Pesticide Application

Calibrating Pesticide Sprayers

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Calibration of pesticide application equipment is the process of adjusting speed, nozzle orifice size, and pressure (and for multi-nozzle booms, the number of nozzles), to apply a precise amount of pesticide mixture uniformly in a precise area. The most important reason pesticides fail to control pests is because of faulty and improperly adjusted (calibrated) equipment.

Before applying pesticides, inspect your application equipment for mechanical problems, including leaky hoses, faulty nozzles, screens and filters, boom height, pressure gauges, etc. Once you confirm that equipment is in proper condition, you are ready to consider the three factors of speed, nozzle orifice size, and pressure.

Tables 1 and 2 show the impact that speed, nozzle orifice size, and pressure have on sprayer output (amount of liquid a sprayer will apply in 1 acre).

Table 1. Relationship between speed and output of a sprayer

Output (MPH)	Speed (GPA)
2	100
4	50
6	33
8	25

Note: The output of a sprayer has a direct inverse relationship to sprayer speed. For example, doubling speed reduces output by 50%. To calculate mph, measure a known distance (in feet), determine the time in seconds needed to travel that distance, then use the following formula:

$$\text{mph} = \frac{\text{distance traveled (in ft)} \times 0.60}{\text{time of travel (in seconds)} \times 88}$$

This can be written as:

$$\frac{\text{distance traveled}}{\text{time of travel}} \times 0.6818$$

Example:

measured distance = 300 ft

time to travel 300 ft = 45 seconds

$$\text{mph} = \frac{300}{45} \times 0.6818 = 4.55 \text{ mph}$$

Table 2 shows the impact of nozzle orifice size and pressure on sprayer output.

Output increases directly according to nozzle orifice size. But, upon doubling pressure, the output only increases by 43%. So, for major changes in output, change speed and/or nozzle orifice size. For example, to reduce output, increase speed or reduce nozzle orifice size. Use pressure for minor adjustments.

Table 2. Effect of nozzle orifice size and pressure on sprayer output

Nozzle orifice size (TeeJet)	Output (GPM) @ 20 psi	Output (GPM) 40 @ psi	% change in output due to pressure	% change in output due to size
8001	0.07	0.1	43	—
8002	0.14	0.2	43	100
8003	0.21	0.3	43	100
8004	0.28	0.4	43	100

Calibrating Knapsack (backpack) Sprayers

The following is a simple method to calibrate knapsack sprayers. First, the operator should complete the following:

- ♦ Be familiar with sprayer functions.
- ♦ Inspect your application equipment to be sure all parts are working properly.
- ♦ Choose the desired nozzle and determine the correct nozzle height.

Using a single nozzle increases the potential for errors in overlap between individual passes. We often use a 4-nozzle boom with our knapsack sprayer for larger areas. With a little practice, you can develop a cadence for walking and pumping; for example, one pump stroke for every 3 steps. This greatly enhances your ability to maintain a steady speed and a steady pumping pace, which results in more uniform pressure and a more precise application.

Because speed, nozzle orifice size, and pressure all affect sprayer output, each individual must calibrate with the specific sprayer he or she will be using. You cannot assume that you will get the same output (gallons per acre) with any knapsack sprayer, if you only calibrate with one. Likewise, another person cannot assume that he or she will walk and pump at the same speed that you do, so he or she cannot assume to apply the exact amount as you, using your calibration.

A. Calibration

With only water in the sprayer:

- ♦ Mark out area (test area). Do this in the area where the pesticide is to be applied.

  Length × width = square feet (ft²).
- ♦ Determine the amount of water used in the test area. Two methods can be used for this.

  Refill method. Put water in the sprayer. Spray the test area and measure the amount of water used by refilling to the original level. If you used the graduated marks on the sprayer, make sure the sprayer is in exactly the same position for both measurements; if it is tilted on one of the measurements, a significant error can result.

  Time method. Record the *time* needed to spray the test area. Then, while stationary, pump at the same pace you used in the test area and spray into a container for the recorded time and measure the amount of water used.
- ♦ Calculate gallons per acre (gal/a) with the following formula:

Formula 1
Amount of gallons per acre:

$$\text{gal/a} = \frac{\text{water used (gal)} \times 43{,}560 \text{ ft}^2\text{/a}}{\text{test area (ft}^2\text{)}}$$

Example:

test area = 12 ft × 30 ft = 360 ft²

water used = 42.2 oz (1 gal = 128 oz)

So, 42.2 oz / 128 oz/gal = 0.33 gallons. Thus:

$$\frac{0.33 \text{ gal} \times 43{,}560 \text{ ft}^2/\text{a}}{360 \text{ ft}^2} = 40 \text{ gal/a}$$

B. Amount of water needed in a given area

Once you have calibrated (output in gal/a), multiply the area to be sprayed (ft²) by sprayer output (gal/a) and divide by 43,560 ft² as shown in the following formula.

Formula 2

Amount of water needed to spray a given area:

$$\frac{\text{area to spray (ft}^2) \times \text{sprayer output (gal/a)}}{43{,}560 \text{ ft}^2/\text{a}}$$

Example:

Sprayer output = 35 gal/a. You want to apply a pesticide in an area measuring 42 ft × 35 ft. How much water will you need?

(42 ft × 35 ft = 1,470 ft²). Thus:

$$\frac{1{,}470 \text{ ft}^2 \times 35 \text{ gal/a}}{443{,}560 \text{ ft}^2/\text{a}} = 1.18 \text{ gal in } 1{,}470 \text{ ft}^2$$

(1.18 gal × 128 oz/gal = 151 oz)

C. Amount of pesticide to add per gallon of water (carrier)

Once you know the volume your sprayer is applying per acre, you are ready to calculate the amount of pesticide to add for each gallon of water (or other carrier) you will use.

Formula 3

Amount of commercial product to add per gallon of water:

$$\frac{\text{desired pesticide rate}}{\text{sprayer output (gal/a)}}$$

Example:

Pesticide rate = 3 qt/a (3 qt = 96 oz)

Sprayer output = 35 gal/a

$$\frac{96 \text{ oz/a}}{35 \text{ gal/a}} = 2.74 \text{ oz per gallon of water}$$

Using the example under Formula 2, in which you sprayed 1.18 gallons of water in an area 42 ft × 35 ft, you would add 2.74 oz of pesticide per gallon of water: 1.18 gal × 2.74 oz = 3.2 oz of pesticide product for the 1,470 ft²

♦ If the desired rate is given as active ingredient (ai), then to determine the amount of commercial product per gallon of water, divide the final number in Formula 3 by the percent ai (expressed as a decimal for dry formulations, or actual pounds ai/gal for liquids). For example, using the same sprayer above, assume you wanted to apply 6.5 lb ai/a of DCPA in 8,000 ft². (Dacthal 70 WP contains 70% of the active ingredient DCPA). First determine the amount of water needed in the area.

Formula 2

$$\frac{8{,}000 \text{ ft}^2 \times 35 \text{ gal/a}}{43{,}560 \text{ ft}^2/\text{a}} = 6.43 \text{ gal in } 8{,}000 \text{ ft}^2$$

Formula 3

$$\text{Dacthal/gallon} = \frac{6.5 \text{ lb ai/a}}{35 \text{ gal/a}} = \frac{0.186}{0.7} = 0.27 \text{ lb}$$

(0.27 lb × 16 oz per lb = 4.25 oz of Dacthal 70 WP per gallon)

You need 6.43 gallons for the 8,000 ft². If you have a 4 gallon sprayer, the first full sprayer will have 4 gallons × 4.32 oz/gal of Dacthal 70 WP = 17.3 oz. The second tank will require 2.43 gallons of water × 4.32 oz/gal = 10.5 oz of Dacthal 70 WP.

If the pesticide were a liquid formulation containing 3 lb ai/gal, divide 0.186 by 3 lb/gal (instead of 0.7). This would give 0.062 gallons of pesticide per gallon of water (0.062 gal × 128 oz/gal = 7.94 liquid ounces of pesticide per gallon of water). Thus, in a 4-gal sprayer, you would add 7.94 oz/gal × 4 gallons = 31.7 oz of pesticide, and in the second sprayer you would add 7.94 oz/gal × 2.42 gallons = 19.3 oz of pesticide.

After you add pesticides (especially certain wettable powder formulations or fertilizers) to a sprayer, the flow rate (output) may be affected. After adding the pesticide, spray into a receptacle for the amount of time used in the test area and return the spray solution to the tank. Using Formula 1, recalculate gallons per acre and correct the amount of pesticide per gallon of water. Most catalogs for spray nozzles have conversion factors to correct for change in density of the spray solution.

Calibrating Powered Ground Sprayers

(Assuming pre-calibration check of hoses, nozzle size, spacing and height, etc.)

A. Calibration using “refill method”

With water only (no pesticide) in the sprayer:

1. Spray in actual area, using uniform pressure and speed.
2. Measure area sprayed (length x width = square feet). Note: effective swath width of boom sprayer = number of nozzles × nozzle spacing.
3. Determine the amount of water used in test area.
4. Calculate gallons/acre using Formula 1.

$$\text{gal/a} = \frac{\text{water used (gal)} \times 43{,}560 \text{ ft}^2/\text{a}}{\text{area sprayed (ft}^2)}$$

Example:

Area sprayed = 12 ft × 300 ft = 3,600 ft²

Water used = 2 gal

Thus:

$$\frac{2 \text{ gal} \times 43{,}560 \text{ ft}^2/\text{a}}{3{,}600 \text{ ft}^2} = 24.2 \text{ gal/a}$$

B. Calibration by time

(This method is recommended with larger sprayers.)

