Chapter 5: Proper Application of Waste Products—Type B

Proper waste application involves knowledge of the waste application system, the soils and crops, and the required buffers that must be adhered to. This chapter will explain the required buffers and all other factors that must be considered when you are trying to determine when and how much waste to apply.

There are three different sets of buffers you should consider when land applying animal waste. The first are those that are required by law. Under the existing 15A NCAC 2H .0200 Nondischarge Rules, you can not land apply animal wastes within 25 feet of perennial streams. Perennial streams are defined as streams indicated by a solid blue line on a United States Geological Survey map. Effective October 1, 1995 for new or expanding swine farms, you may not apply waste of any form within 50 feet of residential property lines and rights-of-way. Furthermore, you may not apply waste within 50 feet of perennial streams. Again, these 50-foot buffers only affect swine farms constructed or expanded after October 1, 1995. You should also review your waste management plan or permit to see if any additional buffers are required.

A 100-foot buffer is required around wells for location of lagoons, other waste treatment facilities, and land application sites. The same processes that can contaminate a well from a lagoon can occur from a land application site if improperly managed or the well is poorly constructed. Even on a properly managed site it is best to maintain the buffer to reduce the potential for problems.

The last buffer is a “good neighbor” buffer. Maintain a minimum distance of 200 feet from any homes or other buildings frequented by people. Furthermore, do not make land applications on days with excessive wind. Drift on these days may irritate neighbors or pollute surface waters.

List the necessary buffers for waste application.

Describe why wind speed and direction should be considered when applying waste.
Proper land application of animal waste involves the use of management strategies to best achieve a balance between:

- optimizing the timing of nutrient application to match crop uptake;
- maintaining adequate storage in the lagoon or storage pond to handle extreme rainfall without overtopping; and
- applying wastewater or manure at a rate and amount such that no direct surface runoff or deep percolation below the root zone occurs.

Application of wastes from a Type B animal waste management facility often involve more than one waste application method. As an operator of a Type B animal waste management system, you must become competent in all the possible application methods. This chapter will describe how to operate and manage irrigation systems, pump and haul (honeywagon) type systems, and manure (solids) spreaders.

More and more dairy/cattle and other animal waste systems are utilizing irrigation as a method of land application for a portion of the wastewater. Irrigation may not be your main application method, but will be covered first.

A responsible system operator must understand how his/her wastewater should be managed, have knowledge of the capacity of his/her system to store and apply wastewater when appropriate, and be able to make prudent management decisions concerning when and how much wastewater to land apply. For a liquid waste management system utilizing irrigation, this decision-making process is called irrigation scheduling, and is generally based on the following flowchart (Figure 5-1).

Irrigation scheduling is the process of answering two basic questions:

- Do I need to irrigate?
- How much wastewater should I apply?
Is the lagoon depth more than the permanent treatment volume?

Is the crop actively growing or within 30 days of being planted?

Is the ground saturated or frozen?

Is it raining or excessively windy?

Record the date, location, and amount of effluent irrigated for each application event.

Irrigate, changing location, after each event.

Evaluate lagoon or storage pond level. Maintain the required storage at all times (freeboard plus 25-year, 24-hour storm).

Obtain a waste analysis within 60 days of application.

At least 1 time per year, set or verify irrigation equipment calibration to apply correct amount without runoff.

Has the target plant-available nitrogen rate for the crop been applied?

Figure 5-1. Nutrient management and irrigation scheduling decision-making flowchart.
DETERMINING WHEN TO IRRIGATE

There are five basic questions that should be answered when deciding to irrigate:

1. Do I have an actively growing crop (or will a crop be planted or actively start growing within 30 days)?
2. Do I have a nitrogen deficit remaining for this crop cycle?
3. Is the liquid level in my lagoon above the minimum storage depth? (Note: This is only relevant for anaerobic lagoons.)
4. Are my land application fields dry enough to be irrigated?
5. Do I have a waste analysis within 60 days of this irrigation?

If the answer to all five questions above is yes, then you should schedule an irrigation. The answer to Questions 1, 3, and 5 are straightforward and should be easy to determine. Question 2 requires a knowledge of how much nutrients you can apply and how much has already been applied. This will be addressed further in the section on Record Maintenance (Chapter 6). The next section will discuss how to determine soil-water content and how to determine irrigation rates.

Basic Soil-Water Relationships

Before attempting to measure or estimate soil-water content, you should understand some basic soil-water relationships. Understanding these relationships will help you determine if fields are dry enough to be irrigated and at what rates. Important terms you should be familiar with include: saturation, field capacity, permanent wilting point, gravitational water, and plant-available water.

To summarize briefly, soil is composed of three major parts: air, water, and solids. The portion occupied by air and water is referred to as the pore volume. At saturation, all soil pores are filled with water. Any water added to the soil under this condition will either run off or leach below the root zone. Saturated conditions are undesirable for good crop growth or wastewater irrigation. Field capacity refers to the point where the soil has
had time to drain away excess water from the large pores by gravity, but still remains in a very moist condition. **Permanent wilting point** is where there is so little water left in the soil that plants cannot remove the water for their use.

Not all of the water added to soil is retained in the soil for use by plants. Wastewater should be applied to soil such that it remains in the root zone for uptake by the crop. Any wastewater not retained in the root zone will likely transport waste nutrients to wherever it goes, resulting in a pollution threat to either surface water, groundwater, or both.

To interpret soil-water measurements and apply them to irrigation scheduling, you must be able to distinguish between two categories of soil-water:

1. **Gravitational Water**—the water in the soil that is free to drain or move by the force of gravity. Gravitational water is computed as the volume of water in the soil between saturation and field capacity. When gravitational water is present in the root zone, the soil is “too wet” to be irrigated with wastewater.

2. **Plant-Available Water (PAW)**—the amount of water held in the soil that is available to plants. It is computed as the difference between the water content at field capacity (referred to as upper limit water content) and the permanent wilting point (often referred to as the lower limit water content). Irrigation should be scheduled to maintain the water content of the soil between these two extremes. If there is no PAW deficit (i.e., the soil-water content is above the upper limit), gravitational water is present and wastewater irrigation should be delayed unless you are operating under emergency conditions.

Soil texture greatly influences the portion of the soil pore volume that can be occupied by gravitational water or plant-available water; therefore, it is important to know your soil texture to determine how much water can be irrigated.

The amount of plant-available water (PAW) that exists in the soil at any given time is commonly expressed as the depth of water per unit depth of soil. Typical units are inches of PAW per foot of soil depth. Estimates of PAW for various soil textural classes are given in published soil survey...
Chapter 5: Proper Application of Waste Products—Type B

reports. These estimates range from less than 0.2 inch of PAW per foot of soil for coarse sandy soils to nearly 2 inches of PAW per foot of soil for silty clay and clay soils (Table 5-1).

Table 5-1. Average Estimated Plant-Available Water for Various Soil Textural Classes

<table>
<thead>
<tr>
<th>Textural Class</th>
<th>Plant-Available Water</th>
<th>Maximum Recommended Application Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse sand and gravel</td>
<td>0.2 to 0.6</td>
<td>0.2</td>
</tr>
<tr>
<td>Sand</td>
<td>0.5 to 1.0</td>
<td>0.4</td>
</tr>
<tr>
<td>Loamy sand</td>
<td>0.8 to 1.5</td>
<td>0.6</td>
</tr>
<tr>
<td>Sandy loam</td>
<td>1.0 to 1.8</td>
<td>0.7</td>
</tr>
<tr>
<td>Loams</td>
<td>1.3 to 2.0</td>
<td>0.8</td>
</tr>
<tr>
<td>Silt loam</td>
<td>1.3 to 2.2</td>
<td>0.8</td>
</tr>
<tr>
<td>Silty clay loam</td>
<td>1.3 to 1.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Clay loam</td>
<td>1.1 to 1.9</td>
<td>0.8</td>
</tr>
<tr>
<td>Sandy clay loam</td>
<td>1.1 to 1.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Silty clay</td>
<td>1.2 to 1.9</td>
<td>0.8</td>
</tr>
<tr>
<td>Clay</td>
<td>1.2 to 1.9</td>
<td>0.8</td>
</tr>
</tbody>
</table>

At the start of irrigation, the water content in the soil should be lower than field capacity (upper limit). The difference between the existing water content and the field capacity water content is the amount that should be irrigated. The drier the soil, the more wastewater that can be safely applied per application, provided this amount does not exceed the required nitrogen application rate. Determining the water content of the soil tells you if the soil is dry enough to be irrigated and if so, how much wastewater can be applied. Maximum recommended wastewater irrigation amounts as influenced by soil texture are shown in Table 5-1.
Estimating Soil-Water Content

Determining whether or not the field is “dry” enough to be irrigated is not always obvious. There are three practical methods of determining if the field is dry enough to be irrigated. These are:

1. a subjective method that involves “feeling” the soil,
2. objective methods utilizing soil-moisture measuring devices, and
3. an accounting approach (checkbook method) to estimate soil water.

One of these three methods for determining soil-water content should be used to estimate the amount of water present in the soil at the start of irrigation.

