Penn State Extension

Irrigation of Liquid Manures

Agricultural and Biological Engineering

abe.psu.edu

Albert R. Jarrett, Professor Emeritus, Agricultural and Biological Engineering F-254
Robert E. Graves, Professor Emeritus Agricultural and Biological Engineering

Introduction

As liquid manure storages become larger, interest in using irrigation technology for land applying manure increases. This fact sheet will provide guidance on how, how much, and how fast liquid manure can be applied to a specific land area using irrigation technology.

Must Remain Environmentally Friendly

Before getting down to details relating to manure irrigation, let's make clear the goals and issues that must always be considered when liquid manure is applied to a field(s). The primary goals must be to

- Apply an appropriate depth of liquid manure uniformly to the field, and
- Apply the liquid manure at a rate that allows all of the liquid to soak into the soil and not flow away from the point of application. In more detail, this means
  - The applied manure may not flow down drainage ways or ditches and subsequently leave the field or reach any body of water (streams, lakes, ponds, etc).
  - The manure does not excessively accumulate in low areas of the field resulting in widely varying or excessive over application of nutrients.

Achieving these goals requires a properly designed and operating irrigation system that is appropriate for the manure being irrigated, the soil type, the topography of the field(s), and the condition of the field(s) at the time of irrigation (crop, cover, water content, weather, expected weather conditions, etc). All fields receiving liquid manure should be evaluated for liquid manure runoff every time manure is irrigated. Evidence during or after application of excessive movement, ponding or loss of manure from the field requires that changes be made immediately in the operating procedures, and possibly changes in equipment and scheduling.

Emergency Response Plan

A well thought-out management plan for operation of a manure irrigation system is essential. The system requires a fool-proof, fail-safe means to detect and correct problems quickly. Clogged nozzles, malfunctioning equipment that continually applies manure in one location, and broken or separated pipes and hoses can quickly cause severe environmental problems. An emergency response plan is required to allow immediate containment and timely clean-up of any spills. Everyone involved with the manure irrigation system should be familiar with this plan and have access to the required authority, labor, and equipment to implement the plan. Various automatic controls such as a "low-pressure kill switch" can shut down a system if a line breaks. Many operators have found it necessary to have one or more full time observers continually checking, sprinklers, pipe, hoses and pumps. When pumping long distances and especially when multiple pumps are involved two or three workers with radio communication are often needed.

Typical problems with irrigating liquid manure include:

- excessive and highly variable application rates
- surface water pollution from broken pipes and malfunctioning irrigation equipment
- overspray or drift of liquid manure onto neighboring properties and highways
- widespread dispersal of odors
- manure runoff due to excessive volumes applied or excessive application rates.
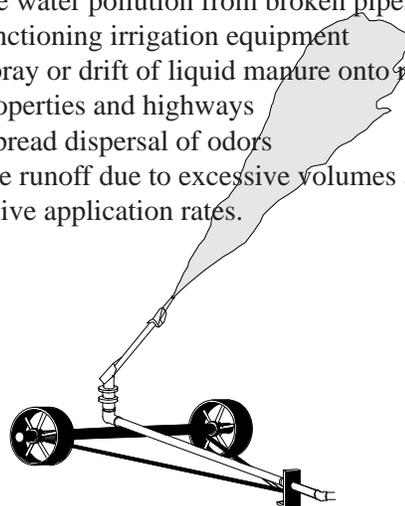
PENNSTATE

Cooperative Extension
College of Agricultural Sciences

Is Your Manure Management Plan Environmentally Friendly?

When developing, reviewing or implementing a nutrient management plan, that includes irrigation of manure, special attention should be given to:

- Management, supervision, and emergency response plans to minimize potential surface or ground water pollution from over application or system malfunction
- The maximum amount of manure applied per hour at any point on the field. (Application rate -usually expressed in inches per hour.) Exceeding the soil's ability to absorb liquid (infiltration rate) will result in manure runoff
- The depth of liquid manure applied during each irrigation session (Application depth - usually expressed in inches)
- The total annual application of nutrients per acre (gallons or tons of manure applied and the pounds of nutrients applied per acre per year)
- Minimizing offensive odors. Atomizing manure and throwing it high in the air will disperse odors further from the field than application methods that keep manure near the ground.
- Minimizing negative public perception. The dark appearance of the manure stream shooting through the air will also draw negative attention to the process. Puddles of manure or even worse, manure running across fields can quickly lead observers to assume careless operation.

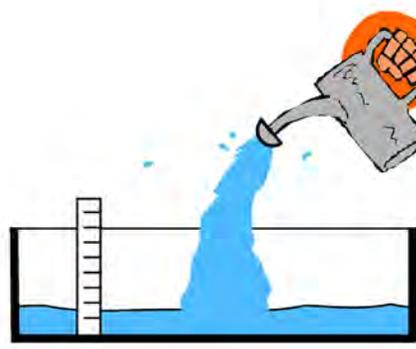## Important Manure Irrigation Terms

Application Depth, D_a is the total depth of manure applied in one irrigation session and is usually expressed in inches. This can be converted to pounds, tons, or gallons per unit area. Pennsylvania regulations (PA-DEP (2006) permit the application of up to 9,000 gallons of liquid manure per acre per day without consideration of the rate at which the manure is applied. The application volume of 9,000 gallons per day is equivalent to a depth of manure applied of 0.33 inches[1].

