some manure weighs more than other manure, which can cause significant error when calculating manure application rates.

Since manures and litters have different densities, an on-farm test should be performed. If a weigh scale for your spreader is not available, determine the load (in tons) of a manure spreader as follows:

1. Weigh an empty 5-gallon bucket.
2. Fill the bucket level full with the material to be spread. Do not pack the material in the bucket but ensure that it settles similar to a loaded spreader.
3. Weigh the bucket again. To calculate the weight of the contents, subtract the empty bucket weight from this weight.
4. To calculate the density (in pounds per cubic ft), multiply the weight of the contents by 1.5.
5. To calculate the tons of material in a spreader load, multiply the manure density by the spreader’s cubic ft capacity and divide by 2,000.

\[
\text{Spreader load (tons) = \frac{\text{weight of 5 gal of manure} \times 1.5 \times \text{spreader capacity (ft')}}{2,000}}
\]

**Spreader calibration (tarp method).** Use the following procedure to calibrate a solid or semi-solid manure spreader with a collection tarp.

1. Locate a large, reasonably smooth flat area where manure can be applied.
2. Weigh the empty bucket and plastic sheet, tarp, or blanket.
3. Spread the plastic sheet, tarp, or blanket smoothly and evenly on the ground.
4. Fill the spreader with manure to the normal operating level. Drive the spreader at the normal application speed toward the sheet spread on the ground, allowing the manure to begin leaving the spreader at an even, normal rate.
5. Drive over the sheet at the normal application speed and settings while continuing to apply manure. If a rear discharge spreader is used, make three passes. First, drive directly over the center of the sheet; then make the other two passes on opposite sides of the center at the normal spreader spacing overlap.
6. Collect all manure spread on the sheet, and place sheet and all in the bucket.
7. Weigh the bucket and manure; then subtract the weight of the empty bucket and ground sheet, giving you the pounds of manure applied to the sheet.
8. To get a reliable average, repeat the procedure three times.
9. Determine the average weight of the three manure applications.
10. Calculate the application rate using the formula below or Table 36-5.

\[
\text{Application rate (tons/acre)} = \frac{21.78 \times (\text{manure weight on tarp, lbs})}{\text{(tarp area, ft}^2\text{)}}
\]

11. Repeat the procedure at different speeds and/or spreader settings until the desired application rate is achieved.

Many times it may be necessary to adjust the application rate. Application rate can easily be changed by increasing or decreasing the speed at which the manure is applied. To perform these calculations, the spreader load (in tons), duration of application (in minutes), and the average width

<table>
<thead>
<tr>
<th>Table 36-5. Calibration of solid manure spreaders.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pounds of Manure Applied to Tarp</strong></td>
</tr>
<tr>
<td></td>
</tr>
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</tr>
<tr>
<td>20</td>
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<td>300</td>
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<td>350</td>
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</tbody>
</table>

**PROBLEM 1**

**Determining application rate (tarp method).**
What is the application rate (tons per acre) if you collect 8.5 pounds of manure on a 10-ft by 10-ft tarp during a calibration run?

Application rate (tons/acre) = \[
\frac{8.5 \text{ lbs of manure} \times 21.78}{10 \text{ ft} \times 10 \text{ ft}} = 1.85 \text{ tons/acre}
\]
Application rate can easily be changed by increasing or decreasing the speed at which the manure is applied.

Any time you make adjustments, change the rpm, or use thicker manure, you should recalibrate the unit.

Application rate (tons/acre) can easily be changed by increasing or decreasing the speed at which the manure is applied. The application rate and travel speed can be found using the following equations:

$$\text{Travel speed (mph)} = \frac{\text{spreader load (tons)} \times 495}{\text{time (min)} \times \text{width (ft)} \times \text{application rate (tons/acre)}}$$

$$\text{Application rate (tons/acre)} = \frac{\text{spreader load (tons)} \times 495}{\text{time (min)} \times \text{width (ft)} \times \text{travel speed (mph)}}$$

When in this type of situation, select the gear in the tractor or truck that most closely matches the required speed (do not adjust PTO speed). If the travel speed is too high or too low, then you need to change the flow rate, altering the time it takes to empty the tank. This is accomplished by changing PTO rpm, by changing valve or gate settings, or by installing an orifice in the flow line. Any time you make adjustments, change the rpm, or use thicker manure, you should recalibrate the unit.

**Spreader calibration (scale method).** An alternative method of calibrating your spreader is to measure the coverage area during a typical application. Conceptually, this process is less complicated than the previous method explained, but the weight area has several limitations. First, as stated earlier, changes in manure moisture or density must be taken into account. Second, applicators must have access to expensive portable weigh scales or have load cells installed on their spreader to perform calibrations. The scale method is very similar to calibrating a liquid manure spreader, which is discussed in the next section. To calibrate a spreader, divide the weight of the applied manure by the coverage area for a given set of spreader settings, PTO rotations, and travel speed.

**Spreader pattern uniformity and determining overlap.** To determine the uniformity of spread and the amount of overlap needed, place a line of small, equally spaced (2-4 ft) pans or trays across the spreader path. The pans should be a minimum of 12 inches by 12 inches (or 15 inches in diameter) but no more than 24 inches by 24 inches and 2 inches to 4 inches deep. Make one spreading pass directly over the center pan. Weigh the contents caught in each pan or pour the contents into equal-sized glass cylinders or clear plastic tubes and compare the amount in each.