Feel Method

The feel method involves estimating soil-water by feeling the soil. This method is easy to use, and many growers schedule irrigation in this way. This method is “subjective” since the results depend on the experience of the person doing the measurement. The value of this method depends on the experience of the operator. Some guidelines for estimating soil-water content by the feel method are given in Table 5-2.

Use of the feel method is demonstrated in the following example. Suppose your irrigation field is a sandy loam soil with a 15-inch root zone. You feel the soil and observe that it forms a weak ball which falls apart. Based on the guidelines given in Table 5-2, you can irrigate 0.3 to 0.4 inch of water per foot of root zone depth. For a 15-inch (1.25-feet) root zone depth, the permissible irrigation amount is:

\[
0.38 \text{ inch } \left( \frac{0.3\text{ in.}}{\text{ft}} \times 1.25\text{ ft} \right) \text{ to } 0.5 \text{ inch } \left( \frac{0.4\text{ in.}}{\text{ft}} \times 1.25\text{ ft} \right)
\]
Table 5-2. “Feel” guidelines for Estimating the Amount of Plant-Available Water to Be Replaced with Wastewater Irrigation as a Function of Soil Texture

<table>
<thead>
<tr>
<th>Available Water Remaining in the Soil</th>
<th>Sands</th>
<th>Loamy Sand</th>
<th>Sandy Loam</th>
<th>Clay, Clay Loam, Sandy Clay Loam</th>
<th>All Other Textures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maximum Recommended Wastewater Irrigation (per foot of effective root zone depth)</td>
<td>When ball is squeezed, no free water appears on soil but wet outline of ball is left in hand</td>
<td>Sticks together only slightly</td>
<td>Forms a ball that breaks easily</td>
<td>Forms a ball; very pliable</td>
<td>Easily ribbons between thumb and forefinger; feels slick</td>
</tr>
<tr>
<td>Wastewater Irrigation</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>75% to 100%</td>
<td>0.1 to 0.2 inch</td>
<td>0.2 to 0.3 inch</td>
<td>0.2 to 0.4 inch</td>
<td>0.2 to 0.4 inch</td>
<td>0.2 to 0.4 inch</td>
</tr>
<tr>
<td>50% to 75%</td>
<td>Appears dry, will not form a ball</td>
<td>Forms weak ball which falls apart</td>
<td>Forms ball; slightly plastic; slightly slick</td>
<td>Forms ball; forms ribbon</td>
<td></td>
</tr>
<tr>
<td>Wastewater Irrigation</td>
<td>0.2 to 0.3 inch</td>
<td>0.3 to 0.4 inch</td>
<td>0.3 to 0.5 inch</td>
<td>0.3 to 0.6 inch</td>
<td></td>
</tr>
<tr>
<td>25% to 50%</td>
<td>Appears dry, will not form a ball</td>
<td>Appears dry, will not form a ball</td>
<td>Somewhat crumbly but holds under pressure</td>
<td>Forms ball under pressure; somewhat pliable</td>
<td></td>
</tr>
<tr>
<td>Wastewater Irrigation</td>
<td>0.3 to 0.5 inch</td>
<td>0.3 to 0.6 inch</td>
<td>0.3 to 0.6 inch</td>
<td>0.3 to 0.7 inch</td>
<td></td>
</tr>
<tr>
<td>0 to 25%</td>
<td>Dry, loose, single-grained, flows through fingers</td>
<td>Dry, loose, flows through fingers</td>
<td>Powdery, dry; easily breaks into powdery condition</td>
<td>Hard, cracked; may have loose crumbs on soil surface</td>
<td></td>
</tr>
<tr>
<td>Wastewater Irrigation</td>
<td>0.3 to 0.5 inch</td>
<td>0.3 to 0.6 inch</td>
<td>0.3 to 0.7 inch</td>
<td>0.3 to 0.7 inch</td>
<td></td>
</tr>
</tbody>
</table>

Soil Moisture Measurement Devices

There are many different methods or devices for measuring soil water. These include the gravitational method, tensiometer, electrical resistance blocks, neutron probe, Phene cell, and time domain reflectometer. These methods differ in reliability, cost, and labor intensity.

Tensiometer and electrical resistance blocks are the most cost-effective and reliable devices for on-farm measurement of soil-water for irrigation in North Carolina. Tensiometers are best suited for sandy, sandy loam, and loamy soil textures while electrical resistance blocks work best in silty or clayey soils. Manufacturers of these devices provide calibration charts and recommended ranges for traditional “fresh” water irrigation. You should
be aware that the calibration curves and recommendations supplied by the manufacturer for these devices were developed for general conditions and are not adequate for specific soil conditions and fields. You should also be aware that wastewater objectives and recommendations are different from fresh water recommendations. The differences will be discussed later in this chapter. For irrigating wastewater, you will get better results if all soil-water measuring devices you use are calibrated for the major soils you are irrigating.

Checkbook Method

The checkbook method is an accounting approach for estimating how much soil-water remains in the effective root zone based on water inputs and outputs (like a daily balance on a bank account based on deposits and withdrawals). Wastewater irrigation is scheduled when the soil-water content in the root zone drops below a threshold level. Some of the simpler checkbook methods keep track of rainfall, evapotranspiration, and irrigation amounts. More sophisticated methods require periodic measurements of the soil-water status and moisture use rates of the crop.

Checkbook methods require detailed daily record keeping which can become time consuming for the more complex methods. One of the advantages of the checkbook approach is that it can be programmed on a computer. Computer programs have been developed to handle the accounting and provide timely and precise scheduling recommendations. To use the checkbook method, you must be able to estimate the rate that water stored in the soil is being used. Water is removed from the root zone by direct evaporation from the soil and transpiration by plants. Collectively, this is referred to as evapotranspiration (ET). Evapotranspiration is affected by many factors and varies seasonally and from day to day. On a hot, rainless day, ET may approach 0.25 inch per day. Thus during dry, summer periods, 1 inch of water could be removed from the soil every 4 days. On the other hand, more than a month may elapse before an inch is removed during prolonged cold-wet winter periods. For these reasons, irrigation amounts must vary seasonally in response to variation in evapotranspiration.

Average daily PET (PET is potential evapotranspiration—the amount of water that can be removed by a combination of the crops and evaporation) estimates for several locations are shown in Table 5-3. These values can be used in the checkbook method on rainless days. When rainfall is characterized by thunderstorms of short duration, the daily values given in
Table 5-3 are also appropriate. On days that are mostly cloudy or with rain during much of the daylight hours, assume the daily ET for that day is zero. The local NRCS maintains average daily values for each county. Actual values can also be obtained from the National Weather Service and are available on the Internet for several locations.

Table 5-3. Average Evapotranspiration from Vegetation Growing in Moist Soils

<table>
<thead>
<tr>
<th>Month</th>
<th>Asheville</th>
<th>Charlotte</th>
<th>Raleigh</th>
<th>Plymouth</th>
<th>Wilmington</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.03</td>
<td>0.04</td>
</tr>
<tr>
<td>February</td>
<td>0.05</td>
<td>0.05</td>
<td>0.05</td>
<td>0.06</td>
<td>0.08</td>
</tr>
<tr>
<td>March</td>
<td>0.07</td>
<td>0.08</td>
<td>0.09</td>
<td>0.10</td>
<td>0.11</td>
</tr>
<tr>
<td>April</td>
<td>0.11</td>
<td>0.12</td>
<td>0.13</td>
<td>0.13</td>
<td>0.15</td>
</tr>
<tr>
<td>May</td>
<td>0.12</td>
<td>0.15</td>
<td>0.16</td>
<td>0.16</td>
<td>0.17</td>
</tr>
<tr>
<td>June</td>
<td>0.15</td>
<td>0.17</td>
<td>0.17</td>
<td>0.17</td>
<td>0.18</td>
</tr>
<tr>
<td>July</td>
<td>0.14</td>
<td>0.16</td>
<td>0.17</td>
<td>0.17</td>
<td>0.18</td>
</tr>
<tr>
<td>August</td>
<td>0.12</td>
<td>0.14</td>
<td>0.15</td>
<td>0.15</td>
<td>0.16</td>
</tr>
<tr>
<td>September</td>
<td>0.10</td>
<td>0.11</td>
<td>0.12</td>
<td>0.13</td>
<td>0.13</td>
</tr>
<tr>
<td>October</td>
<td>0.06</td>
<td>0.07</td>
<td>0.08</td>
<td>0.09</td>
<td>0.10</td>
</tr>
<tr>
<td>November</td>
<td>0.04</td>
<td>0.04</td>
<td>0.05</td>
<td>0.06</td>
<td>0.06</td>
</tr>
<tr>
<td>December</td>
<td>0.02</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.05</td>
</tr>
</tbody>
</table>

Values computed from long-term daily maximum and minimum temperature records using the Thornthwaite method, corrected for measured pan evaporation. Single day value may be higher than shown (up to 0.25 inch/day) but values shown represent long-term average daily values for each month.

To use the checkbook method, you must begin computations when the soil is at a known water content. Field capacity is the usual starting point and should be assumed to occur soon after a rainfall or irrigation of an amount large enough to wet the effective root zone. For many of the well-drained loamy soils found in eastern North Carolina (root zone textures consisting of loamy sand, sandy loam, loam, or sandy clay loam) field capacity can be assumed to occur 1 day after a rainfall or irrigation in excess of 1 inch.