Application Amount is the volume or weight of manure applied per unit area per year or crop. This is usually expressed as gallons per acre or tons per acre. Application amount is used to calculate the amount of nutrients applied per acre.
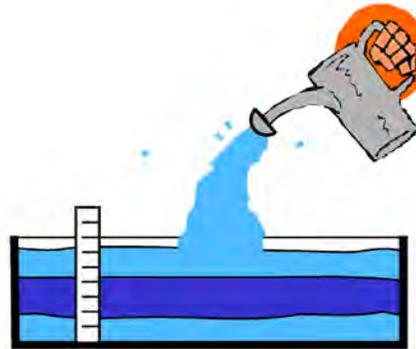
Application Time is the time period during which a specific field location is receiving manure. For example, if you set a bucket in a field where a traveling gun is applying liquid manure, some of the applied manure will fall into the bucket for a period of time starting when the first droplets enter the bucket until the traveling gun passes and the bucket no longer receives any more manure. This period during which the bucket receives manure is the application time, T_a. Note that the application time is not the time required for the traveler to pass across the entire field or the time required to irrigate the entire field (several passes); just the time during which manure is applied to the specific point in the field where the bucket is located.

---

[1] The 9,000 gallons/acre, which is equivalent to 0.33 inches per daily application, can be justified by applying the USDA-NRCS Soil-Cover-Complex method of estimating runoff from watersheds. If the field being irrigated has a Curve Number, CN of 86, the associated maximum retention, S = 1.63 inches. Since the initial abstraction (the rain that is expected to fall before runoff begins), $I_a = 0.2S$, the initial abstraction is 0.33 inches. Using this same theory, we can determine that any field with a runoff CN > 86 is expected to yield runoff from a manure application of 0.33 inches and any field with a CN < 86 could receive a liquid manure application greater than 0.33 inches before runoff would be expected.

Application Rate is the depth of manure applied per minute or hour to a specified location in a field. Application rate has units of inches per hour. The term application rate is used in several different ways by manure irrigators. Application rate from a water application perspective refers to the depth of liquid (water) applied to a point during the time period when the liquid is actually applied (application time, T_a). The application time may be as short as a few minutes to as long as several hours. Using the example in the application time definition where we seek to measure the depth of manure applied as a traveling gun passes a bucket placed in the field, the depth of manure in the bucket after the traveling gun has passed is the application depth, D_a. The Application Rate is the application depth divided by the application time. This can be expressed as

$$A_r = \frac{D_a}{T_a} \qquad (1)$$

where the application rate A_r will normally have units of inches per hour (in/hr). Some times this form of application rate is referred to as the instantaneous application rate.

The term application rate is also sometimes used in manure application, but with a very different meaning. For manure applicators, application rate often refers to the quantity (in tons or gallons) of manure applied to each acre of a field during one application of manure. For example if you spread 2,000 gallons (or 8.3 tons) of manure on a 3.0-acre field, the application rate of manure could be expressed as 8.3 tons/3.0 acres = 2.8 tons/acre (or 667 gallons/acre). This way of expressing application rate is not related to time and is, therefore, not a true "rate". This way of computing application rate is more correctly called "Application Amount" (see the definition above). One reason for the evolution of this second measure of application rate is the desire to know how many pounds of nutrients are being applied to a field during each application or each year. Since most manure nutrient analyses report nutrients in concentration units of "pounds per ton" or "pounds per 1000 gallons", it is easy to multiply the nutrient concentration times the "manure application amount" in tons or gallons applied per acre to determine the total pounds of nutrient applied per acre.

Infiltration Rate is a measure of how rapidly the soil can be expected to soak up liquid manure or the rate at which the liquid manure applied to the soil surface enters the soil. If liquid manure is applied faster than the soil's infiltration rate some of the liquid manure

Table 1. Typical maximum steady-state infiltration rates and loading rates for various soils. (From Geohring and Van Es, 1994).

Soil Type	Infiltration Rates (In/Hr)	Maximum Loading Rates (Gal/Hr/Ac)
Gravel and sand	> 0.8	22,000
Sandy and silty loams	0.4 to 0.8	11,000 to 22,000
Loams	0.2 to 0.4	5,500 to 11,000
Clayey soils	0.04 to 0.2	1,100 to 5,500

Table 2. Maximum application rates. Soils usually absorb water at a faster rate if applied in light applications (3/4 to 1 ½") when soil is dry. (MWPS, 1985).

| Soil Characteristics	Covered (In/Hr)	Bare (In/Hr)
Clay; very poorly drained.	0.30	0.15
Silty surface; poorly drained clay and claypan subsoil.	0.40	0.25
Medium textured surface soil; moderate to imperfectly drained profile.	0.50	0.30
Silt loam, loam, and very sandy loam; well to moderately well drained.	0.60	0.40
Loamy sand, sandy loam, or peat; well drained.	0.90	0.60

becomes available to runoff. Therefore, since runoff of liquid manure during irrigation is to be avoided at all costs, it is important that we gain a more complete understanding of the infiltration process.

The most conservative way to address infiltration is to simply choose the appropriate infiltration rate from Tables 1, 2 and 3. Table 1 relates infiltration rate to the texture of the soil receiving the liquid manure. Therefore, if the soil texture is known, an appropriate infiltration rate can be chosen. Maximum safe application rates and the amounts that maybe applied during any one irrigating session have also been related to specific field conditions such as soil type, surface residue, surface roughness, crop cover, slope (see Tables 2 & 3) and how wet the soil is.

