Guidelines for

THE FOUR Rs OF FERTILIZER MANAGEMENT

in Horticultural Crops

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EXTENSION

Excessive fertilization does not equate to greater crop yields.

Crop yields are optimized when nutrients are efficiently used, which requires fertilizer applications to be based on the ***right source***, the ***right time***, the ***right rate***, and the ***right placement*** (Diaz-Perez *et al*., 2016; Barret *et al*., 2018; Coolong *et al*., 2019; da Silva *et al*., 2018). These are referred as the four Rs of fertilizer management, whose purpose is to supply plants' nutrient requirements, reduce production costs, and mitigate environmental impact.

The objective of the four Rs is to answer the following questions:

What fertilizer source should be used?
When should the fertilizer be applied?
How much fertilizer should be applied?
Where should the fertilizer be applied?

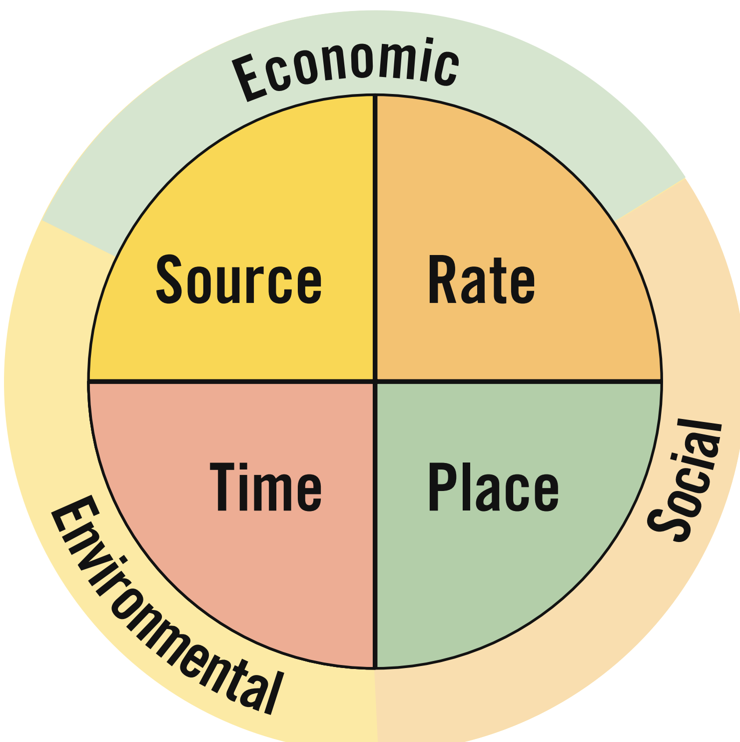

FIGURE 1

The implementation of the four Rs have environmental, economic, and social implications for sustainable crop production.

RIGHT SOURCE

The first element of the four Rs is the fertilizer source, which provides the crop with the appropriate supply of essential nutrients.

Fertilizer sources vary widely—they can have individual nutrients or a combination of nutrients, also known as compound fertilizers. Individual nutrient fertilizers, for example, are urea or ammonium nitrate, which have only nitrogen in their composition. Contrarily, compound fertilizers are the 5-10-15 with nitrogen (5%), phosphorus (10%), and potassium (15%), or the 7-0-7 with nitrogen (7%), phosphorus (0%), and potassium (7%). The best source to use depends on the plant's demand, estimated through leaf tissue sample testing, which provides the level of nutrients, categorized as macronutrients or micronutrients. Macronutrients are usually reported as percent (%) by weight in leaf tissue analyses and consist of nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), and sulfur (S). Micronutrients are reported in parts per million (ppm) and consist of iron (Fe), manganese (Mn), boron (B), zinc (Zn), copper (Cu), nickel (Ni), and others.

Fertilizers are commonly available as solids or liquids and can be organic or inorganic. Solid fertilizers, such as granular fertilizers, are soluble and dissolve rapidly, making nutrients available to plants after application through irrigation or rain. Contrarily, controlled-release fertilizers are examples of solid fertilizers used to provide nutrients over time by breaking down slowly. Liquid fertilizers are products that nutrients are in solution. Consequently, liquid fertilizers are used in conjunction with irrigation and are ready for plants to uptake once applied, this method of fertilization is also called fertigation.

