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# Injector Planner: A Spreadsheet Approach to Fertilization Management for Greenhouse Tomatoes

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## Introduction

Greenhouse production of tomatoes involves the coordination and optimization of many variables, including environment (primarily light, temperature, and relative humidity)(Snyder, 1993a; 1992b), ventilation, carbon dioxide level, water, pollination (Snyder, 1992a; 1993b), and insect and disease management (Harris et al., 1993). One of the most complicated decisions that growers must make is determining the correct amount of nutrient elements required for the crop at each stage of growth, and selecting the most appropriate fertilizers and amounts of each to apply. Correct plant nutrition is one of the most important factors in the health of a crop, and the productivity and quality of fruit.

Greenhouse tomatoes are typically fertilized with automated systems, using timers or irrigation controllers to regulate the volume of nutrient solution applied. The nutrient solution consists of fertilizer dissolved in water, and is applied in a process often referred to as "fertigation." There are two primary systems of mixing fertilizer with water: (1) the bulk tank system; and (2) the injector system, which will be discussed in some detail later.

A computer spreadsheet was developed in an effort to assist growers with the complicated process of determining how much nutrient value is available from the fertilizers that they are considering using for greenhouse tomatoes. The spreadsheet (which performs all of the necessary calculations) was developed for PlanPerfect© version 5.1 (PlanPerfect, 1992) and MS-DOS© version 3.2 or higher (Microsoft), and for IBM© compatible personal computer. It will handle fertilizer calculations for any type of injector (e.g. Anderson, Dosmatic, Dosatron, Hardie, Smith, etc.), and has a special section for fertilizer calculations for growers with bulk tank systems (no injection).

This bulletin is a description of fertilization systems for greenhouse tomatoes, including an explanation of the calculations needed to determine the amount of any nutrient being applied, with examples of output that can be used by growers in designing their own fertilizer programs. This program has been used extensively to generate custom fertilization tables that growers have used to aid in management decisions.

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## Fertilizers

Growers using bulk tank systems or injection systems make similar choices when selecting fertilizers. The first choice is whether to use a commercially blended fertilizer (premixed) or to buy individual fertilizers and weigh them to obtain the required amount of each element. Premixed or self-blended mixtures can be used with either injectors or bulk tanks. The advantage of a premixed fertilizer is convenience because the proper ingredients are already blended to the correct proportions. A grower simply weighs and dilutes the recommended amount of fertilizer in water in the bulk tank (or concentrate tank).

Individual fertilizers, however, allow a grower the flexibility of selecting ingredients to fine tune a fertilization program. This is best accomplished with an injector system, but can also be done with bulk tanks. Buying fertilizers as individual ingredients is also less expensive than premixed types. Some of the most soluble fertilizers used as individual ingredients, and their elemental composition, are shown in Table 1.

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## Bulk Tank System

In the bulk tank system, a large tank (plastic, concrete, steel, polyvinyl chloride [PVC], etc.) is used to hold a dilute fertilizer solution. The diluted solution is pumped directly to the growing medium with no further dilution. In contrast, the injector system uses a small tank to hold a very concentrated fertilizer solution, and a small injector pump meters the concentrate into the water supply line as plants are watered.

A 100-gallon (378-L) bulk tank is fine for one greenhouse bay, whereas a 2,000 gallon (7,570-L) tank is preferable for several greenhouses. The larger the tank, the less frequently it will have to be filled. However, if the tank is too large, it takes a long time for it to empty, which will delay modifications of the mix if needed. For a new grower, or a grower with one or two bays, the bulk tank system is easier to implement and usually results in fewer mistakes.

Mixing and use directions come with these premixed fertilizers. Mixing fertilizer is a matter of adding so many units of dry fertilizer per volume of water. The fertilizer must be completely dissolved in water, since any precipitate (settled out fertilizer) will not reach the plants. Therefore, it may be necessary to stir the solution, either with a "paddle" or with an electric mixer or circulation pump. Or, if precipitation is a problem, the fertilizer can be premixed in a smaller volume of hot water. Care should be taken to check the pH and electroconductivity (EC) of the solution each time a new batch is mixed, as an added protection against mistakes.

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## The Injector System

### *Introduction*

With an injector system, a concentrated mixture of fertilizer solution is diluted with an injector (proportioner) to the final concentration needed by plants. The simplest and least expensive type of injector is a siphon hose (e.g., hozon) proportioner, often used for fertilizing lawns and garden plants. The siphon hose has a fixed (nonadjustable) injection ratio of 1:16, and is not appropriate for commercial production of a greenhouse crop. There are many models of injectors of an in intermediate level of cost and complexity, including Dosmatic, Dosatron, Smith, and Hardy Injectors. One of the most versatile and most expensive is an Anderson Injector.