Table 3. Application rate reduction for sloping ground. (MWPS, 1985).

Slope (%)	Application Rate Reduction (%)
0 to 5	0
6 to 8	20
9 to 12	40
13 to 20	60
> 20	75

There is nothing wrong with the infiltration rates shown in Tables 1 to 3, but experience and our understanding of the physics of infiltration has shown that these values are very conservative. If we examine infiltration rate in more detail, we see, from Figure 1, that infiltration is a time dependent parameter that starts at a very high rate and declines to the soil's permeability (available from NRCS published Soil Survey data), or steady-state infiltration rate. The steady-state infiltration rate is equivalent to the values given in Tables 1 to 3. The time required for the infiltration rate to decline to the permeability varies from soil to soil, but will typically range from an hour or so for coarse-textured soils to many hours for finer textured soils. When conservative tables of infiltration rates are developed the values given are almost always the long-term steady-state infiltration rates; the rate at which water will enter a soil after a very long period of time. Following this very long period the rate of water entry into the soil approaches the soil's permeability. Stated another way, if a soil has an infiltration value of 0.6 in/hr (from Table 1), the rate of water entry into this soil will be greater than 0.6 in/hr and not decline to this steady-state value for many hours. Therefore, at all times before this long-term infiltration rate is reached, the water will actually be entering the soil faster than the Table 1 value. In addition, since most mobile irrigation
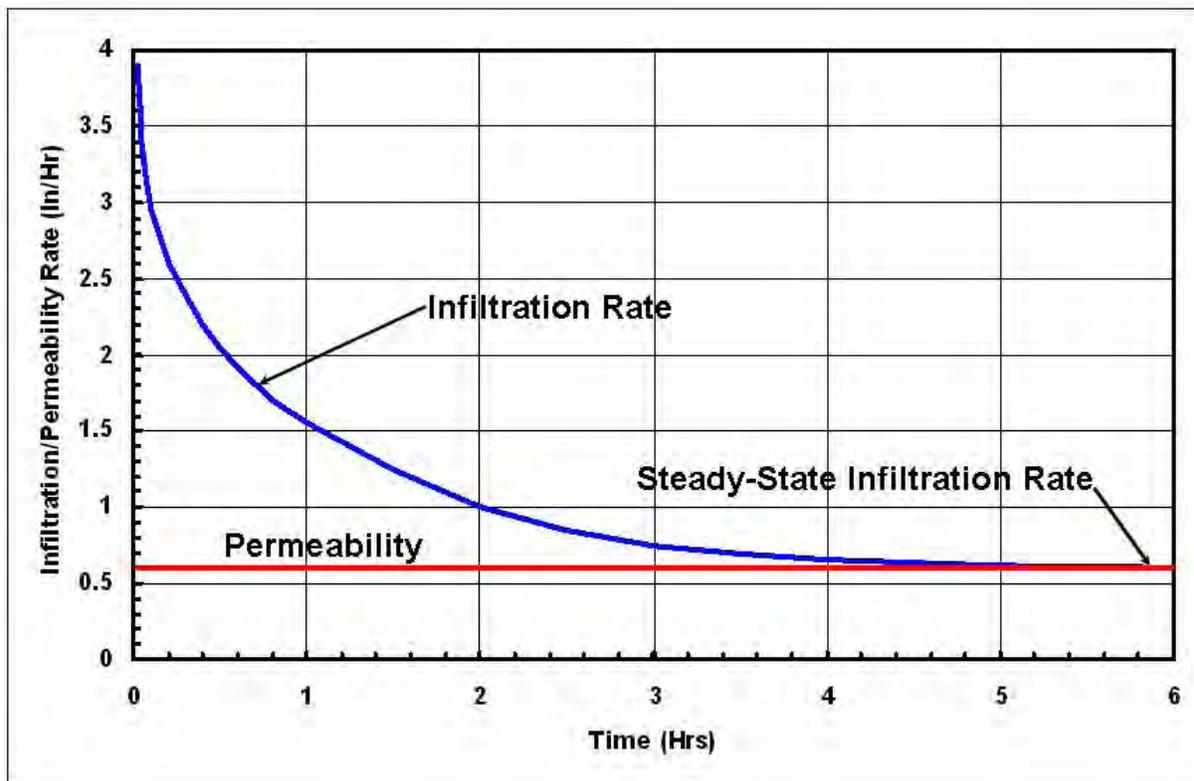
Figure 1. How infiltration rate is related to saturated hydraulic conductivity.

4

systems (traveling guns and center pivots) apply the manure to actual field locations for only a very short time, it follows that the Table 1, 2 and 3 infiltration rates will rarely be reached.

Management and Operation Issues

Over Application
An irrigation system often permits manure application when field conditions prevent operation of wheeled vehicles; even when it's raining. This can result in application of large amounts of liquid manure when soils are wet or saturated. Because of the cost of installing an irrigation system and the apparent ease of pumping manure, over application of nutrients is easy. Close attention to daily, monthly, and annual application depths is essential.

Uneven Application
Irrigation systems designed to supplement rainfall are not necessarily appropriate for applying liquid manure. The consistency of liquid manure and presence of occasional larger solids can plug nozzles, valves, pumps, and pipes. A common solution to this problem is to use sprinklers with large nozzles to minimize plugging. This results in highly variable application patterns and often application rates (inches applied per hour) in excess of the soil's ability to absorb the liquid. The resulting ponding and runoff is at best a nuisance and at worst can cause serious environmental pollution.

