

N E T A F I M U S A



CORN PRODUCTION MANUAL

USING SUBSURFACE DRIP IRRIGATION



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OVERVIEW

Subsurface Drip Irrigation (SDI) is defined as the application of water below the soil surface by micro-irrigation emitters. SDI has been used commercially for irrigating field corn since the early 1990s. In most applications, one dripperline irrigates two rows of corn. If the corn rows are spaced 30 inches then the dripperline would be spaced 60 inches. The dripperline is typically buried 8 to 14 inches deep depending upon soil type and germination conditions. The placement of the dripperline every other row is the most economic setup for field corn production.

More recently, higher density corn plantings (35,000 or more plants per acre) have been employed to maximize yields. To accommodate these higher densities, crop row spacings of 20 inches are being employed. In this case, a dripperline spacing of 40 inches is appropriate while still irrigating two crop rows with one dripperline. The 40 inch dripperline row spacing is more expensive than a 60 inch dripperline spacing, but it accommodates a wider range of rotational crops. Soybeans, corn sunflowers and even wheat can be grown over dripperline spaced at 40 inches. For this reason, more growers are making the extra investment to install the drip system at this spacing.

The spacing between emitters and flow rate per emitter is determined by the soil properties and water availability. The most common method for the scheduling of irrigation is based on crop water use as determined by evapotranspiration (ET), but measurement of soil moisture using sensors is becoming more popular.

SDI is a management tool that allows precise control over the root zone environment of your corn crop. This control often results in consistently high yields. In addition, better water and fertilizer management can help reduce fertilizer inputs, water needs, and runoff. As with any management tool there are trade-offs. Many growers find the well supplying their pivot circle (125 acres) supplies enough water to do a quarter square (155 acres) with a drip system. In this case, they have saved no water, need to use a little more fertilizer and are cultivating 20% more area. Others growers have decided to reduce water consumption and runoff, but have not experienced greater harvests. It is up to you to decide how you want to manage this tool. The aim of this manual is to describe the layout, installation, operation and maintenance of an SDI system on corn. It is meant as a guide to aid in the decision to move to drip technology and how to manage this technology to obtain the desired results.



WHY SUBSURFACE DRIP IRRIGATION ON CORN?

Total fertilizer use on corn is greater than on any other crop grown in the United States. The main interest in using drip irrigation on corn comes from the desire to better manage this increasingly expensive crop input.

Highest Water Use Efficiency of Any Irrigation System

Water loss through evaporation, runoff and deep percolation are virtually eliminated. Studies in Kansas and Nebraska have shown that for corn grown under drip irrigation applied water can be reduced up to 40% with only slight impact on yields.

Adapts to Field Size, Shape and Topography

Drip adapts to any field size and shape - irrigating 100% of your field, maximizing production and minimizing waste. With pressure compensating emitters, hills and slopes are irrigated with high uniformity.

Improves Crop Quality and Bottomline Results

Drip irrigation helps growers improve crop quality and yields. Water and nutrients are used more efficiently so input costs are reduced. Uniform water and fertilizer application through the drip system results in a more uniform crop and higher overall yields.

Reduces Insurance Costs

SDI has very little exposure to the weather and damage from it.

Long Lasting Performance

When properly maintained, a high quality drip system can last up to 25 years or more.

Drip Reduces Operation Costs

Run-off, evaporation and deep percolation means you need to pump more volume for a longer time costing you money. SDI is the most efficient irrigation system using less water and fertilizer saving operational expenses. Drip is well adapted to "No-Till and Minimum Till" systems reducing cultivation costs. Critical aspects that need to be considered:

1. The investment in a drip system can be substantial. Even with this cost it is possible to get payback in two to three years. Analysis of your needs, capabilities and the benefits of an SDI system should be carefully considered.
2. In most cropping areas, the drip system provides enough moisture to germinate your crop. However in some very dry areas, sprinklers or flood irrigation may be needed for crop emergence and stand establishment.
3. The SDI system requires consistent, regular maintenance to ensure it is performing to specification. A suggested maintenance schedule that outlines weekly, monthly and yearly tasks is provided in this manual.
4. SDI is more than a watering device - it is a root zone management tool. To get the most out of it requires careful records of crop and system activity.
5. SDI systems have been in continuous use for over 20 years. Given the potential long life and cost of the system, you must consider crop rotation and cultivation practices such as deep cultivation when formulating a plan for SDI on corn.
6. Rodents can damage your crop and the drip system. A rodent management plan must be implemented. We provide an outline for such a plan in this manual.

DRIP SYSTEM COMPONENTS

Overview

This section of the manual reviews the layout and function of the components required for a typical Subsurface Drip Irrigation (SDI) system. In SDI, the dripperline is permanently buried about 12 inches deep supplying water to, and feeding the roots directly. One advantage of the subsurface delivery of water and nutrients is that the soil surface stays dry, significantly reducing weed pressure. Netafim has experience with sub-surface drip systems in continuous operation for over 20 years. The longevity of your system will depend on factors such as initial water quality, proper operation, regular maintenance and control of rodent populations.

Water

Water sources currently used for flood or mechanized irrigation are generally suitable for drip irrigation of field corn. However, there are special considerations required to ensure the longevity of the drip irrigation system. When utilizing a new water source or if you have known conditions such as high salts, iron or manganese, it is a good idea to have the source water analyzed before system design begins. Water quality issues can be addressed through proper system design and water treatment, but it is most cost effective to do this before the system is installed. Maintenance procedures may also need to be adjusted for specific water conditions. Specific water quality issues are discussed in more details in the operations and maintenance section of this manual.

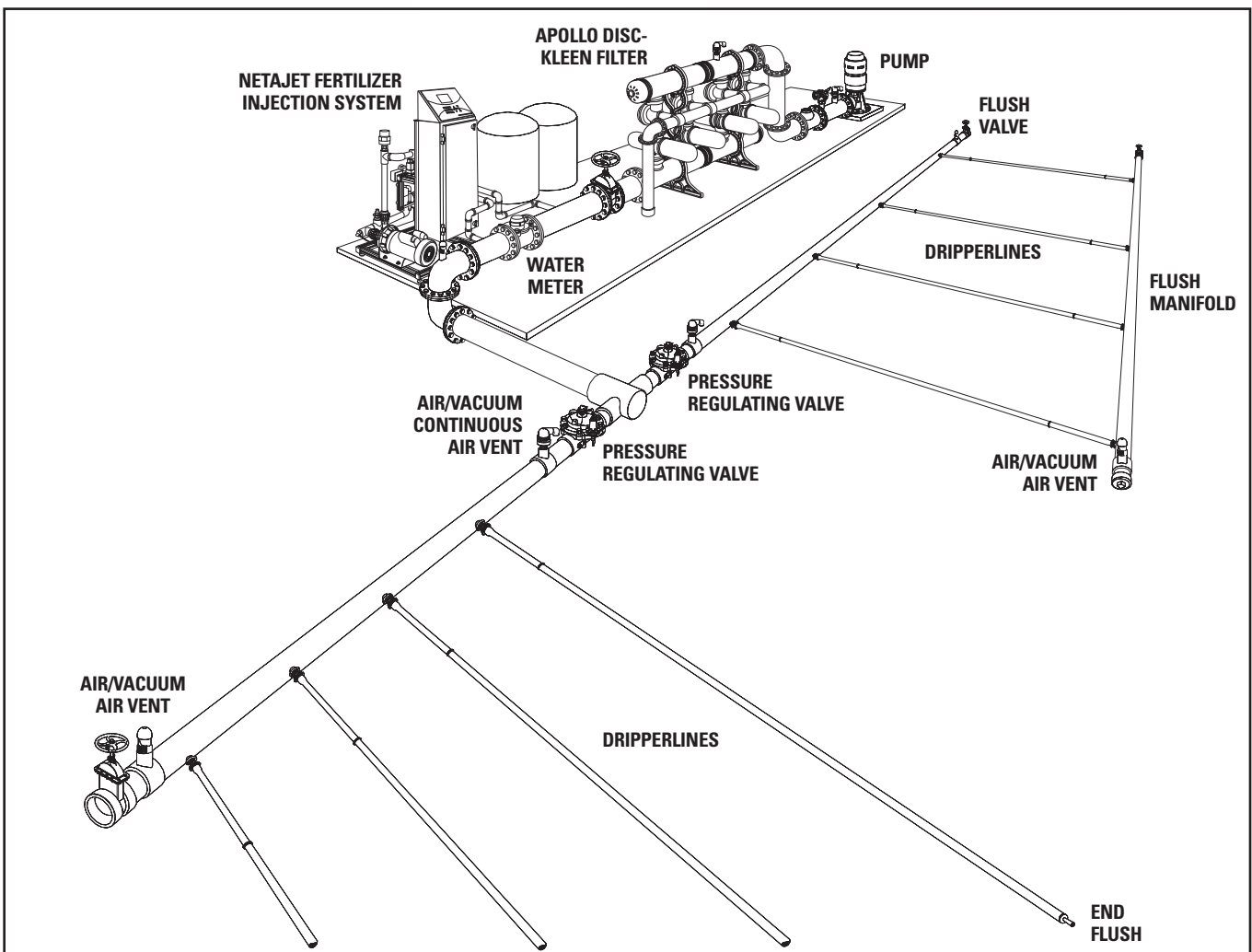


Figure 1. Schematic diagram of the components which comprise a Netafim USA Subsurface Drip Irrigation system.

Basic System Layout

Figure 1 on the previous page is a schematic layout of the components which make up an SDI system. The heart of the system is the dripperline. For corn production, pressure compensating or non-pressure compensating emitters are used depending upon row length and field topography. As the name suggests, pressure compensating emitters produce the same flow rate over a wide range of pressures while the flow rate for non-compensating emitters is a function of the inlet pressure. Pressure compensating emitters are generally more complex and hence more expensive than non-compensating emitters. On sloping terrain, pressure compensating emitters allow uniform water distribution even though the slope will result in large pressure gradients. This can result in significant water savings and improved yield by producing a more uniform crop.

To protect the dripperline a high quality filtration system is recommended. This is typically a disc or media filtration system. Maintaining the dripperline over the long term requires a system for injecting chemicals. Some of these chemicals such as acid will keep your system clean. It is also possible to use this injection system to supply fertilizers directly to the crop roots. With a heavy feeder like corn, supplying fertilizer directly to the roots is the most efficient and effective way to fertilize the crop. Pipeline headers, control and air relief valves round out the rest of the system. Our intent is not to describe the process of system design in detail. Your Netafim Dealer is trained to design and install quality SDI systems. Still it's important to understand how the system is put together and why certain design elements are specified.

Dripperline Specifications

The following dripperline recommendations are meant as guidelines. Soil type, topography and water quality will affect the final design. Your Netafim Dealer is familiar with the local conditions and will recommend dripperline that is appropriate for your area. Dripperline should be installed with GPS where possible so that their position can be determined as necessary. SDI systems always use dripperline with integral drippers. Depending upon local conditions, this dripperline can have either pressure compensating emitters (DripNet PC or UniRam) or non-pressure compensating emitters (Typhoon or Streamline). Factors such as length of run, topography, zone size and water quality all come into play when choosing the right dripper. Regardless of the emitter chosen, there are several basic guidelines to follow.

1. A typical drip installation on corn has a single dripperline buried between two crop rows. Since the most common row spacing for corn is 30 inches, dripperlines are spaced on 60 inch centers. One dripperline feeding two rows of corn. The current trend is toward higher plant densities. To accomplish this, some growers are moving to 20 inch row spacing and in this case a dripperline spacing of 40 inches between rows would be standard. The 40 inch dripperline row spacing is more easily adaptable to a soy rotation and is also ideal for other crop rotations such as wheat or alfalfa. In fact, an SDI system with 40 inch row spacing can be used to irrigate most common agricultural crops. Crop rotation should be considered when choosing the desired spacing between dripperline rows.
2. Dripperlines are generally buried at a depth of 12 inches but may be found 8 to 18 inches deep. Soil texture, germination and rodent pressure are the main considerations for dripperline depth. Sandy soils generally demand a shallower burial to expose the plant roots to the largest possible wetted zone. A shallower burial is also suggested when using the system to germinate the crop. At a depth of 14" or deeper, it is difficult to move water to the surface to germinate corn seed. This is mostly an issue in the arid west where there is little stored moisture in the soil prior to planting. In areas with strong rodent pressure, a deeper dripperline is less likely to cross paths with rodent's teeth. In general, rodents are not fond of sandy soil so the shallower depth is not a concern.
3. The distance between drippers is usually 18 to 24 inches. This may be adjusted to achieve the appropriate application rate.
4. Dripper flow rates of 0.16 to 1.0 GPH may be used depending upon the soil infiltration rate and the application rate desired. Typically 0.18 to 0.4 GPH emitters are used.
5. Dripperline wall thickness of 13 to 35 mil is usually chosen, with 15 mil being most common.

Pump Requirements

The volume output of the pumping station dictates the amount of area that can be irrigated. A simple formula has been derived converting the ET in inches of water per day per acre into gallons per minute per acre.

$$\text{ET (inches/day/acre)} \times 18.86 \text{ (conversion factor)} = \text{GPM/acre}$$

Example: An ET of 0.25 inches per 24 hours per acre would require 4.72 GPM/acre.

This calculation is for a pump running 24 hours. More commonly as a safety factor, systems are sized for 20 hours of operation. To accomplish this, use the following formula:

$$\text{Hours in a day / number of hours desired for irrigation} \times \text{GPM/acre}$$

$$24 / 20 \times 4.72 = 5.66 \text{ GPM/acre}$$

On flat land, the pressure output required of the pump station is mainly dictated by the requirements to flush debris out of the filters and pipes. On hilly terrain, the pressure required to lift water to the highest point must also be considered. Most automatic filters require a minimum of 30 psi to self-clean properly. This is generally the minimum operating pressure of the pump operating a drip system.

Filtration

The filter system protects the drip system from sand and other small particles which can plug the emitters. A well conceived filter system provides maximum operating life of the SDI system. Two types of filter methods are recommended:

1. Sand media filters
2. Netafim disc filters

In general, screen filters are not recommended for long term SDI systems however for very clean water sources they may be acceptable. Sand media and disc filters utilize depth filtration which is most effective at removing suspended particles from the water. The filter system should be set up to clean automatically when the pressure differential across the media is too large. A pressure differential switch in combination with a flushing controller is a common approach for automation of filter cleaning.



Figure 2. Left: example of a Netafim AGF Sand Media filter unit.



Right: example of a Netafim Apollo Disc-Kleen filter unit.

Pressure Regulating Valves

If the recommended dripperline is not compensated, pressure control valves are recommended to achieve the correct working pressure in the drip system. Pressure regulating valves must be adjustable to accommodate higher pressures during flushing.

Air Vents

The sucking in of soil just after shutting down the system causes problems if air/vacuum vents (valves) are not used. For every 50 laterals, there should be one anti-vacuum vent on the highest elevation. It is further recommended that an anti-vacuum vent be mounted on the flushing manifold's highest elevation. A double purpose automatic air vent must be installed at the pump.



Figure 3. Examples of a field installation of Pressure Regulating Valves and Air/Vacuum Relief Air Vents.

Fertilizer Injection System

The system must be designed to supply fertilizer to all irrigation blocks. This can be a completely automated system or a simple injection pump. Please consult your Netafim Dealer to determine which fertilizers may be safely applied through the drip system.



Figure 4. Examples of a Netafim fertilizer injection and irrigation control system.

Water Meters

It is essential to monitor flow in order to monitor the operation of your system and crop water use. The SDI system is designed to produce a specific flow rate at a given pressure. Changes in the flow rate may indicate leaks in the system, improperly set pressure regulating valves or even changes in the well and pumping plant.

Pressure Gauges

Use pressure gauges to ensure that the drip system, filter system and pump operate at the correct pressure. Pressure gauges are also critical in assessing potential problems with the system.

Flush Manifolds

Most permanent SDI systems use flush manifolds so that entire zones can be flushed at a single time (see Figure 1). A manifold at the end of the field also improves system uniformity. The use of flush manifolds is highly recommended to reduce the labor required to properly maintain the system.

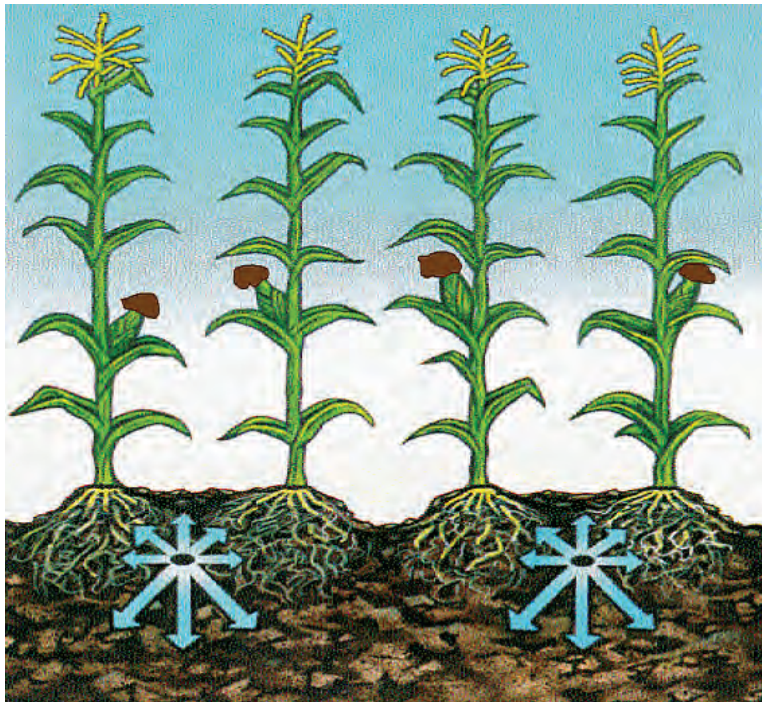


Figure 5. Examples of Netafim Water Meters and Pressure Gauge.

DRIP SYSTEM AGRONOMIC PLANNING

Overview

Spacing between rows of dripperline, depth of placement, emitter spacing and dripper flow rate are the four variables which define an SDI system. These must be matched with soil type, water availability, pump capacity and crop water use to complete the system design. With your input, your local Netafim Dealer provides a customized drip system design and layout. Trained designers familiar with local conditions will ensure you receive a system that will last for years. GPS guided installation allows for precision farming of your corn crop. Consideration of the cropping system, crop rotation and soil conditions is an important part of the design process. This section is not meant as a treatise on the hydraulic design of the drip system, but more of description of the SDI system parameters as they apply to corn production.