1. Determine the *time* to travel a known distance in the actual area to be sprayed.
2. With sprayer stationary, but operating at the same pressure that will be used in the field, collect discharge from each nozzle for the time required in the test run (replace any nozzle that varies 10 percent from the average). Add output of all nozzles to find the total amount of water used.
3. Determine total area sprayed (length × effective swath width).
4. Calculate gal/a using Formula 1.

Example:

Time to travel 330 ft = 45 seconds

No. of nozzles = 12 at 20-inch spacing (effective swath = 12 nozzles × 20 in = 240 in = 20 ft)

Area = 330 ft × 20 ft = 6,600 ft²

Water used in 45 sec = 30 oz/nozzle × 12 nozzles = 360 oz divided by 128 oz/gal = 2.81 gal

Thus:

$$\text{gal/a} = \frac{2.81 \text{ gal} \times 43{,}560 \text{ ft}^2\text{/a}}{6{,}600 \text{ ft}^2} = 18.5 \text{ gal/a}$$

C. Amount of pesticide to add to tank

Formula 3

Commercial product per gallon of spray water or other carriers, such as liquid fertilizer:

$$\frac{\text{Recommended rate/a}}{\text{Sprayer output (gal/a)}}$$

Example:

Desired rate = 4 lb/a of AAtrex 80 WP

Sprayer output = 20 gal/a

Thus: AAtrex 80 WP per gallon of water =

$$\frac{\text{4 lb AAtrex 80WP/a}}{\text{20 gal/a}} = \text{0.2 lb AAtrex 80 WP}$$

$$(0.2 \text{ lb} \times 16 \text{ oz/lb} = 3.2 \text{ oz})$$

In 60 gallons of water, add: 3.2 oz/gal × 60 gal = 192 oz (12 lb) of AAtrex 80 WP

- ♦ Remember, if the recommended rate is given as active ingredient (ai), then to determine the amount of commercial product per gallon of water, divide the final value in Formula 3 by the percent ai (expressed as a decimal for dry formulations, or actual pounds ai/gal for liquids).

Example:

Desired rate = 3 lb/a atrazine

(AAtrex 80 WP contains 80% atrazine)

Sprayer output = 20 gal/a

Thus, the amount of AAtrex to add per gallon of water is:

$$\frac{\text{3 lb ai/a}}{\text{20 gal/a}} = \frac{0.15}{\text{0.8 ai}} = \text{0.188 lb AAtrex 80 WP}$$

Note: 16 oz/lb × 0.188 lb = 3 oz

In 40 gallon tank, add 3 oz/gal × 40 gal = 120 oz (7.5 lb) of AAtrex 80 WP

D. The "1⁄128 acre method"

This is a simple method that more and more applicators are using.

There are 128 ounces in a gallon. If we divide 1 acre (43,560 ft^2) by 128, we have 340 ft^2 (43,560 ft^2 / 128 = 340 ft^2). So, if you find out how many ounces of water you need in order to spray 1/128 of an acre, you can equate this to gallons per acre.

1. Inspect your application equipment to be sure all parts are working properly.
2. Figure the distance you need to travel for the test. The distance of travel varies according to nozzle spacing. Divide 340 ft^2 by the spacing (in feet) between the nozzles on your boom (or use the actual band width for band spraying). For example, if your nozzles are spaced 12 inches apart (1 ft), divide 340 ft^2 by 1 ft.

$$\frac{340 \text{ ft}^2}{1 \text{ ft}} = 340 \text{ ft}$$

   So, 340 feet is the distance of travel for the test.
3. Measure how long (time in seconds) it takes you to drive 340 feet (the test run).
4. Collect liquid from your nozzles for this amount of time at the same pressure you will use in the field. Use the average volume per nozzle (not total volume from all nozzles) as ounces collected. The average ounces collected per nozzle are equal to gallons per acre.

Example:

You have nozzles spaced 22 inches apart. Divide 22 inches by 12 in/ft.

$$\frac{22 \text{ in}}{12 \text{ in/ft}} = 1.83 \text{ ft}$$

Divide 340 ft^2 by 1.83 ft.

$$\frac{340 \text{ ft}^2}{1.83 \text{ ft}} = 185.8 \text{ ft}$$

You need to find out how long it takes you to travel 185.8 ft.

The amount of water (in ounces) that you collect from a nozzle in this amount of time is equal to the gallons of water you will apply to an acre.

Be sure to collect from as many nozzles as possible, and use the average flow rate (add the amount each nozzle discharges in the test time and divide by the number of nozzles). Remember, you should replace any nozzle that varies by more than 10 percent from the average.

The chart below shows the distance you need to travel for each nozzle spacing to spray 1/128 of an acre.

Nozzle spacing or band width (in)	Row travel distance (ft)
6	681
8	511
10	408
12	340
14	292
16	255
18	227
20	204
22	186
24	170

You also can calculate for other spacing that is not shown here.

Band spraying

Sometimes, to reduce the total amount of pesticide you use, you apply pesticide only over a strip down the crop row. This is called band spraying or band application.

Using the traditional method to figure the gallons per acre in the bands (sprayed strips), we need to determine the area of the bands and the amount of water used in a given length of bands. Multiply the band width by the number of bands by their length and measure the amount of water used in the test run. Divide the amount of water used by the area sprayed to get gallons per acre.

Example:

Assume you planted corn in rows that are 30 inches apart, and will apply a herbicide at 3 lb/a, in bands 12 inches wide over the corn rows. In a 600-ft test run with an 8-row corn planter-sprayer, you used 1.2 gallons of water.

$$\text{acres} = \frac{\text{band width} \times \text{number of bands} \times \text{length}}{43{,}560\ \text{ft}^2/\text{a}}$$

$$\frac{1\ \text{ft} \times 8 \times 600\ \text{ft}}{43{,}560\ \text{ft}^2/\text{a}} = 0.11\ \text{acre}$$

Galls/sprayed acre:

$$\frac{\text{gallons used}}{\text{area sprayed}} = \frac{1.2\ \text{gal}}{0.11\ \text{acre}} = 10.9\ \text{gal/a}$$

Note that by using the "1/128" acre method, you can easily determine this directly. In the above example, you collected 1.2 gallons (153.6 oz) from 8 nozzles in 600 ft. This equals 19.2 oz per nozzle in 600 ft. With a 12-inch band, you would need to travel 340 ft to have 1⁄128 of an acre.

$$\frac{19.2\ \text{oz}}{600\ \text{ft}} = \frac{x\ \text{oz}}{340\ \text{ft}}$$

x = 10.9 oz in 340 ft, which equals 10.9 gallons per acre.

How much herbicide would you put in a 150-gallon spray tank for this application? First, determine how many acres you can spray with 150 gallons.

$$\frac{150\ \text{gal}}{10.9\ \text{gal/a}} = 13.8\ \text{acres can be sprayed with one tankful}$$

Since you will apply 3 pounds of herbicide per acre, and the full tank will spray 13.8 acres, you need a total of 3 pounds × 13.8 acres, for a total of 41.3 pounds of herbicide per tankful.

You can verify this result by using Formula 3. Pesticide rate divided by sprayer output will give us the amount of pesticide per gallon of carrier. This is:

$$\frac{3\ \text{lb/a}}{10.9\ \text{gal/a}} = 0.275\ \text{lb/gal} \times 150\ \text{gallons} = 41.3\ \text{lb herbicide}$$

Air-blast Sprayers

Air-blast sprayers normally are used to spray orchards. The text below tells how to calibrate an air-blast sprayer in an orchard.

Figure size of test area

Just as with broadcast spraying, you need to know the size of the test area and how much water you use in the test area. To figure the size of your test area, take the distance between the orchard rows and multiply by the length of your test run. When running through your test run, drive with at least half a tank of water at the same speed you will use to spray the orchard. Be sure to record the amount of time this takes.

Figure the amount of water used

One way to figure the amount of water you used in your test run is to fill the sprayer tank to a certain level, then spray your test area. You then can measure carefully the amount of water needed to refill the tank to the exact level. Remember, the sprayer must be sitting in the same position for both measurements. If the sprayer sits tilted at a different angle when you refill the tank, then you will get the wrong measurement of how much water was used. Also, in a large tank, it is often hard to figure exactly how much water was used. And, you should check each nozzle for flow rate.

But, because of the way the nozzles are spaced around an air-blast sprayer, the high volume, and the pressure of the air blast, it is hard to catch spray from air-blast nozzles. So, we suggest you follow this method:

1. Put one end of a hose over a nozzle and put the other end into a measuring container.
2. With the machine at a stop, measure how much water is in the container after spraying for the same amount of time it took for your test run.
3. Repeat this same procedure with each nozzle.
4. Find the average flow rate.
5. Replace any nozzle that has an output differing more than 10 percent from the average of identical nozzles. Note: Some air-blast sprayers have different-size nozzles at different positions on the sprayer shroud in order to apply the same amount in different parts of the trees. In such cases, make sure that the respective nozzles on each side of the sprayer are discharging the same amount. Read your manual carefully.

Again, take the total amount of water you used in the test time, and then use Formula 1 to calculate gallons per acre.