System Problems
Irrigation systems are not foolproof. Left unattended, a malfunctioning irrigation system can quickly pump large volumes of liquid manure onto fields and subsequently down road ditches, onto neighboring lands, or directly into streams. Some traveling gun and center-pivot systems can become stuck because of poor traction on the manure covered ground. Where traction for self-propelled irrigation units is a concern, traveling gun systems pulled by a cable or hose-pull type mechanism can be an advantage. However, on uneven, or steep terrain, care must be taken to insure that applicator units do not tip over.

Liquid Properties
In general, liquid manure, as it is usually handled by conventional liquid manure pumps and spreaders, is too thick to successfully apply through an irrigation system. While it is possible to design and install a system of pumps, pipes and large-orifice nozzles that can

handle this material, nozzle plugging, over application and runoff often occur. More dilute liquid manure from flush systems and barnyard runoff control systems is easier to irrigate.

Shut-down Procedures
Flushing pipelines with fresh water at the completion of an irrigation session will keep equipment cleaner and also prevent discharges of liquid manure when the system is disassembled. It may even be advisable to irrigate the entire field with fresh water to rinse manure from growing crops.

Other Problems
Liquid that remains after manure has been passed through a solids separator will be easier to pump and less likely to plug sprinkler nozzles because larger solids have been removed. Nutrients in these liquids may still be too concentrated to apply through a large-orifice big-gun unless high travel speeds can be maintained.

Setting up and moving irrigation systems are hard work. When pumps, pipes, hoses, and sprinklers are covered with or filled with manure these tasks can be very unpleasant. When opening and draining lines that have liquid manure in them, it is always important to consider where the manure will drain.

System Design Considerations

Liquid manures can be applied to agricultural cropland through an irrigation system. There are several constraints that must be addressed if these irrigation systems are expected to benefit the producer and protect the environment. These constraints are:
(1) The annual application depth (inches/year) of manure must be limited to the depth that contains the nitrogen and/or phosphorus and other nutrients that can be taken up by the crop grown. The design must be consistent with the Nutrient Management Plan.
(2) The manure must have a solids content and particle size that can easily pass through the sprinkler nozzle(s).
(3) Apply an appropriate depth of liquid manure uniformly to the field at a rate that allows all of the liquid to soak into the soil and not flow away from the point of application into drainage ways or ditches and subsequently leave the field or reach bodies of water.
(4) The depth of liquid manure applied must not exceed 0.33 inches during any one day. This is equivalent to the PA-DEP (2006) requirement of applying less

than 9,000 gallons per acre per day, especially when the manure is applied by a moving irrigation system such as a traveling gun or center pivot system. (5) If more than 0.33 inches of manure is to be applied on any day, the rate of application (inches/hour) must be less than or equal to the soil's infiltration rate, see Tables 1, 2, and 3.

Thumb rules, handbook values and regulatory limits may be adequate for determining project budgets but the final irrigation system design needs to be farm specific. A qualified professional engineer, familiar with soils, climate, management conditions at the farm, and irrigation systems should perform or verify final calculations, system design, installation and standard operating procedures. Properly designed, installed and managed irrigation systems can be an efficient and effective method of uniformly applying liquid manures.

Application of Design Considerations to Specific Irrigation Systems

The design depth and infiltration rate guidelines given above will be discussed in the following sections for (a) traveling guns, (b) pulsing travelers, (c) center pivots, and (d) solid set irrigation systems.

Traveling Guns

A traveling gun is a sprinkler containing a large (>0.5-inch diameter) nozzle mounted on a wheeled unit that is propelled through the field at a speed set by the operator, see Figure 2. Most traveling guns or "travelers" have a range of speeds created by the manufacturer when the unit is built. Liquid manure is pumped through a flexible hose to the sprinkler mounted on the traveler, see Figure 2. The sprinkler


Fig. 2 Traveler

may rotate through a full-circle or may only rotate through a portion (usually 230 to 270 degrees) of the arc. Travelers either have the sprinkler mounted on the take-up reel unit and is pulled through the field as the take-up reel shortens the length of pipe to the hydrant at the edge of the field or the sprinkler is mounted on a separate rig, see Figure 2, that is drawn to the reel unit anchored at the field edge.

Traveling guns are often used to apply liquid manure. Their primary advantage is that they have a large nozzle that can pass some solids without clogging. Generally manures of solids content as high as 8% can be applied through a traveler if the manure is well mixed and the solids have been reduced to small particles.

There are also several disadvantages to using traveling guns to apply manure. These include uneven distribution of liquid; in other words not all areas of the field will receive the same depth of manure. This problem can be compensated for by overlapping the paths about 20%, see Figure 3. Another disadvantage
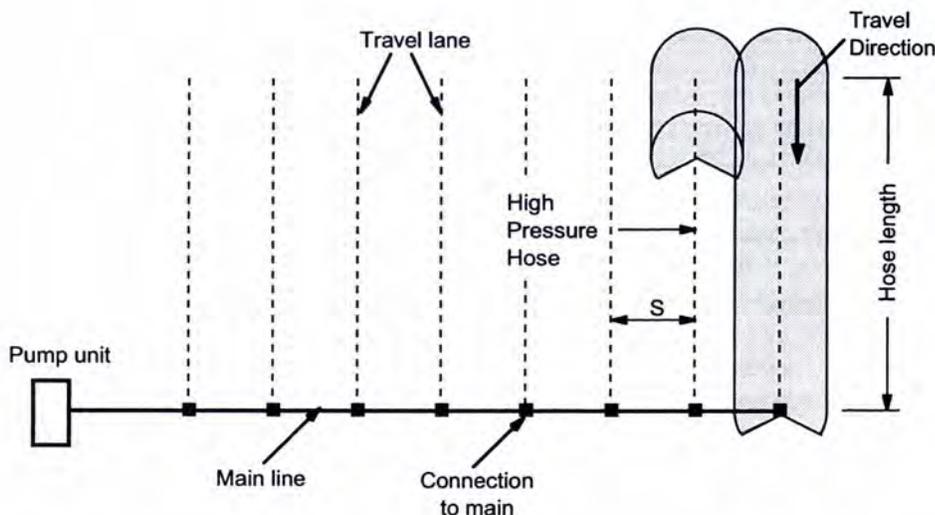
Fig. 3 Operation layout for a traveling gun system. (Adapted from Pair, 1975)