Typical System Layout

For corn planted in 30 inch rows, a typical SDI system will have the dripperline spaced at 60 inches placed in the furrow such that one dripperline feeds two rows of corn. A recent development is corn planted in 20 inch rows. In this case, the rows of dripperline would be spaced 40 inches apart. The dripperline is usually buried at depths ranging from 8 to 16 inches.

At a given row spacing, the flow out of each dripper and the spacing between drippers will determine the application rate. The desired application rate is dependent on the water requirements, water availability and cultural practices. A common system may use 0.16 GPH Typhoon emitters spaced at 24 inches. This will produce an application rate of 0.038 inches/hour or 0.91 inches in a 24 hour period. To take advantage of existing pumps and to maximize the efficiency of your water supply, the SDI system is typically divided into zones or blocks. In the above example the system could be divided into 4 blocks each operating for 6 hours. This results in an application rate of .23 inches per block which is close to the ET for many regions of the country. Your Netafim Dealer will design systems that supply the appropriate amount of water for your region taking into account weather, soil type, cropping system and crop rotation.

Dripperline Spacing

Field corn has been successfully grown using subsurface drip irrigation for over 20 years. Experience has shown that one dripperline buried in the furrow and feeding two rows of corn produces excellent results. This arrangement works at most common row spacings for corn, even if the corn is planted in double rows on each bed. Viewing a drip irrigated corn field one may think that lateral water movement is limited. The surface often appears dry and there is little visual evidence of water below the surface.

Research done by Hansen et al (2008) demonstrates the extent of lateral water movement for subsurface drip irrigation. This work was done on tomatoes but applies to corn fields as well. Figure 6 shows the wetting pattern of clay loam for dripperlines placed at varied depths. At a dripperline depth of 6 inches, some moisture reaches the soil surface with horizontal wetting occurring out to about 12 inches. At depths of 12 and 18 inches, the soil surface remained dry and maximum horizontal wetting of 25 to 30 inches was obtained. This suggests that 60 inch spacing between dripperlines for this soil type is acceptable.

A second factor that will determine dripperline spacing is crop rotation. Current experience shows a subsurface drip system can last up to 20 years so it is important to have a rotation plan in mind prior to installation. In addition to row spacing, dripperline depth and the potential need for sprinkler or flood irrigation to germinate rotation crops must also be considered in your rotation plan. Based on experience, an SDI system with dripperline placed every 40 inches will water the entire soil volume. Thus, it is suitable for most crops with a moderately deep root system. For instance, several growers have successfully cultivated wheat and safflower over SDI systems designed for corn crops. Row crops such as soybeans, tomatoes or cotton can be easily accommodated with a drip system designed for field corn.

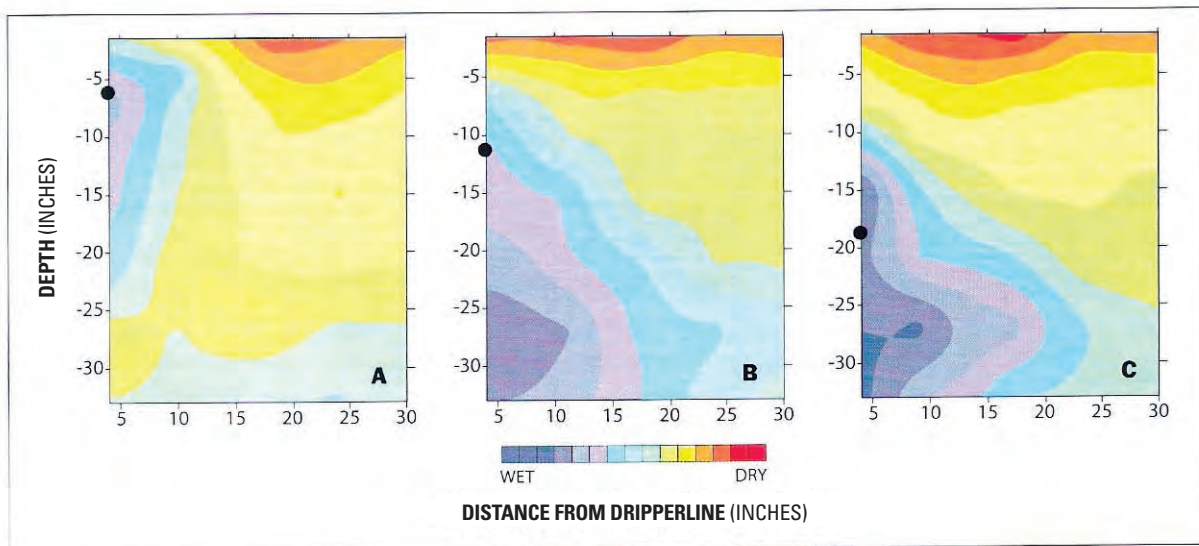


Figure 6. Wetting patterns for subsurface drip irrigation for different dripperline depths. (A) 6 inches deep, (B) 12 inches deep, (C) 18 inches deep
The black dots are the locations of the dripperlines.

Dripperline Depth

It is possible to place the dripperline in a corn field at any depth, but there is little reason to place it shallower than 8 inches. Drinkerline placed at 12 inches or deeper results in little moisture reaching the soil surface potentially reducing weed pressure on your crop (see Hansen et al listed previously). The advantage of a dry soil surface may be a disadvantage when it comes to germinating your crop particularly in very arid regions. In much of the western corn belt, soil moisture from winter snows provides enough moisture for crop germination in the spring regardless of the depth of placement of the dripperline. In dryer regions in the far west, sprinklers may be required for germination of your corn crop. Drinkerline placed at a depth of 8 inches allows for consistent germination of your corn crop under any condition. However, a shallower dripperline will result in a wet surface which may encourage weed growth. In areas with severe rodent pressure, dripperline placement at a depth of 15 to 18 inches may help reduce rodent damage. This is below the depth of the majority of gopher activity.

Recent feedback concerning subsurface drip irrigation shows that it leads to less soil compaction. Corn has a strong root system, which lessens soil compaction or the necessity of follow-up deep cultivations. Follow-up soil preparation for rotation crops does not to be deeper than 10 inches. If the system is installed using GPS rotation, crops can be easily planted relative to the dripperline and deep cultivations can be accomplished between the dripperlines.

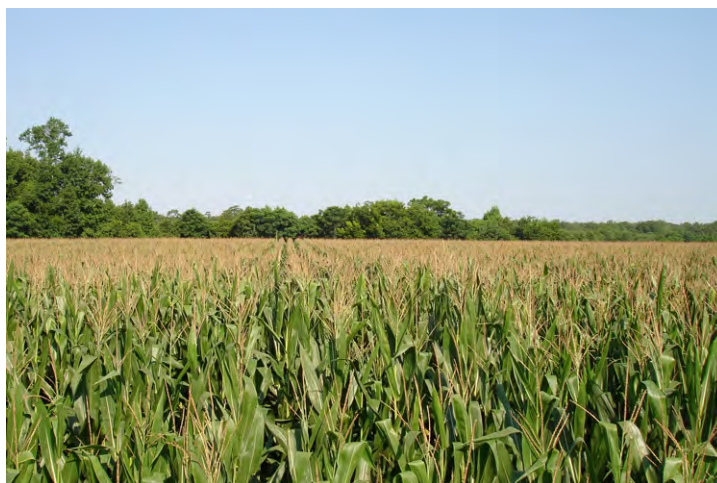
No-Till and Minimum-Till Systems

Subsurface Drip Irrigation (SDI) is well adapted to "No-Till" and "Minimum-Till" systems for several reasons.

1. A properly operated SDI system does not wet the soil surface reducing weed pressure and reducing herbicide application. This saves money in reduced tractor passes and lower crop protection costs.
2. Water movement from the buried dripperline moves primarily through capillary action not via mass flow in the soil. This gentle movement helps maintain and even improve soil structure in No-Till and Minimum-Till cropping situations.
3. The application of water and fertilizer directly to the root zone via SDI is much more effective in No-Till and Minimum-Till situations compared to surface application of water.

Dripper Spacing and Flow Rate

Dripper spacing and flow rate, along with row spacing, determine the water application rate. These are designed to supply adequate water to satisfy the peak water use for your crop (ETc) usually expressed as inches/day. In the U.S., peak ETc usually occurs in July and ranges from 0.25 inches/day to over 0.5 inches per day in much of the irrigated western U.S. The precise peak water use depends upon the climate in your specific area and can be obtained from your local extension service. If you have poor quality water or soil, a leaching factor needs to be added to the system so that the additional water is available as needed. The section on Irrigation and Scheduling includes more information on ET.



Field Preparation

A drip system is expected to last 20 years or more and ground preparation is critical. An SDI system is not just a watering tool, but allows for fertilization over the course of the crop. This is critical to maintaining economic yields over an extended period of time. Still the soil should be properly amended at the time of initial land preparation. Soil samples should be taken and analyzed before establishment to determine what chemical ameliorations are required.

Corn performs best when the soil has a pH range of 6.3 to 7.5. Soils with a pH of 6.0 or lower must be limed. Soils with a pH above 8.2 indicate excess sodium and must be reclaimed. Excess salts in your soil or water can significantly reduce yield. Salinity levels above 3.4 mmho/cm are the threshold above which yields are reduced. In high salinity areas, it is necessary to design the drip system so it can provide adequate leaching. Consult your local extension service for more information on problematic soils in your area. When dealing with problematic soils, it is necessary to allow sufficient time for the reclamation process to take effect before planting. Your local Netafim Dealer can give you guidance in proper field preparation prior to installation which will make installation go smoothly.

Soil Fertility

Fertile soil is fundamental to crop establishment. Even though SDI allows for the application of fertilizers directly to the root zone while the crop is growing, it is important to start out with the right fertility in the seedbed. Analyze a soil sample prior to planting. Follow the recommendations of your local laboratory or extension service to prepare the field for planting. Of particular concern is phosphorous. This nutrient is quite immobile in the soil and an effective pre-plant will start the crop out right. This fertilizer can be broadcast and disked or harrowed. Banding phosphorous with or below the seed has worked well. This method places the phosphorous where it is readily available to the corn and not the weeds. See the section on Fertilization for more information on the fertilizer needs of corn.



SDI SYSTEM STARTUP

Overview

This section offers guidelines for the successful startup and operational testing of an SDI system. Many times the Netafim Dealer will conduct initial start-up and testing of the system. However, during the course of operation there may be times when the system needs to be started after a shutdown, such as the off-season or following repairs. These procedures should be followed after any extended shutdown of your system. All drip system owners should make themselves familiar with the process of start-up and testing of their drip system.

System Start-up

An SDI system should be operated as soon after installation as possible. Installation planning should include well operation and hook-up to the header system so dripperlines can be charged as soon as possible after installation. Filling the system with water inhibits insects as the inflated diameter of the dripperline is too big for their mandibles. The wet soils created by operating the system are a slight deterrent to rodents looking for a chew.

Whether you have just installed a new system or are starting your system up after sitting through the off season, a few simple steps taken before irrigation begins will help ensure optimum system performance.

1. **Flush the well before operation through the filter.** New wells, may discharge sand on start-up. This “plug” of sand can overwhelm the filtration system. Under these conditions, the filtration system will backflush repeatedly without cleaning the system. This occurs because the clean water flow used to flush the filters is so reduced it does not sufficiently clean the dirty filter. In this case, the unit must be disassembled and cleaned by hand. If the well discharges sand on a regular basis, it may be necessary to install a sand separator before your regular filtration system. A sand separator continuously removes sand from the system during operation. Consult your Netafim Dealer for more information on sand separators.
2. **Thorough flushing of the laterals and mains before system operation.** In new systems, chances are good that during installation some dirt and PVC pieces will accumulate in the system. These need to be completely flushed out. A properly designed drip system should have valves installed for flushing mains, submains and dripperlines. Your Netafim Dealer will review their operation prior to turning on the system. The drip system needs to be flushed on a regular basis. Filters do not exclude 100% of particles in the water, often letting through fine silt. This will settle in lines and can clog the system. Debris also can get into the lines after a break has occurred and the system should be flushed after any repairs. Depending upon the condition of the water, this flushing may need to be done as often as once a month or as little as once a year.
3. **Check for leaks in dripperline laterals.** Laterals are occasionally damaged during installation. System start-up is the right time to check for leaks, before the crop canopy expands making repairs difficult. Leaks in the dripperlines usually appear as isolated wet spots on the surface of the field.

Start-up Procedures

1. Disconnect all dripperlines from the sub-header.
2. If possible, run the pump station for a few minutes with the discharge to waste, not through the irrigation system, to flush out any sand.
3. Open mainline flush valves with any submain valves closed and operate the system until discharge water runs clear for 5 minutes. Pay attention to the flow rate, when and how often the filter system backflushes during this operation.
4. Open submain valves, with dripperlines still disconnected, to clear the submains of debris. Make sure muddy water is not pushing into the laterals during this operation.
5. Connect laterals to the submains, without terminating the ends.

6. For each submain, open the control valve until discharge water at the end of the lateral runs clear. If the capacity of the water supply is insufficient to flush all laterals simultaneously, it may be necessary to terminate some laterals, flushing only a few at a time. Close the submain valve.
7. Close the lateral ends.
8. Operate the system until it is fully pressurized and all air is discharged.
9. Check system for leaks and repair.
10. Reflush the lines after leaks are repaired.
11. Check pressure gauges and adjust all pressure regulators or regulating valves as necessary.
12. Check for proper operation of all system components; pumps, controllers, valves, air vents, pressure regulators, gauges, water meters, filter system and chemical injectors.
13. Record readings from all pressure gauges and water meters and check on the frequency of backflush cycle of the filters. If backflushing is frequent, several times an hour, consult your Netafim Dealer.

System Pressure and Flow Tests

Upon initial start-up, it is best to evaluate the uniformity of the drip system. This is accomplished by:

1. Measuring the pressure in the system at various points and comparing this to the design pressure.
2. Reading the water meter or calculating the system flow and comparing the result to the design flow rate.

These evaluations should be conducted as part of system start-up and as an ongoing part of system maintenance. Consult the maintenance section of this manual for a complete program for system care.

System Pressure Evaluation

Drip systems are typically designed to operate between 10 and 25 psi. Measuring the pressure at several points in the drip system is the simplest way to evaluate the performance. A good evaluation will include pressure measurements at a minimum of 3 points along the header end of the field and 3 points at the far end of the field. Because of the relationship of flow rate to pressure for Netafim emitters, this variation in pressure will usually give distribution uniformities of 95% (see Design section). Pressure measurements at more points in the field, including along the length of the laterals, will give a more complete picture of system uniformity, but are usually not necessary if the end pressures are within several psi of the header pressure. Please note, if the system uses pressure compensating emitters, the pressure drop across you system could be 10 or more psi and still be highly uniform. Check with your Netafim Dealer to determine what pressure measurements are reasonable.

System Flow Rate

A water meter is an important component of every drip system. It gives a quick indication of the operational performance of the system and is used to determine proper water application rates. Every new system should be designed with a water meter. Older systems without water meters should be retrofitted with one. The system design should include an estimated system flow rate and the measured flow rate should be within +/- 5% of the designed rate. To calculate the flow rate expected for each zone, use the following formula:

$$\text{Flow rate (GPM)} = (0.2) \times \text{Length of dripperline (ft)} \times \text{Emitter flow rate (GPH)} / \text{Emitter spacing (in)}$$

Converting System Flow Rate to Inches of Applied Water

Irrigation schedules are usually based on evapotranspiration (ET) rates which are expressed in inches of water evaporated over a given time period, usually a day or week. It is simple to convert a flow rate in GPM, either reading a meter or calculated as outlined previously, to inches of water applied per hour by using the following formula:

$$\text{Inches of water applied per hour} = (0.00221) \times \text{Flow rate (GPM)} / \text{Number of acres}$$

For example, a typical SDI system on corn will have 60 inch spacing between dripperline rows with 0.16 GPH emitters spaced at 24 inches. One acre for this system has 42 rows each 208 feet long for a total of 8220 feet. This gives a flow rate 12.10 GPM.

$$(0.00221) \times 17.19 / 1 = .038 \text{ inches per hour which equals } 0.456 \text{ inches in 12 hours}$$

Monitoring Your Drip System

To achieve the high yields and water savings possible with drip irrigation, it is necessary to monitor the system and make adjustments. In addition, regular system monitoring may give advance warning of potential problems.

Monitoring System Pressure and Flow Rates

As presented earlier, measurements of system flow and pressure provide a good picture of the system's performance. Because of the large number of variables at play in an irrigation system, the measured water application rate can not be expected to exactly match the predicted rate. Still, large differences in calculated versus measured values, may indicate a problem with your calculations or a physical system problem such as a broken or clogged line. Over the growing season, changes in the flow rate or pressure in the system can be used to diagnose problems with the system. Table 1, details some of the problems that can be diagnosed by monitoring system pressure and flow rate. This is by no means a comprehensive list but is a good place to start.

With proper care your drip system will last many years. K-State in Colby, Kansas, has had a drip system with older technology continuously operating for 20 years. There is no reason to believe that another 10 to 20 years is possible. As with all of your farm equipment, it all starts with good maintenance.

INDICATION	POSSIBLE PROBLEM
Gradual decrease in flow rate	Emitter plugging Possible pump wear (check pressure)
Sudden decrease in flow rate	Stuck control valve Water supply failure
Gradual increase in flow rate	Incremental damage to dripperline by pests
Sudden increase in flow rate	Broken lateral, submain, main line Pressure regulator failure
Large pressure drop across filters	Debris build-up in filters Inadequate flushing of filters
Gradual pressure decrease at filter inlet	Pump wear or water supply problems
Sudden pressure decrease at filter outlet	Broken lateral, submain, main line Pressure regulator or water supply failure
Gradual pressure increase at filter outlet	Emitter plugging
Sudden pressure increase at filter outlet	Stuck control valve Other flow restrictions
Sudden pressure decrease at submain	Damaged or broken lateral

Table 1. Problems diagnosed from system flow rates and pressures.

GERMINATION AND GROWTH

FIELD CORN PRODUCTION USING SDI - AN OVERVIEW

An SDI system gives precise control over the application of water and fertilizer directly to the root zone. This method of irrigation will work with your current watering and nutritional package, but some refinements in the application of water and fertilizer can greatly improve yields while reducing input costs. This section is simply an introduction to the more detailed sections on Irrigation Scheduling and Fertilization that follow.

There are three critical periods in the lifecycle of corn that greatly affect yield.

1. Seedling growth
2. Pollination
3. Grain filling

Maximum corn yield starts with a strong seedling. The yield potential of the ear is determined 4 weeks after emergence, when the plant is only a foot tall. At this point in the plant's life the embryonic ear is formed. The realization of the potential yield of the embryonic ear occurs during pollination. The need for adequate water during pollination is well documented, but yield is also negatively affected by disease pressure up to and during pollination. An SDI system helps reduce disease pressure by keeping foliage dry during this critical period. Finally, the yield potential of the pollinated ear is realized during grain filling. During this stage, adequate water application is critical while nutritional decisions made earlier in the crop are realized in higher grain weights.