Example calculations for the checkbook method are shown in Table 5-4. In this example, the soil is a sandy loam with an effective root zone of 12 inches. The allowable irrigation volume is the depleted plant-available water content given in Table 5-1 not to exceed the recommended maximum of 0.7 inch for a sandy loam soil. Irrigation would normally be scheduled when about 50 percent of the plant-available water had been depleted.
Table 5-4. Use of the Checkbook Method for Irrigation Scheduling (Raleigh Location)

<table>
<thead>
<tr>
<th>Date</th>
<th>PAW at start of day</th>
<th>% of PAW</th>
<th>Daily PET</th>
<th>Rainfall</th>
<th>Irrigation</th>
<th>Drainage</th>
<th>PAW at end of day</th>
<th>% of PAW</th>
<th>Storage</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-01</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Don’t know initial conditions at this time</td>
</tr>
<tr>
<td>5-02</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>5-03</td>
<td>1.40</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.40</td>
<td>100</td>
<td>0.00</td>
<td>Assume FC reached at end of day after rain</td>
</tr>
<tr>
<td>5-04</td>
<td>1.24</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.08</td>
<td>77</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>5-05</td>
<td>1.08</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.92</td>
<td>66</td>
<td>0.48</td>
<td>OK to irrigate</td>
</tr>
<tr>
<td>5-06</td>
<td>0.92</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.76</td>
<td>54</td>
<td>0.64</td>
<td></td>
</tr>
<tr>
<td>5-07</td>
<td>0.76</td>
<td>0.16</td>
<td>-</td>
<td>0.64</td>
<td>-</td>
<td>-</td>
<td>1.24</td>
<td>89</td>
<td>0.16</td>
<td>Irrigated 0.64 inch</td>
</tr>
<tr>
<td>5-08</td>
<td>1.24</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.08</td>
<td>77</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>5-09</td>
<td>1.08</td>
<td>0.16</td>
<td>0.75</td>
<td>0.27</td>
<td>1.40</td>
<td>100</td>
<td>0.00</td>
<td>Rain exceeded storage so had 0.27 inch of drainage or seepage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-10</td>
<td>1.40</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.40</td>
<td>100</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>5-11</td>
<td>1.24</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.24</td>
<td>89</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>5-12</td>
<td>1.08</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.92</td>
<td>66</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>5-13</td>
<td>0.92</td>
<td>0.16</td>
<td>0.48</td>
<td>-</td>
<td>1.40</td>
<td>89</td>
<td>0.16</td>
<td>Lagoon marker indicates need to irrigate</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-14</td>
<td>1.24</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.08</td>
<td>77</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>5-15</td>
<td>1.08</td>
<td>0.16</td>
<td>-</td>
<td>0.22</td>
<td>-</td>
<td>-</td>
<td>0.98</td>
<td>70</td>
<td>0.42</td>
<td></td>
</tr>
<tr>
<td>5-16</td>
<td>1.14</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.82</td>
<td>59</td>
<td>0.58</td>
<td></td>
</tr>
<tr>
<td>5-17</td>
<td>0.98</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.82</td>
<td>59</td>
<td>0.58</td>
<td>Would like to irrigate</td>
</tr>
<tr>
<td>5-18</td>
<td>0.82</td>
<td>0.16</td>
<td>-</td>
<td>0.50</td>
<td>-</td>
<td>-</td>
<td>1.16</td>
<td>83</td>
<td>0.24</td>
<td></td>
</tr>
<tr>
<td>5-19</td>
<td>1.16</td>
<td>0.16</td>
<td>0.63</td>
<td>0.23</td>
<td>1.40</td>
<td>100</td>
<td>0.00</td>
<td>Rain exceeded storage so had 0.23 inch of drainage or seepage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-20</td>
<td>1.40</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.40</td>
<td>100</td>
<td>0.00</td>
<td></td>
</tr>
<tr>
<td>5-21</td>
<td>1.24</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.24</td>
<td>89</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>5-22</td>
<td>1.08</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.92</td>
<td>66</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>5-23</td>
<td>0.92</td>
<td>0.16</td>
<td>0.08</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.84</td>
<td>60</td>
<td>0.56</td>
<td></td>
</tr>
<tr>
<td>5-24</td>
<td>0.84</td>
<td>0.16</td>
<td>-</td>
<td>0.56</td>
<td>-</td>
<td>-</td>
<td>1.24</td>
<td>89</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>5-25</td>
<td>1.24</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.08</td>
<td>77</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>5-26</td>
<td>1.08</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.92</td>
<td>66</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>5-27</td>
<td>0.92</td>
<td>0.16</td>
<td>1.32</td>
<td>0.68</td>
<td>1.40</td>
<td>100</td>
<td>0.00</td>
<td>Rain with 0.68 inch drainage</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5-28</td>
<td>1.40</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.24</td>
<td>89</td>
<td>0.16</td>
<td></td>
</tr>
<tr>
<td>5-29</td>
<td>1.24</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>1.08</td>
<td>77</td>
<td>0.32</td>
<td></td>
</tr>
<tr>
<td>5-30</td>
<td>1.08</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.92</td>
<td>66</td>
<td>0.48</td>
<td></td>
</tr>
<tr>
<td>5-31</td>
<td>0.84</td>
<td>0.16</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.84</td>
<td>60</td>
<td>0.56</td>
<td></td>
</tr>
</tbody>
</table>

1 Based on a maximum plant-available water content of the example soil of 1.4 inches.
2 Soil storage at end of day is amount of plant-available water depleted. It is computed as:

$$\text{Soil Storage (end of day)} = \text{PAW (start of day)} + \text{PET} - \text{rainfall} - \text{irrigation} + \text{drainage}$$

From Table 5-1, 50 percent depletion for a sandy loam soil ranges from 0.5 to 0.9 inch. Assume the maximum plant-available water content for this soil is 1.4 inch (sandy loam soil in Table 5-1) so that the target depletion value for this soil is 0.7 inch which corresponds to the maximum

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North Carolina State University
recommended for a sandy loam. The crop grown is coastal bermudagrass, and irrigation is recommended during the period from May to October. Since no irrigation was planned prior to May, it is not necessary to maintain a checkbook balance of the soil-water content prior to May. In this example, the checkbook balance begins May 1 and continues throughout the irrigation period.

Since no records were being maintained, the water content on May 1 is not known. The initial content on May 1 can be estimated using the feel method, Table 5-2, or a starting value can be assumed 1 day after a 1 inch or greater rainfall (i.e., field capacity value). Using the latter approach, 1.5 inches of rain occurred on May 3. Since the maximum plant-available water content is 1.4 inches, we can assume that the soil storage is “full” 1 day after the 1.5-inch rainfall. Therefore, we start the water balance on May 4 assuming the plant-available storage on that day is 1.4 inches. Each day thereafter, a balance is computed based on additions to the root zone (rainfall or irrigation) and removal from the root zone (ET, drainage, or seepage).

Soil-water content can be measured or computed reliably by several different methods. Success results from selecting the method that is appropriate for the soils and crops being irrigated and that you feel confident in using. To help select the method that is right for you, contact your Cooperative Extension Service center, Natural Resources Conservation Service office, Division of Soil and Water Conservation, or Certified Technical Specialist.

**Determining How Much to Irrigate**

Irrigation should be scheduled and timed so that:

1. no surface runoff occurs during irrigation,
2. the root zone is not completely saturated at the conclusion of irrigation, and
3. the irrigated water does not leach below the root zone.
The amount of wastewater that can or should be applied during any single irrigation cycle is dictated by how much water the soil can “soak up.” This varies from day to day and is influenced by:

1. **Rainfall**—when and how much it last rained.
2. **Crop maturity**—water uptake rate of the crop.
3. **Soil type**—texture, structure, depth, and cover.
4. **Effective root depth**—dependent on soil characteristics and crop type and age.
5. **Evapotranspiration**—which is influenced by temperature, wind, and relative humidity.

Wastewater irrigation should replace the water that has evaporated from the soil or been removed by plants. This is referred to as the plant-available water deficit. Most water taken up by plants is removed in the upper half of the root zone. For the purpose of scheduling irrigation, this zone is referred to as the effective root depth. Soil conditions in North Carolina limit maximum rooting depths of most crops to 24 to 36 inches so that the effective root depth is typically only 12 to 18 inches. It is within this depth that we estimate or measure the plant-available water deficit to be replaced by irrigation. If the irrigation volume applied exceeds the PAW deficit, the excess either runs off or leaches below the root zone and could potentially contaminate groundwater.

If the soil was completely dry so that the crop was severely wilted, the plant-available water deficit would be the value shown in Table 5-1. In reality, the soil is rarely this dry so that the amount to be replaced will be less than the values shown in Table 5-1. At any given time, the plant-available water deficit could range from none to the maximum values shown in Table 5-1. Recommended wastewater irrigation volumes for a range in soil-water contents and soil textures is shown in Table 5-2.