Fertilizers are commonly identified by their N-P-K analysis (e.g., 10-10-10 or 5-10-15), and under the Georgia Fertilizer Act, fertilizer products must be labeled with their guaranteed analysis to be sold in Georgia. For solid fertilizers, the numbers represent the amount of nutrients expressed as percent weight. For liquid fertilizers, the relationship is based on the density of the solution. Density is mass divided by volume (mass/volume; pounds/gallon) and the delivery of nutrients is based on the volume of solution (e.g., gallons of fertilizer applied per unit area). Secondary nutrients (e.g., Ca, Mg, and S) and micronutrients (e.g., Fe, B, Mn, and Cu) can also be mixed into the fertilizer, which is followed by a notation on the fertilizer label or composition analysis results. Particularly, some liquid fertilizers have particulates suspended in their solution that may clog fine emitters (e.g., microsprinklers and drip nozzles) if the irrigation system is not thoroughly purged after applying fertilizers. Other fertilizers may be reactive and precipitate from solution as particulate. Table 1 provides a list of solubility of mixtures of liquid fertilizers.

TABLE 1

The solubility of mixtures in liquid fertilizers.

FERTILIZER	Urea	Ammonium nitrate	Ammonium sulfate	Calcium nitrate	Nitrate potash	Muriate potash	Sulfate potash	Ammonium phosphate	Fe, Zn, Cu, and Mn sulfate	Fe, Zn, Cu, and Mn chelated	Magnesium sulfate	Phosphoric acid	Sulfuric acid	Nitric acid
Urea	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
Ammonium nitrate	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
Ammonium sulfate	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
Calcium nitrate	Compatible	Compatible	Incompatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
Nitrate potash	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
Muriate potash	Compatible	Compatible	Compatible	Compatible	Incompatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
Sulfate potash	Compatible	Compatible	Low solubility	Incompatible	Incompatible	Low solubility	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
Ammonium phosphate	Compatible	Compatible	Compatible	Incompatible	Incompatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
Fe, Zn, Cu, and Mn sulfate	Compatible	Compatible	Compatible	Incompatible	Compatible	Compatible	Low solubility	Incompatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
Fe, Zn, Cu, and Mn chelated	Compatible	Compatible	Compatible	Low solubility	Compatible	Compatible	Compatible	Low solubility	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
Magnesium sulfate	Compatible	Compatible	Compatible	Incompatible	Compatible	Compatible	Low solubility	Incompatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible
Phosphoric acid	Compatible	Compatible	Compatible	Incompatible	Compatible	Compatible	Compatible	Compatible	Incompatible	Compatible	Compatible	Compatible	Compatible	Compatible
Sulfuric acid	Compatible	Compatible	Compatible	Incompatible	Compatible	Compatible	Low solubility	Compatible	Compatible	Low solubility	Compatible	Compatible	Compatible	Compatible
Nitric acid	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Compatible	Incompatible	Compatible	Compatible	Compatible	Compatible

Compatible fertilizer **Low solubility** **Incompatible fertilizers**

Source: Landis *et al.* (1989)

Manure and/or leguminous plants are alternative fertilizer sources and provide organic material to soils. However, depending on alternative sources of fertilization, analyses are not guaranteed. Table 2 provides suggested ranges of N-P-K for alternative sources of fertilizers. If using alternative sources, the grower should be aware that nutrients bound by organic matter will need to be mineralized by breaking down in the soil. Compared to granular and liquid fertilizers, the availability of nutrients may be delayed and released over longer periods, depending on environmental conditions. Generally, growers should apply alternative fertilizers three to four weeks prior to peak demand by the plants.

Choosing the appropriate fertilizer source depends on the crop. For instance, most vegetable crops can use various sources of nitrogen (e.g., calcium nitrate, urea, or ammonia) and may not be sensitive to nutrients such as chlorine. Contrarily, blueberries, which thrive in acidic soil, demand an ammoniacal nitrogen source and are sensitive to excessive levels of chlorine. Growers can avoid costly mistakes by being aware of fertilizer sources and the demands of the crop prior to establishment. Fertilizer, soil, and leaf tissue sampling helps to identify the types and amounts of nutrients needed to meet crop nutrient demand.