6

of traveling guns is the large droplets that are formed as the manure exits the nozzle. These large droplets hit the crop or soil surface with a great deal of energy; energy that can damage crops and/or compact the soil.

Application Depth is the depth of manure applied to the field during each pass of the traveler. The application depth, D_a can be estimated by first determining the sprinkler's flow rate in gallons per minute (gpm), the speed the traveler moves through the field S_d in ft/min, and wetted diameter of the sprinkler, W_d in feet. From these data, the depth of manure applied during each pass through the field can be determined as

$$D_a = \frac{1.6Q}{W_d S_p} \quad\quad\quad \text{(2)}$$

where D_a = application depth (inches)
  Q = sprinkler flow rate (gpm)
  W_d = sprinkler wetted diameter (feet)
  S_p = traveler speed (ft/min)
  1.6 = constant unit conversion factor

Equation 2 was developed under the assumption that the distance between the traveler paths in the field was equal to the sprinkler's wetted diameter, W_d. Many traveler systems are designed and managed using this assumption to minimize the number of passes required to cover (or irrigate) a field. Because sprinklers do not apply manure uniformly and wind distorts even the best sprinkler distribution, sprinklers are usually spaced so they are some percentage of the sprinkler's wetted diameter apart. Table 4 shows the percent spacings recommended for large sprinklers as a function of wind speed. Traveler paths are generally not more than 80% of the wetted diameter apart. This means that a traveler with a wetted diameter of 190 feet (W_d = 190 feet) would not be used in towpaths spaced more than 0.8(190) = 152 feet apart and this assumes there is no wind.

Table 4. Desirable traveler spacings as a percentage of the sprinkler's wetted diameter. (Adapted from Pair, 1975).

Wind Speed (mph)	Percent of Wetted Diameter
No wind	80
Up to 5	70 to 75
Up to 10	60 to 65
> 10	50 to 55

Great efforts have been made by the big gun manufacturers to create sprinkler nozzles that have the ability to produce a nearly uniform distribution at relatively low pressures. When sprinklers with these nozzles are used on travelers with lane spacings of about 70 to 80 percent of the sprinkler's wetted diameter, the most uniform application of liquid manure occurs.

When the influence of the wind (and related towpath spacing) are added to Equation 2, the sprinkler wetted diameter, W_d is replaced with the spacing between the towpaths S, which is usually from 70 to 80% of the sprinkler's wetted diameter. Thus the total depth of manure applied per irrigation event (or pass) is

$$D_a = \frac{1.6Q}{SS_p} \quad\quad\quad \text{(3)}$$

An example will demonstrate the use of Equation 3.

Example 1. A traveler is to be used to apply liquid manure to a pasture area planted in mixed grasses in early spring. The soil in this field is a silt loam. The sprinkler on the traveler has a flow rate of 200 gpm and throws water 95 feet (so the two radii equal a wetted diameter, W_d of 190 feet). The sprinkler is set to travel through the field at a speed of 3 ft/min and rotates through 230 degrees of arc. This means the sprinkler will traverse a 1,380-foot long field in 460 min (7.7 hr). Determine the depth of manure applied in one pass assuming the sprinkler paths are 150 feet apart.

Solution: To use Equation 3, we need the sprinkler's flow rate, Q = 200 gpm, the towpath spacing, S = 150 feet, and the traveler speed, S_p = 3 ft/min. By substituting these values into Equation 3 we can compute the average depth of water applied to any point in this field as

$$D_a = \frac{1.6(200\text{gpm})}{150\text{ft}(3\text{ft/min})} = 0.71 \text{ inches}$$

Thus one pass of this traveler will apply an average depth of 0.71 inches of liquid manure. It should be noted that the uniformity of this depth may vary greatly depending on the sprinkler's operating pressure. Since this depth of manure application exceeds 0.33 inches, the application rate will need to be checked.

Application Rate. The application rate is the rate at which water (or manure) is applied to any given point in the field. This is also the rate that the soil

must absorb the water (or manure) so that none of the water (or manure) runs off the field. In a field where a traveler is used to apply manure, each traveler operates independently, so it is possible to estimate the application rate, A_r for a traveler based on the sprinkler's flow rate, Q in gpm, the sprinkler's wetted radius, R in feet, and the portion of the circle, φ □in degrees receiving liquid manure as

$$A_r = \frac{96.3Q}{\pi(0.9R)^2} \times \frac{360}{\varphi} = \frac{13624Q}{R^2\,\varphi} \tag{4}$$

where A_r = application rate (in/hr)
   Q = sprinkler discharge (gpm)
   π = the constant 3.14
   R = the sprinkler's radius, which is equal to $W_d/2$ in feet
   φ = portion of circle receiving liquid manure in degrees
   96.3 = unit conversion factor
   360 = the number of degrees in a circle
   13624 = unit conversion factor

Example 1. (continued): Determine the application rate for the field application of liquid manure situation described in Example 1.