Generally, the more an injector costs, the more accurate it is. Often, inexpensive models vary their injection ratio depending on water pressure, which is often variable. This is because the injection is electronically timed rather than being dependent on water volume. Better models are dose-specific, meaning that the amount of concentrate injected is dependent upon a given volume of water passing through a water meter in the injector mechanism. Equally important, the more expensive models are adjustable. A control on the head can be turned (or spacer rings of various sizes can be inserted) to increase or decrease the amount of fertilizer concentrate injected into a given volume of water.

The fertilizer solution is pumped from the concentrate tank to the injector, where it is diluted in the water stream, then onward to a blending tank, and then into the irrigation system. A meter monitors the flow of water, and provides signals indicating the amount of water passing through. This meter can be either mechanical or electrical. The mechanical signal from the meter is a pulse of water, which is sent to the pilot valve (skinner valve). This small volume of water is usually discarded after it passes through the pilot valve.

Fertilizer concentrate is held in small containers (e.g. 10 to 50 gallons). A **minimum** of two heads and two concentrate tanks are needed - - one for calcium nitrate (commonly designated as tank B) and the other for all other nutrients (tank A). This is necessary to prevent the calcium from combining chemically with phosphorus when they are in high concentration. This is especially likely when the pH of the water is high. The resulting compound (calcium hydrogen phosphate) is a very hard precipitate and will clog injectors and irrigation systems. In diluted solutions, these chemical reactions do not occur. If the pH of the source water is higher than 5.8, it is advisable to use a third head to inject acid to keep the solution pH in the 5.6 to 5.8 range for greenhouse tomatoes.

With an injector system, the cost for the large tank used with the bulk tank system is avoided. However, an injector can be expensive. Injectors allow for better control of the fertility level than bulk tank systems, since the dose can usually be adjusted by turning a knob, or some other simple adjustment. Better precision in the fertility program can be achieved by adding more injector heads, as money permits. Ultimately, a head may be used for each fertilizer element and individual adjustments made based on regular tissue analyses.

### *Injector Calibration*

It is imperative to know the injection ratio prior to calculating the amount of fertilizer to mix in the concentrate tanks. Some injectors come with tables that designate the ratio(s), i.e. 1:100, 1:200, 1:320, etc. and can be adjusted, while others are fixed at one setting. Also, the injection ratio can vary over time due to wear. If the injection ratio is not known, it will be necessary to calibrate the injector to determine this important ratio. A calibration procedure is described below.

Using a marked container (beaker, graduated cylinder, or measuring cup) measure the volume of water drawn by the injector in one minute. Then, using 10 marked containers, one at each of 10 emitters in the greenhouse, measure how much water is distributed to plants in one minute. Take an average of the 10 containers in which water was collected in the greenhouse. Then multiply this average amount emitted per plant in one minute by the total number of emitters in the greenhouse (or zone that will be watered at one time). The injection ratio is the ratio of the output to the input (divide the total amount emitted in the greehouse in one minute by the amount drawn in one minute). State the ratio as 1:X where X is the number obtained after dividing the output by the total amount drawn. The concentrated solution is diluted X times with water (there are X parts water for each 1 part of concentrated fertilizer solution).

### *The Anderson Injector*

Since most Mississippi greenhouse tomato growers who use injector systems use the Anderson Injector, it will be discussed in more detail. Such discussion does not endorse one product to the exclusion of others that may be equally suitable.

Injectors, such as the Anderson models, provide the greatest leeway in proportioning fertilizer solutions. While an individual grower's system may contain from two to 16 injectors (pumpheads), most Mississippi growers use between four and six. The most widely used pumphead in Mississippi is a P4, which injects 40 millileters (mL) per stroke; other heads are available. The P1 (10 mL/stroke) head, noticeably smaller, is frequently used for acid injection.

Injection ratios determine the fertilizer application rate. The rate of water flowing through the systems is automatically detected by a water meter, so whether the flow is 20, 30, or 50 gallons per minute, the same proportioning of nutrients is accomplished if the same injection ratio is used. The higher the second number in the ratio, the less fertilizer injected. The ratio means 1 part fertilizer solution per so many parts of water (by volume). For example, a 1:100 ratio yields a solution four times stronger than a 1:400 ratio.