The effective spread width can be found by locating the point on either side of the path center where manure contents caught in the containers are half of what they are in the center. The distance between these points is the

### Problem 2

**Adjusting travel speed.** What speed should you drive if you want to apply 4 tons of manure per acre with a 3-ton spreader? Your spreader application width is 20 ft, and your spreader empties in 6 minutes.

$$\text{Travel speed (mph)} = \frac{3 \text{ tons} \times 495}{6 \text{ min} \times 20 \text{ ft} \times 4 \text{ tons/acre}} = 3.1 \text{ mph}$$
effective spreader width. The outer fringes of the coverage area beyond these points should be overlapped on the next path to ensure a uniform rate over the entire field. “Flat-top,” “pyramid,” or “oval” patterns are most desirable and give the most uniform application. “M,” “W,” “steeple,” or “offset” patterns (Figure 36-6) are not satisfactory, and one or more spreader adjustments should be made. Refer to your owner’s manual for recommendations on spreader adjustments.

**Liquid manure spreaders**

To apply manure at proper rates, liquid tank spreaders must be accurately calibrated. Calibration is the combination of settings and travel speed needed to apply manure at a desired rate and to ensure uniform application. To calibrate a spreader, you must know its capacity, which the manufacturer normally provides in gallons.

**Information to collect**

1. Tank volume, gallons
2. Gear, rpm, and PTO speed
3. Time, minutes, to unload spreader
4. Time, seconds, to travel 100 ft or speed (in mph) of tractor/truck
5. Spread width, ft
6. Spread length, ft

**Figure 36-6. Desirable and undesirable application uniformity.**
Calibration method: liquid manure spreaders.
1. For ease of measuring, spread at least one full load of manure, preferably in a square or rectangular field pattern, with normal overlaps. Record the time, in minutes, it takes to empty the spreader.
2. Determine the spreader’s speed by recording the time it takes the spreader to travel 100 ft. Using the following equation, calculate the travel speed (in mph):

\[
\text{Travel speed (mph)} = \frac{68.18}{\text{time (sec) to travel 100 ft}}
\]

3. Measure coverage length and width, recognizing that the outer fringe areas of the coverage will receive much lighter applications than the overlapped areas.
4. To measure the coverage length,
   a. Use a measuring wheel or
   b. Tire method
      1. Place a paint mark on a tire visible from tractor cab.
      2. Measure the distance traveled by one wheel rotation.
      3. While spreading, count the number of revolutions to empty the spreader.
      4. To determine the length of spread, multiply distance per revolution by the number of revolutions.
5. To determine the coverage area in acres, multiply the length by the width and divide by 43,560.

\[
\text{Coverage area (acres)} = \frac{\text{length (ft)} \times \text{width (ft)}}{43,560 \text{ ft}^2 \text{ per acre}}
\]

6. To determine the application rate in gallons per acre, divide the gallons of wastewater in the spreader by the acres covered.

\[
\text{Application rate for spreader (gal or tons/acre)} = \frac{\text{spreader load volume (gal or tons)}}{\text{coverage area (acres)}}
\]

Reminder: Manufacturers normally provide liquid spreader capacities in gallons. To get tons, multiply by 0.0042.
7. Use the following equation to calculate the travel speed necessary to achieve a desired application rate:

\[
\text{Travel speed (mph)} = \frac{\text{capacity (gallons) } \times 495}{\text{unload time (min) } \times \text{ width } \times \text{ desired rate (gallons/acre)}}
\]

8. If a different application rate is desired, repeat Steps 1 through 5.
Problem 3

Load area (honeywagon).
Your manure application method is a tractor-drawn tanker (honeywagon) with a 3,500-gallon capacity. You apply a load to a field and measure the application area as 35 ft wide by 350 ft long. It takes 1.17 minutes (70 seconds) to empty the spreader, and it took the spreader 20 seconds to travel 100 ft. What is the application rate in gallons per acre?

First figure the coverage area:

Coverage area (acres) = \frac{350 \text{ ft} \times 35 \text{ ft}}{43,560 \text{ ft}^2 / \text{acre}} = 0.28 \text{ acres}

Then figure the application rate:

Application rate for spreader (gal/acre) = \frac{3,500 \text{ (gallons)}}{0.28 \text{ acres}} = 12,500 \text{ gal/acre}

Answer: At the current gear and PTO speed, the spreader applies approximately 12,500 gallons per acre.

What speed should you run if you want to apply 25,000 gallons of manure per acre with the 3,500-gallon spreader?

1. How fast was the spreader traveling?

Travel speed (mph) = \frac{68}{\text{time (sec) to travel 100 ft}}

Travel speed (mph) = \frac{68}{20 \text{ (sec) to travel 100 ft}} = 3.4 \text{ mph}

2. How fast should the spreader be traveling to apply 25,000 gallons per acre?

Travel speed (mph) = \frac{\text{capacity (gallons)} \times 495}{\text{unload time (min)} \times \text{width} \times \text{desired rate (gal/acre)}}

Travel speed (mph) = \frac{3,500 \text{ (gallons)} \times 495}{1.17 \text{ (min)} \times 35 \text{ ft} \times 25,000 \text{ (gal/acre)}} = 1.7 \text{ mph}

Answer: The spreader should travel at 1.7 mph to apply the 3,500 gallons at a rate of 25,000 gallons per acre.
If you are not using a flow meter, you will have to operate the system for at least one hour before you can get an accurate reading...

**Drag hose injectors.** This method calculates the speed required to pull a drag hose application system (Figure 36-2) around the field. If you are not using a flow meter, you will have to operate the system for at least one hour before you can get an accurate reading of the amount of manure you have removed from the storage tank or basin.

To calculate the required speed, you need to know:
- The discharge rate (gpm) from:
  - A flow meter or
  - The manufacturer’s information or
  - The amount removed from manure storage
- The desired application rate, gallons/acre
- The width of application, ft

\[
\text{Speed (mph)} = \frac{495 \times \text{volume/min (gpm)}}{\text{application rate (gal/acre) \times width (ft)}}
\]

To match the calculated speed, select the appropriate gear on the field tractor. If the calculated speed is too fast, you could reduce the volume applied per hour by decreasing the power to the main pump. At the same time, you may also have to reduce the nozzle (or orifice) size to keep adequate pressure in the drag hose. Another way to compensate for an excessive calculated tractor speed is to increase the application width by using a boom-style application and no direct injection.