In most regions of the country, the use of SDI does not affect typical planting procedures and early crop development. The crop is seeded into moist soil with a starter charge of fertilizer. The fertilizer charge can be banded dry fertilizer or a liquid charge. There are many formulations of starter fertilizer. To get the most out of an SDI system, a more complete blend that includes N and P, as well as select micronutrients, may be the best choice depending upon the soil nutrient levels. If soil moisture seems inadequate for seed germination, it may be necessary to wet-up the soil using the drip system. Depending upon the depth of the SDI system, this may take a few days so planning is worthwhile. If you are in an area where adequate soil moisture for germination is usually not found, then it may be worthwhile to consider a shallower burial of the SDI system, say around 8 inches. This will make it easier to drive moisture to the surface.

Irrigation scheduling and fertilization of the growing crop is covered in detail in the following Irrigation and Fertilization sections. To maximize yield, maintaining optimal soil moisture is critical. Given that most SDI systems are designed to provide slightly less than the maximum ET, it may be necessary to irrigate even when soil moisture is adequate to build up moisture reserves in the soil. During rapid growth, nitrogen fertilization must be done on a schedule. UAN 32 is the most common and safest form of N for application through the drip system. To supply an adequate amount, generally one pound of N for bushel of yield may require one or more applications per week. Studies have shown that application of N through the drip system is more efficient than other methods and you may find that yields are maintained with less applied N. Using the drip system for fertilizer application will definitely save on tractor passes.

Later in the season during grain filling you may find that application of additional Phosphorous and Potassium will help yields. Phosphorous is the most tricky fertilizer to apply through the drip system so follow the recommendations outlined in the Fertilization section.

This time is generally when the plant experiences the most water stress so maintaining irrigation is critical. The determination of crop water status should include soil moisture measurements as well as ET data.



Figure 7. Grain filling.

IRRIGATION

Introduction

Subsurface drip irrigation (SDI) will keep the soil closer to the optimum water content, can be applied immediately following cutting and requires less labor than sprinkler or flood irrigation. All of these factors attribute to the higher economic yield possible from using SDI to irrigate corn. Irrigation management has the greatest impact on corn yields than any other input. In addition, proper irrigation practices will maximize the benefits of other crop inputs such as fertilizer and pest control. No irrigation system gives as much control over water and fertilizer management as SDI.

The corn yield response to applied irrigation is similar to most crops. As irrigation increases, so does corn yield, but only to the point where crop needs are met. This point for field corn is slightly above the E_{To} , reference ET for the region. Applying water over and above crop requirements does not improve yield and only adds to the cost of production. Moreover, excess water may increase pest and disease problems decreasing the productivity of your corn stand.

The actual shape of the yield response curve varies from location to location and from year to year. The minimum yield without irrigation, the optimum irrigation level and the maximum potential yield vary based on soil type, rainfall and seasonal temperatures. For any given set of conditions, SDI allows for precise control over root zone moisture and higher yield compared to other irrigation systems.

Soil Factors and Irrigation Scheduling

Soil is the storage from which plants extract water (Figure 8). If too much water is applied, the storage reservoir will overflow and water will run off or percolate below the active root zone of the crop. If the storage reservoir gets too low, the plants will be stressed and yield reduced. The science of irrigation management is to keep the storage reservoir at the correct level so stress and runoff is avoided. An SDI system is the tool to manage water application.

Soil type determines the capacity of the soil reservoir. Soil is composed of particles of varied size, organic matter and pore spaces. Water occupies the smaller pore spaces and is held as a film around the soil particles. Sandy soils with large particles have few large pore spaces and relatively low water holding capacity. Fine textured soils have many smaller pore spaces and as a result have a relatively large water holding capacity.

Plant roots also need air (oxygen) to uptake water and nutrients. The root requirement of oxygen for water uptake is a common observation when plants are over-watered. Flooded plants often wilt even though there is plenty of water around. That's because the roots are starved for air. The amount of air held in the soil is inversely proportional to amount of water held. Thus sandy soils hold relatively more air than water compared to fine soils. The real key to irrigation management is to maintain the balance of water to air.

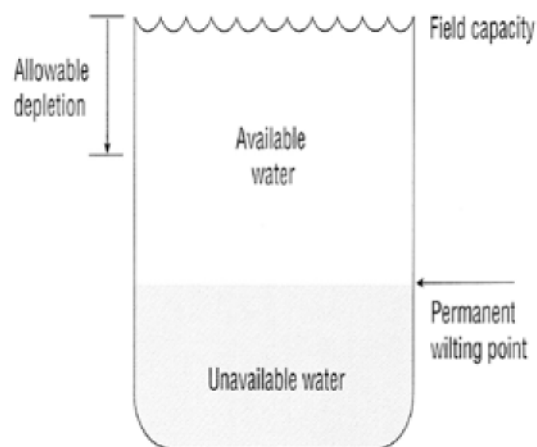


Figure 8. The soil-water reservoir can be thought of as a storage tank with easily available water and water that is bound to the soil and is unavailable for plants to use.

The water status of the soil can be described in the following manner.

1. **Saturation** - the soil is essentially flooded. All pores in the soil contain water. This situation takes place when the rate of water applied exceeds the rate of gravity influenced movement in the soil. This usually occurs immediately after heavy rain or when irrigating using flood and sprinkler systems. The water flow in saturated soil is through the large pores under the influence of gravity.
2. **Field Capacity** - gravity has pulled all the water from the largest pores. The smallest pores hold the water against gravity, while the larger pores are filled with air. This is the optimal condition for crop development; the water is held at a force that is easily overcome by the uptake power of the roots, whereas at the same time the soil is sufficiently ventilated to enable the roots to breathe.
3. **Wilting Point** - not all the water in the soil is available to the plants. The water held in the film around soil particle or in very small pores is held too tight for the plants to remove it. Plants can be observed to wilt even if the soil feels damp. The wilting point is where the water absorption power of the crop cannot overcome the holding power of the soil. Unlike saturation and field capacity which are primarily influenced by the soil, the wilting point is crop dependent as some crops wilt much more easily than others.
4. **Available Water** - the amount of available water is the difference between field capacity, and the wilting point. In a theoretical sense, all of this water is available. However, the available water and allowable depletion are gross large scale descriptions of soil water holding capacity. Soils are not uniform and more importantly crop water extraction will not occur uniformly across the field. Thus, it is not good practice to schedule irrigations to the wilting point. To provide a safety factor, crop irrigation scheduling is designed around "easily available water" which, as a rule of thumb, is assumed to be about 50% of the total available water. This is referred to as the limit of allowable depletion before an irrigation event must be triggered. Soil properties determine the limits of when to irrigate and how much to apply. Corn must be irrigated when no more than 50% of the available water has been depleted. The amount of water to apply is the amount required to fill the soil reservoir to field capacity. Table 2 summarizes typical quantities of available water and allowable depletion for various soil types and for a rooting depth of 4 feet.

SOIL TYPE	AVAILABLE WATER (IN./FT.)	ALLOWABLE DEPLETION (IN./FT.)	AVAILABLE WATER IN 4' ROOT ZONE (IN.)	ALLOWABLE DEPLETION IN 4' ROOT ZONE (IN.)
Coarse Sand	0.5	0.25	2.0	1.0
Loamy Sand	1.0	0.50	4.0	2.0
Sandy Loam	1.5	0.75	6.0	3.0
Fine Sandy Loam	2.0	1.00	8.0	4.0
Clay Loam	2.2	1.10	8.8	4.4
Clay	2.3	1.15	9.2	4.6
Organic Clay Loams	4.0	2.00	16.0	8.0

Table 2. Estimates of available water content and allowable depletion for various soil types.

An allowable depletion of 50% is the maximum limit before an irrigation event must be triggered or there may be loss of yield. This is not the optimum depletion for maximizing corn performance. In general the closer the soil is kept to field capacity the less stress is imposed on the crop and the better the performance. Subsurface drip irrigation allows precise irrigation so that the soil is kept in a narrow, more productive zone of water content.

Irrigation Management

Irrigation management is the scheduling and adjustment of an irrigation program based on the influences of climate and the crop. Irrigation scheduling requires knowledge of the water holding capacity of the soil, as discussed previously, in combination with the water needs of the crop as determined by the crop and its environment. Irrigation and fertigation management is a major factor in maximizing crop productivity and economic returns.

Irrigation Scheduling

The goal of irrigation scheduling is to determine an irrigation duration and frequency that keeps the root zone below field capacity and above the allowable depletion. At this point, the crops roots are exposed to an ample supply of easily available water with sufficient oxygen to promote healthy root growth.

Because drip systems apply water directly to the roots with thousands of water sources throughout the field, they are forgiving of poor irrigation scheduling. However, taking a little time to develop and apply an appropriate irrigation schedule will allow the drip system to operate at maximum efficiency.

Two principle methods are used to schedule irrigation in corn fields. One method is called water budgeting and it involves estimating crop water needs based on the evaporative demand of the environment; the other technique relies on soil-based measurements. Both methods have limitations. The water budgeting method looks at gross water demand and does not specifically look at the crop or soil. Factors are used to adjust for the specific growing conditions. The measurement of soil moisture is limited to the specific areas where measurement devices are placed. If the location of the device is not representative of the entire field, the information can be misleading. The best approach is using a combination of both techniques. Irrigation is most commonly scheduled using water budgeting and verified by measuring soil moisture at select points in the field.

Water Budgeting

Water budgeting involves tracking additions and losses and balancing them. The losses are due to crop water use, any leach requirements and inefficiencies in the irrigation system. The additions are due to irrigation and rainfall. The objective of the water budget method is to maintain soil moisture near the optimum level by keeping track of crop water use and then irrigating to replace the water used. Knowledge of crop water use is essential to using the water budget approach.

Crop water use is also called the evapotranspiration rate (ET). The term evapotranspiration refers to the combined loss of water through evaporation from the soil and from water taken up and evaporated from the plants (transpiration). The rate at which plants use water is determined by the growth stage of the plant, in the case of corn cutting, and the weather. Small plants use less water than large plants and plants generally use more water the hotter or drier the conditions. Wind and clouds also affect the evaporation rate. Figure 9 shows a schematic view of the water use of corn over a growing season.

The reference evapotranspiration rate (ET_o) can be calculated from weather data or measured as evaporation from a calibrated pan of water. Both methods give a close approximation of the environmentally induced evaporation rate from a given area of soil. Real pan evaporators are still used in many parts of the country and are simple to construct (see the end of this section). However, more frequently the ET_o is estimated from weather data which includes, temperature, relative humidity, wind velocity and solar radiation using a modified version of the Penman equation which relates these variables to evaporation rate. A discussion of the Penman equation is beyond the scope of this manual. Suffice it to say that the ET_o for your area is commonly available from a variety of local sources.

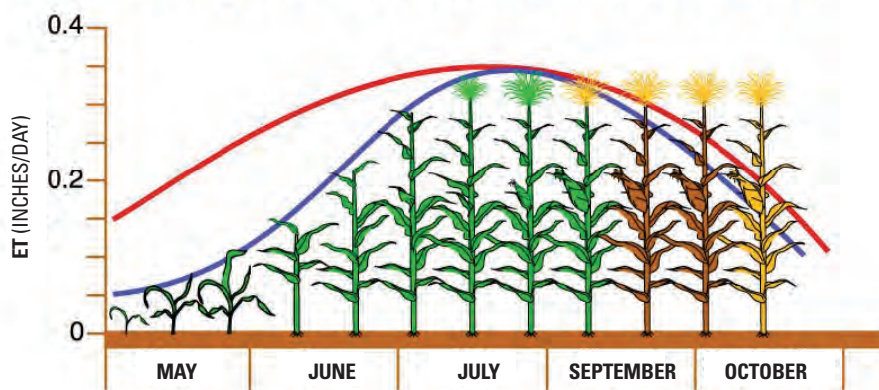


Figure 9. Seasonal water use of corn. The RED line represents the reference ET (ET_o) based on environmental conditions. The BLUE line takes into account the growth stage of the crop.

Actual crop water usage is usually not exactly the same as the reference evaporation rate (ET_o). First, plants regulate how much water they require by closing or opening stomata (small pores in their leaves used to maintain appropriate water levels in the plant). The difference between the actual peak crop water use and the pan evaporation rate is referred to as the crop factor (K_c). The ET of your crop expressed as ET_c can be calculated from the ET_o using the following formula. The following is an example of the calculation of the required irrigation time according to reference evaporation:

$$ET_c = ET_o \times K_c$$

The crop coefficient (K_c) for fully leafed out corn is 1.0. If the ET_o, either measured from a pan or calculated, is 0.4 inches/day then your corn crop will be using:

$$ET_c = 0.4 \times 1.0 = 0.4 \text{ inches/day (2.8 inches/week) for a fully leafed out crop}$$

Under these conditions, irrigations should be scheduled twice per week. An SDI system can be easily set to provide even daily irrigations with little labor input. More frequent irrigations will keep the soil moisture easily available to the plants and increase the speed of regrowth following cutting. During peak ET periods, daily irrigations should be considered.

The water budget system for irrigation is relatively straightforward, but must be adjusted for crop growth stage. Table 3 lists the crop coefficient and irrigation requirements for corn at various growth stages. Using this data daily irrigation requirements - number of hours to return the water that was consumed by the crop - can be calculated.

GROWTH STAGE (%)	CROP COEFFICIENT (K _c)	GROWTH STAGE INDICATORS	REFERENCE ET (ET _o)	DAILY CROP REQUIREMENT ET _c (IN./DAY)
0	0.30	EMERGENCE	0.3	0.09
10	0.30		0.3	0.09
20	0.32		0.3	0.096
30	0.35		0.3	0.105
40	0.40		0.3	0.12
50	0.51		0.3	0.153
60	0.60		0.3	0.18
70	0.70		0.3	0.21
80	0.80		0.3	0.24
90	0.90		0.3	0.27
100	1.00	TASSELING	0.3	0.30
110	1.00		0.3	0.30
120	1.00		0.3	0.30
130	1.00		0.3	0.30
140	0.98		0.3	0.29
150	0.95		0.3	0.285
160	0.92		0.3	0.276
170	0.89		0.3	0.267
180	0.86		0.3	0.258
190	0.83		0.3	0.249
200	0.80	HARVEST	0.3	0.24

Table 3. Crop coefficient and various irrigation requirements at various growth stages.

A common hourly application rate for an SDI system is 0.05 inches/hour. Using this application rate, the required irrigation time at 100% growth would be as follows:

$$\text{Irrigation time} = \text{daily water needs} / \text{hourly rate}$$

$$(0.3 / 0.05) = 6 \text{ hrs/zone for a mature crop}$$

A simple spreadsheet can be used to calculate the ET_c and the irrigation required to fill up the soil reservoir. In the above example, it takes 6 hours to apply the daily ET_c. The plant water needs would be satisfied with a six hour irrigation each day. In practice, 4 blocks could be irrigated with this water supply with each block being irrigated for 6 hours per day. When irrigating multiple blocks, it is a good idea to schedule irrigations so that the same field is not irrigated at the same time each day. In the above example, each of the three fields could be irrigated for 2 hours so that all three fields are irrigated during the day or and at night. While it would be possible to set irrigation at a lower frequency, experience has shown that more frequent irrigations give better results.

Influence of Rainfall on Irrigation

In many regions there is rainfall during the irrigation season. It is necessary to consider the quantity of water provided by the rainfall based on the soil condition and crop. The agronomical term "Effective Rainfall" refers to that part of rainfall considered as available water.

If the rainfall provides less than ¼ inch and is the first rain, there is no need to consider this amount as a water contribution to the soil. Stronger rainfall providing ½ inch or more must be taken in account according to the specific circumstances.

It is difficult to predict which part of rainfall is the effective rain. However, in the case of strong rainfall providing up to 2 inches, the effective rain may be no more than 60% of the total quantity. If a rainfall provides 2 inches or more, only 1 ½ inch will be considered as effective rain and the rest will be runoff.

It is obvious that these calculations require a certain amount of interpretation. It is highly recommended to check the status of the water in the soil in the active root zone using the hands, soil drill or tensiometers before resuming irrigation. The use of a tensiometer may provide valuable information, since the readings will indicate the presence of water in the root zone.

Monitoring Soil Moisture

Measuring the soil moisture content is a good way to check and make adjustments to the irrigation schedule. In areas that receive significant rainfall, soil moisture measurements are critical in assessing the amount of useful water received in a rain event.

There are several practical ways to assess soil moisture content. Experienced irrigation specialists can use the "look and feel" method where the moisture level is determined by handling a soil sample. This is an excellent way to confirm the measurements given by more sophisticated equipment.

Tensiometers measure the strength which the soil is holding onto the water (soil matrix potential). Tension is a measure of the work a plant must do to remove water from the soil. The higher the tension, the harder the plant must work to remove water from the soil. Tension is usually expressed in bar or centibar (1 bar = 100 centibar). The drier the soil, the more tightly the soil holds onto the water and the higher the tension measurement. The main drawback to tensiometers is they require a certain skill to set-up and operate properly.

There are numerous sensors which measure the moisture content of the soil. The most common are moisture blocks and new sensors such as capacitance and resistance sensors are being developed all the time. Moisture content is a measurement of the water contained in the soil as a percentage of the volume of the entire soil solution. In general, sensors do not measure the moisture content directly but use an electronic calculation to infer the water content of the soil. Measurements expressed as moisture content can directly indicate how much water you need to apply to bring the soil to field capacity. The main drawback to these sensors is that they are sensitive to salts in the soil and water. Newer models do a good job of correcting for salt concentration, but they may need to be calibrated more often than you think.

To get a complete picture of the water status of the soil, it's best to take soil moisture measurements at several depths. Portable sensors can simply be inserted at different depths while inexpensive sensors can be buried permanently at the desired depth. Select a minimum of 2 sites to verify conditions across the field. Table 4 illustrates the information obtained by sensors at varied depths.

DEPTH BELOW SURFACE	RESULT
6 inches	Reflects moisture content in the root zone in young or shallow rooted crops
12 inches	Monitors the root zone as plants mature and their root systems enlarge - this is the most active root zone
24 inches	Monitors the degree of leaching below the root zone - the moisture level here should change little during drip irrigation

Table 4. Sensor depth. Actual depth below surface may vary depending upon crop type and rooting depth.

Monitoring Soil Salinity

Even with low salinity water, salt can accumulate in the soil unless some leaching occurs. In addition to the salts that are in the soil and are a part of almost all irrigation water, fertilizers can add to the salt content. It is a good practice to send irrigation water and soil samples to a lab for analysis. In problem areas, consider purchasing an EC sensor which will give instantaneous readouts of water and soil salt conditions. If salt levels are found to be increasing over time, it is necessary to include a leach factor to your irrigation system.