Example: Assume that the rows are 18 feet apart in your orchard, and that you traveled 176 feet in 30 seconds, and that you used a total of 10.5 gallons of water.

$$176\ \text{ft} \times 18\ \text{ft} = 3{,}168\ \text{ft}^2\ \text{area sprayed}$$

Calculate with Formula 1:

$$\frac{10.5\ \text{gal} \times 43{,}560\ \text{ft}^2/\text{a}}{3{,}168\ \text{ft}} = 144.3\ \text{gal/a}$$

Find the ground speed

In some cases, it is important to know your ground speed. Your equipment sprays more pesticide on the target as you move slower and less as you move faster. Never measure speed with your speedometer. When wheels slip in mud or loose dirt, or when tires wear down and get smaller, you can be traveling up to 30 percent slower than your speedometer reads. This can cause you to apply 30 percent too much pesticide. To find your ground speed, follow these steps:

1. In the area where you will spray, mark off a test course.
2. With the spray tank at least half full of water, get your vehicle up to your normal spraying speed. Then, record how many seconds it takes to drive the test course.
3. Multiply your distance in feet by 60 (seconds in a minute) and divide by the time it took to cover your test course multiplied by 88 (at 1 mph you travel 88 feet per minute). This tells you your speed in miles per hour. This can be written as:

$$\text{MPH} = \frac{\text{distance (ft} \times 60)}{\text{time (sec} \times 88)} = \frac{\text{distance}}{\text{time}} \times 0.682$$

Example: You record 60 seconds to drive 176 feet. Thus:

$$\frac{176\ \text{ft}}{60\ \text{sec}} \times 0.682 = 2\ \text{mph}$$

Account for tree size and foliage

Because of the great difference in tree size and the amount of foliage on some trees, you might need to slow down where the volume of tree foliage (called tree row volume or TRV) is greater. Where trees are smaller, you may be able to speed up. Some new sprayers have electronic eyes that regulate sprayer output by TRV or even shut off the sprayer if trees are missing.

Get water-sensitive paper from your pesticide dealer. Place the paper in different parts of the trees to see if your application is even. You might have to change the angle of some nozzles for the spray solution to go through different heights in the trees. Take your time to test your sprayer, using water only. You do not want to be sloppy when you apply pesticides.

Conversion Factors

Equivalents for teaspoonful, tablespoonful, and cup

A measuring cup and measuring spoons, the latter obtainable in nests of several sizes, are useful in making dilutions under practical conditions where great accuracy is not required. The values given below also are useful in transposing the precise measurements of the laboratory into commonly used and understood units when an insecticide is recommended to home gardeners. The values as given are those recognized by the Bureau of Standards.

Conversions

3 teaspoonfuls	=	1 tablespoonful
2 tablespoonfuls	=	1 fluid ounce
16 tablespoonfuls	=	1 cup
8 fluid ounces	=	1 cup
1/2 fluid ounce	=	1 tablespoonful
14.8 milliliters	=	1 tablespoonful
1/2 pint	=	1 cup = 8 oz = 237 milliliters

Equivalents of weight

Avoirdupois, U.S. and Imperial		Metric
1 ounce	=	28.3495 grams
1 pound	=	453.59 grams/0.45359 kilogram
0.0327 ounce	=	1 gram
35.2740 ounces	=	1 kilogram
2.2046 pounds	=	1 kilogram

Liquid measure—United States

16 fluid ounces	=	1 pint (pt)
2 pints	=	1 quart (qt)
4 quarts	=	1 gallon (gal) = 231 cubic inches
1 liter	=	1.056 US liquid qt (0.878 English liquid qt)
1 gallon	=	3.785 liters (English gallon = 4.543 liters)

Area measure—United States

144 square inches (in^2)	=	1 square foot (ft^2)
9 square feet	=	1 square yard (yd^2)
30.25 square yards	=	1 square rod
43,560 square feet	=	1 acre
4,840 square yards	=	1 acre
160 square rods	=	1 acre
208.71 × 208.71 feet	=	1 acre
320 rods	=	1 mile
5,280 feet	=	1 mile
640 acres	=	1 section; 1 square mile

Useful metric—U.S. conversions

1 meter	=	1.093 yd (3.281 ft) (39.370 inches)
1 kilometer	=	0.621 mi
1 yard	=	0.91 meter
1 liter	=	1.056 U.S. liquid qt (0.878 English liquid qt)
1 gallon	=	3.785 liters (English gallon = 4.543 liters)

Capacity of sprayer tanks

The capacity of the tanks of hand or power sprayers, in gallons, may be calculated as follows:

Cylindrical tanks: multiply length by square of the diameter, in inches, by 0.0034.

Rectangular tanks: multiply length by width by depth, in inches, by 0.004329.

Tanks with elliptical cross section: multiply length by short diameter by long diameter, in inches, by 0.0034.

According to United States government standards, the following are the weights avoirdupois for single bushels of the specified grains:

wheat—60 pounds
rye—56 pounds
barley—48 pounds
oats—32 pounds
corn—56 pounds

Some states have specifications varying from these.

Conversion factors

To change:	To:	Multiply by:
inches	centimeters	2.54
feet	meters	0.305
miles	kilometers	1.609
meters	inches	39.37
kilometers	miles	0.621
square inches	square centimeters	6.452
square yards	square meters	0.836
square centimeters	square inches	0.155
square meters	square yards	1.196
cubic inches	cubic centimeters	16.387
cubic yards	cubic meters	0.765
cubic centimeters	cubic inches	0.061
cubic meters	cubic yards	1.308
fluid ounces	cubic centimeters	25.57
quarts	liters	0.946
cubic centimeters	fluid ounces	0.034
liters	quarts	1.057
grains	milligrams	64.799
ounces (avoirdupois)	grams	28.35
pounds (avoirdupois)	kilograms	0.454
grams	grains	15.432
kilograms	pounds	2.205

Gallons per acre

gal/acre	cc/ft²	lb/acre	g/ft²
1	0.0869	1	0.0104
2	0.1738	2	0.0208
3	0.2607	3	0.0312
4	0.3476	4	0.0416
5	0.4345	5	0.0520
6	0.5214	6	0.0624
7	0.6083	7	0.0728
8	0.6952	8	0.0832
9	0.7821	9	0.0936
10	0.8690	10	0.1040

Circles and globes

To find the circumference of a circle, multiply the diameter by 3.1416 or pi times radius squared: ($ð \times r^2$).

To find the area of a circle, multiply the square of the diameter by 0.7854.

To find the surface of a globe, multiply the square of the diameter by 3.1416.

To find the cubic contents of a globe, multiply the cube of the diameter by 0.5236.

Common measures

Cubic measure

1,728 cubic inches = 1 cubic foot
27 cubic feet = 1 cubic yard
144 cubic inches = 1 board foot
128 cubic feet = 1 cord

Linear measure

1 inch = 2.54 cm = 25.4 mm
1 foot = 12 in = 30.5 cm = 0.3048 m
1 yard = 3 ft = 0.9144 m
1 rod = 5.5 yd = 16.5 ft = 5.029 m
1 mile = 160 rods = 1760 yd = 5280 ft = 1.6094 km
1 micron = 0.001 mm
1 millimeter = 0.0394 in = about 1/25 in
1 centimeter = 10 mm = 0.3937 in = about 2/5 in
1 decimeter = 10 cm = about 4 in
1 meter = 10 dm = 3.28 ft = 39.37 in

Square measure

1 square foot = 144 in^2 = 0.0929 m^2
1 square yard = 9 ft^2 = 0.8361 m^2
1 square rod = 272.25 ft^2= 30.25 yd^2= 25.293 m^2
1 acre = 43,560 ft^2 = 4,840 yd^2= 160 rod^2= 0.4047 hectare
1 square mile = 640 a = 259 hectares
1 square meter= 1550 in^2
1 hectare = 2.471 a = 10,000 m^2

Dry measure

1 pint = 33.60 cubic inches = 0.5505 liter
2 pints = 1 quart = 67.20 cubic inches = 1.1012 liters
8 quarts = 1 peck = 537.61 cubic inches = 8.8096 liters
4 pecks = 1 bushel = 2,150.42 cubic inches = 35.2383 liters
1 British dry quart = 1.032 U.S. dry quarts

*Note: A liquid pint contains 28.875 cubic inches or 474 ml.

Weights and volumes of water

One cubic inch of water weighs 0.03617 pound.
One cubic foot weighs 62.42 pounds.
One cubic foot equals 7.48052 gallons.
One gallon weighs 8.345 pounds.
One gallon equals 231 cubic inches.
One liquid quart equals 57.75 cubic inches.

Conversions

1 acre-foot of water weighs 2,719,230 pounds.

Toxicant (lbs/acre)	=	Parts per million	=	Parts per billion
5.453		2.0		2,000
2.727		1.0		1,000
2.455		0.9		900
2.183		0.8		800
1.911		0.7		700
1.639		0.6		600
1.367		0.5		500
1.095		0.4		400
0.823		0.3		300
0.551		0.2		200
0.279		0.1		100
0.24		0.09		90
0.21		0.08		80
0.19		0.07		70
0.16		0.06		60
0.13		0.05		50
0.10		0.04		40
0.082		0.03		30
0.055		0.02		20
0.027		0.01		10
0.024		0.009		9
0.021		0.008		8
0.019		0.007		7
0.016		0.006		6
0.013		0.005		5
0.010		0.004		4
0.0082		0.003		3
0.0055		0.002		2
0.0027		0.001		1

Dilution and Application Tables

Dosage rates (furrow treatments) with different row spacings for 1 lb active ingredient (ai) per acre

