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Irrigation Systems and Nutrient Sources for Fertigation

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Advances in micro-irrigation techniques have facilitated greater adoption of the application of fertilizers to crops through irrigation water; the technique is termed as fertigation. If fertilizers are applied through irrigation systems, savings of 29–78% in application costs may result due to the improved efficiency of fertilizer application, low fertilizer leaching, precise nutrient application, and right-amount and right-time fertilizer application. Although no significant increases in crop yield have been reported (Alva et al. 2005), uptake of major plant nutrients, i.e., nitrogen, phosphorous, and potassium, is higher with fertigation than with conventional methods (Papadopoulos 1988). This publication details selection of a suitable irrigation system and compatible chemicals for efficient fertigation practices.

Selection of an irrigation system for fertigation

Irrigation systems are selected based on their water use efficiency, which varies with the soil properties and crop characteristics rather than the application system itself. Irrigation systems are categorized by their irrigation efficiency, defined as the volume of water beneficially used by the plants relative to the volume delivered by the system (Jensen 2007). Sprinkler and drip systems have substantially high irrigation efficiencies (60–70% and 80–90%, respectively) than that of traditional surface flooding (50–60% efficiency) (Nir 1982, Smajstrla et al. 1991). Flood irrigation techniques utilize more water compared to low-volume, pressurized irrigation systems. In flood irrigation, the water is directed and controlled by constructed basins, borders, and/or furrows. During flood irrigation, the applied water percolates through the plant root zone, resulting in losses of applied nutrients to leaching. On the other hand, low-volume irrigation systems apply water only to the soil around the plants; therefore, agrichemicals can be more effectively applied with such systems. Because the infiltrating water dispenses the fertilizer in the soil, fertilizer distribution depends on the water flow pattern in the particular soil (Hanson et al. 2006). Under flood irrigation, most of the water movement is due to gravity, resulting in excessive drainage. More nutrients may be needed for flood-irrigated fields than those irrigated with low-volume systems (Thompson et al. 2000), which retain the applied water, and hence the nutrients, in the plant root zone (Fares and Alva 2000).

Pressurized irrigation systems offer the ability to use high-frequency fertigation (Boman and Obreza 2002). High irrigation water application efficiency associated with negligible deep percolation in drip irrigation systems makes them ideal for fertigation. Because drip irrigation systems apply controlled and precise amounts of water to the field, negative impacts (i.e., surface runoff, soil erosion, deep percolation, and nutrient loss) are avoided. Prescribed chemical application, reduced application cost, minimum operator hazard, no soil compaction, and less plant injury are among the important advantages of fertigation through drip irrigation systems compared to foliar fertigation via above-ground sprays (Vieira and Sumner 1999).

Common sources of nutrients for fertigation

Nitrogen and nitrogen sources

Nitrogen (N) is an essential prerequisite for almost all crops and is ideal for fertigation due to its complete dissolution in irrigation water. Urea, ammonium nitrate

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(NH_4NO_3), calcium nitrate ($5Ca[NO_3]_2 \cdot NH_4NO_3$), potassium nitrate ($KNO_3$), and ammonium sulfate ($[NH_4]_2SO_4$) are some of the examples of N-containing sources. The N fertilizers are extensively used to prepare single- or multi-nutrient fertilizer solutions. Generally, pH-neutral N sources (i.e., $Ca[NO_3]_2$, KNO_3) are used as N fertilizer materials in fertigation practices. For high-pH soils, acidic sources are useful because they have the potential of reducing soil pH. Common N content sources are given below.

Ammonium nitrate solution (20-0-0) [NH_4NO_3]

Ammonium nitrate fertilizer is one of the most common and widely used sources of N. It can be dissolved in water at a density of 1.26 kg/L (10.5 pounds per gallon).

Urea-ammonium nitrate solution (32-0-0) [$(NH_2)_2 2CO \cdot NH_4NO_3$]

This source of N is manufactured by combining urea (46% N) and ammonium nitrate (35% N) on an equal N content basis. Of the available N sources, urea-ammonium nitrate has the highest N concentration. Calcium nitrate is not generally used with urea-ammonium nitrate, to prevent the formation of insoluble, milky white precipitates that potentially could clog irrigation lines.

Calcium nitrate (15.5-0-0-19 Ca) [$5Ca(NO_3)_2 \cdot NH_4NO_3$]

Calcium nitrate is a rich in nitrate N (NO_3-N) with 1% of ammonium-N (NH_4-N) and calcium (Ca). Calcium nitrate can be mixed with NH_4NO_3, magnesium nitrate ($Mg[NO_3]_2$), KNO_3, and muriate of potash (KCl). However, this product should not be mixed with any products containing phosphate, sulfates, or thiosulfates, to avoid the formation of insoluble precipitates that may result in plugging problems in low-volume drip, trickle, or micro-jet irrigation systems.

Ammonium thiosulfate (12-0-0-26) [$(NH_4)_2S_2O_3$]

Ammonium thiosulfate (ATS) is used as an acidulating agent. When ATS is applied to the soil through fertigation, sulfur-oxidizing bacteria, Thiobacillus spp., oxidize free sulfur (S) to form sulfuric acid (H_2SO_4). Gypsum is formed upon mixing ATS with a lime-rich calcareous soil. Gypsum helps maintain good soil structure. ATS can be mixed with neutral or alkaline phosphate liquid fertilizers or with other N fertilizers. However, it should not be mixed with acidic compounds due to the fact that it will decompose into elemental S and $(NH_4)_2SO_4$. Application of this fertilizer to neutral or acidic soils may result in drastic decreases in soil pH over time. The extent of pH drop varies with the soil type and with the amount of fertilizer applied.