Solution: The application rate is determined by applying Equation 4 using the parameters given in Example 1. Thus the application rate can be computed as

$$A_r = \frac{13624(200)}{952(230)} = 1.31 \text{ in/hr}$$

   Before proceeding with the liquid manure irrigation design, it is very important that you determine if this application rate exceeds the soil's ability to absorb liquid manure or limit your application depth to 0.33 inches/day (9,000 gallons per acre per day).

Pulsing Travelers

   In recent years, pulsing travelers have been introduced and are becoming more popular with manure irrigators. The pulsing traveler is different from the traditional traveler in two ways; (1) The pump delivering liquid manure to the traveling field unit is smaller (the pump delivers manure to the traveling field unit at flow rates that are smaller), and (2) the flexible hose carrying the liquid manure to the field unit can therefore be smaller diameter. In comparison to the traditional traveler, liquid manure is delivered to the field unit more slowly. Instead of the liquid manure being delivered directly to the sprinkler, the liquid manure

is pumped into a storage chamber. When the storage chamber has been fully charged (filled and pressurized), a valve opens and the liquid manure stored in the chamber flows through a pipe to the sprinkler nozzle and is applied to the field. It only takes a few seconds to empty the storage chamber, thus producing the pulsed application of manure to the field. When the chamber has been emptied, the traveler moves forward a small distance and the cycle is repeated. Depending on the speed the pulsing traveler is set to move through the field, the end result is that pulsing travelers generally take much longer to apply a fixed volume of manure than traditional travelers, and they usually apply manure at a lower application rate than traditional travelers. The following example will illustrate:

Example 2. A pulsing traveler is to be used to apply liquid manure to a pasture area planted in mixed grasses in early spring. The soil in this field is a silt loam. The sprinkler on the traveler has a flow rate of 100 gpm and throws water 95 feet (so the two radii equal a wetted diameter, W_d of 190 feet). The sprinkler is set to travel through the field at a speed of 3 ft/min and rotates through 230 degrees of arc. This means the sprinkler will traverse a 1,380-foot long field in 460 min (7.7 hr). Determine the depth of manure applied in one pass assuming the sprinkler paths are 150 feet apart.

Solution: Substitute the sprinkler's flow rate, Q = 100 gpm, the towpath spacing, S = 150 feet, and the traveler speed, S_p = 3 ft/min into Equation 3 as

$$D_a = \frac{1.6(100\text{gpm})}{150\text{ft}(3\text{ft/min})} = 0.35 \text{ inches}$$

   Thus one pass of this pulsing traveler will apply an average depth of 0.35 inches of liquid manure. As with the traditional traveler, the uniformity of this depth may vary greatly depending on the sprinkler's operating pressure. It should also be noted that the speed of the traveler, as well as the pump rate dictate the application depth. Note that the speed in this example was the same as in Example 1 (3 ft/min). If the traveler speed in this example is reduced to 1 ft/min, the application depth increases to 1.00 inches per pass. If the traveler speed is increased to 5 ft/min, the application depth decreases to 0.20 inches per pass.

Application Rate. As with the traditional traveler, the application rate can be computed using equation 4 as:

$$A_r = \frac{13624(100)}{95^2(230)} = 0.66 \text{ in/hr}$$

Center Pivots

A center pivot irrigation system is a single lateral, fixed at one end (the center of the field) and elevated on wheels that transport the lateral around the field at some speed of rotation. Center pivot laterals come in varying lengths from a few hundred feet to over 1000 feet. In Pennsylvania there are very few fields that can fully utilize the capabilities of a center pivot irrigation system. In addition, the center pivot has many disadvantages that make uniform application of manure extremely difficult. These include:

- The sprinklers near the pivot must be very small to apply manure to the small areas near the center of the field. These small sprinklers may have nozzles as small as 1/16 inch; much too small to pass any liquid except clean pure water. To prevent plugging, inner-sprinkler nozzles are usually oversized, thus applying excessive water, and possibly, nutrients. Clogging of small, inner sprinkler nozzles can be reduced by holding the liquid in settling ponds before it is applied to the field.

- A second disadvantage is that the center pivot is a permanent installation. It cannot be moved. This usually leads to over application of nutrients under center pivot systems.

- They do not work well on slopes and varying terrain. The maximum recommended variation in elevation is 30 - 40 feet.

- They do not irrigate corners of fields—they were developed to be used on flat, square quarter sections in the western U.S. They irrigate circular areas very well, but often are not able to irrigate field corners without special equipment.

There are several advantages to using center pivot systems. These include:

- Low labor needed to apply large volumes of manure onto large fields.

- Low operating costs including fuel costs if low-pressure drop-tube sprinklers are used.