**Problem 4**

**Drag hose boom.**
A custom manure applicator measured pumped manure at a rate of 750 gpm. His injector boom is 22 ft wide, and he wants to apply 5,500 gallons per acre.

Using the preceding equation,

\[
\text{Speed (mph)} = \frac{495 \times 750 \text{ gpm}}{5,500 \text{ gal/acre} \times 22 \text{ ft}}
\]

**Answer:** Speed = 3.1 mph

**Spot check applied rate across the width of application.** All of the previous options give you the average application across the width. To check the variation across the application width or along the application length, you need to place a series of containers in the application path. Table 36-6 gives you the information to convert the depth of liquid in the straight-walled container to the application rate.

Because such small depths are involved, the depth method gives only an approximate application rate. A more accurate method involves weighing the contents of the container and converting this weight to an application rate.
Sprinkler irrigation systems

Operating a sprinkler irrigation system differently than assumed in the design alters the application rate, coverage uniformity, and subsequently, the application uniformity. Operating with excessive pressure results in smaller droplets, greater potential for drift, and also accelerates the wear of the sprinkler nozzle. Pump wear tends to reduce operating pressure and flow, leading to smaller droplets. With continued use, nozzle wear results in an increase in the nozzle opening, which will increase the discharge rate while decreasing the wetted diameter. Clogging of nozzles or crystallization of main lines by struvite can result in increased pump pressure but reduced flow at the gun. Plugged intakes will reduce operating pressure. An operating pressure below design pressure greatly reduces the coverage diameter and application uniformity. Field calibration helps ensure that nutrients from liquid manure or lagoon effluent are applied uniformly and at proper rates.

The calibration of a hard-hose or cable tow system involves setting out collection containers, operating the system, measuring the amount of wastewater collected in each container, and then computing the average application volume and application uniformity.

By installing an in-line flow meter, suitable for effluent and/or slurry, in the main irrigation line, you can obtain a good estimate of the total volume pumped from the lagoon during each irrigation cycle. As the following formula indicates, the average application depth can be determined by dividing the pumped volume by the application area:

\[
\text{Average application depth (inches)} = \frac{\text{volume (gallons)}}{27,154 \text{ gal/acre-in} \times \text{application area (acres)}}
\]

The average application depth is the average amount applied throughout the field. This method works well for pivot or linear irrigation units but not as well for impact sprinklers or volume guns. Unfortunately, sprinklers do not apply the same depth of water throughout their wetted diameter. Under normal operating conditions, application depth decreases toward the outer perimeter of the wetted diameter. Big gun sprinkler systems typically have overlap based on a design sprinkler spacing of 70% to 80% of the wetted sprinkler diameter to compensate for the declining application along the outer perimeter. When operated at the design pressure, this overlap results in acceptable application uniformity.

---

**Table 36-6. Liquid manure calibration using a straight-walled pail.**

<table>
<thead>
<tr>
<th>Depth of Manure in Pail, inch</th>
<th>Application Rate, gallons/acre</th>
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<tbody>
<tr>
<td>1/10</td>
<td>2,250</td>
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<td>1/8</td>
<td>2,800</td>
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</tbody>
</table>
When operated improperly, well-designed systems will not provide acceptable application uniformity. For example, if the pressure of an impact sprinkler or volume gun is too low, the application depth will be several times higher near the center of the sprinkler and water will not be thrown as far from the sprinkler as indicated in manufacturers’ charts. Even though the average application depth may be acceptable, some areas receive excessively high applications while others receive no application at all.

When applying wastewater high in nutrients, it is important to determine the application uniformity. Collection containers distributed throughout the application area must be used to evaluate application uniformity.

Many types of containers can be used to collect flow and determine the application uniformity. Standard rain gauges work best and are recommended because they already have a graduated scale from which to read the application depth. Gauges with 0.01-inch graduations should be used for measuring application rates and evaluating sprinkler uniformity. Gauges with larger graduation should only be used for estimating application volumes. Pans, plastic buckets, jars, or anything with a uniform opening and cross section can be used, provided the container is deep enough (at least 4 inches deep) to prevent splash and excessive evaporation, and the liquid collected can be easily transferred to a scaled container for measuring. To simplify application depth computations, all containers should be the same size and shape.

All collection containers should be set up at the same height relative to the height of the sprinkler nozzle (discharge elevation). Normally, the top of each container should be no more than 36 inches above the ground. Collectors should be located so there is no interference from the crop. The crop canopy should be trimmed to preclude interference or splash into the collection container.

Calibration should be performed during periods of low wind and evaporation. The best times are before 10 a.m. or after 4 p.m. on days with a light wind (less than 5 mph). On cool, cloudy days the calibration can be performed anytime when wind velocity is less than 5 mph. Impact sprinkler systems should not be calibrated when winds exceed 3 mph.

To minimize evaporation from the rain gauge, the volume (depth) collected during calibration should be read soon after the sprinkler gun cart has moved one wetted radius past the collection gauges. Where a procedure must be performed more than once, containers should be read and values recorded immediately after each setup.

Solid-set sprinkler irrigation systems. The wastewater application rate from a stationary impact sprinkler or volume gun depends on the flow rate, wetted diameter, amount of time it operates at a location, and sprinkler location pattern. To attain acceptable application uniformity with multiple sprinkler setups, the sprinkler spacing should be 50% to 70% of the sprinkler’s coverage diameter (Figure 36-7).