Row spacing (inches)	Active ingredient per 1,000 lineal ft (grams)	Amount commercial product* (granules) per 1,000 lineal ft									
		1% granules		5% granules		10% granules		15% granules		50% granules	
		grams	*oz*	*grams*	*oz*	*grams*	*oz*	*grams*	*oz*	*grams*	*oz*
12	10.4	1,041.0	36.7	208.2	7.3	104.1	3.7	69.4	2.4	20.8	0.73
13	11.3	1,128.0	39.8	225.6	7.9	112.8	4.0	75.2	2.6	22.6	0.80
14	12.2	1,215.0	42.9	243.0	8.6	121.5	4.3	81.0	2.9	24.3	0.86
15	13.0	1,301.0	45.9	260.2	9.1	130.1	4.6	86.7	3.0	26.0	0.92
16	13.9	1,388.0	48.9	277.6	9.8	138.8	4.9	92.5	3.3	27.8	1.00
17	14.8	1,475.0	52.0	295.0	10.4	147.5	5.2	98.3	3.4	29.5	1.04
18	15.6	1,562.0	55.1	312.4	11.0	156.2	5.6	104.1	3.7	31.2	1.10
19	16.5	1,648.0	58.1	329.6	11.6	164.8	5.8	109.9	3.8	32.9	1.16
20	17.4	1,735.0	61.2	347.0	12.2	173.5	6.1	115.6	4.0	34.7	1.22
21	18.2	1,822.0	64.3	364.2	12.8	182.1	6.4	121.5	4.2	36.4	1.28
22	19.1	1,909.0	67.3	381.8	13.5	190.9	6.7	127.3	4.5	38.2	1.34
23	20.0	1,995.5	70.4	399.0	14.1	199.5	7.0	133.0	4.7	39.9	1.40
24	20.8	2,083.0	73.5	416.6	14.7	208.3	7.3	138.9	4.9	41.6	1.50
30	26.0	2,604.0	91.9	520.8	18.4	260.4	9.2	173.6	6.1	52.0	1.80
36	31.2	3,124.0	110.2	624.8	22.0	312.4	11.0	208.3	7.3	62.5	2.20
42	36.4	3,644.0	128.5	728.8	25.7	364.4	12.8	242.9	8.6	72.9	2.57
60	52.0	5,206.0	183.6	1041.2	36.7	520.6	18.4	347.1	12.2	104.1	3.70

* Commercial product also may be called formulated product.

Insecticides dilutions

	Amount of active ingredient (ai) recommended per acre								
	0.125 lb	0.25 lb	0.5 lb	0.75 lb	1 lb	1.5 lb	2 lb	2.5 lb	3 lb
	Amount of commercial product* needed to obtain the above amounts of ai								
10%–12% emulsifiable concentrate (contains 1 lb ai per gal)	1 pt	1 qt	2 qt	3 qt	1 gal	1.5 gal	2 gal	2.5 gal	3 gal
15%–20% emulsifiable concentrate (contains 1.5 lb ai per gal)	0.33 qt	0.66 qt	1.33 qt	2 qt	2.66 qt	1 gal	1.33 gal	1.66 gal	2 gal
25% emulsifiable concentrate (contains 2 lb ai per gal)	0.5 pt	1 pt	1 qt	3 pt	2 qt	3 pt	1 gal	5 qt	1.5 gal
40%–50% emulsifiable concentrate (contains 4 lb ai per gal)	0.25 pt	0.5 pt	1 pt	1.5 pt	1 qt	3 pt	2 qt	5 pt	3 qt
60%–65% emulsifiable concentrate (contains 6 lb ai per gal)	0.167 pt	0.33 pt	0.66 pt	1 pt	1.33 pt	1 qt	2.66 pt	3.33 pt	2 qt
70%–75% emulsifiable concentrate (contains 8 lb ai per gal)	0.125 pt	0.25 pt	0.5 pt	0.75 pt	1 pt	1.5 pt	1 qt	2.5 pt	3 pt
25% wettable powder	0.5 lb	1 lb	2 lb	3 lb	4 lb	6 lb	8 lb	10 lb	12 lb
40% wettable powder	5. oz	10 oz	1.25 lb	1.875 lb	2.5 lb	3.75 lb	5 lb	6.25 lb	7.5 lb
50% wettable powder	0.25 lb	0.5 lb	1 lb	1.5 lb	2 lb	3 lb	4 lb	5 lb	6 lb
5% dust	2.5 lb	5 lb	10 lb	15 lb	20 lb	30 lb	40 lb	50 lb	60 lb
10% dust	1.25 lb	2.5 lb	5 lb	7.5 lb	10 lb	15 lb	20 lb	25 lb	30 lb

* Commercial product also may be called formulated product.

Trees per acre and trees passed per minute at various ground speeds for several tree spacings

Tree spacing (ft)	10	12	16	20	25	30	35	40
Trees/acre	435.2	302.5	170.0	108.9	69.7	48.4	35.6	27.2
Trees/min. at:								
1 mph	8.8	7.3	5.5	4.4	3.5	2.9	2.5	2.2
1.5 mph	13.2	11.0	8.2	6.6	5.3	4.4	3.8	3.3
2 mph	17.6	14.6	11.0	8.8	7.0	5.9	5.0	4.4
2.5 mph	22.0	18.3	13.7	11.0	8.8	7.3	6.3	5.5
3 mph	26.4	22.0	16.5	13.2	10.6	8.8	7.5	6.6

Weight of powder required to prepare different amounts of spray mixture at different dosage levels

Recommended dosage per 100			Weight of commercial product required to prepare spray mixture									
			50 gal		20 gal		10 gal		5 gal		1 gal	
lb	*oz*	*g*	*oz*	*g*	*oz*	*g*	*oz*	*g*	*oz*	*g*	*oz*	*g*
0.25	4	113	2	56	0.8	23	0.4	11	0.25	6	0.04	1
0.50	8	227	4	113	1.6	45	0.8	23	0.40	11	0.08	2
1.00	16	454	8	227	3.2	91	1.6	45	0.80	23	0.16	5
1.50	24	681	12	340	4.8	136	2.4	68	1.20	34	0.24	7
2.00	32	908	16	454	6.4	182	3.2	91	1.60	45	0.32	9
3.00	48	1,362	24	681	9.6	272	4.8	136	2.40	68	0.48	14
4.00	64	1,816	32	908	12.8	363	6.4	182	3.20	91	0.64	18
5.00	80	2,270	40	1,135	16.0	454	8.0	227	4.00	113	0.80	23

Volume of liquid pesticide required to prepare different amounts of spray mixture at different dilutions

Dilution of spray required	Recommended dosage of commercial product in 100 gallons of water			Volume of commercial product required to prepare spray for									
				50 gal		20 gal		10 gal		5 gal		1 gal	
	cups	*pt*	*qt*	*pt*	*cc*	*pt*	*cc*	*cc*	*tsp*	*cc*	*tsp*	*cc*	*tsp*
1:3,200	0.5	0.25	0.12	0.125	59.15	0.05	23.7	11.8	2.4	5.9	1.2	1.18	0.2
1:1,600	1.0	0.50	0.25	0.250	118.5	0.10	47.7	23.7	4.8	11.8	2.4	2.37	0.5
1:800	2.0	1.00	0.50	0.500	236.6	0.20	94.6	47.3	9.6	23.7	4.8	4.73	1.0
1:400	4.0	2.00	1.00	1.000	473.2	0.40	189.3	94.6	19.6	47.3	9.2	9.46	1.9
1:200	8.0	4.00	2.00	2.000	946.4	0.80	378.6	189.3	38.3	94.6	19.2	18.93	3.8
1:100	16.0	8.00	4.00	4.000	1,892.8	1.60	757.1	378.6	76.6	189.3	38.3	37.86	7.7
1:50	32.0	16.00	8.00	8.000	3,785.6	3.20	1,514.2	757.2	153.2	378.6	76.6	75.71	15.3
1:25	64.0	32.00	16.00	16.000	7,571.2	6.40	3,028.5	1,514.2	306.4	757.1	153.7	151.42	30.6

Soil fumigation calibration: flow rate per nozzle in cc per minute for ground speed of 1 mile per hour

	Nozzle spacing				
Gallons per acre	**6 inches**	**8 inches**	**9 inches**	**10 inches**	**12 inches**
5	19	26	29	32	38
6	23	31	34	38	46
7	27	36	40	45	53
8	31	41	46	51	61
10	38	51	57	64	77
20	77	102	115	128	153
25	96	128	143	159	191
30	115	153	172	191	229

Formulations and Concentrations

The common types of insecticide formulations are wettable powders, emulsifiable concentrates, dusts, solutions, aerosols, baits, granules, flowables, and soluble powders.

Wettable powders (WP) are dry forms of insecticides in which the toxicant is absorbed or adsorbed on inert materials that can be mixed readily with water because a wetting agent has been added. These form a suspension-type spray which must be kept agitated in a sprayer tank.

Emulsifiable concentrates (EC) contain an insecticide and an emulsifying agent in a suitable solvent. These are diluted with water to form an emulsion and applied as sprays.

Dusts (D) usually are made by diluting the toxicant with finely ground, dried plant materials or minerals. These include wheat, soybean, walnut shells, talc, clay, or sulfur.

Solutions are liquid forms of insecticides which are dissolved in suitable solvents such as petroleum distillates or liquid gas. Oilbase cattle sprays, household sprays, and gas-propelled aerosols are examples of insecticide solutions.

Aerosols are air suspensions of solid or liquid particles of ultramicroscopic size which remain suspended for long periods.

Baits consist of a poison or poisons plus some substances which will attract the insect.

Granules (G) are formed by impregnating the insecticide upon an inert carrier of 30 to 60 mesh particle size.

Soluble powder (SP)—a powder formulation that dissolves in water.

Flowable (Fl)—a liquid or viscous concentrate of suspendible pesticide in water.

Fumigant—a substance or mixture of substances which produce gas, vapor, fume, or smoke intended to destroy insects, bacteria, rodents, or other organisms.