Urea

Urea is commonly available as a dry, solid fertilizer (46-0-0) or as a liquid solution (23-0-0). Commercially available urea contains about 2.25% biuret, a byproduct that is formed during the manufacturing process. For foliar application, urea with less than 0.25% biuret is recommended, as a higher percentage of biuret can inhibit plant growth.

Urea sulfuric acid [$CO(NH_2)_2 \cdot H_2SO_4$]

This is an acidic fertilizer that combines urea and sulfuric acid. When urea is applied to soil, it increases the soil pH and enhances N losses via ammonia volatilization. Combined application of urea and sulfuric acid reduces both ammonia volatilization and soil pH, and thereby reduces the ammonia damage to plant roots that occurs when only urea is used as a nutrient source.

Potassium nitrate (13-0-46) [KNO_3]

Potassium nitrate is an expensive fertilizer component compared with other K sources. It is an excellent choice of potassium fertilizer for areas with highly saline irrigation water. Potassium nitrate is less soluble than KCl but more soluble than K_2SO_4.

Phosphorus and phosphorus sources

Plants generally need phosphorus (P) early in their life cycle, which makes P an important pre-plant amendment if already deficient in the soil. Later-stage application of P via fertigation is adopted if P deficiency symptoms appear in plants any time during the growing season. Phosphorous is the most critical element used in fertigation because of its solubility in water, especially in presence of other nutrients, such as calcium (Ca). Most of the commercially available fertilizers contain phosphoric acid (P_2O_5) as water-soluble and citrate-soluble phosphate. Because P is not easily dissolved in irrigation water, it is less likely to leach through many soils. Phosphorous attached to eroded soil particles can be transported to water bodies via surface runoff, causing pollution. It is important to know that injection of P fertilizers into irrigation systems may cause emitter plugging due to the formation of precipitates when P is mixed with certain fertilizers. For irrigation water rich in Ca and Mg (magnesium), solid precipitation in the irrigation lines is expected if P is used in fertigation. Most of the dry phosphorus fertilizers (e.g., ammonium phosphate ($[NH_4]_3PO_4$) and superphosphates) are not injected with irrigation water due to their low solubility in the water. The P fertilizers, such as mono-ammonium phosphate (MAP), di-ammonium phosphate (DAP), mono basic potassium phosphate, P_2O_5, liquid ammonium polyphosphate, and urea phosphate, are water soluble and can be used in fertigation.

Phosphoric Acid (0-54-0)

Phosphoric acid is a water-soluble, syrupy liquid that is used with many formulations of N, P, and K mixtures, but not with any of the Ca fertilizers. The use of Ca fertilizer with P_2O_5 results in the formation of insoluble calcium phosphate ($Ca_3[PO_4]_2$), which can plug irrigation pipes, emitters, and drippers of the irrigation system.

Potassium and potassium sources

Potassium is one of the major nutrients and its major sources include potassium chloride (KCl), potassium nitrate (KNO_3), and potassium sulfate (K_2SO_4). When mixed with other fertilizers, K may generate solid precipitants. Since the solubility of K_2SO_4 is very low, it is therefore seldom used in fertigation. Potassium thiosulfate is another common source of K that can be mixed with urea and ammonium polyphosphate solutions in absence of acidic fertilizers. The major K sources are presented below, along with their merits and demerits.

Potassium chloride (0-0-62) [KCL]

Potassium chloride is one of the least expensive, most popular, and highly water soluble fertilizer source for K nutrients. However, KCl is not useful if the irrigation water has high salinity levels.

Potassium sulfate (0-0-52) [K_2SO_4]

Potassium sulfate is one of the best alternatives to KCl in high-salinity areas and simultaneously presents a source of sulfur. It is less soluble than either KCl or KNO_3.

Potassium thiosulfate (0-0-25-17) and (0-0-22-23) [$K_2S_2O_3$]

Potassium thiosulfate, usually available in two grades, is a neutral to basic, clear, liquid solution. This fertilizer can be blended with other fertilizers, except acidic blends (i.e., pH <6.0). In order to avoid the formation of precipitates, it is always useful to conduct small blending tests in a jar prior to injection.

Other nutrients and their sources

The majority of metal micronutrients are not used in fertigation due to their low solubility in water. Thus, micronutrients including copper (Cu), iron (Fe), manganese (Mn), and zinc (Zn) are applied to the soil surface.

Management practices for high fertigation efficiency

Fertigation efficiency depends on many factors. Other than the irrigation system and fertigation system design, these factors include soil type, crop stage, chemical type, fertigation time, and irrigation water quality. Soil types, along with the physical and chemical characteristics of the soil (i.e., texture, pH, or percentage of Na, Ca, and other elements that enhance adsorption of the applied nutrients), influence the performance of a fertigation operation. For example, sandy soils require more frequent fertigation in smaller doses compared to clay loams. Soils with P-fixation characteristics also require frequent and small doses of P. Similarly, if the soil has a high pH, the application of NH_4 fertilizer will result in loss of NH_3 via volatilization. Plant nutrient requirements vary with the plant's phenological growth stage; lesser amounts of nutrients are required during the initial growth stages than at later growth stages. Therefore, fertigation is generally more effective at high-growth, rapid-development stages than at low-, slow- or no-growth stages. High nutrient application rates, low plant nutrient uptake, and shallow crop rootzones pose a potential risk of nutrient leaching losses upon excessive irrigation or following heavy rainfall events.

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