Determining application rates.
1. Determine the operating pressure in the field by installing a pressure gauge on the sprinkler riser or mounting a gauge on a volume gun. Verify the nozzle type and size on the sprinkler.
2. Determine the flow rate in gpm from available manufacturer’s literature.
3. Determine the coverage diameter in feet from available manufacturer’s literature.
4. From Step 2, calculate the required sprinkler spacing (SS) as 50% to 65% of the coverage diameter. Refer to Figure 36-7 for a diagram of a stationary sprinkler setup.

\[ SS \ (\text{ft}) = \text{wetted diameter} \times \text{percent overlap (as decimal)} \]

5. Calculate the average application rate, inches/hr.

\[
\text{Average application depth (inches/hr)} = \frac{96.3 \times \text{sprinkler flow rate (gpm)}}{\text{sprinkler spacing (ft) \times lateral spacing (ft)}}
\]

6. Determine the number of inches of wastewater that was applied.

\[
\text{Application volume (inches)} = \# \ \text{of hrs} \times \text{application rate (inches/hr)}
\]

7. The N applied per acre (lb N/ac) is calculated by multiplying the inches of wastewater applied from Step 6 by the pounds of N in a 1,000 gallons of wastewater and then multiplying this result by 27.

\[
\text{Nitrogen applied (lb N/ac)} = 27 \times \text{application volume (inches) \times} \quad \text{lb N/1,000 gallons}
\]
PROBLEM 5

Mr. Smith is using a solid-set volume gun system to apply lagoon effluent to spray for 2 hours. The volume gun was operated at 90 psi with a 0.75-inch nozzle. The manufacturer’s specifications for the gun are provided in Table 36-7. Smith wants to set up his sprinklers with a 60% overlap. His effluent was analyzed to have a plant-available nitrogen (PAN) concentration of 3.5 pounds per 1,000 gallons.

Step 1.
Nozzle size = 0.75-inch nozzle, operating pressure = 90 psi

Steps 2 and 3.
From Table 36-7. With a 0.75-inch nozzle at 90 psi, the flow rate is 155 gpm and the wetted diameter estimated as 306 ft.

Step 4.
Required sprinkler spacing, assuming a 60% sprinkler spacing.

\[ SS (ft) = 306 \text{ ft} \times 0.6 \]
\[ SS = 183.6 \text{ ft}; \text{ use } 180 \text{ ft} \]

Step 5.
Application rate

\[ \text{Average application rate (inches/hr)} = \frac{96.3 \times 155 \text{ (gpm)}}{180 \text{ (ft)} \times 180 \text{ (ft)}} \]

Application rate = 0.46 inches/hr

Step 6.

Application volume (inches) = 2 hrs x 0.46 (inches/hr)
Application volume = 0.92 inches

Step 7.
Amount of PAN applied

\[ \text{Nitrogen applied (lb N/ac)} = 27 \times 0.92 \text{ (inches)} \times 3.5 \text{ lbs PAN/1,000 gallons} \]
Amount of N applied = 86.94 lbs N/ac
**Solid-set irrigation calibration method.** Rain gauges or other collection containers should be spaced in a grid pattern fully enclosing the “effective” wetted area defined by the sprinkler spacing. The most common spacing pattern for stationary sprinklers is a square spacing where the distance between sprinklers is the same as the spacing between laterals. The spacing between sprinklers and laterals is normally between 50% to 65% of the sprinkler-wetted diameter specified by the manufacturer.

Collection gauges should be placed 1/4 of the lateral line length from the main and no further apart than 1/4 of the wetted sprinkler radius or effective sprinkler spacing. (For example, if the effective spacing is 80 ft, spacing between gauges should be no more than 20 ft).

The grid pattern and number of gauges required to complete the calibration depends on the pattern of operating the irrigation system. The size of the calibration area should be no less than the “effective” area of one sprinkler. When sprinklers are arranged in a rectangular or square pattern with proper overlap, an “effective area” receives flow from four sprinklers. Thus, a minimum of four sprinklers should be included in the calibration.

The reliability of the calibration generally improves as more sprinklers are included in the calibration area. As described in the preceding paragraph, if all sprinklers contributing flow to the calibration area are functioning correctly, it is necessary to include only the minimum number of sprinklers. But, a malfunctioning sprinkler can greatly influence the calibration results. Its effect on the calibration depends on the calibration setup and number of sprinklers being calibrated, the malfunctioning sprinkler’s position within the calibration area, the direction of the prevailing wind, and the nature of the malfunction. For these reasons, it is extremely important to observe the performance of every sprinkler contributing to the calibration while the calibration is being performed and to record any obvious performance irregularities. The more sprinklers that can be included in the calibration, the more representative the calibration results will be of the entire field, and the less influence one malfunctioning sprinkler will have on the calibration results.

### Table 36-7. Sprinkler performance chart.

<table>
<thead>
<tr>
<th>Operating Pressure, psi</th>
<th>Nozzle Size, inches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.5</td>
</tr>
<tr>
<td></td>
<td>Flow rate, gpm&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>60</td>
<td>55</td>
</tr>
<tr>
<td>70</td>
<td>60</td>
</tr>
<tr>
<td>80</td>
<td>64</td>
</tr>
<tr>
<td>90</td>
<td>68</td>
</tr>
<tr>
<td>100</td>
<td>72</td>
</tr>
<tr>
<td>110</td>
<td>76</td>
</tr>
<tr>
<td>120</td>
<td>—</td>
</tr>
<tr>
<td>130</td>
<td>—</td>
</tr>
</tbody>
</table>

<sup>1</sup> gpm is gallons per minute.

Note: If your exact numbers are not listed in the table, then estimate your value based on the numbers nearest yours.
To minimize evaporation from the rain gauge, the volume (depth) collected during calibration should be read as soon as a zone or sprinkler is shut off. Where a procedure must be performed more than once, containers should be read and values recorded immediately after each different setup.