TABLE 2

Values of nitrogen (N), phosphorus (P), and potassium (K) for manure applications and crop residues.

Source	N	P_2O_5	K_2O
	lb/ton		
Cattle manure	5 – 10[1]	3	3
Poultry manure	25 – 50[1]	20	10
Pig manure	5 – 10[1]	2	2
Horse manure	6 – 12[1]	3	6
Liquid poultry manure	7 – 15[1]	5 - 20	5 - 10
Alfafa sod	50 – 100[2]	0	0
Hairy vetch	50 - 100	0	0
Ladino clover sod	60	0	0
Crimson clover sod	50	0	0
Red clover sod	40	0	0
Birdsfoot trefoil	40	0	0
Lespedeza	20	0	0
Tops and roots	40	0	0
Grain harvest residue	15	0	0

[1]Lower values for fall-and winter- applied manure and higher values for spring-applied manure. Use these tables only if manure being used has not been analyzed.

[2]75% stand = 100 – 0 – 0, 50% stand = 75 0 – 0, and 25% stand = 50 – 0 – 0.

Source: Reiter *et al.* (2019), *Southeastern U. S. Vegetable Crop Handbook*

RIGHT TIME

The second practice of the four Rs is application timing. Timing is mostly determined from crop nutrient demands, but soil types are also a consideration.

Plants require specific levels of nutrition throughout the crop season. Perennial crops like peaches, pecans, blueberries, and blackberries have the greatest uptake of nutrients early in the season to support development and replenish reserves used during flowering and initial growth. Generally, 50-60% of the total nutrition is applied by fruit set to immature fruit. For most fruiting crops, there are indicators like fruit color change or pit hardening that indicate the end of fertilization until after harvest. Depending on the crop and harvest timing, fertilizer may be applied up to 15 to 30 days prior to the historical first killing frosts.

In annual crops such as vegetables and small fruits, fertilizer timing depends on the stage of crop development (Figure 2). Early in the season, most crops have low nutrient requirements because seeds provide most of the nutrients required for plant establishment. At this stage, excessively applying fertilizer is not necessary and only reduces fertilizer use efficiency, a term that describes how well plants can use the fertilizer applied. Still, soil nutrient availability is important and low rates of fertilizer should be applied to induce root growth after germination. In the case of transplanting, plants need to anchor in the soil, so nutrient availability is important to ensure that transplants become established. Phosphorus fertilizers are particularly appropriate for the early season because they induce root growth. After plants become established, they are in the vegetative stage of crop

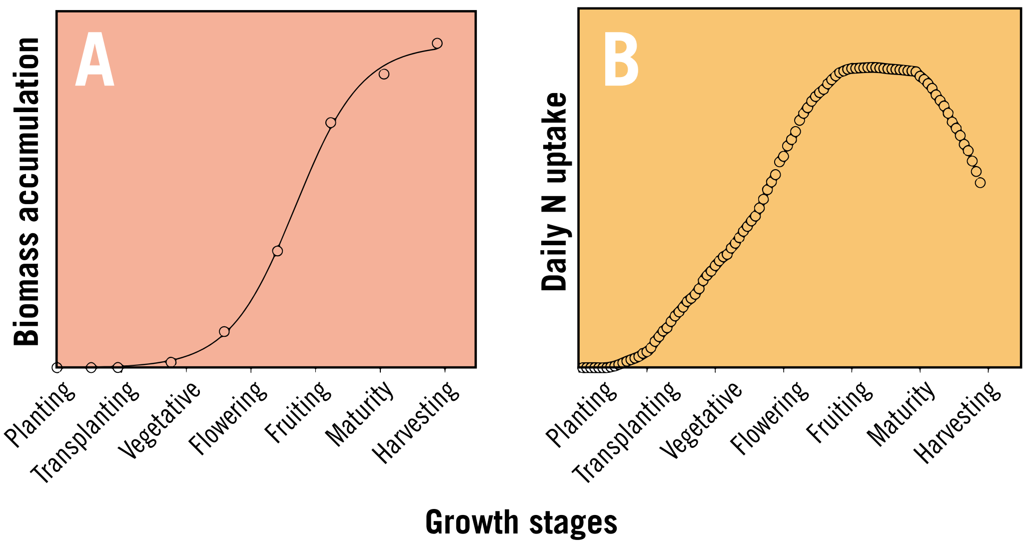

FIGURE 2

Representative biomass accumulation (A) and daily nitrogen uptake (B) of vegetable crops according to the growth stages of crop development.