The Anderson Model D system commonly used in Mississippi has dial settings from 1 to 10. The dial setting of 1 indicates a 1:3200 ratio while dial setting 10 indicates a 1:320 ratio (10 times stronger). The choice of dial setting for each fertilizer concentrate is determined by how much of each nutrient is needed. The ability to alter ratios by changing the dial setting is the main reason to invest in injector systems. This allows better flexibility and control over nutrition of the greenhouse tomato crop.

These injector systems are very precise instruments. Fertilizer must be accurately measured to maintain that precision.

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## Fertilizer Solubility Limits

It is important that fertilizers completely dissolve; otherwise, they will settle out in the tank and plants will not receive their full dose. Also, undissolved fertilizer can clog emitters. There are limits to how much of a fertilizer will dissolve in water called **solubility limits**. Table 2 shows the solubility limits of some fertilizers in 100 gallons or 100 liters of cold water. Putting more than these amounts of fertilizer in this volume of cold water will result in some fertilizer not being completely dissolved. When solubility problems arise, it may be necessary to (1) mix the fertilizer with either a circulating pump or a mechanical mixer, or (2) use hot water (180 °F, 82 °C).

Solubility limits are not a problem for most of the common fertilizers used in greenhouse tomato production. However, potential problems do exist for potassium sulfate and potassium nitrate (Table 2). Potassium sulfate has a limit of 83 pounds per 100 gallons, which is equivalent to about 13 ounces per gallon. Often, in order to obtain enough potassium when using potassium sulfate as the main source with an injector system, it is necessary to dedicate more than one head to this fertilizer. Potassium nitrate is limited to about 1 pound per gallon.

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## P and K Conversions

All recommendations for phosphorus and potassium are based on actual elemental P and actual K, not phosphate ($P_2O_5$) and potash ($K_2$). When calculating phosphorus or potassium content of the fertilizer solution, be aware that the middle number in the fertilizer grade is in the form of phosphate or $P_2O_5$ (not phosphorus, P) and the third number is in the form of potash or $K_2$ (not potassium, K.) To convert between units, use the formulas in Table 3.

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## Calculating Fertilizer Elements
## The Manual Approach

If is often necessary to know how much of a fertilizer element (such as nitrogen) a fertilizer solution contains. The concentration is most commonly expressed in units of parts per million (ppm). This means, simply, the number of parts of a fertilizer element per million parts of water, on a weight basis. For example, 1 part nitrogen per 1 million parts of water is 1 ppm. Or, 1 pound of nitrogen per 1 million pounds of water is 1 ppm.

The easy-to-use formulas that follow simplify calculating the concentration of any fertilizer element in water. Simple multiplication, division, and addition can be used to determine exactly how much of each fertilizer element is being fed to plants.

The following formulas can be used to calculate the amount of any fertilizer element, not just nitrogen. There is essentially only one formula. However, if an injector system is being used, there is another factor to use, namely the injection ratio. With a bulk tank system, there is no injector, and therefore no injection ratio, so this number is left out.

## Case #1

For an injector system use the following equation:

PPM = (% nutrient in fertilizer) X (lb added to tank) X (16 oz per lb) X (0.75) x (100/gal of concentrate) X (1/ratio of injector)

## Case #2

For a bulk tank system use the following equation:

PPM = (% nutrient in fertilizer) X (lb added to tank) X (16 oz per lb) X (0.75) x (100/gal of bulk tank)

**Example 1.** With the use of 25 lb of a 15-11-29 fertilizer in a 30-gal concentrate tank, and an injector set at a 1:100 ratio, how much nitrogen is being fed to the plants?

Since this is an injector system, use formula #1.

PPM = (15) X (25) X (16) X (0.75) X (100/30) X (1/100)
PPM = 150 ppm nitrogen

Similar calculations for P and K would indicate that 48 ppm P and 240 ppm K are being used. One should be sure to use the elemental and not the molecular values for P and K as shown in Table 3 (11% $P_2O_5$ X 0.437 = 4.8% P; 29% $K_2$ X 0.83 = 24% K).

**Example 2.** If a bulk tank system is being used with 5 lb of 8- 5-16 fertilizer, and the bulk tank holds 600 gal of fertilizer solution, and 3 lb of potassium nitrate is added to be sure the plants get enough nitrogen, how much nitrogen are the plants getting?

Since this is a bulk tank system, use formula #2.