Operating patterns affect collection container layout and calibration procedures and results. Typical patterns for stationary sprinklers include

**Square sprinkler spacing operated as a block** (two or more adjacent laterals operating at the same time)(Figure 36-8). *Volume gun systems:* This procedure should be repeated for each gun or hydrant contributing to the area being calibrated. This operating situation results where one or two guns are moved from hydrant to hydrant throughout the field. Since stationary big guns should not be operated “head to head” (multiple sprinklers operating side-by-side and throwing water on the same area simultaneously), guns must therefore be operated individually for the same amount of time to complete the calibration.

As depicted in Figure 36-8, the calibration area may be positioned or centered between the two laterals. Four sprinklers contribute area in the setup. With no wind effects, all four sprinklers should contribute equal flow to the calibration area (provided all sprinklers are functioning properly). If one of the four sprinklers is functioning improperly, the calibration results are not biased by its position within the calibration area.

An application uniformity greater than 75 is excellent for stationary sprinklers. An application uniformity between 50 to 75 is in the “good” range and is acceptable for wastewater application. Generally, an application uniformity below 50 is not acceptable for wastewater irrigation with stationary sprinklers. If the computed $U_c$ is less than 50, system adjustments are required. Contact your irrigation dealer or technical specialist for assistance.

---

*Figure 36-8. Collection container layout to calibrate sprinklers or volume guns in a square sprinkler spacing operating as a block.*
PROBLEM 6

Block pattern with two or more laterals operating at the same time (scenario shown in Figure 36-8).

1. Determine the effective sprinkler area. This is the area defined by SS along a lateral multiplied by the spacing between laterals. (Example: 80 ft by 80 ft is typical for a solid-set wastewater system). The effective sprinkler area is the minimum area to be included in the calibration area. 
   Note: The calibration area can be more than the effective area of one sprinkler.

2. Determine the necessary spacing between collection gauges (1/4 the sprinkler spacing). For an effective SS of 80 ft, the rain gauge spacing should not exceed 20 ft (80 ft/4 = 20 ft). Gauges closest to the sprinklers should be placed a distance of 1/2 the gauge spacing from the sprinkler. For a gauge spacing of 20 ft, the first row of gauges should be 10 ft from the lateral line or sprinklers.

3. Determine the number of gauges required. The minimum number is 16.
   \[
   \text{Number of gauges} = \frac{\text{calibration area (ft}^2\text{)}}{\text{gauge area (ft}^2\text{)}}
   \]

Example:

Calibration area = 80 ft x 80 ft = 6,400 ft\(^2\)

Gauge area = 20 ft x 20 ft = 400 ft\(^2\)

Number of gauges = \(\frac{6,400 \text{ ft}^2}{400 \text{ ft}^2}\)

4. As Figure 36-8 shows, set out gauges in a rectangular pattern equally spaced at the distance determined in Item 2 (20 ft) within the calibration area.

5. Operate the system for the normal operating time for a full cycle. Record the time of operation (duration in hrs).

6. Immediately record the amounts collected in each gauge.

7. Add the amounts in Item 6 and divide by the number of gauges. This is the average application depth (inches).

\[
\text{Average application depth} = \frac{\text{sum of amounts collected in all gauges}}{\text{number of gauges}}
\]
8. Calculate the deviation depth for each gauge. The deviation depth is the difference between each individual gauge value and the average value of all gauges (Item 7). Record the absolute value of each deviation depth (absolute value means the sign of the number [negative sign] is dropped and all values are treated as positive). The symbol for absolute value is a straight thin line. For example, |2| means treat the number 2 as an absolute value. It does not mean the number 121. The symbol is used in formulas in the text.

Deviation depth =

\[|\text{Depth collected in gauge } i - \text{average application depth}|\]

“i” refers to the gauge number

9. To get the average deviation, add the amounts in Item 8 to get the “sum of the deviations” from the average depth and divide by the number of gauges.

Application rate depth =

\[\frac{\text{sum of deviations (add amounts computed in Item 8)}}{\text{number of gauges}}\]

10. The precipitation rate (inches/hour) is computed by dividing the average application depth (inch) by the application time (hours).

Precipitation rate = \[\frac{\text{average application depth (inch)}}{\text{application time (hrs)}}\]

11. Determine the application uniformity. The application uniformity is often computed using the mathematical formula referred to as the Christiansen Uniformity Coefficient \(U_c\). It is computed as follows:

\[U_c = \left[1 - \frac{\text{average deviation (Item 9)}}{\text{average depth (Item 7)}}\right] \times 100\]

12. Interpret the calibration results. The higher the index value, the more uniform the application. An index of 100 means that the uniformity is perfect—that the exact same amount was collected in every gauge.
One lateral operating with no overlap between laterals. A typical case when large-volume gun sprinklers are operated in narrow fields or smaller irrigation systems that use single laterals of impact sprinklers (Figure 36-9). The procedure must be repeated for each gun/sprinkler or sprinkler position (hydrant) contributing to the effective area being calibrated. This operating situation results where one or two guns are moved from hydrant to hydrant throughout the field or when a single row of impact sprinklers are operated where they do not overlap another sprinkler. Since stationary big guns should not be operated “head to head” (two or more sprinklers throwing water on the same area simultaneously), two adjacent guns must be operated individually to complete the calibration.

The calibration procedure is similar to those above except outer edges do not receive overlap and must be excluded from the effective area calculations. Collection gauges may be centered between two adjacent sprinklers.

A general rule in irrigation design is to assume that the width of the effective area is between 50% to 65% of the wetted diameter of the sprinkler (often 60% is used). The first calibration approach accepts this design guideline that the effective width of the lateral is 60% of the wetted diameter of one sprinkler. As Figure 36-9 shows, 16 gauges are set out (eight gauges on each side of the lateral) with all 16 gauges positioned within the effective sprinkler width. The outer edges are ignored at the onset of the calibration. Flow from all sprinklers is assumed and then averaged to compute the average application depth for the effective area.