Constructing Your Own Pan Evaporator

It is possible to construct your own pan evaporator. The pan is round-shaped with a diameter of 48 inches and a depth of 10 inches. It is fabricated from galvanized steel, coated with aluminum paint, and installed on a wooden platform. A pallet works great. The pan base must be at least 2 inches above the ground. The pan is filled with water to about 2 inches under the brim. The pan must be placed in an open space. There should not be any tall objects such as buildings or trees that could cast a shadow on the pan or obstruct the wind at a radius of 175 feet. There should not be weeds around the pan at a radius of 75 feet. A level reading must be performed daily at the same time, usually in the early morning. The reading will display the evaporation value of the previous day. If a reading is not taken during the weekend, it is possible to take the reading after the weekend and to calculate the average for each day. It is a good idea to keep permanent records because these readings could serve as a valuable tool for planning the water quantities required for irrigation in different seasons.

Note: Deficit irrigation, an irrigation schedule that deliberately keeps soil moisture below field capacity, can be used to conserve water during times of interrupted supply. Recent research has shown that deficit irrigation used at correct times during the growing season can result in significant water savings with little effect on yield. Because entire sections of the field are irrigated uniformly, drip irrigation is better suited than all other irrigation systems for precise deficit irrigation.



Figure 10. Evaporation pans.

FERTILITY

Subsurface Drip Corn Fertility

Subsurface drip irrigation applies fertilizer directly to the root zone - nutrification. This is the most efficient method to deliver fertilizer, water, and chemicals to irrigated crops such as corn. The ability to use the SDI system for delivering these inputs means more effective timing and utilization of fertilizers without the additional cost of traditional application practices thereby reducing both labor and energy. As a result, it is possible to maintain a near optimum level of nutrients in the soil solution, available to the plants, helping promote plant health, production and return per unit applied.

This guide is not meant as a complete treatise on corn nutrition. It is meant as a guide to properly feed your crop using the SDI system. A more thorough approach to nutrient management in the Midwest is found in an appendix.

Essential Plant Nutrients

Fourteen mineral elements are needed in varying amounts for plant growth. In the case of corn, nutrients are not only required to produce the grain, which is approximately 50% of the total yield, but the additional fodder which makes up the other 50% - see Table 5. The nutrients most often required by corn are nitrogen, phosphorous, potassium, calcium, magnesium and zinc. The remaining elements are also important, but vary in amounts and frequencies depending on the region. Table 6 shows the percent dry matter and pounds per acre used at 240 bu/acre.

Evaluating the nutrient status of the crop and soil is a key aspect of designing a fertility program for the corn crop. This evaluation can be done by visual observation of previous crops, soil analysis and plant tissue testing. Using all three provides the best results. Always examine your crop looking for nutrient deficiencies that might exhibit symptoms such as light green streaking in the leaves common with zinc deficiency. Consult you local extension for visual guides for each of the nutrient deficiencies that are common in your region. Unfortunately, visual symptoms can often be confused with insect injury, diseases and restricted root growth. In addition, once a deficiency results in a visual symptom there has already been a yield reduction. Therefore, it is good to be familiar with deficiency symptoms in the odd case they are manifested during growth, but more emphasis should be placed on soil and tissue samples.

ESSENTIAL ELEMENTS	SYMBOL	APPLICATION
Nitrogen	N	Frequently
Phosphorous	P	Frequently
Potassium	K	Frequently
Calcium	Ca	Less Frequent
Magnesium	Mg	Less Frequent
Sulphur	S	Frequently
Iron	Fe	Less Frequent
Manganese	Mn	Less Frequent
Chlorine	Cl	Seldom
Boron	B	Seldom
Zinc	Zn	Frequently
Copper	Cu	Seldom
Molybdenum	Mo	Seldom
Nickel	Ni	Seldom

Table 5. Elements and applications.

COMPOUND DRY MATTER	% TOTAL	LB./ACRE @ 240 bu
Grain	48	11,520
Stalks	22	5,325
Leaves	10.6	2,565
Sheaths	5.3	1,283
Husks	4.3	966
Shanks	1.5	363
Cobs	7.5	1,815
Tassels	.5	122
Lower Ears	.5	122
Silks	.2	48
Total	100	24,203
Total lbs. N/Acre	259	
Total lbs. P/Acre	117	
Total lbs. K/Acre	219	

Table 6. Percent dry matter and pounds per acre.

Soil tests provide an estimate of nutrient availability for uptake by plants. Soil tests must be taken prior to planting and the soil amended based on the laboratory recommendations for corn. If possible, soil samples should be taken at a depth of 8 inches, 24 inches and sometimes 36 inches. This will give an indication about nutrient movement in the soil and uptake by the plants.

Taking soil samples from a drip irrigated field is slightly different than sprinkler or flood irrigated fields. The drip system creates a wetted area in the soil profile. Nutrients injected through the drip system are only found in this wetted area. It is important to sample within this wetted area to get a good assessment of the fertility of the soil. The goal is to test near the dripperline but not to hit it. This can be tricky. It is a good idea to develop some type of marker system so you can find an appropriate spot. Some growers rely solely on soil testing to determine their fertilizer regime during the life of the crop. However, it is more common to use tissue tests for this purpose. The objective of soil testing is to get a fertility map of the field.

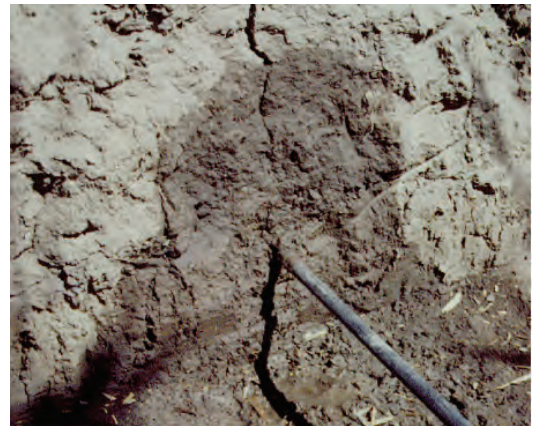


Figure 11. Wetted soil area around dripperline.

Samples should be taken from areas that are troublesome as well as productive regions often referred to as benchmark areas. The benchmark areas should be chosen so that they can be located year after year.

Plant tissue testing is by far the most precise method of determining the nutrient needs of corn. Such tests are the best reflection of what nutrients the plant has taken up and are far more accurate than soil tests. Plant tissue tests give rapid feedback on the current fertility status of the plants and the effectiveness of fertilization. Plant tissue samples should be taken at V4-V5, 25-30 plants, V12-V14, the first collared leaf down from the whorl, 25-30 plants prior to tassel, and R2 blister. Collect two leaves, the ear leaf and the first leaf above the ear, 25-30 samples.

Tissue tests can determine only the single most limiting nutrient, the tissue concentration of other nutrients even if in short supply may appear to be normal because of reduced growth. Therefore, after a deficiency is corrected another tissue sample should be taken and analyzed to see if other elements are limiting growth. Also, low nutrient concentrations in plant tissue may not mean a deficiency in the soil. A problem affecting plant roots such as nematodes, insects or herbicide damage will reduce nutrient uptake. This is a good reason to use a combination of tissue and soil analyses. Table 7 shows some recommended nutrient levels at various growth stages.

CORN GROWTH STAGE	N %	S %	P %	K %	Mg %	Ca %	Fe (ppm)	Zn (ppm)
V2	4.5	0.19	0.48	4	0.15	0.34	190	60
V4	4.3	0.22	0.49	3.7	0.17	0.35	185	58
V6	4.1	0.24	0.49	3.5	0.18	0.37	174	55
V8	3.9	0.25	0.46	3.2	0.19	0.39	164	50
V10	3.75	0.25	0.43	2.9	0.2	0.41	150	48
V12	3.6	0.24	0.4	2.6	0.21	0.42	141	45
V14	3.45	0.24	0.38	2.35	0.21	0.48	137	40
Tassel	3.35	0.23	0.35	2.25	0.21	0.46	134	40
R1 Silking	3.15	0.21	0.33	2.2	0.21	0.47	134	40
R2 Blister	2.8	0.19	0.29	2.05	0.22	0.5	140	30
R4 Dough	2.5	0.16	0.26	2	0.22	0.54	150	27
R5 Early Dent	2.32	0.15	0.22	1.9	0.21	0.57	152	23
R6 Dent	2	0.14	0.21	1.85	0.21	0.58	150	22

Table 7. Recommended nutrient levels.

Correcting Nutrient Deficiencies

There are several strategies for correcting nutrient deficiencies in corn fields with SDI. During field preparation, it is recommended to broadcast or knife in and incorporate appropriate levels of fertilizer according to soil tests to achieve adequate levels in the soil. During the growth of the crop, nutrients are supplied through the SDI system to maintain vigor and maximize yield. Depending upon soil type, fertigation may be done as frequently as once or twice a week. Even though the nutrients supplied via the SDI system are delivered directly to the root zone, they should be applied a minimum of one to three weeks before the expected need. Table 8 shows the nutrient requirements for corn based on the stages of growth for a yield of 240 bushels. These rates will vary by region but timing of application remains the same.

CORN GROWTH STAGE	DAYS AFTER PLANTING	NITROGEN LB./ACRE	P205 LB./ACRE	K20 LB./ACRE
Early	0 - 25	19	4	22
Rapid Growth	25 - 50	84	27	104
Silk	50 - 75	75	36	72
Grain	75 - 100	48	25	36
Mature	100 - 125	14	8	8
TOTALS	Harvest	240	100	240

Table 8. Nutrient requirements based on the stages of growth for a yield of 240 bushels.

Not all fertilizer formulations are suitable for injecting through the SDI system. The fertilizers must be soluble and have a low propensity for reacting with the water and forming precipitates. Figure 12 lists many common fertilizers that are compatible with the drip system. Your local Netafim Dealer will guide you in the right direction regarding fertilizers which are not compatible with the drip system.

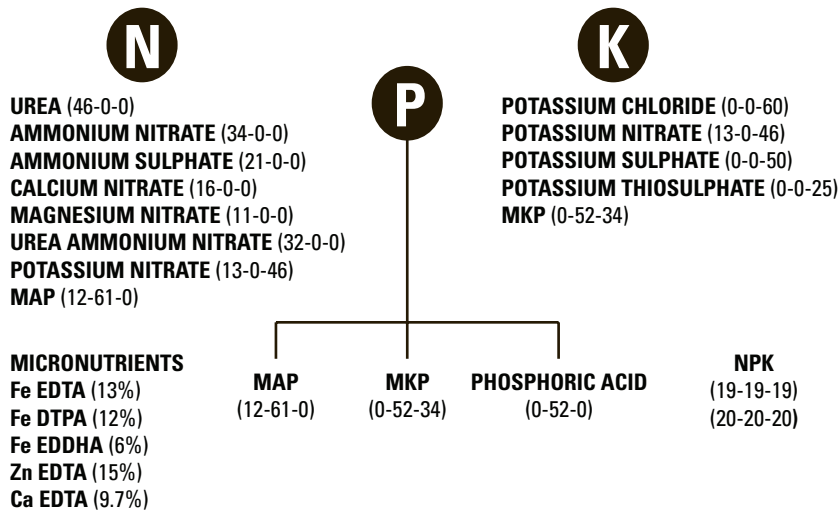


Figure 12. Soluble fertilizers suitable for application through a drip system.

Above sources of N, P & K are not all water soluble. Nitrogen should be UAN and phosphate blends that do not contain any 10-34-0 should be discussed. In areas where drip irrigation is prevalent, fertilizer formulators can be found to produce the desired nutrient mix. In areas where fertilizer dealers are not familiar with fertilizers compatible with drip irrigation, consult your local Netafim Dealer or representative.

When choosing the right fertilizer to put through the drip system, of particular concern are elements that may react with each other or with the water and form precipitates which may clog the drip system. Polyphosphates (10-34-0 and 11-37-0) can not be injected into SDI systems as they contain a high % of polyphosphates and NH₃ and the NH₃ is more of a problem than the polyphosphates. The products used most successfully are a mixture of ortho and polyphosphates. Gold Start 10-10-10 is a good example of a blended fertilizer with very little NH₃ which must be avoided as it is highly reactive with calcium and magnesium in the water. Sulfates can also react with calcium and magnesium to form gypsum in the dripperline. In most cases, micronutrients are supplied as chelates which are highly soluble and available to the plant.

Nitrogen

Nitrogen is one of the major plant nutrients required with corn production. Paying close attention to application rates and timing will greatly affect return on investment. Nitrogen is also one of the most mobile nutrients that can be leached readily with excess water from rain or irrigations. The corn plant doesn't require significant amounts of N until 3 weeks after germination. SDI eliminates the early preplant applications of large amounts of N common in growing furrow or sprinkler irrigated corn.

Phosphorous

Phosphorous is also one of the major nutrients required for corn. Starting the field with appropriate phosphorous levels is critical to a good stand. Any good quality source of phosphorous can be incorporated in the field as a preplant. Corn responds very well to liquid P starter fertilizers sprayed into the seed drill. In high pH soils, it is not recommended to mix zinc with the P because it tends to tie up quickly in the soils and become unavailable to the plant. Phosphorous sources appropriate for application through the drip system include, Mono Ammonium Phosphate (MAP), Mono Potassium Phosphate (MKP) and phosphoric acid. MKP is expensive, but highly soluble and an excellent source of potassium as well as phosphorous. Again in high pH water, it might be necessary to amend the water with sulphuric acid to lower the pH and keep the P in solution. Dry sources of P may also be used if placed in an area where the early root development will find it. Phosphoric acid is good if the pH of the soil or water is a little high, but it is also expensive. When using phosphoric acid, be aware of high calcium and magnesium levels in the water as they may react.

Potassium

Potassium is the forgotten nutrient. It is often available in adequate amounts, but the crop will still respond to added potassium. There are several good choices for adding potassium through the drip system. Potassium chloride is generally the cheapest but potassium sulfate, ammonium thiosulfate, and potassium thiosulfate are good choices if you need added sulphur. Mono Potassium Phosphate is an expensive but excellent source of potassium and phosphorous. Don't forget that corn uses one unit of K for every unit of N applied. Keep a close watch on K levels in the tissue tests.

Sulphur

It is important to have an adequate level of sulphur in the soil prior to planting. However, soil tests are not a reliable method for predicting sulphur deficiency in a growing crop. The best approach is to determine if there is a history of sulphur deficiency in your area. If sulphur is needed, the most economical practice is to broadcast apply and incorporate elemental sulphur at 200 to 300 pounds per acre. At this rate, elemental sulphur can last 4 to 7 years. The elemental sulphur will be gradually converted to the phytoactive sulphate form. To ensure a long slow release, the particle size of the sulphur should range from 10 percent 100 mesh to 60 percent 6 mesh. The finer 100 mesh particles will convert to sulphate faster than the larger particles. A good source of S, K, and Mg is KMAG, a mined dry fertilizer Potassium Magnesium Sulfate. For injecting sulphur through an SDI system, KTS is a good source.

Iron

Iron deficiency must be confirmed with a tissue test. Chelated iron is the best choice for application through the drip system.

Boron

Corn needs this nutrient early from germination to V5 and late in pollination to maturity. Watch tissue levels and apply when necessary. It is only required in very small amounts and is usually one of the minors supplied in common micro element packages added to liquid fertilizers.

Calcium and Magnesium

Calcium and magnesium are important in the pollination production and pollination of the ear. The levels of these nutrients in the soil should be adjusted prior to planting. Alkaline water or soil can contain a lot of calcium and magnesium in comparison to potassium, which makes it important to apply maintenance potassium even if the soil analysis indicates adequate potassium levels. Gypsum and magnesium sulfate are good sources for these nutrients.

Fertigation

Fertigation is the application of liquid or dissolved water soluble fertilizer through the irrigation system in a controlled and efficient manner. The best way to maximize the performance of corn is to install a fertigation unit that will accurately inject fertilizers into the water supply for uptake by the crop.

Corn yield is a function of kernel count and kernel weight. The number of kernels per acre will vary based on other components including plants per acre, ears per plant and kernels per ear. The number of kernels per ear is a function of ear length (kernels per row) and kernel rows per ear. Generally both of these traits begin to be determined between V6 and V8 as the ear shoots are formed. Thus, it may be prudent to install a sophisticated watering system that has fertigation capabilities in order to apply the required nutrients as quickly and effectively during all stages of growth not allowing fertility to become a limiting factor.

Figure 13 is a more sophisticated irrigation control and fertigation system. This system controls multiple valves and has multiple injection pumps. It also allows monitoring of the EC and pH in the water during fertigation. This is important because drip irrigation applies fertilizer mixed with water directly into the active root zone. Excess fertilizer such as N can cause the EC to increase to a level that could damage tender roots. Remember that most fertilizers are salts and too much is not good. Growers with poor quality water and complex irrigation requirements may be better served with such a system. Your Netafim Dealer can supply a system that is appropriate for your environment.



Figure 13. Netafim fertilizer injection system.

DRIP SYSTEM MAINTENANCE

The maintenance of an SDI system centers on identifying the factors which can lead to reduction of the performance of the drip system and procedures to mitigate these negative impacts. Factors that can slow or stop flow through the drip system include; suspended material, chemical precipitation, biological growth, root intrusion, soil ingestion and crimping of the dripperline. To ensure maximum system life requires reducing or eliminating the impact of these negative factors. This may require water treatment and a systematic program for regular maintenance. In this section, we outline the various potential issues that can adversely affect the drip system and offer procedures to mitigate the potential damage.

Water Quality

The type of emitter plugging problems will vary with the source of the irrigation water, either surface or ground water. In general, algae and bacterial growth are usually associated with the use of surface water. Whole algae cells and organic residues of algae are often small enough to pass through the filters of an irrigation system. These algae cells can then form aggregates that plug emitters. Residue from decomposing algae can accumulate in pipes and emitters and support the growth of slime-forming bacteria. Surface water can also contain larger organisms such as moss, fish, snail, seeds and other organic debris that must be adequately filtered to avoid plugging problems. Groundwater, on the other hand, may contain high levels of minerals that can challenge emitter function. Water from shallow wells (less than 100 feet) often will produce plugging problems associated with bacteria. Chemical precipitation is more common with deep wells.

A water quality analysis can give the grower a “heads up” on potential trouble areas for the drip system. This test should be accomplished before the final design of the system to ensure that proper components are installed to address any problem areas. Many laboratories around the United States have Water Quality Analysis services available which are able to conduct a “Drip Irrigation Suitability Test”. The analysis should include testing for pH, dissolved solids, manganese, iron, hydrogen sulfide, carbonate and bicarbonates. Table 9 lists the more common water quality issues with drip irrigation. Having a water analysis in the moderate or even severe category does not mean drip irrigation cannot be used, but only that special precautions must be applied to prevent problems. Consult your local Netafim Dealer for more information on water quality and drip irrigation.