PPM from 8-5-16 = (8) X (5) X (16) X (0.75) X (100/600) = 80 ppm N
PPM from $KNO_3$ = (13.75) X (3) X (16) X (0.75) X (100/600) = 83 ppm N
Total PPM nitrogen = 80 + 83 = 163

## *Derivation of Formulas*

The formulas above are based on the following: 1 ounce of any 100% soluble fertilizer in 100 gallons of water always equals 75 ppm. This is always true, regardless of what is being dissolved in the water. It does assume tht the fertilizer is completely dissolved.

Why is this true? First of all, 1 gallon of water weighs 8.34 pounds. Then, if we take 1 ounce of any fertilizer (or anything else soluble) and put it into 100 gallons of water, we are putting that 1 ounce in 834 pounds of water (834 lb X 16 oz/lb). One part in 13,344 equals 0.0000749 (divide 1 by 13,344). Since we have 0.0000749 parts per 1, to find how many parts per million this is, multiply it by 1,000,000. So, 0.0000749 X 1,000,000 equals 74.94 ppm; rounded off, this is 75 parts per million (ppm).

Now, to find out the concentration of a fertilizer element in water, we need to know the weight of the fertilizer and the percent strength of the fertilizer, since they are never 100% strength. A 15-11-29 fertilizer is 15% nitrogen fertilizer in a 100-gallon water tank, and we want to know how many ppm N this is. We would set up the equation as follows:

ppm N = (1 lb) X (15% N) X (16 oz/lb) X (0.75) = 180 ppm N

We are using 0.75 rather than 75 because this permits us to use the percent nitrogen (15%) rather than the decimal form (0.15). The above formula will work as long as you are mixing 100-gallon batches.

What if you have a larger or smaller tank? You simply set up a multiplier to adjust the equation. If you have a 500-gallon tank, you would multiply by 100/500, which will adjust the amount in 500 gallons down to what it would be in 100 gallons (since this is how the first rule we discussed is set up). If we are using 5 pounds of the 15% fertilizer in 500 gallons, the equation would be:

ppm N = (5 lb) X (15% N) X (16 oz/lb) X (0.75) X (100/500) = 180 ppm N

If you had a smaller tank, say 25 gallons, and used 1/4 pound of the 15% fertilizer, the equation to adjust the amount in 25 gallons up to 100 gallons would be as follows:

ppm N = (0.25 lb) X (15% N) X (0.75) X (100/25) = 180 ppm N

When using an injector, you also need to know the injection ratio. Multiply the injection ratio by the rest of the equation. If you have determined that you are using a 1:100 injector, and are using 50 pounds of a 15% nitrogen fertilizer in a 50-gallon stock solution (concentrate), set up the equation as follows:

ppm N = (50 lb) X (15% N) X (16 oz/lb) X (0.75) X (100/50) X (1/100) = 180 ppm N

We set up the injector ratio as 1/100 since the injector is diluting the concentrate with water 100 times.

This system will work with any injector ratio and any size concentrate tank. Simply enter in the numbers to customize the formula to your own system.

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## The Spreadsheet Approach

While these equations are not difficult to use, especially when a calculator is handy, they can be time-consuming and cumbersome when used frequently. It was for this reason that a spreadsheet program was developed. While many growers do not have access to personal computers at this time, the program has proven to be very useful by providing growers with spreadsheet-generated tables based on individual growers' injector type, injection ratios, choice of fertilizers (premixed or individual), and amount of fertilizer per gallon mixed.

To facilitate the process of determining the correct setting for an injector, all of the equations used in calculating parts per million (ppm) have been put into a spreadsheet program, which is run on an IBMÆ compatible personal computer. This spreadsheet calculates how much of each nutrient is supplied from each fertilizer used, at each dial setting. For example, it tells how many ppm N and how many ppm Ca are supplied from calcium nitrate for each dial setting, 1 to 10. The program will work for any type of injector system, any ratios, and has been modified to work with bulk tanks as well.

## *Micronutrients*

The micronutrient source used in the tables is a customized premixed form from Frit Industries (Ozark, AL), referred to as Compound 111 or Minors Blend. The Minors Blend is 6.67% Fe, 3.34% Mn, 5.5% Zn, 3.34% Cu, 1.34% B, and 0.017% Mo. When mixed at 6.3 pounds per 100 gallons of water, with a 1:100 injection ration, it will provide 5 ppm Fe, 4 ppm Zn, 2 ppm Cu, 2 ppm Mn, 1 ppm B, and 0.1 ppm Mo.