As the same figure also shows, collection gauges are centered between Guns 2 and 3 or Guns 3 and 4. (The actual location depends on the length of the lateral). In this setup, the procedure is performed twice since only two guns or gun locations contribute to the calibration.

An application uniformity greater than 75 is excellent for stationary sprinklers. An application uniformity between 50 to 75 is in the “good” range and is acceptable for wastewater application. Generally, an application uniformity below 50 is not acceptable for wastewater irrigation. If the computed $U_c$ is less than 50, system adjustments are required. Contact your irrigation dealer or technical specialist for assistance.

Figure 36-9. Collection container layout to calibrate one lateral of sprinklers or volume guns with no overlap between laterals.
PROBLEM 7

Single lateral or gun sprinkler with no overlap from adjacent laterals (scenario shown in Figure 36-9).

1. Determine the wetted diameter of a sprinkler or field width.
2. Determine the necessary spacing between collection gauges. The spacing in the direction along the lateral should be 1/4 of the effective sprinkler spacing. The gauge spacing perpendicular to the lateral should be 1/8 of the wetted diameter or width of the field.

Spacing between collection gauges parallel to lateral = 
\[
\frac{\text{effective sprinkler spacing (ft)}}{4}
\]

Spacing between collection gauges perpendicular to lateral = 
\[
\frac{\text{sprinkler-wetted diameter (ft)}}{8}
\]

3. Determine the number of gauges required.
   - The minimum number is 32 to perform the procedure in one setup (both sides of lateral at the same time).
   - One side of lateral calibrated at a time requires 16 gauges, procedure performed twice, once on each side of the lateral.

4. As Figure 36-9 shows, set out gauges in a rectangular grid pattern, spaced at the distances determined in Item 2. Be sure to label gauges by rows (rows should be oriented parallel to and outward from the lateral line). The first row of gauges should be located 1/2 of the gauge spacing from the lateral.

5. Operate the system the normal operating time for a full cycle. Record the time of operation (duration in hours).

6. Immediately record the amounts collected in each gauge. If only one side of the lateral is calibrated at a time, after you record the collection amounts, empty and move the collection containers to the other side and repeat Steps 4 through 6 for exactly the same time duration as recorded in Item 5.

7. Add the “nonzero” amounts collected and divide by the number of gauges with a nonzero amount. This is the “preliminary” average application depth (inches) within the “wetted” calibration area.

\[
\text{Average application depth} = \frac{\text{sum of nonzero amounts collected}}{\text{number of nonzero gauges}}
\]

8. Determine the average application depth by rows parallel to the lateral. Include zero catches in the row computations.

\[
\text{Average row application depth} = \frac{\text{sum of collection amounts from all gauges on the row}}{\text{number of row gauges}}
\]
9. Identify and delete those rows whose average application depth (Item 8) is less than 1/2 of the preliminary average application depth (Item 7).

10. Determine the effective application width. The boundary is defined as the distance from the lateral to the last row furthest from the lateral that is retained.

11. Determine the average application depth within the effective area. Add amounts from all gauges in rows within the effective width (rows retained in Item 9 and Item 10).

\[
\text{Corrected average application depth} = \frac{\text{sum amounts collected in rows within effective width}}{\text{number of gauges within the effective width}}
\]

12. Calculate the deviation depth for each gauge. The deviation depth is the difference collected in each usable gauge and the average application depth (Item 11). Record the absolute value of each deviation depth. Absolute value means the sign of the number (negative sign) is dropped and all values are treated as positive. The symbol for absolute value is a thin straight line.

\[
\text{Deviation depth} = |\text{depth collected at position } i - \text{average application depth (Item 11)}|
\]

“i” refers to the gauge position within the effective calibration area

13. Add the amounts in Item 12 to get the “sum of the deviations” from the average depth and divide by the number of gauges.

\[
\text{Application deviation depth} = \frac{\text{sum of deviations (add amounts computed in Item 12)}}{\text{number of gauges within the effective width}}
\]

14. Using the \( U_c \) mathematical formula, determine the application uniformity, which is computed as follows:

\[
U_c = \left(\frac{\text{average depth (Item 7)} - \text{average deviation (Item 13)}}{\text{average depth (Item 7)}}\right) \times 100
\]

15. Interpret the calibration results. The higher the index value, the more uniform the application. An index of 100 means that the uniformity is perfect—the exact amount was collected in every gauge.
Traveling gun systems. Hard-hose and cable tow traveling guns are calibrated by placing a row (transect) of collection containers or gauges perpendicular to the travel direction (Figure 36-10). The outer gauge on each end of the row should extend past the farthest distance the gun will throw wastewater to ensure that the calibration is performed on the “full” wetted diameter of the gun sprinkler. Multiple rows increase calibration accuracy.

Containers should be spaced no further apart than 1/16 of the wetted diameter of the gun sprinkler not to exceed 25 ft. At least 16 gauges should be used in the calibration. A minimum of 16 gauges should be used to calibrate hard-hose travelers except where the wetted diameter from large guns exceeds 400 ft. (The maximum recommended spacing between gauges is 25 ft × 16 = 400 ft.) As Figure 36-10 shows, gauges should be set at least one full wetted diameter of throw from either end of the travel lane.

The system should be operated so the minimum travel distance of the gun cart exceeds the wetted diameter of throw. Application volumes should be read as soon as the last gauges stop being wetted.

Calibration method.
1. Estimate the gun’s wetted diameter. Check the actual operating pressure at the sprinkler, and verify the nozzle type and size. Determine the wetted diameter from the manufacturer’s charts.
2. Determine the number of collection gauges and spacing between gauges. For a wetted diameter of 320 ft, the rain gauge spacing should not exceed 20 ft (320 ft/16 = 20 ft).
3. Label gauges outward from the gun cart as either left or right (L1, L2, L3, etc.; R1, R2, R3, etc.)
4. As labeled and shown in Figure 36-10, set out gauges along a row equally spaced at the distance determined in Item 2 (20 ft). The row should be at least one wetted diameter from either end of the pull. The first gauge on each side of the travel lane should be 1/2 of the gauge spacing from the center of the lane. For a gauge spacing of 20 ft, L1 and R1 should be 10 ft from the center of the lane.