development, at which point fast leaf expansion and increase of leaf area index. Fertilizer applications should ensure soil nutrient availability to completely cover the canopy. Once the crop canopy is covered, plants will start to flower and fruit, which means that the plants are reproducing. At this point, fertilizer application is fundamental, because soil nutrient availability is the key influencing factor of crop yield and/or fruit quality.

Soil types also affect the timing of fertilizer application. In the coarse soils of Georgia (e.g., sandy and loamy sand soils), where most vegetable and perennial crop production is located, timing of fertilizer application plays an important role on crop yield. Nutrient loss due to nitrogen or potassium leaching are commonly caused by heavy rainfall events or excess of water application during irrigation events. Splitting the fertilizer application is a strategy that provides proper soil nutrient availability in each stage of crop development. Using soil moisture sensors and irrigation scheduling strategies (da Silva *et al*., 2019) also helps to minimize soil nutrient loss.

RIGHT RATE

The third practice of the four Rs is the right rate, which varies among crops and should be determined according to stages of crop development and the nutrients (e.g., N, P, and K) required at each stage.

Proper fertilizer rates will ensure nutrient availability during important periods of the growing season, while the monitoring soil nutrient availability through soil samples will help to avoid ovefertilization and nutrient leaching below the root zone.

Table 3 has a list of recommended fertilizer rates for macronutrients including nitrogen, phosphorus, and potassium. Adequate nitrogen fertilizer rates will ensure plant growth, high leaf density, and canopy closure, however, nitrogen has high soil mobility that results in soil nitrogen leaching when irrigation is not properly managed or in the case of heavy rainfall events. A common visual symptom of low nitrogen availability is yellowing leaves (Figure 3), indicating that nitrogen fertilizer should be supplied to avoid yield loss. Contrary to nitrogen's high soil mobility, phosphorus is a nutrient with low soil mobility, and it's required in the early season due to its role in cell division, which ensures root growth after seed germination or root anchoring after transplanting. A single fertilizer application of phosphorus early in the season is typically sufficient in vegetable production areas. Potassium induces flowering and fruiting, and a lack of potassium reduces the concentration of soluble solids in the fruit tissue, also known as Brix, which affects yield quality (e.g., sweetness of watermelon). Commonly, both potassium and nitrogen are mixed as compound fertilizers and their applications increase from mid- to late season. Other macronutrients (e.g., calcium, sulfur, and magnesium) and micronutrients are also important for crop development and the right rate of application should be determined based on soil sample analysis, which will avoid plant toxicity and reduce the cost of production.

Fertilizer rates can be precisely applied when the growing fields are mapped and soil nutrient levels are georeferenced using GPS. this way fertilizers can be applied at rates based on nutrient availability on the soil mapping, which is also called variable rate fertilization. Practicing the variable rate fertilization is part of using precision agricultural methods and the implementation of such methods that will help on decision makes will depend on technology, cost, and practicality.

Over fertilization seems unrealistic for most of growers, still it is very common if recommendations are not followed and/or soil sample analysis are not performed. Proper rates of fertilizer application will most likely optimize yield production and reduce costs with inputs.

FIGURE 3

A comparison between bell pepper plants under low and recommended nitrogen fertilizer applications.

TABLE 3

Recommended total rates of nitrogen (N), phosphorus (P205), and potassium (K20) fertilizers according to the crop.