TYPE OF FACTOR	MINOR	MODERATE	SEVERE
SUSPENDED SOLIDS (ppm)			
Inorganic	< 10	10 - 100	> 100
Organic	< 10		> 10
CLOGGING (ppm)			
Iron	0.0 - 0.1	0.1 - 0.4	0.4 +
Manganese	0.0 - 0.2	0.2 - 0.4	0.4 +
Sulfides	0.0 - 0.1	0.1 - 0.2	0.2 +
Calcium Carbonate	0.0 - 50.0	50.0 - 100	.0 - 50.0
BIOLOGICAL			
Bacteria Populations	10,000	10,000 - 50,000	10,000

Table 9. Water quality factors and their influence on crop and drip system performance.

Suspended Solids

Suspended solids in the incoming water are the most common stress impinging upon the drip system and the easiest to control. Each and every Netafim emitter has a large filter built into the unit to keep suspended particles from being trapped in the labyrinth. This filter is located toward the center of the drip pipe so that it can be cleaned by flushing the dripperline. This built-in filter plays an important role in the longevity of the SDI system. Thus, most water used for drip irrigation must be filtered to remove suspended solid particles that can lodge in the emitters and reduce or even stop the flow. These particles can be either organic such as algae or inorganic such as sand. Each manufacturer recommends a filtration level based on the technology of the emission device. The Netafim emitters commonly used for corn production require 120 mesh filtration. This is the lowest filtration requirement of any commercial drip irrigation product. That means that the emitters are more reliable ensuring long service even under harsh conditions.

Surface water generally contains a combination of organic and inorganic suspended particles. These include algae, moss, aquatic animals as well as suspended sand, silt and clay particles. Filtering this mix of material is a challenge that is best accomplished using three-dimensional filtration, such as disc or sand media. Well water generally has lower levels of suspended solids which can be handled using disc filtration or in cases of very low contaminant levels screen filters. If large quantities of sand are being generated by the well, a sand separator may be installed before other filters. Filters for SDI should automatically clean (backflush) during operation when the contaminant levels get high enough (see Drip System Components for more information).

Chemical Precipitation

Chemical plugging usually results from precipitation of one or more of the following minerals: calcium, magnesium, iron or manganese. The minerals precipitate from solution and form encrustations (scale) that may partially or completely block the flow of water through the emitter. Water containing significant amounts of these minerals and having a pH greater than 7, has the potential to plug emitters. Particularly common is the precipitation of calcium carbonates, which are temperature and pH dependent. An increase in either pH or temperature reduces the solubility of calcium in water and results in precipitation of the mineral.

When groundwater is pumped to the surface and discharged through a micro-irrigation system, the temperature, pressure and pH of the water often changes. This can result in the precipitation of calcium carbonates or other minerals to form scale on the inside surfaces of the irrigation system components. A simple test for identifying calcium scale is to dissolve it with vinegar. Carbonate minerals dissolve and release carbon dioxide gas with a fizzing, hissing effervescence.

Iron is another potential source of mineral deposits that can plug emitters. Iron is encountered in practically all soils in the form of oxides, and it is often dissolved in groundwater as ferrous bicarbonate. When exposed to air, soluble ferrous bicarbonate oxidizes to the insoluble or colloidal ferric hydroxides and precipitates. The result is commonly referred to as "red water" which is sometimes encountered in farm irrigation wells. Manganese will sometimes accompany iron, but usually in lower concentrations.

Hydrogen sulfide is present in many wells. Precipitation problems will generally not occur when hard water, which contains large amounts of hydrogen sulfide, is used. Hydrogen sulfide will minimize the precipitation of calcium carbonate (CaCO_3) because of its acidity.



Figure 14. Dripper with calcium precipitate. The black pieces are parts of the cut-away plastic dripperline and not contaminants.

Fertilizers injected into a drip system may contribute to plugging. This may be the result a chemical reaction that occurs when different fertilizers are mixed or because the fertilizer in question is not completely soluble. This type of plugging is completely preventable. To determine the potential for plugging problems from fertilizer injection, the following test can be performed:

1. Add drops of the liquid fertilizer to a sample of the irrigation water so that the concentration is equivalent to the diluted fertilizer that would be flowing in the lateral lines.
2. Cover and place the mixture in a dark environment for 12 hours.
3. Direct a light beam at the bottom of the sample container to determine if precipitates have formed. If no apparent precipitation has occurred, the fertilizer source will normally be safe to use in that specific water source.

Biological Growth

A micro-irrigation system can provide a favorable environment for bacterial growth, resulting in slime buildup. This slime can combine with mineral particles in the water and form aggregates large enough to plug emitters. Certain bacteria can cause enough precipitation of manganese, sulfur and iron compounds to cause emitter plugging. In addition, algae can be transported into the irrigation system from the water source and create conditions that may promote the formation of aggregates.

Emitter plugging problems are common when using water that has high biological activity and high levels of iron and hydrogen sulfide. Soluble ferrous iron is a primary energy source for certain iron-precipitating bacteria. These bacteria can attach to surfaces and oxidize ferrous iron to its insoluble ferric iron form. In this process, the bacteria create a slime that can form aggregates called ochre, which may combine with other materials in the micro-irrigation tubing and cause emitter plugging. Ochre deposits and associated slimes are usually red, yellow, or tan.

Sulfur slime is a yellow to white stringy deposit formed by the oxidation of hydrogen sulfide. Hydrogen sulfide (H_2S) accumulation in groundwater is a process typically associated with reduced conditions in anaerobic environments. Sulfide production is common in lakes and marine sediments, flooded soils, and ditches; it can be recognized by the rotten egg odor. Sulfur slime is produced by certain filamentous bacteria that can oxidize hydrogen sulfide and produce insoluble elemental sulfur.

The sulfur bacteria problem can be minimized if there is no air-water contact until water is discharged from the system. Defective valves or pipe fittings on the suction side of the irrigation pump are common causes of sulfur bacteria problems. If a pressure tank is used, the air-water contact in the pressure tank can lead to bacterial growth in the tank, clogging the emitter. The use of an air bladder or diaphragm to separate the air from the water should minimize this problem.



Figure 15. Filamentous sulfur slime completely clogging a small water meter.

Root Intrusion

Plant roots tend to grow toward soil areas with the highest water content. Because of this tendency, roots can clog subsurface drip systems by growing into the emitter openings. Plant roots tend to “hunt” for water when it is in short supply thus, the problem seems to be more acute when irrigation is not sufficient for the plant’s needs. This is a particular problem in systems that are left unused for part of the season. Several strategies can be employed to reduce the possibility of root intrusion.

1. Short frequent irrigations keep adequate water in the root zone so the roots have no need to look for water.
2. Acid injection that lowers the pH to less than 4 will discourage root growth and can be used to clean roots out of emitters with small amounts of root intrusion. High concentrations of chlorine (100 to 400 ppm), N-pHURIC, phosphoric or metam sodium (Vapam) will also destroy roots in the emitters.
3. In areas where it is allowed, trifluralin is an effective inhibitor of root growth and can be used to prevent root intrusion.
4. Seamed tape encourages roots to grow along the seam and into the emitter. Netafim products are designed without a seam to discourage this intrusion.

Soil Ingestion

Soil ingestion is not a problem in properly designed SDI systems. Soil ingestion occurs when soil is sucked into the dripperline. When a drip system is shut off, the water continues to flow to the low end of the field creating a vacuum at the higher end, sucking saturated soil into the line. A properly designed drip system will minimize this potential problem. Supply manifolds must be equipped with vacuum relief vents. These vents allow air to flow into the dripperlines when the system is shut off. Using high quality Netafim vents will allow sufficient air into the system. Insufficient air will create a vacuum the same as no vent. This is not a good place to skimp.

Crimping of the Dripperline

Pinching of the dripperline can occur as the result of soil disturbance by equipment or drying out. Because the SDI system for corn is generally buried between eight to sixteen inches deep, equipment pressure and drying out are not usually problems. Still because it is difficult to correct crimping in an SDI system, many corn growers are setting up their system so there is minimum traffic on the dripperlines. The lines are installed using GPS and the field is laid out so there are specific traffic rows, like a wide bed. This setup does not adversely affect yields since any time traffic runs over plants, yields for those plants are reduced.



MAINTENANCE PROCEDURES

Filter Maintenance

Follow the standard instructions for the maintenance of the filter system. Filters are the first line of protection for the drip system and they need regular maintenance to operate at a high level. On a bi-weekly basis observe the system as it completes a backflush cycle. Make sure all pressures are within the system limits before and after backflushing. Check the operation of backflush valves, pressure differential switches and the controller. Make sure to clean the command filter. At the end of the season, check the media level in media tanks. Scum can build up on disc filters and the discs may need to be cleaned with acid. In areas that experience a freeze, drain all water from the filter, valves and command system.

Dripperline Flushing

To minimize sediment build up, regular flushing of drip irrigation pipelines is recommended. The system design should be such that a minimum flush rate of 1.5 ft/sec can be obtained in the lines. Valves large enough to allow sufficient velocity of flow should be installed at the end of mains, submains and manifolds. Also, allowances for flushing should be made at the ends of lateral lines. Begin the flushing procedure with the mains, then proceed to submains, manifolds and finally to the laterals. Flushing should continue until clean water runs from the flushed line for at least two minutes. A regular maintenance program of inspection and flushing will significantly help prevent emitter plugging. Flushing is required both at system startup and shutdown. At shutdown it is best to flush all fertilizer from the lateral lines prior to shutting the irrigation system down.

Chemical Treatment

Chemical treatment is often required to prevent emitter plugging due to microbial growth and/or mineral precipitation. The attachment of inorganic particles to microbial slime is a significant source of emitter plugging. Chlorination is an effective measure against microbial activity. Use chlorine and all other chemicals only according to label directions. Acid injection can remove scale deposits, reduce or eliminate mineral precipitation and create an environment unsuitable for microbial growth.

CHLORINE INJECTION

Overview

Chlorination is the most common method for treating organic contaminants. Active chlorine is a strong oxidizer and as such, is useful in achieving the following:

1. Prevent clogging and sedimentation of organic substances.
2. Destroy and decompose sulfur and iron bacteria, as well as accumulated bacterial slime in the system.
3. Improve performance of filtration systems while reducing backflush water.
4. Clean systems of organic sediments (chlorine has no effect on scale deposits).

If the micro-irrigation system water source is not chlorinated, it is a good practice to equip the system to inject chlorine to suppress microbial growth. Since bacteria can grow within filters, chlorine injection should occur prior to filtration.

Liquid sodium hypochlorite (NaOCl), laundry bleach, is available at several chlorine concentrations. The higher concentrations are often more economical. It is the easiest form of chlorine to handle and is most often used in drip irrigation systems. Powdered calcium hypochlorite (CaCOCl_2), also called High Test Hypochlorite (HTH), is not recommended for injection into micro-irrigation systems since it can produce precipitates that can plug emitters, especially at high pH levels. The following are several possible chlorine injection schemes:

1. Inject continuously at a low level to obtain 1 to 2 ppm of free chlorine at the ends of the laterals.
2. Inject at intervals (once at the end of each irrigation cycle) at concentrations of 20 ppm and for a duration long enough to reach the last emitter in the system.
3. Inject a slug treatment in high concentrations (50 ppm) weekly at the end of an irrigation cycle and for a duration sufficient to distribute the chlorine through the entire piping system.

The method used will depend on the growth potential of microbial organisms, the injection method and equipment, and the scheduling of injection of other chemicals.

When chlorine is injected, a test kit should be used to check to see that the injection rate is sufficient. Color test kits (D.P.D.) that measure “free residual” chlorine, which is the primary bactericidal agent, should be used. The orthotolidine-type test kit, which is often used to measure total chlorine content in swimming pools, is not satisfactory for this purpose. D.P.D. test kits can be purchased from irrigation equipment dealers. Check the water at the outlet farthest from the injection pump. There should be a residual chlorine concentration of 1 to 2 ppm at that point. Irrigation system flow rates should be closely monitored and action taken (chlorination) if flow rates decline.

Chlorination for bacterial control is relatively ineffective above pH 7.5, so acid additions may be necessary to lower the pH to increase the biocidal action of chlorine for more alkaline waters. Since sodium hypochlorite can react with emulsifiers, fertilizers, herbicides, and insecticides, bulk chemicals should be stored in a secure place according to label directions.

Recipe for Chlorine injection

WARNING! Active chlorine solutions are dangerous to human beings and animals. The manufacturer’s instructions must be followed very carefully. When using chlorine, proper protection for the eyes, hands and body parts must be worn; i.e. glasses, gloves, shoes, etc. Chlorine contact with the skin can cause serious burns, contact with the eyes can cause blindness and swallowing may be fatal. Prior to filling any tank with chlorine solution, be sure it is absolutely clean of fertilizer residue. Direct contact between chlorine and fertilizer can create a thermo-reaction, which can be explosive. This is extremely dangerous! The direct contact of chlorine and fertilizer in the irrigation water after it has been injected into the system is not hazardous.

The contact of free chlorine in water and nitrogenous (ammonium and urea) fertilizer creates the combination of chlor-amine which is called “combined chlorine”. Hence, if possible, avoid any application of ammonium or urea fertilizers together with chlorination.

In the case that chlorination is required, it is recommended to ask your local Farm Extension Service for assistance in the computation and application methods.

Sodium hypochlorite is transported by tanks. It should be stored in a clean tank without any remnants of fertilizers. The tanks should be painted white and placed in a shaded area. In field, storage should not exceed 20 days. In case of gas chlorine, transportation, storage and general handling should be carried out in accordance with the manufacturer’s specific instructions under supervision of the relevant authorities.

Concentration and Injection Point

It is important to remember that chlorine concentration decreases as time and distance from the injection point increases. The lowest concentration will always be found furthest from the injection point. The injection point should be as close as possible to the treated system.

The required concentration of active chlorine is a result of the chlorination objective.

CHLORINATION OBJECTIVE	APPLICATION METHOD	REQUIRED CONCENTRATION	
		SYSTEM HEAD	SYSTEM END
Prevent Sedimentation	Continuous Chlorination	3 - 5 ppm	.05 - 1 ppm
	Intermittent Chlorination	10 ppm	1 - 2 ppm
System Cleaning	Continuous Chlorination	5 - 10 ppm	1 - 2 ppm
	Intermittent Chlorination	15 - 50 ppm	4 - 5 ppm

Table 10. Required chlorine concentration by objective.

When the purpose of chlorination is improving filtration performance, the injection point should be close to the filtration plant to assure even distribution throughout the filters. Chlorine concentration downstream of the filter battery should be no less than 1-2 ppm for constant chlorination and three times more for intermittent chlorination.

For continuous chlorination, the injection should start after pressurizing the system. For intermittent chlorination, the procedure should be as follows:

Start: By flushing the system.

Injection: Inject required amount over time, preferably at the beginning of the cycle.

Contact Time: Preferably one hour, but not less than thirty minutes.

Flush: At the end of the process, open the end of the line, flush out and run fresh water for an hour.

Calculations - Liquid Chlorine

Use the following to determine the proper injection rate of chlorine in terms of GPH:

1. Choose the proper chlorine solution factor:
5% chlorine solution: the factor is = 2.00
10% chlorine solution: the factor is = 1.00
15% chlorine solution: the factor is = 0.67
2. Multiply the solution factor by the treated flow in terms of GPM.
3. Multiply by the desired chlorine concentration in terms of ppm.
4. Multiply by the factor of 0.0006.
5. The result will be the required injection rate of chlorine in terms of GPH.

For example: The chlorine solution is 10%, the flow is 100 GPM and the desired chlorine concentration is 10 ppm.

Chlorine Solution Factor X Flow (GPM) X Desired Chlorine Concentration X 0.0006 = Chlorine Injection Rate (GPH)

$$10 \times 100 \times 10 \times 0.0006 = 0.6 \text{ GPH}$$

The injection rate of the chlorine solution will be 0.6 GPH.

Calculations - Chlorine Gas

Use the following to determine the proper injection rate of chlorine in terms of Lbs./Hour:

1. Determine the flow of the treated zone in terms of GPM.
2. Multiply the flow by the desired chlorine concentration in terms of ppm.
3. Multiply it by the factor of 0.0005.
4. The result will be the injection rate of the gas in terms of pounds per hour (lbs./hr).

For example: The flow is 100 GPM, the desired concentration is 10 ppm.

Flow (GPM) X Desired Chlorine Concentration (ppm) X 0.0005 = Chlorine Injection Rate (lbs./hr)

$$100 \times 10 \times 0.0005 = 0.5 \text{ lbs./hr}$$

The injection rate of the chlorine gas will be 0.5 lbs./hr.

ACID INJECTION

Overview

Acid can be used to lower the pH of irrigation water to reduce the potential for chemical precipitation and to enhance the effectiveness of the chlorine injection. Sulfuric, hydrochloric, and phosphoric acid are all used for this purpose. Acid can be injected in much the same way as fertilizer; however, extreme caution is required. The amount of acid to inject depends on how chemically base (the buffering capacity) the irrigation water is and the concentration of the acid to be injected. One milliequivalent of acid completely neutralizes one milliequivalent of bases.

If acid is injected on a continuous basis to prevent calcium and magnesium precipitates from forming, the injection rate should be adjusted until the pH of the irrigation water is just below 7.0. If the intent of the acid injection is to remove existing scale buildup within the micro-irrigation system, the pH will have to be lowered more. The release of water into the soil should be minimized during this process since plant root damage is possible. An acid slug should be injected into the irrigation system and allowed to remain in the system for several hours, after which the system should be flushed with irrigation water. Acid is most effective at preventing and dissolving alkaline scale. Avoid concentrations that may be harmful to emitters and other system components.

Phosphoric acid, which is also a fertilizer source, can be used for water treatment. Some micro-irrigation system operators use phosphoric acid in their fertilizer mixes. Care should be used with the injection of phosphoric acid into hard water since it may cause the precipitation of calcium carbonate.

For safety, dilute the concentrated acid in a non-metal, acid-resistant mixing tank prior to injection into the irrigation system. When diluting acid, always add acid to water, never water to acid. The acid injection point should be beyond any metal connections or filters to avoid corrosion. Flushing the injection system with water after the acid application is a good practice to avoid deterioration of components in direct contact with the acid.

Acids and chlorine compounds should be stored separately, preferably in epoxy-coated plastic or fiberglass storage tanks. Acid can react with hypochlorite to produce chlorine gas and heat; therefore, the injection of acid should be done at some distance (2 feet), prior to the injection of chlorine. This allows proper mixing of the acid with the irrigation water before the acid encounters the chlorine.