Figure 36-10. Calibration setup for hard-hose travelers.
5. Operate the system until the gun has completely passed all collection containers. Record the “starting” time that wastewater begins to be applied along the row of gauges and the “ending” time when wastewater is no longer being applied anywhere along the row. Also record the distance traveled in feet for the time of operation.

6. Immediately record the amounts collected in each gauge.

7. Identify those gauges that fall outside the effective lane spacing (Figure 36-10). This volume is the overlap volume that is collected when the system is operating on the adjacent lane.

8. Superimpose (left to right and vice versa) the gauges just outside the effective width with the gauges just inside the effective width. Add the volumes together.

For the layout shown in Figure 36-10, add the volume (depth) collected in gauge R8 (outside the effective lane spacing) to volume (depth) collected in gauge L5 (inside the effective lane spacing). Similarly, R7 is added to L6; L8 is added to R5; and L7 is added to R6. This is now the application volume (depth) within the effective lane spacing adjusted for overlap.

9. Add the amounts collected in all gauges and divide by the number of gauges within the effective area. This is the average application depth (inches) within the effective lane spacing.

\[
\text{Average application depth} = \frac{\text{sum of amounts collected in all gauges}}{\text{number of gauges within effective width}}
\]

10. Calculate the deviation depth for each gauge. The deviation depth is the difference between each individual gauge value and the average value of all gauges (Item 7). Record the absolute value of each deviation depth. Absolute value means the sign of the number (negative sign) is dropped and all values are treated as positive. The symbol for absolute value is a straight thin line. For example, \(|2|\) means treat the number 2 as an absolute value. It does not mean the number 121. The symbol is used in formulas in the text.

\[
\text{Deviation depth} = \left| \text{depth collected in gauge } i \right| - \text{average application depth}
\]

“i” refers to the gauge number

11. Add the amounts in Item 10 to get the “sum of the deviations” from the average depth and divide by the number of gauges to get the average deviation.

\[
\text{Average deviation depth (inches)} = \frac{\text{sum of deviations (add amounts computed in Item 10)}}{\text{number of gauges within effective lane spacing}}
\]

12. The precipitation rate (inches/hr) is computed by dividing the average application depth (inch)(Item 9) by the application time (hrs)(Item 5)

\[
\text{Precipitation rate (inches/hr)} = \frac{\text{average application depth (inches)}}{\text{application time (hrs)}}
\]
13. Compute the average travel speed.

\[
\text{Average travel speed} = \frac{\text{distance traveled (ft)}}{\text{time (minutes)}}
\]

14. Using the \( U_c \) mathematical formula, determine the application uniformity, which is computed as follows:

\[
U_c = \left( \frac{\text{average depth (Item 9)} - \text{average deviation (Item 11)}}{\text{average depth (Item 9)}} \right) \times 100
\]

15. Interpret the calibration results. The higher the index value, the more uniform the application. An index of 100 means that the uniformity is perfect—the exact same amount was collected in every gauge.

For travelers with proper overlap that are operated in light wind, an application uniformity greater than 85 is outstanding and very rare. Only about 10% of travelers operate at such a high level of uniformity.

Application uniformity between 70 to 85 is in the “good” range and is acceptable for wastewater application. Generally, an application uniformity below 70 is considered unacceptable for wastewater irrigation using travelers. If the computed \( U_c \) is less than 70, system adjustments are required. Contact your irrigation dealer or technical specialist for assistance.

Center pivot and linear move irrigation systems. As Figure 36-11 illustrates, center pivot and linear move irrigation systems are calibrated by placing a row (transect) of collection containers parallel to the system. Two or more rows increase calibration accuracy.

For center pivot systems with more than three towers, place the first collection container beside the first moving tower (140-180 ft from the boss tower).
tower [pivot point]). This setup will miss the area between the boss and first
tower, but it is necessary to omit this section through this zone. The area
missed will be less than 3 acres and will usually represent less than 10% of a
typically sized system. If the system has only one moving tower, place the
first container 50 ft from the boss tower. Place equally spaced containers at
the end of the system. For lateral move systems, place containers throughout
the entire length of the system.

Containers should be spaced no further apart than 1/2 of the wetted
diameter of rotary impact sprinklers, or 1/4 of the diameter of gun sprinklers or
50 ft, whichever is less. On systems with spray nozzles, collection containers
should be spaced no further than 30 ft. A 20- to 25-ft spacing is generally
recommended for all types of sprinklers, which will result in six to eight
collection containers between each tower. Collection containers should be
placed so they intercept discharge from a range of lateral distances from the
sprinkler (midpoint, quarter point, directly under sprinkler, etc.). This goal can
be accomplished by selecting a catch can spacing different from a multiple of
the sprinkler spacing along the lateral. Where end guns are used, the transect
of collection containers should extend beyond the gun’s throw.

The system should be operated so the minimum travel distance exceeds
the sprinkler wetted diameter for the containers closest to the boss tower.
Application volumes should be read as soon as all gauges stop being wetted.