Wastewater irrigation objectives and recommendations are different from fresh water recommendations. When irrigating with fresh water, the objective is to keep the soil moist for optimum growing conditions. This is desirable for all crops, but during dry periods, all of the water needed by the crop cannot be supplied from wastewater. The fresh water irrigation
required in addition to rainfall to maintain moist conditions throughout a typical cropping season is 6 to 10 inches. Usually, the irrigation volume required to supply the nitrogen requirement is only 2 to 5 inches. Thus, not all PAW deficits can be replenished with wastewater irrigation without over application of N.

Evaporation during irrigation is also a consideration in determining how much to irrigate. The amount irrigated should not be less than the anticipated potential evapotranspiration (PET) for the day. These amounts are shown in Table 5-3. If the amount irrigated is less than the daily PET, most of it will evaporate soon after application with little infiltration into the soil. When this occurs, most of the applied nitrogen is lost to the atmosphere through the process of ammonia volatilization which is also environmentally undesirable. In general, when the soil is dry during the summer, the irrigation amount should not be less than 0.25 inch of irrigation. When temperatures are cold and PET is very low, such as during the winter, smaller irrigation amounts even as low as 0.1 inch are acceptable. Since most irrigation occurs during the growing season when PET is near the daily maximum, minimum irrigation amounts will typically be 0.2 inch or greater.

Another factor affecting irrigation amount is the soil intake rate (infiltration rate). The soil intake rate is the rate that the soil can soak up the irrigated wastewater. The soil intake rate decreases the longer water is applied. The intake capacity of most clayey or silty soils begins to be exceeded by the time 0.5 to 0.6 inch has been applied. Continuing to irrigate could result in surface ponding and possible runoff of the irrigated wastewater which is a water quality violation that could result in penalties or fines. Soil intake rate is also dependent on the crop type, thickness of the stand, and slope of the land. Some typical ranges for various soil textures are shown in Table 5-5. Application rates in excess of these values could result in ponding and runoff.

**Explain the relevance of irrigation precipitation rate to soil infiltration capacity.**
Table 5-5. Approximate Water Infiltration Rates for Various Soil Textures and Slopes

<table>
<thead>
<tr>
<th>Slope</th>
<th>0 to 3%</th>
<th>3% to 9%</th>
<th>9+%</th>
</tr>
</thead>
<tbody>
<tr>
<td>inches per hour</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sands</td>
<td>&gt;1.00</td>
<td>&gt;0.70</td>
<td>&gt;0.50</td>
</tr>
<tr>
<td>Loamy sands</td>
<td>0.70 to 1.00</td>
<td>0.50 to 1.00</td>
<td>0.40 to 0.70</td>
</tr>
<tr>
<td>Sandy loams and fine sandy loams</td>
<td>0.50 to 1.00</td>
<td>0.40 to 0.70</td>
<td>0.30 to 0.50</td>
</tr>
<tr>
<td>Loams and silt loams</td>
<td>0.30 to 0.70</td>
<td>0.20 to 0.50</td>
<td>0.15 to 0.30</td>
</tr>
<tr>
<td>Sandy clay loams and silty clay loams</td>
<td>0.20 to 0.40</td>
<td>0.15 to 0.25</td>
<td>0.10 to 0.15</td>
</tr>
<tr>
<td>Clays, sandy clays, and silty clays</td>
<td>0.10 to 0.20</td>
<td>0.10 to 0.15</td>
<td>&lt;0.10</td>
</tr>
</tbody>
</table>

Source: Sprinkler Irrigation Association Journal. For poor vegetative cover or surface soil conditions, actual rates may be as much as 50 percent less than shown.

Sandy soils have high intake capacity and runoff is not much of a concern. But, sandy soils also have low plant-available water-holding capacity (PAW). For example, consider a deep sandy soil that has only 0.5 inch of plant-available water per foot of soil depth. For an effective root depth of 1.5 feet, the maximum plant-available water deficit is only 0.75 inch.

\[
1.5 \text{ ft} \times \frac{0.5 \text{ in. PAW}}{\text{ft}} = 0.75 \text{ in. PAW}
\]

For this example, if the application amount during any single irrigation cycle exceeds 0.75 inch, some of the applied wastewater will leach below the root zone and potentially pollute groundwater.

Taking all of the above factors into account, recommended wastewater irrigation amounts for a single irrigation cycle are in the range of 0.25 to 0.75 inch per foot of effective root zone depth. There may be an occasion when the appropriate irrigation amount falls outside this range such as when irrigation must occur during cold periods when PET is low, when the soil has an unusually deep root zone providing a greater amount of plant-available water storage, or to satisfy emergency action guidelines. But, these situations are exceptions and should not occur on a regular basis.

Regardless of the calculated rate, you as the system operator should monitor each waste application to verify adequate infiltration of the waste into the soil. An irrigation cycle should be stopped if ponding and runoff start to occur.

Explain how to determine how much water to irrigate.

Explain how/why irrigation amounts need to be adjusted seasonally.
Chapter 5: Proper Application of Waste Products—Type B

Operational Considerations

A key component of the irrigation design is to select the proper combination of system components so that the system precipitation rate does not exceed the intake rate of the soil. Several terms may be used to express the rate at which water is being applied to a field during irrigation. Terms you should be familiar with include: discharge rate, precipitation rate, and application volume.

Discharge Rate

Discharge rate is the volume of water exiting a sprinkler per unit of time, and is normally expressed in terms of gallons per minute (gpm). Discharge rate can also be referred to as sprinkler flow rate. Manufacturers publish discharge rates for their sprinklers as a function of operating pressure and orifice diameter of the nozzle. You should always have a copy of the manufacturer’s discharge specifications for the sprinklers on your system. Discharge characteristics for three typical sprinklers used for wastewater irrigation are given in Table 5-6. For example, a Rainbird Model 70 sprinkler operated at 55 psi with a 9/32-inch diameter nozzle has a discharge rate of 17.2 gpm. Discharge characteristics for typical big guns are shown in Table 5-7. For contrast, notice how much higher discharge rates are for the gun sprinklers than the rotary impact sprinklers.

Table 5-6. Discharge Characteristics for Rotary Impact Sprinklers Used with Permanent Stationary Irrigation System

<table>
<thead>
<tr>
<th>Nozzle Size</th>
<th>Operating Pressure (PSI)</th>
<th>50</th>
<th>55</th>
<th>60</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Flow GPM</td>
<td>Diameter FT</td>
<td>Flow GPM</td>
</tr>
<tr>
<td>Nelson F70APV</td>
<td></td>
<td>12.8</td>
<td>128</td>
<td>13.6</td>
</tr>
<tr>
<td>1/4</td>
<td></td>
<td>16.0</td>
<td>134</td>
<td>16.8</td>
</tr>
<tr>
<td>9/32</td>
<td></td>
<td>16.3</td>
<td>131</td>
<td>17.2</td>
</tr>
<tr>
<td>Rain Bird 70 CWH</td>
<td></td>
<td>12.9</td>
<td>124</td>
<td>13.6</td>
</tr>
<tr>
<td>1/4</td>
<td></td>
<td>16.3</td>
<td>131</td>
<td>17.2</td>
</tr>
<tr>
<td>9/32</td>
<td></td>
<td>16.3</td>
<td>133</td>
<td>17.1</td>
</tr>
<tr>
<td>Senniger 7025 RD-1-DF</td>
<td></td>
<td>13.0</td>
<td>127</td>
<td>13.6</td>
</tr>
<tr>
<td>1/4</td>
<td></td>
<td>16.3</td>
<td>133</td>
<td>17.1</td>
</tr>
</tbody>
</table>
Precipitation Rate

Precipitation rate is normally expressed as unit depth of water (inch) per unit of time, (usually an hour). The precipitation rate (inches per hour) depends upon discharge rate and coverage diameter. The precipitation rate is computed by first converting the discharge rate to a unit depth of water (inch) per unit of area (such as acre or square feet), then dividing by the wetted area of the sprinkler. Another important concept is total application volume (also expressed as application depth, inch) which is computed based on the amount of time the system operates at a given rate on a given field. Your target application volume represents the total volume (gallon/acre) needed to satisfy the PAN needs of the crop. This application volume is used for planning; rarely can you apply this much water during one irrigation cycle.

Wastewater analyses are often expressed in terms of pounds of plant-available nitrogen (lb PAN) per 1,000 gallons of wastewater. When irrigating, it is often preferable to express irrigation amounts as an equivalent depth of water per acre, for example, 1/2 inch per acre. Therefore, it is often necessary to convert between application volume expressed as gallons per acre and application volume expressed as an inch per acre. One inch of water spread over an acre, referred to as acre-inch, is equal to 27,154 gallons.