Hydrochloric, sulfuric, and phosphoric acids are all highly toxic. Always wear goggles and chemical-resistant clothing whenever handling these acids. Acid must be poured into water; never pour water into acid.

Recipe for Acid Injection

- Safety Precautions:** Contact of the acid with the skin can cause burns. Contact with the eyes could be extremely dangerous. During treatment, and especially when filling containers with acid, wear protective goggles, clothes and boots. Follow the instructions on the Material Safety Data Sheet (M.S.D.S.) attached to the acid.
- Problems of Corrosion:** Polyethylene and PVC tubes are resistant to acid. Aluminum, steel (with or without inner concrete coating) and asbestos-cement pipes are damaged by corrosion. In every case, resume normal water flow through the system after completion of treatment for at least one hour in order to flush any remaining acid. The importance of flushing cannot be over emphasized when the pipes used are particularly sensitive to corrosion.
- Method of Operation:** Acid can be applied through the drip irrigation system by a fertilizer pump resistant to acids or by conventional control head with a fertilizer tank.

Application of Acid by Fertilizer Pump

The goal of acid treatment is to lower the pH level of the water in the irrigation system to values between two to three for a short time (twelve - fifteen minutes). This is achieved by injection of a suitable quantity of acid into the system. Follow these instructions:

1. Clean the filters.
2. Flush the system with clean water as follows: flush the main pipes, then the distribution pipes and finally the drip laterals. Use the highest pressure possible for flushing. Deactivate the pressure regulators and flush the laterals, a few at a time. Flushing with clean water will prevent blockage during treatment.
3. Determine the discharge of the water from the system through which the acid will be injected and the discharge of the fertilizer pump.
4. Calculate the required amount of acid that should be injected into the system in order to get 0.6% of acid concentration in the irrigation water.
5. Inject the acid into the system within fifteen minutes and only after the system has reached maximum operation pressure.

NOTE: Acids suitable to be injected in 0.6% concentrations are:

Nitric acid	60%
Phosphoric acid	75% - 85%
Sulfuric acid	90% - 96%
Hydrochloric acid	30% - 35%

In many cases the most economical acids are sulfuric acid (battery acid) and hydrochloric acid (swimming pool acid).

Calculation Method

The injection rate of the acid to the treated zone can be calculated as follows:

$$\text{System Flow (GPM)} \times \text{0.36/acid \% in Decimal Form} = \text{Injection Rate (GPH)}$$

For example: Sulfuric acid 90% with System Flow of 100 GPM

$$100 \times (0.36 / .9) = 40 \text{ GPH}$$

Because the acid is to be injected only for 15 minutes, the total acid required is 10 gallons.

NOTE: Under certain conditions; i.e., hard water with a very high pH, there might be a need to raise the acid concentrate in the system to 1%. Please consult a Netafim Representative prior to such a treatment.



IRON CONTROL SYSTEM FOR DRIP IRRIGATION

Introduction

Iron deposits create severe clogging problems in drip systems. Iron deposit is described as a filamentous amorphous gelatinous type of brown-reddish slime, that precipitates from water which contains iron. Iron deposits get stuck in emitters and cause complete plugging of the system.

The problem exists in well water areas where the groundwater aquifers are formed mainly of sandy soils or organic muck soils (very common in Florida) usually with a pH of below 7.0 and in the absence of dissolved oxygen. These waters contain ferrous iron (Fe^{+2}) which is chemically reduced, 100% water soluble and serves as the primary raw material for slime formation.

Iron bacteria, mainly from the filamentous genres like Gallionella Sp. Leptolhris and Sphaerotihus and less from the rod type like Pseudomonas and Enterobacter, when present in the water, react with the ferrous iron (Fe^{+2}) through an oxidation process. This changes the iron form to ferric iron (Fe^{+3}) which is insoluble. The insoluble ferric iron is surrounded by the filamentous bacteria colonies that create the sticky iron slime gel that is responsible for clogging the emitter.

Concentrations of ferrous iron as low as 0.2 ppm are considered as a potential hazard to drip systems (H.W. Ford 1982). Between 0.2 - 1.5 ppm emitter clogging hazard is moderate. Concentrations above 1.5 ppm are described as severe (Bucks and Nakayama -1980). Practically any water that contains concentrations higher than 0.5 ppm of iron cannot be used in drip systems unless they are treated chemically or otherwise. Experiments in Florida indicate that chlorination successfully controls iron slime when iron concentrations were less than 3.5 ppm and the pH was below 6.5 (Nakayama and Bucks -1986). It is also stated that long term use of water with a high level of iron may not be suitable for drip irrigation. The literature mentions that water containing more than 4.0 ppm cannot be efficiently chemically treated and it should undergo a pond sedimentation process before pumping it back to a drip system.

Iron Control Methods

There are several ways to control iron slime problems. The common denominator of all treatments is prevention of the formation of slime. Basically there are two preventive treatments:

1. Stabilization (Precipitation Inhibitors)

Stabilization treatments keep the ferrous iron in solution by cleaning it with sequestering agents. Such agents include various poly phosphates and phosphonate.

2. Oxidation

This type of treatment oxidizes the soluble "invisible" ferrous iron into the insoluble "visible" ferric iron. It will then precipitate, so it can be physically separated from the water by means of filtration.

The second procedure is generally the less expensive for severe iron problems in supply water. Various means to oxidize iron include chlorination and aeration. There are also other oxidizers, but they are generally more expensive. Chlorine injection for iron control is normally handled in the same manner as continuous chlorine injection outlined previously, with residual chlorine levels of 1 to 2 ppm. Aeration is most often applied to settling ponds using sprayers or agitators to react iron with air. In this case, the pond becomes a pre-filtration component.

Sedimentation - Filtration

A sand media filter is the most appropriate filter for settling down the oxidized iron and filtering it from the water. When designing a filtration system for iron removal it is good practice to oversize the filter units. Larger units with slower water velocity will allow oxidized iron to settle and the resultant water will be easier to filter. This is the same principle as exhibited in settling ponds.

Scale Inhibitors

Scale inhibitors, such as chelating and sequestering agents, have long been used by other industries. A number of different chemicals are being marketed for use in micro-irrigation systems to prevent plugging. Many of these products contain some form of inorganic polyphosphate that can reduce or prevent precipitation of certain scale-forming minerals. These inorganic phosphates do not stop mineral precipitation, but keep it in the sub-microscopic range by inhibiting its growth. Probably the most commonly used of these materials is sodium hexametaphosphate, as little as 2 ppm can hold as much as 200 ppm calcium bicarbonate in solution.

Sodium hexametaphosphate is not only effective against alkaline scale, but also forms complexes with iron and manganese and can prevent deposits of these materials. Although the amount of phosphate required to prevent iron deposits depends on several factors, a general recommendation is 2 to 4 ppm phosphate for each ppm of iron or manganese.

These phosphates are relatively inexpensive, readily soluble in water, nontoxic and effective at low injection rates.

Pond Treatment

Algae problems which often occur with surface water sources such as a pond can be effectively treated with copper sulfate (CuSO_4). Dosages of 1 to 2 ppm (1.4 to 2.7 pounds per acre foot) are sufficient and safe to treat algae growth. Copper sulfate should be applied when the pond water temperature is above 60°F. Treatments may be repeated at 2 to 4 week intervals, depending on the nutrient load in the pond. Copper sulfate should be mixed into the pond (i.e., sprinkled into the wake of a boat). The distribution of biocides into surface water must be in compliance with EPA regulations.

Copper sulfate can be harmful to fish if alkalinity, a measure of the water's capacity to neutralize acid, is low. Alkalinity is measured volumetrically by titration with H_2SO_4 and is reported in terms of equivalent CaCO_3 . Repeated use of copper sulfate can result in buildup to levels toxic for plants.

RODENT MANAGEMENT STRATEGIES

Unmanaged populations of rodents in agricultural fields cause significant damage and loss of productivity in a wide range of crops. Small rodents such as mice and voles damage young and older trees alike in nurseries and orchards by girdling the tender saplings and branches. Studies in New York show up to a 66% reduction in apple yields as a result of girdling by an over-population of voles. In field crops, these small mammals love to unearth and devour newly planted seeds and snack on the young seedlings that survive. Larger rodents such as pocket gophers damage field crops by eating the root system out from under the plant. Colorado State University Cooperative Extension Bulletin # 6.515 states, "pocket gophers reduce productivity of portions of alfalfa fields by 20 to 50%". Rodents can also cause damage to farm equipment and infrastructure. They may gnaw on small diameter cables and irrigation pipes. The mounds created by larger rodents can damage or disrupt harvesting equipment while the tunnels can cause leaks in irrigation channels and even small earthen dams.

There is no single, simple method for managing rodent overpopulation on agricultural lands. Control of these potential pests requires a well designed plan that is executed on a consistent basis. The formation of a systematic plan for



Figure 16. Mouse in dripperline.

managing rodents in subsurface drip irrigated fields requires research into the predominant species in your region and rules regulating how these populations may be managed. It is not the purpose of this section to be a comprehensive manual on rodent population control throughout North America. This document is meant to outline the components of a well thought out rodent control plan and to guide growers to local resources to help them formulate such a plan. A reference list at the end of this section will assist you in finding more information on your local conditions.

A wide variety of rodents may inhabit agricultural lands, from voles, mice and rats to ground squirrels and gophers. The two volume set, *Prevention and Control of Wildlife Damage* edited by Hygnstrom, Timm and Larson is a

comprehensive resource for all types of human animal interaction with special attention given to animal behavior. In general, rodents responsible for the majority of damage to agricultural crops and systems live underground for at least part of their lives. A physiological feature of rodents is that their teeth grow continuously. As a result these animals must chew to wear down their teeth so that they fit in the mouth else the animal will starve. Both the feeding and the need to gnaw effect damage on crops and equipment. In the following discussions general applications to all rodents will be presented and species specific actions included when appropriate.

Management of rodent populations on agricultural land generally falls into the following categories.

1. Habitat modification and exclusion to reduce population pressure
2. Trapping and removal
3. Use of repellents to deter invasion
4. Use of repellents to deter gnawing
5. Extermination

Each category will be discussed with respect to protecting crops and equipment.

Habitat Modification to Reduce Rodent Pressures

Existing rodent pressures, either from surrounding fields or within a newly planted field, is the first source of conflict between rodents, your crop and equipment. A cultivated block surrounded by unkempt ground or by open fields infested with rodents represents a continuous battle. Thus, the first step in an integrated rodent management program is to reduce the pressure of high rodent populations in the entire area. First take a visual count of rodent presence in

the surrounding fields. Large rodents such as pocket gophers will leave telltale mounds. Smaller animals such as mice and voles will not be as obvious. The presence of “runways” in grassy areas is one sign of small rodent activity. Assessing the rodent population in the general area will give you an indication of the intensity of the management required to protect your crop and irrigation system.

After assessing the situation, establish a buffer zone around the field. Elimination of weeds, ground cover and litter around the field will reduce habitat suitability. Cultivating this area is a good deterrent for small rodents as it destroys runways and may kill them outright. Larger animals such as pocket gophers can burrow under in this area, but the lack of food may slow them down. If cultivation is not an option weed control is still imperative especially for pocket gopher management. Weeds often have large tap roots which are the preferred food for gophers while fibrous rooted grasses are less appealing. The opposite is true for smaller rodents which enjoy the cover that grasses provide. Thus, in plantings of corn which have a fibrous root structure, the main rodent pressure may be mice and other small rodents. The resources listed here as well as your local extension service can help you characterize the primary rodent pressures for your area and crop.

Trapping and Removal

Trapping can be an effective method to reduce the population of large rodents such as pocket gophers on small to medium sized fields (< 50 acres). Trapping is also effective for cleaning up remaining animals after a poison control program. In the case of smaller rodents such as mice, trapping is not usually cost effective because these animals have such rapid reproduction rates. Body-gripping traps work exceptionally well for capturing pocket gophers. Traps can be set in the main tunnel or in a lateral, preferably near the freshest mound. Consult some of the specific pocket gopher control guides listed at the end of this section for details on how and where to set these traps. Gophers usually visit traps within a few hours of setting so newly placed traps should be checked twice daily. If a trap has not been visited within 48 hours, move it to a new location. Trapping is usually more effective in the spring and fall when the gophers are actively building mounds. The information at the end of this section lists several sources for traps.

Repellents

The rodent repellents can be divided into two large categories, those that affect the population at large and those that repel the rodent from gnawing on cables or small diameter tubing such as dripperline. Two repellents proven effective in reducing rodent populations over a large area - owl boxes and wet soil. Owl boxes are being employed in greater numbers as part of a rodent management program. The principle is simple, the higher the owl population, the fewer the rodents. The application of owl boxes to deter rodents is becoming more prevalent. This technique works especially well for small bodied rodents such as mice, but also affects larger rodents because owls prey on the young. Consult your local extension service for the design and placement of owl boxes appropriate for your area.

Wet soil, but not flooding, can be an effective deterrent for rodents that spend much of their time in tunnels. The repellent effect of wet soil seems to be the result of poor oxygen transfer through the wet soil. Rodents that live in tunnels depend upon the air traveling through the soil for oxygen. In wet soils, the rate of oxygen diffusion is greatly reduced and produces an environment inhospitable to the rodents. Flooding the soil, to drown the rodents is not as effective. The rodents are mobile enough to avoid drowning and most have tunnels designed to avoid the wettest areas in the field in the case of heavy rains. The soil need not be saturated to affect the population. In practice, the use of soil wetness to repel rodents is limited because many crops require soil drying before harvest and because the irrigation system is off for a period of time.

Other general repellents are not effective in rodent management over a large area. Sound or ultrasound generators have not been proven effective in driving out rodents. Taste repellents such as capsicum may affect some rodents such as voles, but have less effect on pocket gophers.

Targeted repellents, those applied on or around the object you wish to protect, a sapling, cable or dripperline have not received much formal study but has promise when combined with a plan to reduce overall populations. Proper dripperline installation practices can reduce rodent, specifically mouse damage. When plowing thinwall dripperline in deep installations, the installation shank can leave cracks in the soil and a path down to the dripperline that mice love to follow, chewing as they go.

Best installation practices dictate that following installation cracks in the soil be sealed by running a tractor tire over cracks created by the plow. This will close the opening in the soil made by the plow and cut off easy access by mice or voles to the loose soil around the dripperline.

The following installation procedures can significantly reduce potential rodent damage to subsurface dripperlines. It is highly recommended that all these procedures be followed.

1. Prepare a buffer area around the field and apply rodenticides according to a plan drawn up with your local extension agent if rodent pressures are high.
2. Have the field as free of crop residue as possible. Field mice are especially fond of plant residues.
3. Apply dripperline as deep as practical for the crop being grown. Installations of the dripperline at depths greater than 12 inch exhibit less rodent damage.
4. Apply a repellent or toxicant as you install the dripperline.
5. Pack the shank slit with front tractor tires to reduce ready made paths for small rodents. The front tires should be narrow, single ribbed, cultivating tires (see Figure 17) and the front of the tractor must be weighted. This operation must be completed the same day as installation.
6. Run the system for 12 hours per zone within two weeks of completing the installation. Installing the tube in the fall and running the first water in the spring is asking for problems. The help of local extension agents and pest control specialists. Many growers have implemented successful plans for rodent management on their fields protecting the investment in their irrigation system and improving yields. To be effective, any rodent control plan must be diligent and consistent in a time frame determined by the extent of the rodent pressure in the general area.



Figure 17. Tractor on left installing thinwall dripperline while tractor on right packs soil left open by shank.

Rodents, especially pocket gophers, are often most active in the fall and early spring. It is often at these times, when the irrigation system is not being used that most damage occurs. Experience has shown that properly applying an acid treatment when the system is shut down reduces rodent damage. Acidification of the dripperline is standard practice for end of the season cleaning and a slight modification of this process may also help to protect dripperlines from rodent damage.

1. Flush each zone at pressures recommended by your dealer.
2. If the field is dry, pre-water each zone for 6 hours.
3. Inject N-pHuric at 200 ppm for 1 hour before shutdown of each zone. Shut down zones leaving N-pHuric in the lines.

Chemigating with a properly labeled pesticide that has a strong odor or fumigation effect such as thiram (a fungicide) will cause many rodents to keep away from buried dripperlines. This may be an effective technique for early season deterrence. Under all conditions, make sure the pesticide is properly labeled for use in your area.

Extermination

Several rodenticides, including toxicants and anticoagulants, have been registered with the federal government and are in current use for managing rodent populations. Please check with your local extension service for those labeled for your area and always follow the application directions. In general, placing approved bait around the perimeter of the field prior to irrigation system installation will reduce rodent pressures on a new field. For pocket gophers, a mechanical "burrow builder" that releases bait is effective in perimeter applications. Hand baiting tunnels is time consuming but effective for the trained applicator. The usual treatment for gophers is bait plowed in every other furrow and around the perimeter of the field. Fumigants applied in the tunnels are usually not as effective as toxicants and trapping because they tend to diffuse which gives the gopher enough time to escape.

Rodent Management Action Plan

An integrated approach must be taken to reduce rodent damage to crops and equipment. This plan must involve reducing acceptable habitats for rodents close to the field and may involve trapping or poisoning to control active populations. In addition, the dripperline itself can be protected using the repellent effect of some pesticides and slightly acidifying the soil around the lines.

Fall and spring are the most active time for rodents and these seem to be the worst seasons for damage. Thus any management program must focus on these seasons. Do not underestimate the wealth of reference materials and the help of local extension agents and pest control specialists. Many growers have implemented successful plans for rodent management on their fields protecting the investment in their irrigation system and improving yields. To be effective, any rodent control plan must be diligent and consistent in a time frame determined by the extent of the rodent pressure in the general area.