**Calibration method.**

1. Determine the wetted diameter of the sprinkler, gun, or spray nozzle.
2. Determine the necessary spacing between collection gauges. The
   spacing should not exceed 50 ft. The recommended spacing is 25 ft or
   less.
3. Determine the number of gauges required. Label gauges outward from
   the boss tower.
4. Place gauges along a row as labeled and shown in Figure 36-12,
   equally spaced at the distance determined in Item 2. The row should be
   in the direction of system travel and at least 1/2 the sprinkler wetted
diameter from the sprinkler nearest the boss tower.
   *Note: The alignment of the row relative to the center pivot system does not matter
   as long as the system operates completely over each collection gauge. For most
   setups, the gauges closest to the boss tower will control how long the system must
   be operated to complete the calibration.*
5. Operate the system until the sprinkler nearest the boss tower has
   completely passed the collection containers. Record the time of
   operation (in minutes) and distance traveled (in ft) at a reference point
   along the system (usually the last tower).
6. Immediately record the amounts collected in each gauge.
7. Add the amounts in Item 6 and divide by the number of gauges. This is
   the average application depth (inches).

\[
\text{Average application depth} = \frac{\text{sum of amounts collected in all gauges}}{\text{number of gauges}}
\]

8. Where an end gun is used, identify those gauges at the outward end
   where the depth caught is less than 1/2 of the average application depth
   computed in Item 7. The distance to the last usable gauge is the effective
   radius of the system from which the effective acreage is computed.
9. Re-compute the average application depth for the “usable” gauges identified in Item 8 that fall within the effective width of the system. (Eliminate gauges on the outer end of the system where the depth caught is less than 1/2 of the average application depth.)

Note: All gauges interior to the “effective width” of the system are included in the computations regardless of the amount caught in them.

10. Compute the reference travel speed and compare to the manufacturer’s chart.

\[
\text{Travel speed (ft/minute)} = \frac{\text{distance traveled (ft)}}{\text{time (minutes)}}
\]

11. Calculate the deviation depth for each “usable” gauge. The deviation depth is the difference between each individual gauge value and the average value of all gauges (Item 9). Record the absolute value of each deviation depth. (Absolute value means the sign of the number [negative sign] is dropped, and all values are treated as positive). The symbol for absolute value is a straight thin line. For example, \( |2| \) means treat the number 2 as an absolute value. It does not mean the number 121. The symbol is used in formulas in the text.

\[
\text{Deviation depth} = |\text{depth collected in gauge i} - \text{average application depth}|
\]

“i” refers to the gauge number

12. Add the amounts in Item 11 to get the “sum of the deviations” from the average depth and divide by the number of gauges to get the average deviation.

\[
\text{Average deviation depth} = \frac{\text{sum of deviations (add amounts computed in Item 11)}}{\text{number of usable gauges}}
\]
13. Using the $U_c$ mathematical formula, determine the application uniformity, which is computed as follows:

$$U_c = \frac{\text{average depth (Item 7)} - \text{average deviation (Item 12)}}{\text{average depth (Item 7)}} \times 100$$

14. Interpret the calibration results. The higher the index value, the more uniform the application. An index of 100 means that the uniformity is perfect—the exact same amount was collected in every gauge.

For center pivot and linear move systems operated in light wind, an application uniformity greater than 85 is common. An application uniformity between 70 to 85 is in the “good” range and is acceptable for wastewater application. Generally, an application uniformity below 70 is considered unacceptable for wastewater irrigation using center pivots and linear move systems. If the computed $U_c$ is less than 70, system adjustments are required. Common problems include clogged nozzles, sprinklers not rotating properly, inadequate system pressure, sprinklers installed in the wrong order, end gun not adjusted properly, wrong end gun nozzle, and/or worn nozzles. Contact your irrigation dealer or technical specialist for assistance.

For center pivot and linear move systems operated in light wind, an application uniformity greater than 85 is common.
APPENDIX A
Regulatory Compliance Assessment: Land Application Equipment

The goal of this assessment tool is to help you identify the regulations related to land application equipment that apply to your operation. For each issue listed (left column) of the worksheets, identify if this issue is currently regulated and determine if your operation is in compliance with these rules (right column).

<table>
<thead>
<tr>
<th>Regulator Issue</th>
<th>Is this issue addressed by regulations?</th>
<th>Is my livestock/poultry operation in compliance?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Are there specific rules or buffers that must be followed when using a particular piece of equipment or method of application?</td>
<td>___ Yes ___ No If “Yes,” summarize:</td>
<td>___ Yes ___ No</td>
</tr>
<tr>
<td>If irrigating, does your irrigation system have to be designed or reviewed by a Professional Engineer or Certified Irrigation Designer?</td>
<td>___ Yes ___ No If “Yes,” summarize:</td>
<td>___ Yes ___ No</td>
</tr>
<tr>
<td>Are you required to calibrate your application system? How often?</td>
<td>___ Yes ___ No If “Yes,” summarize:</td>
<td>___ Yes ___ No</td>
</tr>
<tr>
<td>What are the maximum precipitation rates or daily application rates for your soils or farm?</td>
<td>Maximum precipitation rate = _________ inches/hr Maximum daily application = _________ inches</td>
<td>___ Yes ___ No</td>
</tr>
<tr>
<td>Is your application equipment operating below these levels?</td>
<td>___ Yes ___ No If “Yes,” summarize:</td>
<td>___ Yes ___ No</td>
</tr>
<tr>
<td>Are you required to have safety features installed or plans developed to minimize discharges or spills?</td>
<td>___ Yes ___ No If “Yes,” summarize:</td>
<td>___ Yes ___ No</td>
</tr>
<tr>
<td>Other:</td>
<td>___ Yes ___ No If “Yes,” summarize:</td>
<td>___ Yes ___ No</td>
</tr>
</tbody>
</table>
About the Author
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References

Glossary
Absolute value. When the sign of the number [negative sign] is dropped, and all values are treated as positive). The symbol for absolute value is a straight thin line.

Average application depth. Average amount of manure applied throughout a field.

Calibration. Combination of settings and travel speed needed to apply manure at a desired rate and to ensure uniform application.

Deviation depth. Difference between each individual gauge value and the average value of all gauges.

Head to head. Two or more sprinklers simultaneously throwing water on the same area.

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