If a 1:100 injection ratio is available, 6.3 pounds can be mixed with 100 gallons and the injector would dilute it 1:100. If this ratio is not available, it is necessary to select the appropriate injection ratio and concentration to obtain the same dilution.

## Using Spreadsheet-Generated Tables

The spreadsheet program works by calculating the parts per million for each fertilizer at various mixed concentrations and injection ratios. It uses the same formulas discussed for manual calculations. The advantage of putting these formulas into a computer program is that thousands of equations can be calculated and updated in a second or less to reflect various combinations of injection ratios, fertilizers concentrations, and choice of fertilizers. Also, tables can be generated and printed for use by growers on their own site.

The equations use the fertilizer element values indicated in Table 4. The phosphorus and potassium values in this table have been converted to elemental values rather the molecular forms shown on fertilizer bags, to maintain accuracy of the generated tables. This is called a "lookup table," since the equations in the spreadsheet look for the fertilizer being used and find the appropriate elemental composition to use.

Tables 5 to 19 are examples of the spreadsheet- generated tables.

The first series of tables is for use by growers using the Anderson Injector system. The column to the left is the dial setting number (1 to 10) followed by the injection ratio for each setting. In Table 5, for example, individual fertilizers are listed along the top of the table; under these are the lb/gal mixed in the concentrate tanks. The bulk of the table shows the ppm of each element supplied for the fertilizers listed, at each injection ratio. The injection ratios listed in Tables 5 to 11 are those of the Anderson Model D Injector, and are appropriate only for the injection ratios listed.

When using the program on a computer, the lb/gal and the injection ratios can be changed as needed to reflect changes made (or being considered) in the fertilizer system. All ppm values in the table are instantly recalculated.

While Table 5 shows the ppm for most of the macronutrients, it does not include phosphorus. Phosphorus is usually supplied either with phosphoric acid or monoammonium phosphate (MAP). These values are shown in

Table 6. Table 6 is for a P1(acid) head and includes the apropriate injection ratios for that head. Use Table 7 for a P4 head.

Micronutrient calculations for Anderson Injector users are performed in Table 8. The fertilizer used is a premixed form as discussed above. In most cases, using the injection ratios shown, 1 lb/gal at a dial setting of #2 will provide the correct concentration of all micronutrients. When using micronutrients in the same concentrate tank with magnesium sulfate (epsom salt), it is necessary to mix ½ lb/gal and use dial setting #4 (since the magnesium sulfate needs dial setting #4 to obtain 48 ppm Mg when mixed at 3 lb/gal).

The spreadsheets can also be used with premixed fertilizers. The next three tables are for growers using one of the popular greenhouse tomato fertilizers. Table 9 shows the ppm when using 15- 10-30, Table 10 when using 4-18-38, and Table 11 when using 8-5-16.

The spreadsheet program is also a useful tool for calculating fertilizer ppm for use in bulk tank systems. Tables 12 to 15 are for bulk tank use. These tables are configured differently. Rather than showing the ppm of elements at different injection ratios, these tables show the ppm when mixing in different sizes of bulk tanks (100, 500, 1,000, and 2,000 gallons).

Table 12 shows the ppm of macronutrients derived from individual fertilizers; micronutrients are calculated in Table 13 for use with bulk tanks. One example of using a premixed fertilizer in bulk tanks is shown in Table 14, using 15-10-30.

To show the utility of the spreadsheet program with other types of injectors besides Anderson Injectors, Tables 16 to 19 have been created using injection ratios obtained from a grower using a Hardie Injector. The ratios shown in these tables are specific for the model and configuration used by that particular grower, so the values should not be used for any other Hardie system. Table 16 shows ppm of elements for a system using individual fertilizers with a Hardie Injector. Phosphorus sources are shown in Table 17, while micronutrients are in Table 18. The premixed fertilizer, 15-10-30 is used in Table 19.

Each grower should calibrate his own injector (see callibration section). Tables can ten be generated for specific needs.

The use of computer spreadsheets can help simplify the complex decision making needed when using fertilizer injector systems or bulk tank systems to fertilize greenhouse tomatoes. Even for growers who do not have access to personal computers, customized tables can be generated to calculate fertility based on individual needs (fertilizer concentration in concentrate tanks, choice of injector, and fertilizers used). The use of these spreadsheets has been instrumental in helping some Mississippi greenhouse tomato growers fine tune their fertilization programs.

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