POCKET GOPHER MANAGEMENT SUPPLIES

TOXICANTS

ANTICOAGULANTS (CHLOROPHACINONE & DIAPHACINONE)

B & G Chemicals and
Equipment Co. Inc.
10539 Maybank
Dallas, TX 75345-0428
(214) 357-5741
(800) 345-9387
(214) 357-4541 FAX

J.T. Eaton & Co. Inc.
1393 E. Highland Rd.
Twinsburg, OH 44087
(216) 425-7801
(800) 321-3421
(216) 425-8353 FAX

HACCO, Inc.
Box 7190
Madison, WI 53707
(608) 221-6200
(608) 221-6208 FAX

STRYCHNINE AND ZINC PHOSPHATE

B & G Chemicals and
Equipment Co. Inc.
10539 Maybank
Dallas, TX 75345-0428
(214) 357-5741
(800) 345-9387
(214) 357-4541 FAX

Pocatello Supply Depot
USDA-APHIS Wildlife
Services
238 E. Dillon St.
Pocatello, ID 83201
(208) 236-6920
(208) 236-6922 FAX

RCO, Inc.
Box 446
Junction City, OR 97448
(503) 995-8160
(800) 214-2248

York Distributors
120 Express St.
Plainview, NY 11803
(516) 932-0600
(800) 645-6007
(516) 932-4316 FAX

FUMIGANTS

ALUMINUM PHOSPHATE

Douglas Products and
Packaging Co.
1500 E. Old 210 Hwy.
Liberty, MO 64068
(800) 223-3684
(816) 781-1043 FAX

Pestcon Systems, Inc.
Box 339
Wilson, NC 27894
(800) 548-2778
(919) 243-1832 FAX

Research Products Co.
Box 1460
Salina, KS 67402-1460
(913) 825-2181
(913) 825-8908 FAX

Van Waters & Rogers
Box 24325
Seattle, WA 98124-1325
(206) 889-3400
(206) 889-4100 FAX

GAS CARTRIDGES

Dexon Industries
1450 W. 228th St
Torrance, CA 90501
(310) 326-8373
(800) 421-2934
(310) 325-0120 FAX

Pocatello Supply Depot
USDA-APHIS Wildlife
Services
238 E. Dillon St.
Pocatello, ID 83201
(208) 236-6920
(208) 236-6922 FAX

South Dakota Dept. of
Agriculture - Rodent
Control Fund
Anderson Bldg.
Pierre, SD 57501
(605) 773-3724 FAX

Van Waters & Rogers
Box 24325
Seattle, WA 98124-1325
(206) 889-3400
(206) 889-4100 FAX

BAIT APPLICATION DEVICES AND MATERIALS

BURROW BUILDER

Rue R. Elston Co.
706 N. Weber
Sioux Falls, SD 57103
(605) 336-7716

The Perry Company
Box 7187
Junction City, OR 97448
(817) 756-2137
(800) 792-3246

RCO, Inc.
Box 446
Junction City, OR 97448
(503) 995-8160
(800) 214-2248

Wilco Distributing, Inc.
1215 W. Laural Ave.
Lompoc, CA 93436
(805) 735-2476

PROBES & BAIT DISPENSERS

Eckroat Seed Co.
1106 N. Eastern Ave.
Box 17610
Oklahoma City, OK 73117
(405) 427-2484

Rue R. Elston Co.
706 N. Weber
Sioux Falls, SD 57103
(605) 336-7716

Quinn Mfg. Co.
44201 Chapman Road
Anaza, CA 92539
(909) 763-4590

Wilco Distributing, Inc.
1215 W. Laural Ave.
Lompoc, CA 93436
(805) 735-2476

TRAPS

M & M Fur Co.
Box 15
Bridgewater, SD 57319
(605) 729-2532
(800) 658-5554

H & J Spencer & Sons
Box 131
Grainsville, FL 32602
(904) 372-4018

Wildlife Management
Supplies
Critter Control, Inc.
640 Starkweather Rd.
Plymouth, MI 48170
(313) 435-6300
(800) 451-6544

FURTHER READING

Clark, J.P., ed. Vertebrate pest control handbook, 4th Edition. State of California, Dept. of Food and Agric., Division of Plant Industry, Integrated Pest control Branch. 1994

Hanson, B.R., W. Bendixen and D.M. May. 2000 Patterns of soil moisture, soil salinity and soil nitrate under drip irrigation of row crops. Proceedings 2000 Irrigation Association of Australia May 23-25.

Hygnstrom, S.E., R.M. Timm and G.E. Larson, eds. Prevention and Control of Wildlife Damage. University of Nebraska, Institute of Agric. And Natural Resources; USDA/APHIS, ADC and Great Plains Agric. Council, Wildlife Committee. 1994

REFERENCE WEBSITES

The following web sites offer excellent information on the management of pocket gophers and mice and provide lists of additional resources:

www.ext.colostate.edu/PUBS/NATRES/06515.pdf

Colorado State University Extension

www.extension.usu.edu/htm/publications

Utah State University Cooperative Extension

www.icwdm.org/Publications/WildlifePublications.asp

Internet Center for Wildlife Damage Management

www.berrymaninstitute.org/pdf/gopher/pdf

Utah State University Cooperative Extension

www.ipm.ucdavis.edu

UC Davis Integrated Pest Management Program

www.snohomish.wsu.edu/garden/verturl.htm

Washington State University Extension, Snohomish County

Corn Production Handbook



Kansas State University
Agricultural Experiment Station
And Cooperative Extension Service

Nutrient Management

Total fertilizer use on corn is greater than on any other crop grown in the United States and is likely second only to wheat in Kansas. Even with good overall crop management, few Kansas soils will sustain profitable corn production without supplementation of several crop nutrients from fertilizers, manures, and/or legume rotations. Typical symptoms for some of the most common nutrient deficiencies are illustrated in photos 1 to 8. While estimates vary, each bushel of corn grain harvested from Kansas fields removes about 0.9 pounds of nitrogen (N), 0.33 pounds of phosphate (P_2O_5) and 0.26 pounds of potassium (K_2O) per acre. The approximate removal of these and other nutrients by corn grain and stover for a 150 bushel per acre crop are given in Table 9. This data shows that harvesting only the

grain removes considerably less nutrients than if the entire crop is harvested for silage.

Determining Fertilizer Need

Fertilizer and lime need can best be determined by using several tools: soil tests, local research information, on-the-farm research trials, crop nutrient removal, plant analysis, past experience, or a combination of these. Soil test interpretations are based on many years of research work conducted across the state. Reliable interpretations can be made for the likelihood of obtaining a response assuming that crop yield potential is not restricted by factors other than the nutrient in question. The most reliable means of determining fertilizer need is by soil testing regularly with continual support from the other

Nutrient Management Photos

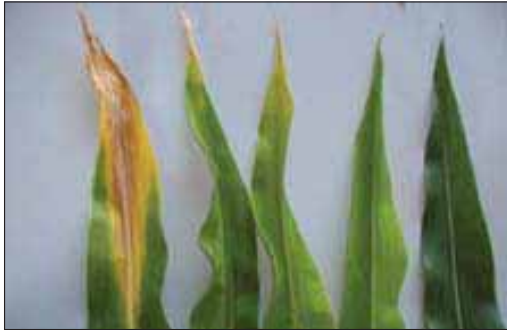


Photo 1. Nitrogen deficiency (left) through nitrogen sufficiency (right).



Photo 2. Nitrogen sufficient (left) nitrogen deficient (right).



Photo 3. Early season phosphorus deficiency.



Photo 4. Late-season phosphorus response.



Photo 5. Potassium deficiency.



Photo 6. Potassium deficiency.



Photo 7. Iron deficiency.



Photo 8. Iron deficiency.

methods listed. Remember, however, laboratory soil test results are no better than the sample collected in the field.

In addition to guiding fertilizer needs for the current crop, soil test results have long-term value. In fact, the value of a long-term, sound soil testing program is increased immensely when viewed in an historical context. By keeping soil test records over a period of years for an individual field, these records become an excellent means of assessing the adequacy of the fertilizer program being followed. For example, an increase in the soil test values in successive samplings for a nutrient indicates that the application rate is in excess of the amount being used by the plants. If the soil test level for the nutrient is above the medium interpretation level (30 ppm Bray P1 or Mehlich 3 extractions) then a reduction in rate or no application will likely not reduce corn yields. In contrast, a decrease in soil test values over time indicates that crop removal has been greater than the application rate which may not be in the producers best interest — especially if the soil test has dropped into the low interpretation level. After several successive soil samplings, monitoring soil test levels may become the most important use of the soil test program.

A complete set of Kansas State University recommendations is provided in the publication *Soil Test Interpretations and Fertilizer Guidelines*, MF-2586.

Nitrogen

Nitrogen management decisions for corn are dependant on several factors, including: water management if irrigated, soil texture, options available for nitrogen fertilizer application, manure application history, soil organic matter content, residual soil profile nitrate-N content, residue management system, previous crop, and tillage system adjustments.

While nitrogen application rate is the first thing that often comes to mind when discussing improved corn nitrogen use efficiency, the time and method of nitrogen application are as important to efficient nitrogen use as nitrogen application rate. How the nitrogen is applied, how much nitrogen is applied and when nitrogen is applied all have dramatic effects on nitrogen use efficiency by the corn crop. **Additionally, for irrigated crop production, nitrogen management must begin with water management.**

In Kansas, widely varying soils, climate, and cultural conditions have large effects on expected nitrogen use efficiency for a specific nitrogen-management program. Much of the corn production in Kansas is on irrigated, coarse textured sands where nitrogen leaching is the main factor reducing nitrogen-use efficiency. Minimizing the potential for nitrogen leaching loss is the most important factor for improved crop production profitability and environmental protection under these conditions. This is especially important in areas with a relatively shallow aquifer.

At the same time, there is significant irrigated acreage in Kansas with medium-fine textured soils. Denitrification is the main cause for concern in these areas because there is minimal potential for significant nitrogen leaching. The same is true for dryland corn production on the claypan soils of southeast Kansas and other scattered poorly drained soils in the central and eastern parts of the state. For dryland production in the western part of the state, timing applications so that N is moved into the soil profile with limited precipitation is important for making most efficient use of applied nitrogen.

The nitrogen recommendation algorithm is based on expected yield (YG), soil organic matter content (SOM), legume crop nitrogen credits, manure application/method of application, nutrient credits, irrigation water nitrate-N content, and the 24 inch residual soil profile nitrogen test.

$$\text{Corn nitrogen Recommendation} = (1.6 \times \text{YG}) - (\text{SOM} \times 20) - \text{Profile N} - \text{Legume N} - \text{Other N Credits}$$

For irrigated production, N guidelines are capped at 300 pounds nitrogen per acre while dryland production is capped at 230 pounds nitrogen per acre.

Suggested recommended nitrogen application rates are directly tied to yield goal. Yield records should be used to set individual realistic, but progressive, yield goals for each field. Appropriate yield goals for a specific field should be high enough to take advantage of high production years when they occur, but not so high as to jeopardize environmental stewardship and/or profitability when environmental conditions are not so favorable. Appropriate yield goals fall between the average yield obtained in a field over the past 3 to 5 years

Table 9. Approximate amount of nutrients removed by 150 bushel corn crop per acre.*

Element	Quantity in		Element	Quantity in	
	Grain lbs	Stover lbs		Grain lbs	Stover lbs
Nitrogen	135	68	Chlorine	4	68
Phosphorus (P ₂ O ₅)	50	38	Iron	0.10	1.80
Potassium (K ₂ O)	40	155	Manganese	0.05	0.25
Calcium	13	35	Copper	0.02	0.08
Magnesium	10	29	Zinc	0.17	0.17
Sulfur	11	8	Boron	0.04	0.12
			Molybdenum	0.005	0.003

* N, P and K estimates adapted from K-State research and other state land grant university information. Secondary and micronutrient estimates adapted from Barber, S.A. and R.A. Olson, 1968. Fertilizer use on corn. In *Changing Patterns in Fertilizer Use*.

to near the highest yield obtained in a specific field. The producer should set the individual field yield goals.

In Kansas for corn production, 20 pounds nitrogen per acre per year are credited for each 1 percent soil organic matter in the surface 6 to 7 inches soil depth. Previous-crop soybeans are credited at 40 pounds nitrogen per acre for a following corn crop. Alfalfa is credited at from 0 to 120 pounds nitrogen per acre for a following crop, depending on how good the alfalfa stand is and how much grassy weeds have infested the stand. Sweet clover is credited at roughly the same amount as alfalfa while red clover is credited from 0 to 80 pounds nitrogen per acre depending on the stand density (Table 10).

Manure nitrogen credits depend on the method of manure application, time until manure is incorporated, organic and mineral nitrogen contents of the specific manure used, and the number of years since the manure was applied. Specific guidelines for crediting manure for nutrient application can be found in the Kansas State University publication *Estimating Manure Nutrient Availability*, MF-2562.

While the profile nitrate-N test is strongly suggested for developing nitrogen application rate guidelines, it is not necessarily suggested that it needs to be used on every acre, every year. It is strongly suggested that these profile soil samples are collected for nitrate-N analysis when there is a relatively higher probability of significant profile nitrogen. There are also conditions when the likelihood of significant nitrate-N accumulation in the soil profile is relatively low. Table 11 provides some general guidelines for the use of the soil profile nitrate-N test. If possible, profile nitrogen samples should be collected to a depth of 2 feet. For areas of the state where the profile depth is less than 2 feet (clay pan, rock, etc.), samples should be collected the depth of the existing profile.

Field comparisons conducted by Kansas State researchers indicate little agronomic difference between nitrogen materials when properly applied. Material selection should be on the basis of cost (applied), availability of material, adaptability to farm operations, and available dealer services.

Nitrogen application for corn can be made at several times with equal results on most land in Kansas. Nitrogen may be applied before planting, at planting time, and/or as

Table 10. Corn nitrogen credits for various previous crops in rotation.

Previous Crop	Corn N Credit
• Corn, wheat, sorghum, sunflowers	0 lbs N/A
• Soybeans	40 lbs N/A
• Alfalfa – > 5 plants/ft ²	120 lbs N/A
• Alfalfa – 2-5 plants/ ft ²	80 lbs N/A
• Alfalfa – 1-2 plants/ ft ²	40 lbs N/A
• Alfalfa – < 2 plants/ ft ²	0 lbs N/A
• Red clover – excellent stand	80 lbs N/A
• Red clover – fair stand	40 lbs N/A
• Red clover – poor stand	0 lbs N/A
• Sweet clover – excellent stand	110 lbs N/A
• Sweet clover – fair stand	60 lbs N/A
• Sweet clover – poor stand	0 lbs N/A

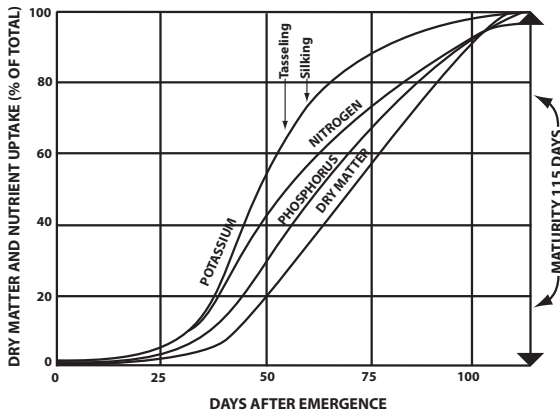
a sidedressing after corn is up. The best time/method for nitrogen application depends on the individual field likelihood of significant nitrogen loss and the specific production operation, time, equipment and labor availability. Nitrogen uptake by corn is quite rapid in a period starting about 25 days after emergence and by the time of silking 60 percent of the total nitrogen has been taken up (Figure 7).

If the potential for significant nitrogen loss is present, nitrogen applications should be timed so that nitrogen is available when needed for this rapid growth. A small amount of nitrogen may be applied in a starter fertilizer to meet early season needs. Preplant nitrogen applications, except on sandy soils, can be made in late fall or spring with little concern for leaching loss. On sandy soils, preplant nitrogen applications should be delayed until spring. Nitrogen application should also be delayed on fine textured soils subject to standing water or flooding. If nitrogen is applied sidedress, the applications should be made early (i.e. five-leaf stage) to avoid weather conditions preventing application. With sprinkler irrigation on sandy soils, application of the nitrogen through the irrigation system has been quite satisfactory. Application of nitrogen through irrigation systems under other soil condi-

Table 11. Likelihood Of Significant Profile Nitrogen Carryover

Higher Probability Of Significant Profile Nitrogen – Profile Nitrogen Test More Valuable	Lower Probability Of Significant Profile Nitrogen – Profile Nitrogen Test Less Valuable
<ul style="list-style-type: none"> • Medium-Fine Textured Soils • Recent History Of Excessive N Rates • Previous Crop <ul style="list-style-type: none"> • Lower than expected yield • Drought affected • Fallow • Previously destroyed stands of alfalfa/clovers • Manure Application or History • Warm, Late Falls and/or Early, Warm Springs 	<ul style="list-style-type: none"> • Sandy soils • Appropriate N Rate History • Previous Crop <ul style="list-style-type: none"> • Soybeans (immediately preceding) • Higher than expected yield history • Expected yields history • Excessive Precipitation • No Manure or Biosolid Application History • Increased Rotation Intensity

Figure 7. The uptake of nutrients by a corn plant and the increase in dry matter in relation to the number of days after emergence. (Source: Hanway, J.J. 1960. *growth and Nutrient Uptake by Corn*, Iowa State University Extension Pamphlet No. 277).



tions is possible, but the fertilizer distribution is no better than the water distribution. Do not use any nitrogen material that contains free ammonia when applying through a sprinkler system unless special precautions are taken.

Kansas Nitrogen BMPs.

Dryland corn production in Kansas reaches from the western Cornbelt of northeast Kansas that has the potential for yields of 150 to 200 bushels per acre, to western Kansas with an annual precipitation of 15 to 20 inches and where yield potentials are typically 100 bushels per acre or less to the shallow clay-pan soils of southeast Kansas and that have the potential for 150 bushel per acre corn but is often affected by high winter/early spring denitrification nitrogen losses or drought conditions. The point is, there is no one BMP (best management practice) package for the state.

Following are a few general nitrogen BMPs for corn production under various systems in Kansas. In general, the greatest potential for nitrogen movement to groundwater is in our irrigated systems on sandy soils. Shallow aquifers in some of these areas greatly increases the risk of nitrate-N movement to groundwater. On medium-fine textured irrigated soils and poorly drained and/or claypan soils, managing denitrification loss is of greater importance than leaching.

Nitrogen BMPs for Irrigated Sands Corn Production

- Implement irrigation scheduling/management program
- Manage other controllable factors (e.g. other nutrients, weed management, etc.)
- Manage potential nitrogen leaching
- Split nitrogen application – no fall nitrogen application
- Include starter NP, NPS, or NPKS application
- Consider including 30 to 40 pounds nitrogen per acre starter applied (not with the seed)

- Consider N-Serve with anhydrous ammonia for shallow aquifer locations
- Subsurface/knife nitrogen applications always good.
- Include some early nitrogen with preplant, pre-emerge weed control program
- Apply split nitrogen applications through sprinkler system if available
- Make sure adequate nitrogen is applied early in case irrigation water not needed
- Make sure last nitrogen application is made by tasseling or shortly after (7 to 14 days)

Nitrogen BMPs for Irrigated Medium-Fine Textured Soils

- Implement irrigation scheduling/management program
- Manage other controllable factors (e.g. other nutrients, weed management, etc.)
- Manage for potential nitrogen denitrification loss
- Split applications should be considered (fall or spring preplant, starter, sidedress)
- Anhydrous ammonia preferred for fall application
- Include starter NP, NPK, or NPKS application
- Consider including 30 to 40 pounds nitrogen per acre starter applied (not with the seed)
- Subsurface/knife applications always good.
- Make sure last nitrogen application is made by tasseling or shortly after (7 to 14 days)

Nitrogen BMPs for Dryland Corn Production

- No fall N applications to clay-pan soils of southeast Kansas or poorly drained central-eastern Kansas soils (denitrification)
- Avoid fall nitrogen applications to bottomland soils frequented with waterlogged conditions (denitrification)
- Manage other controllable factors (e.g. other nutrients, weed management, etc.)
- Include starter NP, NPK, or NPKS application
- Consider including 30 to 40 pounds nitrogen per acre starter applied (not with the seed)
- Include some early nitrogen with preplant, pre-emerge weed control program
- Sidedress application desirable on frequently waterlogged soils
- Make sure adequate nitrogen is applied early in crop growth and development
- For western Kansas, make applications early to improve potential for movement into root zone
- Subsurface/knife applications always good
- If unincorporated nitrogen application, surface band application preferred.