Example:

If you wish to apply 0.4 inch of irrigation water, how many gallons per acre should you apply?

\[
0.4 \text{ in.} \times \frac{27,154 \text{ gal}}{\text{acre-inch}} = 10,861 \text{ gal/acre}
\]

Example:

Your waste analysis indicates that you have 2.5 pounds PAN per 1,000 gallons. If you wish to apply 75 pounds of PAN, how many inches should you apply?
First, find the waste application rate (see Formula 4 on page 3-19.)

\[
\text{Waste application rate} = \frac{75 \text{ lb PAN} \times 1,000}{2.5 \text{ lb PAN per 1,000 gal}} = 30,000 \text{ gal/acre}
\]

Then convert the application volume to a depth:

\[
\frac{30,000 \text{ gal/acre}}{27,154 \text{ gal/acre-inch}} = 1.1 \text{ in.}
\]

**Example:**

If your target application volume to achieve the required annual PAN is 3.0 inches, and you should apply no more than 0.5 inch at each irrigation, how many times must you irrigate? To answer this, use the following formula:

\[
\text{Number of waste applications needed} = \frac{\text{total in. (or tons) needed to achieve desired PAN}}{\text{application volume in. (or tons)/application event}}
\]

\[
\text{Number of waste applications needed} = \frac{3 \text{ in. needed to achieve desired PAN}}{0.5 \text{ in./application event}} = 6 \text{ application events}
\]

This calculation is used only to estimate the number of irrigation events needed for a given situation. Based on earlier comments, you will be making adjustments for application volumes based on soil and weather conditions. You may have application volumes ranging from 0.25 to 0.6 inch per cycle for the above example. HOWEVER, you must never exceed the irrigation volume for a field that is dictated by your waste management plan.

*Note: Most irrigation systems do not completely cover a field with wastewater during operation. For example, a 30-acre pasture may only receive wastewater application onto 26 acres due to the layout of the field, buffers that must be observed, and operational parameters of the irrigation system. A wastewater application design and the appropriate records must reflect the area which receives wastewater; in this case 26 acres as opposed to the total field size.*
### Table 5-7. General Flow Rates and Coverage Diameter for Big Gun Sprinklers

#### Taper Bore Nozzle

<table>
<thead>
<tr>
<th>Gun Model</th>
<th>0.5</th>
<th>0.75</th>
<th>1.0</th>
<th>1.5</th>
<th>2.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>100T</td>
<td>50</td>
<td>50</td>
<td>115</td>
<td>260</td>
<td>205</td>
</tr>
<tr>
<td>150T</td>
<td>60</td>
<td>65</td>
<td>126</td>
<td>275</td>
<td>225</td>
</tr>
<tr>
<td>150R</td>
<td>70</td>
<td>75</td>
<td>137</td>
<td>290</td>
<td>245</td>
</tr>
<tr>
<td>200T</td>
<td>80</td>
<td>85</td>
<td>146</td>
<td>300</td>
<td>260</td>
</tr>
<tr>
<td>200R</td>
<td>90</td>
<td>95</td>
<td>155</td>
<td>310</td>
<td>275</td>
</tr>
<tr>
<td>300R</td>
<td>100</td>
<td>105</td>
<td>164</td>
<td>320</td>
<td>290</td>
</tr>
<tr>
<td>300R</td>
<td>110</td>
<td>110</td>
<td>172</td>
<td>330</td>
<td>305</td>
</tr>
<tr>
<td>300R</td>
<td>120</td>
<td>120</td>
<td>180</td>
<td>340</td>
<td>320</td>
</tr>
</tbody>
</table>

#### Ring Type Nozzle

<table>
<thead>
<tr>
<th>Gun Model</th>
<th>0.71</th>
<th>0.86</th>
<th>0.97</th>
<th>1.56</th>
<th>2.00</th>
</tr>
</thead>
<tbody>
<tr>
<td>100R</td>
<td>50</td>
<td>74</td>
<td>100</td>
<td>245</td>
<td>130</td>
</tr>
<tr>
<td>150R</td>
<td>60</td>
<td>81</td>
<td>110</td>
<td>260</td>
<td>143</td>
</tr>
<tr>
<td>150R</td>
<td>70</td>
<td>88</td>
<td>120</td>
<td>270</td>
<td>155</td>
</tr>
<tr>
<td>200R</td>
<td>80</td>
<td>94</td>
<td>128</td>
<td>280</td>
<td>165</td>
</tr>
<tr>
<td>200R</td>
<td>90</td>
<td>99</td>
<td>135</td>
<td>290</td>
<td>175</td>
</tr>
<tr>
<td>200R</td>
<td>100</td>
<td>105</td>
<td>143</td>
<td>300</td>
<td>185</td>
</tr>
<tr>
<td>200R</td>
<td>110</td>
<td>110</td>
<td>150</td>
<td>310</td>
<td>195</td>
</tr>
<tr>
<td>200R</td>
<td>120</td>
<td>120</td>
<td>157</td>
<td>315</td>
<td>204</td>
</tr>
</tbody>
</table>
To attain acceptable application uniformity, stationary sprinklers are typically arranged in a square pattern at a spacing of 50 to 65 percent of the wetted diameter. A typical layout for stationary sprinklers is shown in Figure 5-2. The orifice size, spacing, and operating pressure are selected from manufacturer’s literature to achieve the desired overlap and uniformity of coverage.

**Figure 5-2. Typical layout of a stationary sprinkler system. Sprinkler spacing is typically 50 to 65 percent of wetted diameter.**

### Compute the precipitation rate for a stationary sprinkler irrigation system.

**Formula 8**

\[
\text{Precipitation rate (in./hr)} = \frac{96.3 \times \text{sprinkler flow rate (gpm)}}{\text{sprinkler spacing (ft)} \times \text{lateral spacing (ft)}}
\]
Procedure for computing precipitation rate:

1. Determine the sprinkler flow rate and wetted diameter from manufacturer’s literature.

   From Table 5-6, Rainbird Model 70 with a 9/32-inch diameter nozzle operated at 55 psi:

   Sprinkler flow rate = 17.2 gpm

   Wetted Diameter = 133 feet

2. Recommended sprinkler spacing is 50 to 65 percent of wetted diameter. Using a value of 60 percent:

   Design sprinkler spacing = 0.6 \times 133 \text{ ft} = 79.8 \text{ ft}

   Sprinklers are normally spaced in equal multiples of 20 feet based on typical pipe length. Therefore, the design spacing would be 80 feet: for example, the sprinkler spacing along the lateral would be 80 feet and the lateral spacing would be 80 feet such that the effective area of a sprinkler would be 80 feet by 80 feet.

3. Precipitation rate is then computed as:

   \[
   \text{Precipitation rate (in./hr)} = \frac{96.3 \times 17.2 \text{ gpm}}{80 \text{ ft} \times 80 \text{ ft}} = 0.26 \text{ in./hr}
   \]

   The application volume is then computed as the precipitation rate multiplied by the operating time. In most cases, you will estimate the desired application volume based on soil conditions as described above. If this is the case, you then compute the time required to operate the system to achieve the desired application volume. For example, if the desired application volume is 0.6 inch, then the required operating time for the system would be:
Chapter 5: Proper Application of Waste Products—Type B

Determine the operational time necessary to apply a desired application volume or nitrogen application amount.

Formula 9

\[
\text{Time of operation (hr)} = \frac{\text{application volume (in.)}}{\text{precipitation rate (in./hr)}}
\]

\[
\text{So:}
\]

\[
\text{Time of operation (hr)} = \frac{0.6 \text{ in.}}{0.26 \text{ in./hr}} = 2.3 \text{ hr}
\]

Determination of Precipitation Rates for Traveling Gun Sprinklers

The precipitation rate in inches per hour for a traveling gun sprinkler is generally not affected by travel speed. This situation occurs because at any given position within the wetted diameter, water is being applied for at least an hour or longer. The precipitation rate is affected by the angle of rotation of the gun sprinkler. For example, if the gun only makes a half circle (180 degrees of rotation), the precipitation rate is twice that of a gun making a full circle (360 degrees of rotation). The precipitation rate for a traveling gun sprinkler is computed by the formula:

\[
\text{Precipitation rate (in./hr)} = \frac{96.3 \times \text{sprinkler flow rate (gpm)}}{3.14 \times \left(0.9 \times \text{sprinkler radius (ft)}\right)^2} \times \frac{360}{\text{w}}
\]

where “w” is the angle of rotation expressed in degrees. If the gun sprinkler rotates a full circle, then w is 360 degrees, whereas if the rotation is only a half circle, w is 180 degrees. In practice, the angle of rotation should be in the range of 315 to 330 degrees.

Example:

What is the precipitation rate for a gun sprinkler if the operating pressure is 80 psi, the nozzle diameter is 1.0 inch, and the angle of rotation is 320 degrees?

From Table 5-7, for a gun sprinkler operated at 80 psi with a 1.0 inch diameter taper bore nozzle, the discharge rate is 260 gpm and the wetted diameter is 355 feet.
For a wetted diameter of 355 feet, the wetted radius is:

\[ \frac{355 \text{ ft}}{2} = 177.5 \text{ ft} \]

The precipitation rate is then computed as:

\[
\text{Precipitation rate (in./hr)} = \frac{96.3 \times 260 \text{ gpm}}{3.14 \times (0.9 \times 177.5 \text{ ft})^2} \times \frac{360}{320} = 0.35 \text{ in./hr}
\]

**Example:**

What would be the precipitation rate in the previous example if the angle of rotation was only a half circle?

\[
\text{Precipitation rate (in./hr)} = \frac{96.3 \times 260 \text{ gpm}}{3.14 \times (0.9 \times 177.5 \text{ ft})^2} \times \frac{360}{180} = 0.62 \text{ in./hr}
\]

*Note: The precipitation rate for a traveling gun sprinkler increases rapidly as the angle of rotation decreases. Since the infiltration capacity of many soils is less than 0.5 inch per hour, it is important that the gun sprinkler rotate as much of a full circle as possible so that the precipitation rate does not exceed the infiltration capacity of the soil.*

**Determination of Application Volume (Depth) for a Traveling Gun Sprinkler**

The volume of wastewater applied by a traveling gun depends on the flow rate, lane spacing, travel distance, and travel speed. The travel lane spacing should be approximately 70 to 80 percent of the sprinkler’s wetted diameter as shown in Figure 5-3. The application volume is computed by the formula:

\[
\text{Application volume (in.)} = \frac{19.3 \times \text{sprinkler flow rate (gpm)}}{\text{lane spacing (ft)} \times \text{travel speed (in./min)}}
\]

*Compute the precipitation rate and application volume for a traveling gun sprinkler.*
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Example:

What is the application volume for a gun sprinkler if the operating pressure is 80 psi, the taper bore nozzle diameter is 1.0 inch, and the travel speed is 3 feet per minute?