Computing insecticide concentrations

To determine the percent active ingredient in a spray mixture:

$$\frac{\text{lb of formulation used} \times \text{\% of active ingredient}}{\text{gallons of spray mixture x 8 (lb per gal water)}}$$

Example: 4 pounds of 25% malathion wettable powder were mixed with 100 gallons of water. What percent malathion is in the spray?

$$\frac{4 \times 25}{100 \times 8} = 0.125\%$$

To determine the pounds of wettable powder needed to mix a spray containing a given percentage of active ingredient:

$$\frac{\text{gal of spray wanted} \times \text{\% of active ingredient wanted} \times 8 \text{ (lb per gal water)}}{\text{\% of active ingredient in formulation used}}$$

(pounds of wettable powder)

Example: How many pounds of 12% gamma isomer BHC wettable powder are needed to make 100 gallons of spray containing 0.03% gamma isomer BHC?

$$\frac{100 \times 0.03 \times 8}{12} = 2 \text{ pounds}$$

To determine the gallons of emulsifiable concentrate needed to mix a spray containing a given percentage of active ingredient:

$$\frac{\text{gal of spray wanted} \times \text{\% of active ingredient wanted} \times 8 \text{ (lb per gal water)}}{\text{lb active ingredient per gal in formulation used} \times 100}$$

(gallons of concentrate)

Example: What volume of 4 lb/gal parathion emulsifiable concentrate is needed to make 50 gallons of spray containing 0.25% parathion?

$$\frac{50 \times 0.25 \times 8}{4 \times 100} = 0.25 \text{ gal}$$

To determine the pounds of dust needed to mix a dust containing a given percentage of active ingredient:

$$\frac{\text{\% of active ingredient} \times \text{lb of mixed dust wanted}}{\text{\% active ingredient in formulation used}}$$

Example: 5 pounds of 3% diazinon dust is wanted. How much talc should be added to 50% diazinon powder to make the dust?

$$\frac{3 \times 5}{50} = 0.3 \text{ lb of 50\% diazinon}$$

Answer: 4.7 lb of talc to make the 5 lb of 3% diazinon dust.

Chemigation Guidelines

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Introduction

Chemigation is a term that is customarily defined as the application of chemicals, such as pesticides or system maintenance compounds, through an irrigation system. Comparatively, fertigation refers to plant nutrients (fertilizers, including organic compounds) and soil amendments applied by means of irrigation water. Fertigation, as a practice, has become more encompassing to include the irrigated application of reclaimed process water from food processing facilities and animal effluent (lagoon water). Generally, compounds used strictly for water treatment – such as a pH buffering material – may be exempt from chemigation regulations; however, state regulations should be examined prior to an application to determine the statutory status of these compounds.

Because of human safety concerns and environmental contamination risks inherent with chemigation applications, irrigation systems intended for chemigation applications must be properly designed, equipped, and maintained. Furthermore, chemigation demands that operators possess the skill, training, and proficiency to safely set-up, calibrate, maintain, and competently operate a chemigation system. In fact, pesticide label instructions as regulated by EPA and states with chemigation regulations require that an applicator must be knowledgeable about the chemigation system (i.e., injection apparatus and irrigation system) and that the individual responsible for its operation, or that someone under the supervision of the responsible person, must be capable of shutting down the system and of making necessary adjustments should the need arise.

A chemigation system includes the chemical injection apparatus and auxiliary equipment as well as the irrigation system. An irrigation system is inclusive of all components that comprise the irrigation water distribution infrastructure (e.g., pump, mainline, laterals) and application system (e.g., center pivot, solid set, dripline). No distinction as to ownership of components is made regarding the irrigation system or the injection apparatus. The applicator is responsible for the operation and performance of the entire chemigation system, regardless of component ownership. Chemigation requirements apply both to pressurized and to non-pressurized irrigation systems (e.g., furrow, rill, or flood).

Applying agrochemicals through an irrigation system has some advantages relative to other methods of application. Advantages often cited with chemigation include:

- more timely application of a pesticide when field conditions preclude other application methods;
- minimal surface and subsurface compaction of susceptible soil types;
- little mechanical damage to crops relative to other ground apparatuses;
- activation of moisture-dependent chemicals; and
- reduced risk of applicator exposure.

Chemigation has negative aspects as well. These inherent problems must be considered before undertaking a chemigation application. Among the factors to be considered are:

- additional personnel training and enhanced operator skill required to proficiently operate the irrigation system and injection apparatus;
- risk of water source contamination resulting from backflow;
- hazard of surface water contamination because of overspray or soil surface runoff;
- risk of corrosive damage to the irrigation system;
- longer application time relative to other methods of application;
- potential for equipment malfunction while personnel are not at the application site;
- high dependency on distribution uniformity of the irrigation system to assure product effectiveness and crop safety; and
- additional cost of installation and maintenance of anti-pollution devices.

Because of the risk of bystander exposure, chemigation may not be a suitable practice if the treatment site is near public areas (e.g., parks, golf courses, parking lots, walking trails), residences, businesses, schools, clinics or hospitals, or other high-risk sites that are vulnerable to overspray or physical drift. Before each pesticide application, the treatment site and surrounding area must be assessed to determine if the application will endanger or be a potential hazard to workers, bystanders, domestic animals, fish or wildlife, ground or surface water, or neighboring crops.

Federal and State Statutes

Chemigation is regulated by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), as amended. The United States Environmental Protection Agency (US EPA) oversees the enforcement of FIFRA. Accordingly, the US EPA is responsible for authorizing a pesticide's use for chemigation. (Although the US EPA does not regulate fertigation, the practice may be subject to state laws and rules. Fertigation is the process of applying fertilizers—including organic compounds, soil amendments, animal effluent, and reclaimed water—through an irrigation system.)

If a pesticide has been authorized by the US EPA for chemigation, the product label must specify instructions for its use. These conditions of use include, in part, the following: (a) the type of irrigation system through which the product can be applied, (b) backflow prevention devices required on the irrigation water supply system to prevent contamination of the water source, (c) special antipollution measures for connections to public water systems, (d) backflow prevention devices on the chemigation injection line, (e) a system interlock to discontinue product injection in event of an irrigation system malfunction, (f) system flushing requirement, (g) application monitoring guidelines, (h) treatment area posting, and (i) the quantity of water to be applied. This information and other instructions usually appear under the label section "General Directions for Chemigation." Safety devices are intended to prevent environmental degradation—primarily source water contamination resulting from a backflow event into the water source—and human exposure.

If the US EPA has not authorized a pesticide for chemigation, the label must include the statement, "Do not apply this product through any type of irrigation system." If the label makes no reference to chemigation, it is implicitly understood that the pesticide cannot be used for chemigation.

Federal regulation and state chemigation laws or rules (if they exist) require safety devices on chemigation equipment to protect the source water from backflow, spills, and pollutant discharges. Properly selected, maintained, and calibrated equipment is vital to a successful—and legal—chemigation application. As written above, a chemigation application includes the irrigation system and the injection apparatus, and the applicator is responsible for the proper operation of both. Therefore, prior to each chemigation, the applicator should assess the operational integrity of safety devices and the mechanical soundness of the application and injection systems. Equipment performance should be routinely checked during an application. Operational and safety procedures should be confirmed with everyone involved in the application.

Not all irrigation systems can be used to apply chemicals. If intended for use in chemigation, the pesticide label will specify requirements for the irrigation system and the injection apparatus. Additionally, many states have enacted rules that further govern chemigation as a practice. These rules consider geophysical characteristics, climatic conditions, product-related incidences, or pesticide use profile (rate, timing, or frequency) unique to that state.

Before considering chemigation as a method of application, several pre-application factors must be considered. These factors include:

- pesticide label requirements concerning applicator training, pesticide licensing, personal protection equipment, decontamination supplies, etc;
- water source;
- location of the treatment area relative to sensitive sites (e.g., occupied buildings, neighboring crops, roadways, businesses, public gathering sites, hospitals, clinics, nursing homes, schools, daycare facilities, etc.);
- soil properties (structure, texture, depth, and organic matter that affect permeability and water holding capacity);
- topography (slope, aspect);
- geological features (karsts, fractured bedrock);
- irrigation system integrity;
- distribution uniformity of the irrigation system;
- weather (wind speed and direction, atmospheric inversions, air stagnation);
- physical or vapor drift, overspray, and soil surface runoff;
- presence of endangered or threatened species;
- human activity near the treatment area;
- economic feasibility given the cost of specialize equipment; and
- core competencies of pesticide handlers.

Label Provisions and State Regulations

Federal law requires that chemigation safety devices for the irrigation system and injection apparatus must be listed on the pesticide label, a requirement since April 1988. Label use instructions and restrictions or prohibitions are intended to mitigate environmental risks, such as pesticide contamination of source water; to minimize direct human contact to pesticide-laden irrigation water or to pesticide residue on equipment surfaces; and to diminish bystander exposure.

In addition to the devices listed on the pesticide label, states with chemigation rules (and occasionally local ordinances) may stipulate additional equipment requirements, operational procedures, injection equipment placement restrictions, chemigation permits, system inspections, or operator certification. States with chemigation laws or rules require safety devices be appropriately sized (generally based on an industry-recognized or a professional society standard), correctly installed, properly functioning, and adequately maintained. Some states require laboratory testing of chemigation equipment to verify adherence to established performance standards prior to approval for chemigation use. Before undertaking a chemigation application, chemigation operators must understand label instructions and be knowledgeable about state laws and rules as well as local ordinances.

Pesticide label instructions and state regulations governing pesticide use periodically change. Therefore, pesticide labels should be read and the instructions understood before each use, and state rules should be periodically reviewed for changes. Titles and section citations for the Idaho, Oregon, and Washington State chemigation rules appear below.

Idaho (IDAPA 02.03.03): Rules Governing Pesticide and Chemigation Use and Application

Oregon (OAR 690-215-0017): Oregon Rules Regarding Chemigation and Fertigation Back-Siphon Prevention

Washington (WAC 16-202-1001): Washington State Chemigation Rules

Idaho and Washington State Departments of Agriculture, and the Oregon Water Resources Department, maintain a webpage on their respective websites that contains chemigation-related information. The Internet addresses for agencies with the legislated authority to enforce chemigation rules appear below.