Generally, center pivot irrigation systems should not be used to apply manure unless the design is overseen by a qualified engineer. The field should also be regularly evaluated to ensure that the proper amount and uniformity of manure is being applied.
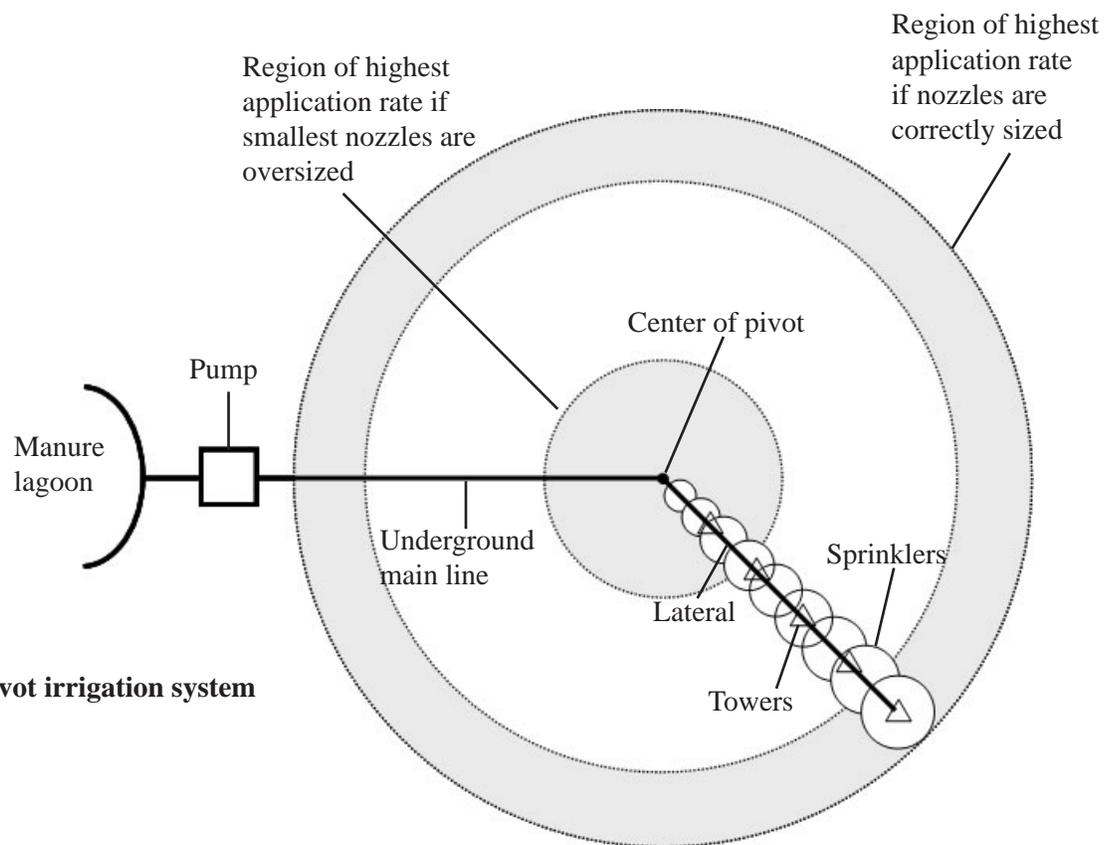
Fig. 4 Center Pivot irrigation system

9

Application Depth. The average depth of manure applied during each pass of a center pivot irrigation system can be computed by first determining the pump flow rate to the center pivot, Q in gpm, the time required to make one complete pass (revolution if the center pivot goes full circle), T in hours to make one pass, and the effective radius, R of the center pivot. The effective radius should be the length of the center pivot's lateral, L, plus the radius, r of the last sprinkler at the very end of the center pivot; thus R = L + r. If these data are available, and it is known how many degrees of arc, φ the center pivot covers in each pass, the depth of manure applied, in inches, during each pass of the center pivot is

$$D_a = \frac{11000QT}{\varphi R^2}$$

(5)

Application Rate. The system designer is the best source of determining the application rate of a center pivot system. One method is to place collection buckets at several locations along the length of the pivot and measure the amount of time they receive liquid and the depth they receive. Dividing the depth of manure by the length of time the bucket was receiving manure will yield the application rate. The highest rate computed (from all the bucket-positions evaluated) should be used as the application rate for the center-pivot system. This is the application rate that should be less than the soil's infiltration rate if no manure runoff is to occur.

Jensen (1983) has derived a formula that can be used to estimate the maximum application rate under center-pivot irrigation systems designed to apply supplemental irrigation water. This formula assumes all the sprinklers on the center-pivot lateral are correctly sized to apply water uniformly over the entire field. When the sprinklers are correctly selected, the maximum application rate occurs at the location in the field that receives water the shortest length of time and this is the portion of the field under the last sprinkler at the end of the lateral, often a big gun. (see Fig. 4) The application rate formula requires the lateral length, L in feet, the pivot's total flow rate, Q in gpm, and the radius, r of the largest sprinkler on the lateral (most often the last sprinkler on the lateral near the edge of the field).

$$A_r = \frac{122.5Q}{Lr}$$

(6)

The 122.5 is a unit conversion constant. The application rate computed from Equation 6 reflects how rapidly the soil must infiltrate manure if no manure runoff is to occur. The following example will show how these equations are best used.

Example 3. A center pivot irrigation system will be used to apply manure to a field growing hay on a silt loam soil. The pivot lateral is 500 feet long and the total flow rate of manure flowing to the lateral is 600 gpm. The radius of the end gun is 100 ft and the center pivot is designed to make one pass over 200 degrees of arc in 2.7 hrs. Determine (1) the depth of manure applied during each revolution and (2) the maximum application rate under the center pivot's lateral.