From Table 5-7, for a gun sprinkler operated at 80 psi with a 1.0-inch nozzle, the discharge rate is 260 gpm and the wetted diameter is 355 feet.

If the lane spacing is 75 percent of the wetted diameter, the lane spacing is

\[ 0.75 \times 355 \text{ ft} = 266 \text{ ft} \]

The travel speed needs to be expressed in inches per minute. A travel speed of 3 feet per minute is equal to 36 inches per minute.

\[ 3 \text{ ft/min} \times 12 \text{ in./ft} = 36 \text{ in./min} \]

The application volume is then computed to be:

\[ \text{Application volume (in.)} = \frac{19.3 \times 260 \text{ (gpm)}}{266 \text{ ft} \times 36 \text{ in./min}} = 0.52 \text{ in.} \]

Determination of Travel Speed for a Traveling Gun Sprinkler

In many cases, you may desire to determine the travel speed required to apply a desired waste application depth. The travel speed is computed by the formula:

\[ \text{Travel speed (in./min)} = \frac{19.3 \times \text{sprinkler flow rate (gpm)}}{\text{lane spacing (ft)} \times \text{application volume (in.)}} \]

Example:

What travel speed is necessary to apply 0.6 inch with a gun sprinkler if the operating pressure is 80 psi, and the taper bore nozzle diameter is 1.0 inch?

From Table 5-7, for a gun sprinkler operated at 80 psi with a 1.0-inch nozzle, the discharge rate is 260 gpm and the wetted diameter is 355 feet.
If the lane spacing is 75 percent of the wetted diameter, the lane spacing is:

\[
0.75 \times 355 \text{ ft} = 266 \text{ ft}
\]

\[
\text{Travel speed (in./min)} = \frac{19.3 \times 260 \text{ gpm}}{266 \text{ ft} \times 0.6 \text{ in.}} = 31.4 \text{ in./min}
\]

**Figure 5-3. Typical layout of a traveling gun irrigation system. Lane spacing is typically 70 to 80 percent of wetted diameter.**

**System Calibration**

Information presented in manufacturer’s charts are based on average operating conditions with relatively new equipment. Discharge rates and application rates change over time as equipment gets older and components wear. In particular, pump wear tends to reduce operating pressure and flow. With continued use, nozzle wear results in an increase in the nozzle opening, which will increase the discharge rate while decreasing the wetted diameter.
You should be aware that operating the system differently than directed in the design will alter the application rate, diameter of coverage, and subsequently the application uniformity. For example, operating the system with excessive pressure results in smaller droplets, greater potential for drift, and accelerated wear of the sprinkler nozzle. Clogging of nozzles can result in pressure increase. Plugged intakes or crystallization of mainlines will reduce operating pressure. Operating below design pressure greatly reduces the coverage diameter and application uniformity.

For the above reasons, equipment should be field calibrated on a regular basis to ensure proper application rates and uniformity. Field calibration at least once every three years is recommended. Calibration involves collecting and measuring flow at several locations in the application area. Many types of containers can be used to collect flow and determine the application rate. Rain gauges work best because they already have a graduated scale from which to read the application amount without having to perform additional calculations. However, pans, plastic buckets, jars, or anything with a uniform opening and cross-section can be used provided the liquid collected can be easily transferred to a scaled container for measuring.

For stationary sprinklers, collection containers should be located in a grid pattern throughout the application area at several distances from sprinklers. Collection gauges should be spaced 1/4 the effective sprinkler spacing apart. For traveling guns, sprinklers should be located along a transect perpendicular to the direction of pull. Set out collection containers no further than 25 feet apart along the transect on both sides of the gun cart. You should compute the average application rate for all collection containers and the application uniformity for the system. Calibration procedures are outlined in Appendix I for each type of system. You should obtain a uniformity coefficient of 0.5 or greater for stationary sprinkler systems, and the uniformity coefficient for a traveling gun system should exceed 0.6. If the uniformity coefficient computed for your system is less than these values, contact your irrigation dealer or technical specialist for assistance.
Many of the decisions on when and how much to irrigate wastewater are determined by the liquid nature of the waste and the potential for runoff. With slurry or solids application, these decisions surrounding liquid application are not as critical. Certainly, it is still your job as the system operator to ensure that the applied wastes will not run off the property, but the solid nature of the wastes greatly reduces the tendency of these materials to run off site. Therefore, the decision process for waste application is more related to the stage of crop growth and whether the crops need nutrient applications. Another important issue is the “trafficability” of the fields, or how easily your equipment can be operated to obtain uniform waste application without rutting the field or causing soil compaction. Once the decision has been made to perform waste application, you must be aware of your equipment’s waste application rate. This requires the calibration of the land application equipment.

A certain percentage of the nutrients in slurry and solid manures is tied up in the organic portion of the waste and is not immediately available for plant uptake. These nutrients will slowly become available to plants over the course of several years. To satisfy your waste management plan, you are only required to keep track of the nutrients that are available for the first crop. It is possible, but quite tedious, to develop a system to determine the “carry-over” nutrients from the organic portion of the manure. It is beyond the scope of this training to do this exercise, and as mentioned it is not required at this time. However, you may wish to consider this issue to help minimize the potential for over application of nutrients (especially nitrogen) that may be detrimental to your crops, soils, or groundwater.

**CALIBRATION OF MANURE SPREADERS**

Effective utilization of manure is not possible if you do not know how much is being spread over a given area. Calibration of your spreader is a simple and effective way of improving utilization of nutrients in manure more effectively. Only by knowing the application rate of your spreader can you correctly apply manure to correspond to your crop needs and prevent water quality problems through the over application of animal manure.

Applicators can apply manure, bedding, and wastewater at varying rates and patterns, depending on forward travel and/or PTO speed, gear box settings, gate openings, operating pressures, spread widths, and overlaps. Calibration defines the combination of settings and travel speed needed to...
apply manure, bedding or wastewater at a desired rate and to ensure uniform application.

**Liquid Manure Spreaders**

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

**Calibration method:**

1. Spread at least one full load of waste, preferably in a square or rectangular field pattern for ease of measuring, with normal overlaps.

2. Measure the length and width of coverage, recognizing that the outer fringe areas of the coverage will receive much lighter applications than the overlapped areas.

3. Multiply the length by the width and divide by 43,560 to determine the coverage area in acres.

   \[
   \text{Coverage area (area of rectangle in ft}^2\text{)} = \text{length (ft)} \times \text{width (ft)}
   \]

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

4. Divide the gallons of wastewater in the spreader by the acres covered to determine the application rate in gallons per acre.

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

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

**Example:**
Your waste application method is a tractor-drawn tanker (honeywagon) with a 2,500-gallon capacity. You apply a load to a field and measure the application area as 22-feet wide by 280-feet long. What is the application rate in gallons per acre?

First, figure the coverage area:

\[
\text{Coverage area (acres)} = \frac{280 \text{ ft} \times 22 \text{ ft}}{43,560 \text{ ft}^2} = 0.14 \text{ acre}
\]

Then figure the application rate:

\[
\text{Application rate for spreader (gal/acre)} = \frac{2,500 \text{ gal}}{0.14 \text{ acre}} = 17,857 \text{ gal/acre}
\]

**Spreader Capacity**

Liquid spreader capacities are normally rated by the manufacturer in gallons. Multiply by 0.0042 to get tons.

Solid and semisolid spreaders are rated by the manufacturer either in bushels or cubic feet (multiply bushels by 1.25 to get cubic feet). Most spreaders have two rating capacities: (1) struck or level full, and (2) heaped. Calibration of solid manure spreaders based on its capacity (volume) is difficult to estimate accurately because the density of solid and semisolid manures are quite variable. Density is the weight of the manure per volume of manure (pounds per cubic foot). Manure density varies 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 the spreader holds, you are overlooking the fact that some manure weighs more than other manure. This can cause a significant error when calculating manure application rates.
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Since manures and litters have different densities, an on-farm test should be done. To determine the load (tons) of a manure spreader:

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. Subtract the empty bucket weight from this weight to calculate the weight of the contents.