Idaho

http://www.agri.state.id.us/AGRI/Categories/Pesticides/chemigation/indexChemigationmain.php

Oregon

http://arcweb.sos.state.or.us/pages/rules/oars_600/oar_690/690_215.html

Washington

http://agr.wa.gov/PestFert/ChemFert/

Safety Devices to Protect Source Water from Possible Contamination

The irrigation system may include a physical piping connection between the application tank or chemical-laden water in the irrigation mainline and the source water through which backflow may occur; this is referred to as a cross connection. Backflow can result from either “back-siphonage” or “back-pressure.” Backflow safety devices are installed to prevent backflow of contaminates into the source water through cross connections.

Back-siphonage is the reversal of normal flow in a pipeline towards the water supply when the pressure in the pipeline is less than the atmospheric pressure, resulting in a partial vacuum. The vacuum caused by a differential pressure gradient between two points in the piping system causes a siphoning action. An example of back-siphonage is water cascading down the wellhead casing at irrigation pump shutdown. Another example is pumping water over a hill with no or inadequate vacuum relief valve(s) at the pipe’s apex to vent the pipeline in the event of loss of head pressure at the pump.

Back-pressure is backflow resulting from an increase in the downstream pressure that is above the water supply pressure. This can occur when the irrigation system is operating at a higher pressure than the water supply system due to booster pumps or cross connections with other higher pressure pumping systems. Back-pressure may also occur at shutdown if an irrigation system is at a higher elevation than the water source.

Before considering a chemigation application, the irrigation system must be evaluated. In addition to being well-maintained and structurally sound, the system must have the required antipollution safety devices correctly installed and properly operating. In addition, the injection equipment must be compatible with the chemical being used.

The distribution uniformity of the irrigation system should also be evaluated prior to a chemigation application. The distribution uniformity of the irrigation system can be determined through a field procedure utilizing “catch can” tests. Information collected from this test is used to diagram the application uniformity of an irrigation system. Poor uniformity causes uneven distribution, with some areas receiving too much water while other areas receive too little. Over- or under-irrigation to any portion of the application area means that pesticide applications are equally in error. With a higher distribution uniformity value, there is a greater likelihood that the same amount of water (and chemical) is being applied throughout the treatment site. A minimum distribution uniformity of 85 percent is recommended for pressurized irrigation systems.

If the water source is dedicated only to irrigation, the backflow devices listed below are required on irrigation systems being used for chemigation. There are only two exceptions: An air gap or a reduced-pressure backflow preventer is used as the backflow device. (Some states may recognize engineering controls, such as a gooseneck pipe [barometric] loop. However, state statutes may require inspection and approval of engineering controls by authorized agency personnel.) US EPA has also authorized equipment not otherwise specified on the pesticide label. Prior to a chemigation application, state regulations should be reviewed for additional requirements. Backflow devices must be installed in accordance with manufacturer's specifications or, in their absence, with accepted industry practice. Device placement and installation must also be compliant with state rules. Local ordinances (municipal or county) may require backflow safety devices other than those listed below. **Safety devices must be inspected and maintained on a regular basis**.

- Spring-loaded irrigation mainline check valve or wafer valve
- Vacuum relief valve
- Low pressure drain
- Inspection port (Idaho, Oregon, and Washington State requirement, although not required by US EPA)

Irrigation Mainline Check Valve

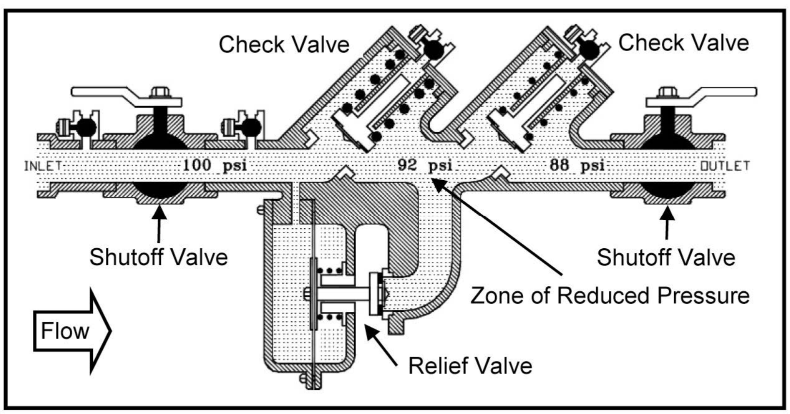

Figure 1. Reduced-pressure backflow preventer required on public (municipal) water systems and domestic potable water sources.

Diagram reproduced from the *Cross Connection Control Manual* (6th ed.) with permission from the Pacific Northwest section of the American Water Works Association.

An irrigation mainline check valve must be placed in the irrigation mainline upstream from the chemical injection point. The check valve is the principal mechanism to prevent contamination of the source water from backflow. The valve must be spring loaded and have a watertight seal. Accordingly, there should be no metal-to-metal surfaces where the check valve contacts its seat. Idaho State Department of Agriculture (ISDA) requires that check valves be tested and authorized by an independent laboratory before the device will be referenced in "Idaho's List of Approved Chemigation Equipment." Although Washington State does not require verification of device performance, it does consult the Idaho list of approved devices. However, if a cross connection is possible between a chemigation system and a municipal water supply, only those devices as approved by Oregon's cross-connection control requirements in OAR chapter 333 or as listed in Washington State Department of Health, Drinking Water Division's referenced USC-Approved Assemblies list (http://fccchr.usc.edu/list.html) can be installed. The landowner is responsible for testing the device to verify that it is installed and functions properly. They are also responsible for annual testing.

A reduced pressure-principle backflow preventer (RPBA) is required when an actual or potential physical connection exists between a public (municipal) water system and any source of a non-potable liquid (such as pesticide or fertilizer-laden water), solid, or gas. The RPBA consists of two independently acting spring-loaded check valves separated by a spring loaded differential pressure relief valve (or atmospheric port; refer to **Figure 1**). The same cross-connection control requirements are applied to potable water sources for domestic use under the Idaho, Oregon, and Washington State chemigation rules.

The vacuum relief valve vents air into the irrigation pipeline with the loss of system pressure such as at pump shutdown, thereby preventing a vacuum that could result in back-siphonage. The vacuum relief valve should be located at top dead center of the irrigation pipeline and upstream of the mainline check valve. A combination valve (air release and vacuum relief) may also be used. The valve should be checked periodically to ensure that debris has not jeopardized its proper operation. The size of the vent port is governed by the diameter of the irrigation mainline.

If most of the irrigation system is a lower elevation than the pump, installation of a vacuum relief valve downstream of the mainline check valve will help prevent the potential collapse of the irrigation pipeline in the event of rapid pipeline drainage.

Sump and Low-Pressure Drain

The sump and low-pressure drain must be placed immediately upstream of the irrigation mainline check valve and at the bottom dead center of the pipeline. The sump intercepts leakage past the mainline check valve. Therefore, the sump collar, if it exists, should not extend beyond the inside surface of the bottom of the pipeline. The low-pressure valve purges leakage from the pipeline that can occur if the irrigation mainline check valve does not seal at irrigation system shut down.

The low-pressure drain is a self-actuating valve with a 2- to 5-psi spring. The spring-loaded valve opens when pressure drops in the irrigation mainline, and then closes when the system repressurizes. The low-pressure drain should have an opening of at least 3/4-inch in diameter. Organic material and sand in irrigation water and high calcareous water can foul the valve. Valve operation should be frequently checked. If water continually leaks after irrigation system shut down, there is a good chance that the seal on the irrigation mainline check valve needs to be replaced. A drain hose of sufficient length to discharge check valve leakage at least 20 feet from the water source should be attached to the low-pressure drain.

Inspection Port

Although not usually referenced on pesticide labels, states with chemigation rules require an inspection port. (As pesticide labels are updated, an inspection port is being added as a required device). The inspection port allows access to physically manipulate and visually assess the operation of the irrigation mainline check valve and the low-pressure drain. Consequently, the inspection port must be positioned immediately upstream of the irrigation mainline check valve and directly above the low-pressure drain. To aid in the manual manipulation of the check valve and low-pressure drain, the access port should be at least four inches in diameter.

Freshwater Outlet

A freshwater outlet at the injection site is not required. However, it is a convenient source of water for equipment cleanup, rinsing empty pesticide containers, mixing chemicals, or handler decontamination. The water outlet **must** be located upstream of the irrigation mainline check valve and as far as possible from the injection point. This will prevent the discharge of chemical-laden water through the outlet. The outlet should never be used as an injection port. Ideally, the port should be clearly labeled as "Non-potable Water" to prevent confusion by pesticide handlers and agricultural workers as a drinking water source.

The mainline check valve, vacuum relief valve, low-pressure drain, and inspection port can be purchased as an integrated device, commonly referred to as a chemigation mainline check valve (see **Figure 2**). An approved irrigation mainline wafer check valve in combination with a "spool"—a device consisting of a vacuum relief valve, low-pressure drain, and inspection port—installed on the upstream side of the wafer check valve is the functional equivalent of a chemigation mainline check valve. The mainline check valve or a wafer check valve with a spool must be correctly installed on the irrigation mainline and be properly operating prior to the irrigation system being used for chemigation.