Crop	Nitrogen *(lb/acre)*	Recommended nutrients based on soil tests							
		Soil phosphorus level (P_2O_5 lb/acre)				Soil potassium level (K_2O lb/acre)			
		Low	Med	High	Very High	Low	Med	High	Very High
SNAP BEAN	40 to 80	80	60	40	20	80	60	40	20
BROCCOLI	150 to 225	200	100	50	0	200	100	50	0
CABBAGE	150 to 225	200	100	50	0	200	100	50	0
CUCUMBER									
Bareground	80 to 160	150	100	50	25	200	150	100	25
Plasticulture	120 to 150	150	100	50	25	150	100	50	25
ONION									
Bulb	90 to 150	200	200	50	0	200	100	50	0
Green	150 to 175	200	100	50	0	200	100	50	0
WINTER SQUASH									
Bareground	80 to 90	150	100	50	0	200	150	100	0
Plasticulture	80 to 150	150	100	50	0	200	150	100	0
SUMMER SQUASH	100 to 130	150	100	50	0	150	100	50	0
WATERMELON									
Nonirrigated	70 to 90	150	100	50	0	200	150	100	0
Irrigated	100 to 150	150	100	50	0	200	150	100	0
Plasticulture	125 to 150	150	100	50	0	200	150	100	0
TOMATO									
Bareground for sandy loams and loamy sands	80 to 90	200	150	100	0	300	200	100	0
Bareground for loam and clay	75 to 80	200	150	100	0	250	150	100	0
Plasticulture	130 to 210	200	150	100	0	420	345	275	0

Source: Reiter *et al.* (2019), *Southeastern U. S. Vegetable Crop Handbook*

RIGHT PLACE

Fertilizer placement is the fourth practice of the four Rs. Placement is an integral part of fertilizer management and directly affects the efficiency of nutrient uptake by the plant.

Fertilizer can be uniformly distributed across the soil surface, which is referred to as broadcast or topdressing fertilizer application. Broadcast fertilizer application places the nutrient on the soil surface and depends on water from rain or irrigation to dissolve the nutrients into the soil. It requires inexpensive equipment and is suitable for readily soluble and soil mobile nutrients. After the fertilizer application, nutrients can be incorporated into the soil to help reduce loss from erosion and volatilization. Incorporating fertilizer into the soil can be accomplished with disk, chisel plow, or moldboard implements. Unfortunately, low soil mobility nutrients, such as phosphorus and copper, have diminished availability when applied with the broadcast method. Further, broadcast fertilizers are readily available to weedy species, which increases competition for nutrients and water.

Fertilizer can also be banded or side dressed, meaning that the fertilizer is placed into a specific location relative to the crop. Banded fertilizer is applied out of reach of seeds and plantlets to avoid salt burn but within reach as roots develop. For developed and mature plantings, banding fertilizer is similar to broadcasting, except that the fertilizer is placed over the root zone of the plants, avoiding placement to row middles. Banding fertilizer requires specialized equipment, which may add to the cost of production. However, this placement of fertilizer application reduces the amount of fertilizer applied and improved fertilizer use efficiency.

A third method of fertilizer placement is fertigation, through which fertilizer is directly applied to the crop root zone through irrigation water, making nutrients available for immediate uptake. Liquid fertilizers are commonly used in fertigation, so the nutrient solution follows the water unless the nutrient binds with a soil constituent like organic matter and colloids. Proper irrigation management is key to enhance nutrient availability when fertilizer is fertigated; otherwise, nutrients will be pushed below the crop root zone. For instance, sandy soils in southwest Georgia should be frequently irrigated for short periods of time instead of a single, long irrigation event, which would not allow water and nutrients to penetrate deeply enough, since these soils have poor soil water holding capacity. It is important to highlight that fertigation events should account for the system to pressurize, deliver the nutrients, and flush without leaching nutrients from the crop root zone.

SUMMARY

The four Rs (right source, right time, right rate, and right place) are production practices to maximize fertilizer efficiency, minimize environmental impact, and produce the highest return from input costs. The four Rs are key considerations of crop management decision-making and should help plan fertilizer applications based on the crop, field, and delivery system. Most importantly, following the four Rs demands commitment by the grower to engage in all phases of crop production to minimize losses due to unintended management practices. For further information on crop production, fertilization, and the four Rs, please consult your county University of Georgia Cooperative Extension agent.

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