4. Multiply weight of contents by 1.5 to calculate pounds per cubic feet, density.

5. Multiply the manure density by the cubic feet capacity of the spreader and divide by 2,000 to get the tons of material in a spreader load.

\[
\text{Spreader load (tons)} = \frac{\text{weight of 5 gal manure} \times 1.5 \times \text{spreader capacity (ft}^3\text{)}}{2,000}
\]

**Solid and Semisolid Manure Spreaders**

In order to calibrate a spreader for solid manure (20 percent or more solids), the following materials are needed:

1. Bucket

2. Plastic sheet, tarp, or old bedsheets. An even size, 8 feet by 8 feet, 10 feet by 10 feet, or 12 feet by 12 feet, will make calculations easier.

3. Scales
Calibration method:

1. Locate a large and reasonably smooth, flat area where manure can be applied.

2. Spread the plastic sheet, tarp, or bed sheet smoothly and evenly on the ground.

3. 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.

4. Drive over the sheet at the normal application speed and settings while continuing to apply manure. If a rear discharge spreader is used, three passes should be made: First, drive directly over the center of the sheet; the other two on opposite sides of the center at the normal spreader spacing overlap.

5. Weigh the empty bucket and plastic sheet, tarp, or blanket.

6. Collect all manure spread on the sheet and place it into the bucket.

7. Weigh bucket and manure and subtract the weight of the empty bucket and ground sheet. This will give you the pounds of manure applied to the sheet.

8. Repeat the procedure three times to get a reliable average.

9. Determine the average weight of the three manure applications.

10. Calculate the application rate using the following formula or Table 5-8:

\[
\text{Application rate (tons/acre)} = \frac{\text{lb manure collected}}{\text{sheet length (ft) \times sheet width (ft)}} \times 21.78
\]

\text{Formula 17}

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

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

Application rate (tons/acre) = \( \frac{8.5 \text{ lb manure}}{10 \text{ ft} \times 10 \text{ ft}} \times 21.78 \)

\[ = 1.85 \text{ tons/acre} \]

<table>
<thead>
<tr>
<th>Table 5-8. Calibration of Solid Manure Spreaders</th>
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</thead>
<tbody>
<tr>
<td>Pounds of Manure Applied to Sheet</td>
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<tr>
<td>-----------------------------------------------</td>
</tr>
<tr>
<td>Size of Ground Sheet</td>
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<td>-----------------------------------------------</td>
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</tbody>
</table>

Many times it may be necessary to adjust the rate in which waste is applied from the way it is normally spread. Changes in application rate can easily be done by increasing or decreasing the speed in which the waste is being applied. In order to perform these calculations, the spreader load (tons), duration of application (minutes), and the average width (feet) of a normal application needs to be known. The application rate and travel speed can be found using the following equations:

**Formula 18**

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

**Formula 19**

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

What speed should you run if you wish to apply 4 tons of manure per acre with a 3-ton spreader? Your spreader application width is 20 feet and your spreader empties in 6 minutes.

\[
\text{Travel speed (mph)} = \frac{3 \text{ tons} \times 495}{6 \text{ min} \times 20 \text{ ft} \times 4 \text{ tons/acre}} = 3.1 \text{ mph}
\]

Spreader Pattern Uniformity

To determine the uniformity of spread and the amount of overlap needed, place a line of small pans or trays equally spaced (2 to 4 feet) 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 equally 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 is half of what it is in the center. The distance between these points is the 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 “lopside” patterns are not satisfactory and one or more of the spreader adjustments should be made. These patterns are described in the calibration section found in Appendix I.

1. Name three negative consequences of not following a proper pumping schedule. ...................................... see pages 5B-1 to 5B-33

2. What buffers must be observed during waste application? ............................................................................see page 5B-1

3. What are the five questions you should ask yourself before deciding to irrigate wastewater? ..........................see page 5B-4
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4. Explain the importance of estimating soil moisture prior to waste application. .................................................................see page 5B-6

5. Explain the importance of plant-available water and soil-intake rate. ..................................................................................see page 5B-14

6. Explain how you can measure or calibrate your actual waste application (in inches) from an irrigation system. .....see page 5B-26

7. Explain how to calibrate your waste application from a manure spreader or tanker. ................................................. see pages 5B-28 to 5B-31

8. Explain the importance of knowing the capacity and travel speed when using a liquid or solid manure spreader. ..........see page 5B-32

In the previous three chapters, you have been introduced to a number of formulas used to help determine how to properly apply animal waste at agronomic rates. The use of these formulas requires that you know the following items about your operation:

1. Type of operation

2. Number of animals

3. Pounds of plant-available nitrogen (PAN) per 1,000 gallons of liquid or per ton of waste

4. Acreage of each field to receive waste applications, crop rotation for that field, and field number

5. Records or estimate of crop yield for each field

6. Type and specifications of waste application equipment, including:
   - operating pressure
   - nozzle diameter
   - flow or delivery rate in gallons per minute (gpm)
• diameter of throw of wastewater

• travel speed settings for traveling equipment

• tank or spreader capacity in gallons, pounds, tons, or bushels

• travel speed of tractor if pulling manure spreader

• number of sprinklers if solid-set system

• degrees of rotation of the sprinkler

7. Estimate of infiltration rates on each field *

* Note: This number will vary with field conditions. See Chapter 5 for specifics on estimation of infiltration rates.

With the above information, you can make all of the calculations that will allow you to properly operate your waste application equipment so that agronomic rates are not exceeded. Important conversion factors and formulas that are used for proper waste application are summarized on the following pages. Most of these formulas are also included on the Record Forms IRR-2, SLUR-2, and SLD-2, so that you can actually make your calculations on these forms as you work through them. The record forms do not include the equations for irrigation equipment application rate or travel speed.
CONVERSION FACTORS

1 acre = 43,560 square feet

1 acre-inch = 27,154 gallons

Lane spacing for traveling gun = 70% to 80% wetted area

Lane spacing for stationary gun = 50% to 65% wetted area

\( mg/l = \text{pounds per 1,000 gallons} \)

\( \frac{120}{1} \)

1 cubic foot (ft\(^3\)) = 7.48 gallons

\( \text{Gallons} \times 0.0042 = \text{tons} \)

\( \text{Bushels} \times 1.25 = \text{cubic feet} \)

1 bushel of manure = 75 pounds

IMPORTANT FORMULAS—TYPE B

1. Volume of wastewater generated

   \[
   \text{Volume of wastewater generated} = \text{number of animals} \times \frac{\text{gal of wastewater}}{\text{animal per year}}
   \]

2. Waste application rate for priority nutrient (pounds per acre)

   \[
   \text{Application rate (lb PAN/acre)} = \frac{\text{realistic yield (tons, bushels, etc.)}}{\text{acre}} \times \frac{\text{lb PAN}}{\text{unit of yield}}
   \]

3. Acres needed for waste application

   \[
   \text{Acres needed for waste application} = \frac{\text{gal (or tons) of waste produced annually}}{\text{waste application rate gal (or tons)/acre}}
   \]
4. **Application rate (gallons per acre)**

\[
\text{Application rate (gal/acre)} = \frac{\text{crop PAN requirement (lb/ac)}}{\text{acre}} \times \frac{1,000}{\text{lb PAN per 1,000 gal}}
\]

5. **Application rate (tons per acre)**

\[
\text{Application rate (tons/acre)} = \frac{\text{crop PAN requirement (lb/ton) from waste analysis}}{\text{lb PAN/ton}}
\]

6. **Pound of plant-available nitrogen applied per acre**

\[
\text{lb PAN/acre applied} = \frac{\text{application rate (gal) of waste applied}}{\text{acre}} \times \frac{\text{lb PAN per 1,000 gal}}{1,000}
\]

7. **Number of waste applications needed**

\[
\text{Number of waste applications needed} = \frac{\text{total in. (or tons) needed to achieve desired PAN application volume}}{\text{in. (or tons)/application event}}
\]

8. **Precipitation (application) rate for stationary equipment, inches per hour**

\[
\text{Precipitation rate (in./hr)} = \frac{96.3 \times \text{sprinkler flow rate (gpm)}}{\text{sprinkler spacing (ft)} \times \text{lateral spacing (ft)}}
\]

9. **Time of irrigation system operation (hours)**

\[
\text{Time of operation (hr)} = \frac{\text{application volume (in.)}}{\text{precipitation (application) rate (in./hr)}}
\]

10. **Precipitation (application) rate for traveling gun; inches per hour, where “w” is the angle of rotation expressed in degrees**

\[
\text{Precipitation rate (in./hr)} = \frac{96.3 \times \text{sprinkler flow rate (gpm)}}{3.14 \times [0.9 \times \text{sprinkler radius (ft)}]^2} \times \frac{360}{w}
\]

11. **Application volume (depth) for traveling gun; inches**

\[
\text{Application volume (in.)} = \frac{19.3 \times \text{sprinkler flow rate (gpm)}}{\text{lane spacing (ft)} \times \text{travel speed (in./min)}}
\]
12. **Travel speed for traveling gun; inches per minute**

\[
\text{Travel speed (in./min)} = \frac{19.3 \times \text{sprinkler flow rate (gpm)}}{\text{lane spacing (ft)} \times \text{application volume (in.)}}
\]

13. **Area of a rectangle**

\[
\text{Area of rectangle (ft}^2\text{)} = \text{length (ft)} \times \text{width (ft)}
\]

**Area of a circle**

\[
\text{Area of circle (ft}^2\text{)} = 3.14 \times (\text{circle radius})^2
\]

14. **Coverage area for application**

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

15. **Application rate for spreader**

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

16. **Determination of spreader capacity**

\[
\text{Spreader load (tons)} = \frac{\text{weight of 5 gal manure} \times 1.5 \times \text{spreader capacity (ft}^3\text{)}}{2,000}
\]

17. **Application rate calibration for solids spreader (tons/acre)**

\[
\text{Application rate (tons/acre)} = \frac{\text{lb manure collected} \times 21.78}{\text{sheet length (ft)} \times \text{sheet width (ft)}}
\]

18. **Application rate for litter (solids) spreader (tons/acre)**

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

19. **Application speed for solids spreader (mph)**

\[
\text{Travel speed (mph)} = \frac{\text{spreader load (tons)} \times 495}{\text{time (min)} \times \text{width (ft)} \times \text{application rate (tons/acre)}}
\]
On the next few pages are example problems using these formulas. For more practice using these formulas, there are additional problems in Appendix E.