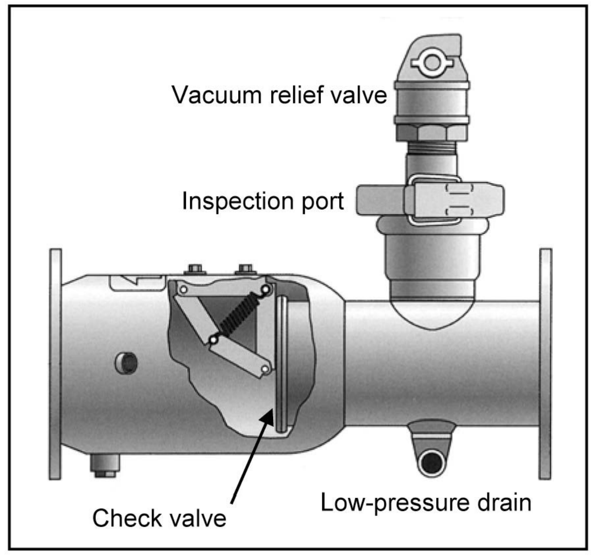

Figure 2. Irrigation mainline chemigation valve.

Reprinted with permission from Pierce Fittings.

Injection Apparatus

Antipollution devices on the injection system prevent the backflow of water from the irrigation mainline through the injection line into the application tank. The devices also prevent drainage or siphoning of product from the application tank into the irrigation system caused by gravity flow or hydraulic gradient pressure. Besides wasting the chemical, the area around an overflowed application tank could be deemed as a contaminated site, requiring specific cleanup and disposal procedures.

Injection Line Check Valve

The chemigation section on pesticide labels contains the following statement about injection line check valves.

"The pesticide injection pipeline must contain a functional, automatic, quick-closing check valve to prevent the flow of fluid back toward the injection pump. The pesticide injection pipeline must also contain a functional, normally closed, solenoid-operated valve located on the intake side of the injection pump and connected to the system interlock to prevent fluid from being withdrawn from the supply tank when the irrigation system is either automatically or manually shut down."

However, US EPA has recognized alternative technology in place of the two devices referenced on the pesticide label. In accordance with the "List of US EPA Authorized Alternative Chemigation Safety Equipment," an injection line check valve can be substituted for both a quick-closing check valve and a normally closed solenoid-operated valve. The injection line check valve must maintain, at a minimum, 10 psi opening (cracking) pressure. Higher opening pressure will be necessary if the injection point is lower in elevation than the application tank so as to compensate for hydraulic head pressure exerted from product in the tank. In situations where siphon action induced by irrigation system drainage could compromise the opening pressure of the injection line check valve, either a vacuum relief valve must be installed in the irrigation system downstream of the injection point or a normally open valve can be inserted into the chemical injection line between the application tank and the injection pump.

The injection line check valve must be attached to the irrigation pipeline. The valve, including the pliable seal, must be made of chemical-resistant materials. Some states require use of a state-approved injection line check valve that has been tested by an independent laboratory to verify conformance with established performance standards.

System Interlock

The system interlock will shut down the chemical injection unit when there is either a loss in irrigation water pressure or a reduction in irrigation mainline pressure that adversely affects chemical distribution. An electrical interlock is interconnected with the electrical controls at the irrigation control panel, the electrical power source for the chemical injection pump. Consequently, if the irrigation pump stops or if water pressure decreases below a preset range, the pressure switch will shut the electrical power off at the control panel, which will deenergize the electrical outlet that powers the injection pump. A dual interlock is advised. In the event that the injection pump shuts down, electrical interlock controls will shut down the irrigation system.

Other interlock systems include the installation of normally closed solenoid valves—electric or hydraulic—in the chemical injection line between the application tank and the injection pump and between the chemical injection pump and the injection point on the irrigation system. Solenoid valves open when the pre-set activation pressure is attained in the irrigation mainline. Mechanical interlock systems can be coupled between an irrigation pump driven by an internal combustion engine and the chemical injection equipment from the engine's electrical system or from an electric generator.

Figure 3 is an illustration of a chemigation apparatus used with a pressurized irrigation system. Many variations in design and set up are possible for a chemigation system. To verify the adequacy of a chemigation system, contact the state department of agriculture, or, in Oregon, the Water Resources Department, and request technical assistance from pesticide compliance staff or staff responsible for back-siphon prevention equipment.

Before installing an injection system, check with state authorities or dealers about laws and rules governing injection systems in your area, including requirements regarding permits, pesticide record keeping and reporting, antipollution devices, and injection equipment construction. Local ordinances may also apply.

Calibration

The supervising applicator should calibrate the injection apparatus before each application and periodically throughout the application.

Pump manufacture's data provide a good starting point and may help decrease trial and error. However, the conditions under which the bench test is conducted by the pump manufacturer are different from that experienced under field conditions. Also, pump wear, temperature, and product density and viscosity will alter the pumping rate. Regardless of the type of pressurized pump, the procedure is generally the same when performing a calibration.

Water Volume

The amount of water that will be used during the chemigation will influence irrigation system operation and the injection pump setting. The following factors must be considered when determining water volume:

- Application efficiency of the irrigation system
- Distribution uniformity of the irrigation system
- Capacity and speed of the irrigation system
- Type (i.e., insecticide, fungicide, herbicide) of pesticide
- Solubility of the pesticide, which is affected by formulation (i.e., flowables, wettable powders, solutions) and water temperature and quality
- Label-specified water application rate (i.e., acre-inch, gallons per acre)
- Soil type and infiltration rate (a consideration of runoff potential)
- Injection pump output
- Desired spatial placement of the chemical in the soil profile or plant canopy

Measurements

Calibration, of course, is all about accurate measurements. Naturally, calculation procedures will vary depending on the type of irrigation system. However, regardless of the irrigation system, the following values must be determined:

- Acreage or square footage treated
- Application rate (e.g., milliliters, ounces, or pints of chemical per unit area)
- Volume of water to be applied (e.g., acre-inch or gallons)
- System speed for self-propelled irrigation systems, typically measured in feet per minute

Center pivot or linear (lateral) move speed should be performed with a fully charged irrigation system on firm wheel paths. The control panel setting should be set at the same speed that will be used during the chemigation.

Basic Steps

Calibration is similar for most types of irrigation systems. There are seven basic steps:

1. Determine the size of the treatment area (i.e., circle, square, rectangle, triangle, etc.)
2. Determine the application rate (e.g., milliliters, ounces, pints)
3. Determine the amount of pesticide required for the treatment area
4. Determine irrigation system travel speed (linear move or center pivot) or set time (for solid set systems)
5. Determine the injection time
6. Determine injection timeframe during the irrigation cycle (a consideration with drip or solid set systems)
7. Determine the chemical pump injection rate in ounces or gallons per hour
8. Determine the chemical injection pump setting to deliver the desired injection rate

In addition to the chemical, the calibration process must consider the carrier (usually water) and adjuvants. Some chemicals require a dilution rate to keep the product in suspension. Also, to ensure that the injection pump is operated within 30 to 80 percent of its output range, it may be necessary to increase the bulk volume by adding water into the application tank. An injection pump should never be operated near or at its minimum or maximum output.

Care should also be taken to ensure that the injection point is not too near the first sprinkler. To ensure ample mixing of the chemical in the irrigation mainline, the injection point should be located at least 10 pipe diameters upstream of the first sprinkler.

Monitoring

Throughout the chemigation application, the injection equipment and irrigation system should be periodically inspected for proper operation. Some chemigation labels, particularly soil fumigant labels, specify how often a chemigation system must be monitored. Many states, such as Washington, specify how often a system must be checked to determine proper function. A chemigation application should be immediately discontinued whenever it poses a risk to people, sensitive environmental areas, or to property.

To ensure handler safety, the area around the control panel(s), water pump, application tank, and injection pump must be free of chemical residue. To minimize the potential for human exposure (as well as electrical hazard), it is recommended that nozzles that overspray injection equipment or electrical control panel(s) be disabled throughout the application.

A description of the inspection procedure and the frequency at which system monitoring will occur should be written in the operation plan. While at a chemigation site, it may be prudent to record weather conditions (e.g., wind speed and direction, temperature), document injection or treatment site observations, and confirm injection calibration. Applicators often maintain "Run Logs" or "Chemigation Worksheets" for this purpose.

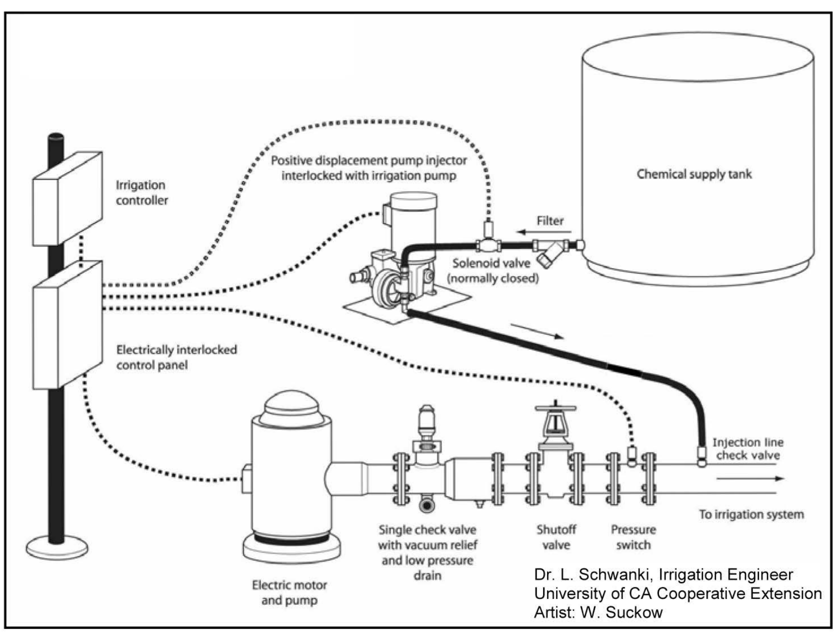

Figure 3. Example of a chemigation systems for a pressurized irrigation system.

Reprinted courtesy of Dr. Larry Schwanki, University of California.