Solution: The depth of manure applied during each revolution can be computed from equation 5 as

$$D_a = \frac{11000(600)(2.7)}{200(600)^2} = 0.25 \text{ inches}$$

Assuming the effective radius is the lateral length of 500 ft plus the 100-ft radius of the sprinkler.

Assuming the center pivot's sprinklers have been selected to yield a uniform application depth, the maximum application rate can be determined from equation 6 as

$$A_r = \frac{122.5(600)}{500(100)} = 1.47 \text{ in/hr}$$

Solid Set Irrigation System

Solid set irrigation is a system of irrigation sprinklers and piping placed in a field. The piping is usually spaced a distance of one sprinkler radius apart on each lateral, see Figure 5. This creates a square spacing of sprinklers within the field. The piping may either be buried PVC or steel to create a permanent system or it may be aluminum pipe, which is very portable and can be easily moved from one location to another. Solid set irrigation systems are rarely used to apply liquid manure. The sprinklers are generally small with nozzles that are too small to freely pass the manure solids. If the manure to be applied has very low solids content and the solids are small, it may be possible to use a solid set system. The application rates are very uniform and often quite low, both advantages to good manure application. On the other hand, solid set systems are usually not moved often enough and excessive depths of manure are applied leading to runoff and/or over application of nutrients.
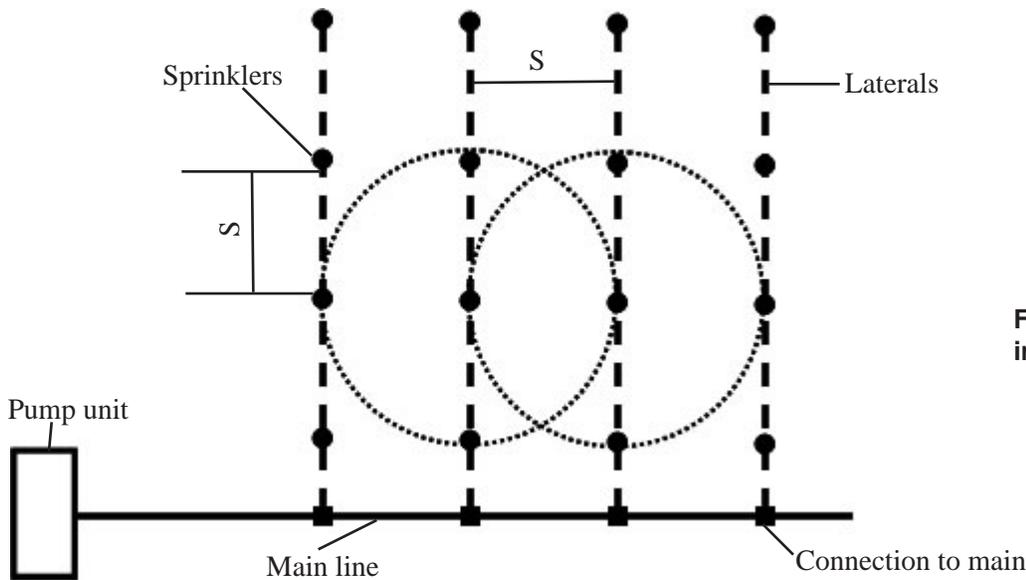
Fig. 5 Solid Set irrigation system

Application Rate. Solid set irrigation systems consist of multiple sprinklers (usually smaller sprinklers than are used on travelers) located on pipelines called laterals with the sprinklers spaced about a wetted radius (one-half the wetted diameter) apart. When sprinklers are placed in square stationary positions with uniform overlap as in a solid set irrigation system, the average application rate, A_r experienced at any point in the field can be computed as

$$A_r = \frac{96.3Q}{S^2}$$ **(7)**

where A_r = application rate in inches per hour
$\quad$ Q = sprinkler discharge (gpm)
$\quad$ S = distance between sprinklers in a square spacing (feet)
$\quad$ 96.3 = unit conversion factor

The following example will show how application rate and application depth can be determined for a solid set system.

Example 4. Sprinklers with 200-foot wetted diameters are used to apply liquid manure in a field of hay with silt loam soil. These sprinklers are placed on a 100- by 100-foot square spacing (S = 100 feet). Each sprinkler discharges 50 gpm. Compute the application rate. If manure is applied with this sprinkler system for 4.0 hours, what depth of manure was applied?

Solution: The application rate for a 100- by 100-foot square spacing of sprinklers can be computed as

$$A_r = \frac{96.3(50)}{100^2} = 0.48 \text{ in/hr}$$

Applying manure at 0.48 in/hr for 4 hours yields an application depth of (0.48 x 4 =) 1.92 inches of manure applied.

References

Jensen, M. E. 1983. Design and Operation of Farm Irrigation Systems. ASAE Monograph # 3, Am. Soc of Ag. And Biol. Engr. 2950 Niles Rd., St. Joseph, MI 49085

MWPS. 1985. *Livestock Waste Facilities Handbook* MWPS18. Midwest Plan Service. Ames, IA

Pennsylvania Department of Environmental Protection (PA-DEP). 2006. Nutrient Management Rules and Regulations, Title 25; Chapter 83, Subchapter D, Sections 83.201 to 83.491. State Conservation Commission, 2301 North Cameron St., Harrisburg, PA 17110.

Pair, C. H. 1975. *Sprinkler Irrigation*. Sprinkler Irrigation Association, 13975 Connecticut Avenue, Silver Springs, MD 20906.

Reviewed 8/2014