**PROBLEM 1**

You use a box spreader and you apply 1 ton of solids over a 30-foot wide by 100-foot long area. What is your application rate in tons per acre?

First find the coverage area:

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

\[
\text{Coverage area (acres)} = \frac{30 \text{ ft} \times 100 \text{ ft}}{43,560 \text{ ft}^2 \text{ per acre}} = 0.069 \text{ acre}
\]

Then find the application rate:

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

\[
\text{Application rate for spreader (tons/acre)} = \frac{1 \text{ ton}}{0.069 \text{ acre}} = 14.5 \text{ tons/acre}
\]

**PROBLEM 2**

You are spreading solids from a dairy dry stack using a box spreader with a 250-cubic foot capacity. The weight of one 5-gallon bucket of solids is 17.5 pounds. What is the spreader load in tons?

\[
\text{Spreader load (tons)} = \frac{\text{weight of 5 gal manure} \times 1.5 \times \text{spreader capacity (ft}^3\text{)}}{2,000}
\]

\[
\text{Spreader load (tons)} = \frac{17.5 \text{ lb} \times 1.5 \times 250 \text{ ft}^3}{2,000} = 3.3 \text{ tons}
\]


**PROBLEM 3**

The material in Problem 2 is applied over a 40-foot wide by 220-foot long area. What is the application rate in tons per acre?

First, find the coverage area:

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

\[
\text{Coverage area (acres)} = \frac{40 \text{ ft} \times 220 \text{ ft}}{43,560 \text{ ft}^2 \text{ per acre}} = 0.2 \text{ acre}
\]

Now you can determine the application rate:

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

\[
\text{Application rate for spreader (tons acre)} = \frac{3.3 \text{ tons}}{0.2 \text{ acre}} = 16.5 \text{ tons/acre}
\]

**PROBLEM 4**

During the calibration of a solids spreader, 12.5 pounds of material is applied over a 12-foot wide by 12-foot long tarp. What is the application rate in tons per acre?

\[
\text{Application rate (tons/acre)} = \frac{\text{lb of manure collected \times 21.78}}{\text{sheet length (ft) \times sheet width (ft)}}
\]

\[
\text{Application rate (tons/acre)} = \frac{12.5 \text{ lb manure collected} \times 21.78}{12 \text{ ft} \times 12 \text{ ft}} = 1.9 \text{ tons/acre}
\]
**Problem 5**

A spreader with a 3.3-ton load applies waste in a 40-foot wide strip with an application rate of 16.5 tons per acre. It takes 2 minutes for the spreader to empty its load. What was the travel speed of the spreader?

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

\[
\text{Travel speed (mph)} = \frac{3.3 \text{ tons} \times 495}{2 \text{ min} \times 40 \text{ ft} \times 16.5 \text{ tons/acre}} = 1.2 \text{ mph}
\]

**Problem 6**

If the spreader in Problem 5 needed to apply 10 tons per acre of manure to meet the requirements of a waste utilization plan, how fast should the spreader be driven?

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

\[
\text{Travel speed (mph)} = \frac{3.3 \text{ tons} \times 495}{2 \text{ min} \times 40 \text{ ft} \times 10 \text{ tons/acre}} = 2 \text{ mph}
\]

**Problem 7**

A spreader being pulled at 3 mph empties a 3.5-ton load in 1.5 minutes with an application width of 20 feet.

**Question 1:**

What is the application rate in tons per acre?

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

\[
\text{Application rate (tons/acre)} = \frac{3.5 \text{ tons} \times 495}{1.5 \text{ min} \times 20 \text{ ft} \times 3 \text{ mph}} = 19.25 \text{ tons/acre}
\]
**Question 2:**

How fast would the operator need to drive if he wished to change his application rate to 14.5 tons/acre?

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

\[
\text{Travel speed (mph)} = \frac{3.5 \text{ tons} \times 495}{1.5 \text{ min} \times 20 \text{ ft} \times 14.5 \text{ tons/acre}} = 4 \text{ mph}
\]

**PROBLEM 8**

Your target nitrogen rate for your crop is 150 pounds per acre per year. However, you wish to split this into 3 applications of 50 pounds N per acre. Your waste analysis shows 2.0 pounds of N per 1,000 gallons. How much wastewater should you apply to obtain 50 pounds of N per acre?

\[
\text{Application rate (gal/acre)} = \frac{\text{crop PAN requirement (lb/ac)} \times 1,000}{\text{lb PAN per 1,000 gal}}
\]

\[
\text{Application rate (gal/acre)} = 50 \text{ lb/ac} \times \frac{1,000}{2.9 \text{ lb}} = 25,000 \text{ gal/acre}
\]

**PROBLEM 9**

Based on the information from Problem 8 above, how many inches of wastewater must you apply to reach your target of 50 pounds PAN per acre?

Conversion factor: 1 acre-inch = 27,154 gallons

\[
\frac{25,000 \text{ gal/acre}}{27,154 \text{ gal/acre-inch}} = 0.92 \text{ in.}
\]
**PROBLEM 10**

You operate a stationary irrigation system with a sprinkler flow rate of 14 gpm and a system layout with sprinkler spacing of 80 feet and lateral spacing of 80 feet.

**Question 1:**
What is the precipitation rate in inches per hour?

\[
\text{Precipitation rate (in./hr)} = \frac{96.3 \times \text{sprinkler flow rate (gpm)}}{\text{sprinkler spacing (ft)} \times \text{lateral spacing (ft)}}
\]

\[
\text{Precipitation rate (in./hr)} = \frac{96.3 \times 14 \text{ gpm}}{80 \text{ ft} \times 80 \text{ ft}} = 0.21 \text{ in./hr}
\]

**Question 2:**
Based on Problem 9, you wish to apply 0.92 inch of wastewater. How long must you operate the stationary system to deliver the desired depth of application?

\[
\text{Time of operation (hr)} = \frac{\text{application volume (in.)}}{\text{precipitation (application) rate (in./hr)}}
\]

\[
\text{Time of operation (hr)} = \frac{0.92 \text{ in.}}{0.21 \text{ in./hr}} = 4.4 \text{ hr (4 hr:24 min)}
\]

**PROBLEM 11**

You land apply your manure with a manure spreader because it is too dry and thick for irrigation or a tank spreader. Your waste analysis shows it contains 16 pounds N per ton of manure. Your cropping sequence is corn (grain) followed by winter wheat (grain). The average yield you have recorded over the past 5 years is 90 bushels of corn and 35 bushels of wheat. How many tons of manure per acre can you apply to maintain agronomic rates?
You must first find out the allowable nitrogen loading to the field, per acre.

From Table 3-5, you see that corn for grain uses 1.0 to 1.25 pounds of N per bushel (select 1.1), and wheat for grain uses 1.7 to 2.4 pounds of N per bushel (select 2.0).

The corn needs:

\[
\text{Application rate (lb PAN/acre)} = \frac{\text{realistic yield (tons, bushels, etc.)}}{\text{acre}} \times \frac{\text{lb PAN}}{\text{unit of yield}}
\]

\[
\text{Application rate (lb PAN/acre)} = \frac{90 \text{ bu}}{\text{acre}} \times \frac{1.1 \text{ lb PAN}}{\text{bushel}} = 99 \text{ lb PAN/acre}
\]

The wheat needs:

\[
\text{Application rate (lb PAN/acre)} = \frac{\text{35 bu}}{\text{acre}} \times \frac{2.0 \text{ lb PAN}}{\text{bu}} = 70 \text{ lb PAN/acre}
\]

With this cropping sequence, the total N needed is:

\[
99 + 70 = 169 \text{ lb PAN/acre}
\]

Now you can determine how many tons per acre of manure to apply. Each ton of manure supplies 16 pounds of N, and you need 169 pounds of N per acre.

\[
\text{Application rate (tons/acre)} = \frac{\text{crop PAN requirement (lb/ac)}}{\text{lb PAN/ton (from waste analysis)}}
\]

\[
\text{Application rate (tons/acre)} = \frac{169 \text{ lb/ac}}{16 \text{ lb PAN/ton (from waste analysis)}} = 10.5 \text{ tons/acre}
\]

Note: This application rate is the total for BOTH crops and should NOT be applied with a single application.