Personal Protection Equipment (PPE)

The federal and state-adopted Worker Protection Standard regulations require all workers involved in any aspect of handling, mixing and/or loading, or applying a pesticide must be trained as a pesticide handler or must have a pesticide license. The WPS requires agricultural employers and commercial pesticide handler employers to provide specific information and protections to workers, handlers, and other persons when WPS-labeled pesticide products are used on agricultural establishments (i.e., farms, forest operations, plant nurseries, or enclosed space production) in the production of agricultural plants. It also requires owners of agricultural establishments to provide certain protections for themselves and their immediate family, requires handlers to wear the labeling-specified clothing and personal protective equipment when performing handler activities, and to take measures to protect workers and other persons during pesticide applications.

As with any other method of pesticide application, chemigation activities require that personal protective equipment be worn. The extent of personal protection equipment required is dependent on the task(s) being performed and chemical applied. At a minimum, applicators and other pesticide handlers must wear a long-sleeved shirt, long pants, shoes, socks, and, at times, chemical-resistant gloves and protective eyewear. Additional personal protection equipment is generally required during mixing and when repairing or handling contaminated equipment during an application. Before setting-up equipment, the "Personal Protection Equipment" section of the pesticide label must be read to ensure that proper personal safety equipment is available and, if necessary, that applicators and other pesticide handlers have been properly trained in its use. For respirator use, the individual must be medically qualified as well as trained and fit-tested on the manufacturer type, model, and size of respirator that will be worn.

Operational and Maintenance Plan

To ensure a safe and effective chemigation application, observational procedures, operational policies, and an emergency response protocol should be detailed in a written plan. The plan should be maintained at the application site and available to anyone involved in the chemigation application.

The Operation and Maintenance Plan should include maintenance and troubleshooting guidelines or checklists that will guide those involved with the application to more skillfully perform chemigation-related tasks, including the inspection process, maintenance requirements, and troubleshooting procedures.

A pre-application site assessment should also be a component of the plan. The perimeter of the treatment area should be visually inspected for the presence of adjoining sensitive areas or of unauthorized personnel. An appraisal should also be made of backflow devices, injection equipment, and the overall irrigation system. Site hazards should also be noted and, if possible, corrected.

A complete Operational and Maintenance Plan should include the following:

- Diagram or photograph of the treatment area with sensitive sites, problematic geological features, and physical hazards
- List or drawing of sensitive areas that may be subject to drift, overspray, or soil runoff
- Description of management practices to prevent drift, overspray, and soil surface runoff
- Description of backflow prevention equipment or other devices to prevent back-pressure and back-siphonage
- Description of the calibration and recalibration process
- Description of the monitoring process and inspection procedures
- Description of field posting requirements and posting locations as well as signage removal procedures;
- Expected system flush time and flushing procedures
- Description of safety procedures to prevent unauthorized entry into the treated area or mitigation procedures in the event of unauthorized entry
- List of authorized on-site personnel with phone numbers
- Description of response procedures and emergency contact information in the event of an emergency shutdown

Emergency Preparedness and Incident Response Plan

To protect the applicator, pesticide handlers, agricultural workers, and bystanders, a current emergency response plan must be readily available to assist applicators, coworkers, or emergency response personnel in case of a pesticide accident or spill, an environmental contamination event, or human injury. The existence of a plan will also help to reduce the potential for human health risks or to mitigate environmental hazards.

The plan may include the following components:

- General emergency response procedures (i.e., immediate steps taken to mitigate an emergency)
- Specific response procedures in the event of a spill on public roads or a contamination event involving surface water or ground water
- Contact information for in-house emergency response personnel (e.g., safety officer, supervisor, applicator-in-charge)
- Contact names and phone numbers for utility services (e.g., phone, cable, gas, electrical, irrigation district)
- Phone numbers for local or regional emergency services (e.g., city police, sheriff department, fire department, ambulance, hospital, Poison Control Center, CHEMTREC). Emergency contacts are often listed on the pesticide label or the Safety Data Sheet (SDS) (formerly called Material Safety Data Sheet, or MSDS)
- Contact information for chemical sales representatives
- Contact information for applicable governmental agencies (e.g., state department of agriculture or environmental agency)
- Copy of the complete pesticide label and SDS
- Contact information for businesses located in proximity to and for people living close to the treatment site
- Personal protection equipment requirements
- List of emergency equipment and cleanup supplies to be on-site during the application

Beginning with the Phase I (December 2010) soil fumigant labels, EPA will require the preparation of a written, site-specific soil fumigant management plan (FMP) prior to each application. These written plans, which outline response procedures in the event of a mishap, will help prevent fumigant-related accidents and bystander exposure or to effectively mitigate events should they occur. The FMP will include many of the elements referenced in the Operation and Maintenance Plan and in the Emergency Preparedness and Incident Response Plan.

Flushing

After completing every chemigation application, the chemical injection pump, injection line, application tank, and other equipment should be flushed with untreated water to prevent precipitates (chemical deposits) from forming and to purge all chemical residue from the lines. Tank rinsate should be injected into the irrigation system and applied onto the target area. The irrigation pump should be operated until the chemical is flushed from the irrigation system and until residue is washed from system surfaces. Flushing the injection and irrigation system reduces the potential for human exposure from contaminated surfaces, minimizes the potential for system corrosion and accumulation of precipitates, and decreases the potential for product incompatibility with subsequent chemicals.

Generally, the irrigation system should be flushed at least for the same length of time that was necessary to fully pressurize the irrigation system. Another practice is to inject a fluorescent dye solution at the end of the chemigation application to track water movement through the irrigation system to ensure that treated water has been purged from the irrigation system prior to irrigation pump shut down.

In Summary

Anyone who chemigates must comply with relevant federal regulations and state laws or rules. Rules are sometimes revised and new ones come into effect. For this reason, pesticide labels should be read before each application and personnel with the department of agriculture or the duly authorized environmental agency should be regularly consulted to determine if state laws or rules have changed.

Conversion Factors for Pump Calibration		
To convert from	**To**	**Multiply by**
Gallons/hour	Ounces/minute	2.13333
	Ounces/second	0.03556
	Milliliters/minute	63.0902
	Milliliters/second	1.0515
Ounces/minute	Gallons/hour	0.46875
Ounces/second		28.1250
Milliliters/minute		0.01585
Milliliters/second		0.95102

Liquid Flow Conversion Factors (U.S.)		
Given Value	**Conversion Factor**	**Equivalent Value**
	Multiply >	
	< Divide	
Volume (water)		
Gallon(s)	231.0	Cubic inches
	0.1337	Cubic feet
Cubic feet	1728.0	Cubic inches
	7.48	Gallons
Acre-feet	43,560.0	Cubic feet
	325,000.0	Gallons
	12.0	Acre-inches
Flow (water)		
Gallons per minute	0.00228	Cubic ft per second
	1,440.0	Gallons per day
	8.0208	Cubic ft per hour
	7.480	Gallons per second
Cubic ft per second	448.831	Gallons per minute
	646,316.883	Gallons per day
	0.992	Acre-inch per hour
	1.983	Acre-feet per day
Pressure (water)		
Feet of water	0.0295	Atmospheres
	0.4335	Pounds per square inch

Chemigation demands a high degree of training and skill in handling chemicals and in setting up, maintaining, and calibrating equipment. As with any method of pesticide application, human safety is a primary concern and potential environmental hazards must be assessed and minimized. It is the applicator's responsibility to demonstrate that an operation will not result in reasonably foreseeable harm to humans, surface water, groundwater, or desirable plants or animals.

Before each chemigation application, the irrigation system and the injection equipment must be evaluated to assess its integrity and to evaluate its performance in accordance with manufacturer's specifications, established industry standards, or state rules. It is also the operator's responsibility to ensure that safety equipment is installed and is functioning properly, and that the injection system is correctly calibrated - regardless of ownership. The applicator must understand the operation of the irrigation and injection systems and be familiar with the required safety equipment. The applicator of record is ultimately responsible for all aspects of a chemigation application.

Applicators, pesticide handlers, and agricultural workers must be protected by means of proper oral notification and/or field posting, appropriate decontamination supplies, suitable PPE, and adhering to restricted-entry intervals. Agricultural workers should be alerted that equipment may be contaminated with pesticide residue. Site safety necessitates that a pesticide accident and spill response plan also be in place prior to and readily available to pesticide handlers throughout the application. Site assessments should be undertaken to determine the location of sensitive areas and hazardous conditions. Because of poor distribution uniformity and issues with overspray and physical drift onto non-target areas, it is recommended that endguns be disabled throughout a chemigation application.

Agricultural employers must ensure all pesticides are used consistent with the pesticide product label at all times, including following the WPS requirements when applicable, and provide each agricultural worker and pesticide handler with the protections as required by the WPS. |Although some protective requirements for workers and handlers (PPE, REI, field posting, etc.) are clearly listed on product labeling, other WPS requirements are referenced on pesticide labels with the following statement: "It is violation of federal law to use a pesticide product in a manner inconsistent with its labeling."

Additional information about chemigation guidelines is posted to the above-mentioned websites. If you have questions about chemigation as a practice, state chemigation rules, or pesticide label instructions, please contact the following individuals in the respective state for which the question applies.

Westy Pickup
Idaho State Department of Agriculture (ISDA)
Phone: (208) 312-1987
Email: Westy.Pickup@isda.idaho.gov
ISDA Chemigation Webpage: https://agri.idaho.gov/main/chemigation

Kristopher Byrd
Oregon Water Resources Department
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Email: kristopher.r.byrd@state.or.us
Oregon Water Resources Department Webpage: http://www.oregon.gov/owrd/pages/index.aspx

Tom Hoffmann
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WSDA Chemigation & Fertigation Webpage: http://agr.wa.gov/PestFert/ChemFert/