Phosphorus and Potassium

Phosphorus is required for many metabolic processes within the plant. Photosynthesis, respiration, carbohydrate synthesis and utilization, cell division, reproduction, and energy transfer all require phosphorus within the plant. If

phosphorus becomes deficient, crop growth, grain production, and profitability all will suffer. Phosphorus deficiencies in corn include: small and stunted seedlings (Photo 3), purplish leaf coloration (especially seedlings in cold, wet years), delayed maturity (delayed silking and tasseling) (Photo 4), thin stems and poorly developed root systems. While purpling of young seedling leaves is the most often mentioned deficiency symptom in corn, anything that inhibits root growth may cause corn seedlings to become purple. Additionally, some hybrids are more prone to purpling of leaves than others.

Although less phosphorus is found in plants than either nitrogen or potassium, sizeable amounts are removed in the harvested portions of crops. For corn, regional estimates of the amount of phosphorus removed are in the range of 0.30 to 0.38 pounds of P_2O_5 equivalent removal with each bushel of corn grain. For Kansas, research indicates that about 0.33 pounds P_2O_5 per bushel is contained in one bushel of corn. Lower grain phosphorus values may result on low phosphorus testing soils, while higher grain phosphorus contents are likely with high or very high phosphorus soil test values.

Kansas State University corn phosphorus recommendations provide two main options for producers, depending on circumstances for specific fields and situations. *Sufficiency* phosphorus fertility programs are intended to estimate the long-term average amount of fertilizer phosphorus required to, on the average, provide optimum economic return in the year of nutrient application while achieving about 90 to 95 percent of maximum yield. In some years, greater amounts of nutrient are required for optimum yield and economic return, while in other years less than recommended amounts of nutrient would suffice. There is little consideration of future soil test values and soil test values will likely stabilize in the *low*, crop responsive range. Figure 8 presents the general model used for phosphorus management by Kansas State University.

Build-maintenance recommendations are intended to apply enough phosphorus to build soil test values to a target soil test value over a planned time frame (typically 4 to 8 years) and then maintain soil test values in a target range future years. If soil test values exceed the target range, no phosphorus is recommended with the exception of low starter applied rates if desired. Build-maintenance fertility programs are not intended to provide optimum economic returns in a given year, but rather attempt to minimize the probability of phosphorus limiting corn yields while providing for near maximum yield potential.

Both sufficiency and build-maintenance programs have advantages and disadvantages, depending on the needs and expectations of specific producers, fields and situations. Both approaches are based on identifying the *critical* phosphorus soil test value. The critical soil test value is the phosphorus soil test value above which the soil is normally capable of supplying phosphorus to crops in amounts sufficient to achieve about 90 to 95 percent of maximum yield — or single year optimum economic growth. Figure 8 illustrates

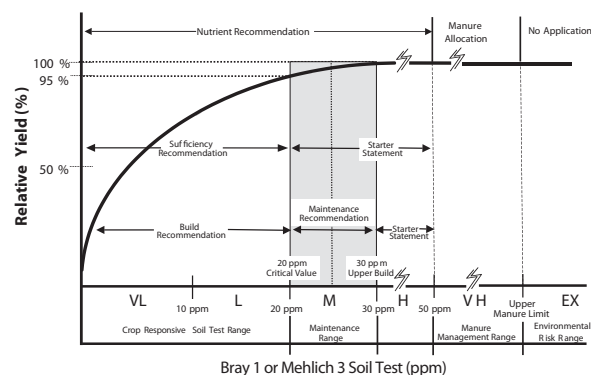
the concepts of both sufficiency and build-maintenance approaches to phosphorus nutrient management.

Sufficiency programs minimize phosphorus inputs in the early years of adopting this approach, but recommended application rates eventually stabilize at phosphorus rates that maintain soil test values in the crop responsive range. Generally, fertilizer phosphorus application rates equal to crop removal are needed to maintain soil test phosphorus levels. Since phosphorus soil test values are eventually maintained in the crop responsive range, fertilizer phosphorus applications are required each year in order to take care of crop needs. If fertilizer phosphorus application is skipped in a particular year, overall crop production profitability would be expected to suffer. For sufficiency programs, no fertilizer phosphorus is recommended at soil test values much above the critical phosphorus soil test value.

Build-maintenance programs require somewhat higher phosphorus rates in the early build phase of the program (for soils initially testing in the crop responsive range), but application rates eventually stabilize at phosphorus rates that maintain soil test values at a desired targeted level. The targeted soil test value will be just above the critical phosphorus soil test values. By building or maintaining soil phosphorus test values in the targeted range, the soil will be capable of supplying crop phosphorus nutritional needs for 1 or 2 years without the application of fertilizer phosphorus.

Sufficiency programs fit best for short land tenure situations (generally 2 to 3 years or fewer) and in situations of cash flow shortages. Adoption of a sufficiency phosphorus fertility program requires the application of fertilizer phosphorus and potassium every year if soil test levels are not above the critical phosphorus soil test value. This lack of flexibility is due to the fact that soil test values are maintained in the crop responsive range over the long term. Build-maintenance programs generally fit best for longer land tenure situations (3 to 4 years and longer), when flexibility in application rate in a given year is desired (after soil tests built to targeted non-responsive range), when the producer desires to maintain soil tests at a given value over the long-term or other farmer specific reasons.

Figure 8. Phosphorus Management Model.



As a result, both *sufficiency* and *build-maintenance* programs are appropriate phosphorus nutrient management strategies depending on the individual producer situations, goals and objectives for specific fields. Producers may adopt different phosphorus management approaches for individual fields within their operation.

Sufficiency phosphorus and potassium recommendations for corn are presented in Table 12. Included is the equation used to generate these guidelines. These recommendations are intended to, on the average, provide for optimum economic return in the year of application. If more phosphorus is removed in the corn grain than is supplied from various nutrient sources, soil tests values would be expected to decline over time. The information in Table 12 also provides an estimate of the amount of P₂O₅ and K₂O equivalent removed in corn grain at various yield levels.

The estimated amount of P₂O₅ required to build phosphorus soil test values are presented in Table 13. As a general rule-of-thumb, about 18 pounds P₂O₅ in excess of crop removal is required to increase the Bray P-1 or Mehlich 3 soil test one part-per-million for the surface 6 inches of soil. Sandy soils and shallower tillage will typically require less and fine-textured soils containing larger amounts of clay and deeper tillage operations may require more. In addition

to the amount of phosphorus required to build up soil test phosphorus, enough P₂O₅ needs to be applied to replace the amount removed in the crop in order to maintain phosphorus soil tests. Crop removal is about 0.33 pounds P₂O₅ per bushel of corn grain removed.

Phosphorus can be applied either preplant broadcast, preplant banded with nitrogen (dual placement), placed in a starter band near the seed or placed directly with the seed. Banded applications are recognized as being most efficient, particularly when small amounts are applied on very acid or calcareous soils low in soil test phosphorus. Savings in time at seeding achieved by broadcasting rather than banding may offset lower efficiency for the broadcast application.

Starter applications can be placed in direct contact with the seed or placed to the side and below the seed (preferred). If placed in contact with the seed, the starter material should contain no more than 8 to 10 pounds per acre of nitrogen plus potash. The nitrogen and potash can cause germination damage. Recently, research has shown that applying starter phosphorus mixed with 30 to 40 pounds of additional nitrogen in a surface band an 1 or 2 inches to the side of the seed slot to be an effective method of starter application for high surface residue corn production systems.

Table 12. Phosphorus and Potassium Sufficiency Recommendations for Corn Production.

Phosphorus Sufficiency Recommendations for Corn ¹						Potassium Sufficiency Recommendations for Corn ¹					
Mehlich 3 Bray P1 Soil Test	Yield Goal (Bu/A)					Exch. K	Yield Goal (Bu/A)				
	60	100	140	180	220		60	100	140	180	220
(ppm)	Lb P ₂ O ₅ /A					(ppm)	Lb K ₂ O/A				
0-5	55	60	70	75	80	0-40	70	80	85	95	100
5-10	40	45	50	55	60	40-80	45	50	55	60	65
10-15	25	25	30	30	35	80-120	20	20	25	25	30
15-20	15	15	15	15	15	120-130	15	15	15	15	15
20+	0 ²	0 ²	0 ²	0 ²	0 ²	130+	0	0	0	0	0
Crop Removal ³	20	33	46	59	73	Crop Removal ³	16	26	36	47	57

Corn Sufficiency P Rec = [50 + (Exp Yield × 0.2) + (Bray P × -2.5) + (Exp Yield × Bray P × -0.01)]

If Bray P is greater than 20 ppm, then only a NP or NPKS starter fertilizer suggested

If Bray P is less than 20 ppm, then the minimum P Recommendation = 15 Lb P₂O₅/A

Corn Sufficiency K Rec = [73 + (Exp. Yield × 0.21) + (Exch K × -0.565) + (Exp Yield × Exch K × -0.0016)]

If Exch K is greater than 130 ppm then only a NPK or NPKS starter fertilizer is suggested

If Exch K is less than 130 ppm then the minimum K Recommendation = 15 Lb K₂O/A

Table 13. Phosphorus Build-Maintenance Corn Recommendations

Bray P1 Soil Test	4-Year Build Time Frame Yield (Bu/A)			6-Year Build Time Frame Yield (Bu/A)			8-Year Build Time Frame Yield (Bu/A)		
	60	140	220	60	140	220	60	140	220
(ppm)	Lb P ₂ O ₅ /A			Lb P ₂ O ₅ /A			Lb P ₂ O ₅ /A		
0-5	99	125	151	72	99	125	59	86	112
5-10	76	102	129	57	84	110	48	74	101
10-15	54	80	106	42	69	95	37	63	89
15-20	31	57	84	27	54	80	25	52	78
20-30 ⁴	20	46	73	20	46	73	20	46	73
30+	0 ²	0 ²	0 ²	0 ²	0 ²	0 ²	0 ²	0 ²	0 ²

Table 14. Potassium Build-Maintenance Recommendations for Corn

Exch. K Soil Test	4-Year Build Time Frame Yield (Bu/A)			6-Year Build Time Frame Yield (Bu/A)			8-Year Build Time Frame Yield (Bu/A)		
	60	140	220	60	140	220	60	140	220
(ppm)	- -	Lb K ₂ O/A	- -	- -	Lb K ₂ O/A	- -	- -	Lb K ₂ O/A	- -
0-40	263	284	305	181	201	222	139	160	181
40-80	173	194	215	121	141	162	94	115	136
80-130	72	93	113	53	74	95	44	65	85
130-160 ⁴	16	36	57	16	36	57	16	36	57
160+	0	0	0	0	0	0	0	0	0

Preplant applications, broadcast or dual applications, can be made in the fall or spring and the broadcast application should be thoroughly incorporated because phosphorus does not move appreciably in the soil.

Liquids and solids, as well as varying orthophosphates and polyphosphates, are all equally effective when applied at similar rates and in a similar fashion. Research conducted by Kansas State University indicates that all commonly available phosphate fertilizers are agronomically equal. Therefore, selection of a phosphorus source should be made on the basis of product availability, adaptability to specific application technique employed, adaptability to specific operations, and cost.

Potassium (K) is required in larger amounts than any other nutrient except nitrogen. Unlike other crop nutrients, potassium is not a part of any plant part or compound – it is present as a soluble ion in plant sap. While it is not a structural component of various plant compounds and structures, however, it is required to activate many plant enzymes and plays a key role in plant water balances. As with other essential plant nutrients, if potassium becomes deficient, crop growth, grain production and profitability will all suffer. Potassium deficiencies are exhibited first on the lower, older plant parts since potassium is mobile within plants (Photos 5 and 6). Potassium deficiencies are normally most severe in very wet (especially if compacted) or very dry years.

For corn, estimates of the amount of potassium removed are in the range of 0.24 to 0.30 pounds of K₂O equivalent removal with each bushel of corn grain. The higher removal value is a standard established by past research at several Corn Belt universities, while Kansas State University information suggests about 0.26 pounds of K₂O removed with each bushel of corn grain production. If the corn is harvested as silage, much more potassium is removed than if only the grain is harvested.

Like phosphorus, a soil test is your best guide to potassium need. Unfortunately, the potassium soil test is less reliable (accurate) than several other soil tests for identifying soils likely to provide an economical response to applied potassium. Keep in mind that research relative to interpreting potassium soil test values is much more limited than for phosphorus.

In Kansas, the frequency of soils deficient in potassium is much less than for phosphorus and most soils can provide adequate potassium nutrition to growing crops, although the incidence of soils testing in the low-medium soil test ranges

seems to be increasing. Sandy soils across the state are most likely to test marginal in soil test potassium, while medium-fine textured soils in the eastern third of the state seem to be more frequently low in exchangeable soil test potassium. Historically, potassium deficiencies were most likely to appear in the eastern third of the state in years of low rainfall. In recent years, however, potassium deficiencies of corn in Kansas have become much more common than in years past — especially for reduced/no-tillage systems in the eastern one-third to one-half of the state.

Like phosphorus, Kansas State University provides producers two main options for managing potassium, depending on circumstances for specific fields and situations. *Sufficiency* potassium fertility programs are intended to estimate of the long-term average amount of fertilizer potassium required to, on the average, provide optimum economic return in the year of nutrient application while achieving about 90 to 95 percent of maximum yield. In some years greater amounts of nutrient are required for optimum yield and economic return, while in other years less than recommended amounts of nutrient would suffice. There is little consideration of future soil test values and soil test values will likely stabilize in the *low*, crop responsive range. (Table 12).

The uptake of potassium is almost 80 percent completed at silking time (Figure 7.) Most of the potassium taken up is returned to the soil in the leaves, stalks, and plant residue, unless these plant parts are removed for silage or other forms of feed (Table 9). Additional potassium should be applied in the cropping sequence when corn is grown for silage.

Potassium can be applied preplant-broadcast or as a starter. Broadcast applications should be thoroughly incorporated to place the potassium in the root zone. The most common potassium source is muriate of potash (potassium chloride), however, potassium sulfate and potassium-magnesium sulfate are other common sources of potassium. White and red potash are both found in the marketplace and are agronomically equal. However, red potash should not be used in formulating liquid solution fertilizers.

Lodging of corn at maturity has been a problem in some areas of Kansas and has resulted in considerable harvest loss. Research has shown that lodging occurs due to many stress factors, weather, insect and disease damage, varieties, date and rate of planting, and nutrient imbalance. Adequate potassium

is essential for sturdy stalks. Research has shown that potassium fertilization can reduce lodging on medium- to low-test soils. However, application of high rates of potassium fertilizer for insurance against lodging is not recommended. Proper fertilization with adequate levels of all nutrients plus general good crop management practices are the best way to minimize lodging. Weather conditions also play a major role in lodging.

Sulfur, Zinc, Iron, and Chloride

Secondary and micronutrient research on corn has demonstrated the need for added sulfur, zinc, chloride and iron in some situations. Calcium is relatively abundant in the majority of Kansas soils. Liming of acid soils supplies sufficient calcium and a deficiency of this element would not be expected. Research with boron, copper and manganese has not revealed any consistent responses and these elements should not be a problem for optimum corn yields.

Magnesium research in Kansas has not shown a grain yield response to magnesium. Observations have been made of relatively low magnesium in plant samples analyzed, but with no yield increase to added magnesium. Sandy soils of low cation exchange capacity would be the most likely soils to be low in magnesium.

Sulfur may be of concern on sandy, low-organic matter soils. Sulfur yield responses have been noted on irrigated sandy soils in Kansas only when sulfur levels in the irrigation water are low. Much of the irrigation water in Kansas contains appreciable sulfur and this reduces the likelihood of sulfur response. Soil test sulfur levels alone are poor predictors of the likelihood of sulfur response. More research is needed on magnesium and sulfur before any general recommendations or soil test interpretations can be made. Farmers concerned with these two elements should try them on a small area on their own farms.

The need for zinc can be predicted by using the DTPA soil test extraction. Soil test values of less than 0.5 ppm should receive an application of zinc, while soil test values of 0.6 to 1.0 ppm are marginal for corn production. Zinc is most likely deficient on fields where the topsoil has been removed and in

fields with a relatively high yield potential. Zinc may be foliar applied for in-season rescue treatment but is best managed using soil applications of a high water-soluble zinc fertilizer at or before planting.

Iron deficiency is most likely to occur in the western half of Kansas on soils where erosion or leveling has exposed highly calcareous subsoil, low in organic matter. Foliar iron applications or manure application are often the best (only) options for managing iron deficient soils for corn production.

Corn has also been shown to respond to chloride if the 2-foot profile chloride test is low. Twenty pounds of chloride is recommended for corn production if the soil profile chloride test is less than 7 parts per million. Potassium chloride (potash) and ammonium chloride solution are the most common sources of chloride for Kansas corn production.

While crop responses to boron have occasionally been noted in far southeast Kansas, care should be used when applying this nutrient since toxicities are possible. Boron should only be applied to corn if the soil test in southeast Kansas is less than 1.0 part per million and the application rate should be limited to 1 pound per acre. Do not band apply boron. Nutrient deficiencies of other nutrients (copper, manganese, molybdenum, and nickel) have not been documented in Kansas.

Liming

Lime recommendations are based on a program of maintaining the soil in a productive condition. Although corn is not the most responsive crop to lime, the liming of acid soils should not be ignored. The benefits in any one season may not be great, but for the continued production of corn and other crops on the land, liming is a sound practice. Little corn yield response to lime is likely in most areas of Kansas (except southeastern Kansas) at soil pHs above 5.5 because of higher soil pHs in the subsoil. In the eastern third of Kansas, lime is recommended on all soils with a pH of 6.0 or less. For the western two-thirds of Kansas, lime is recommended on soils with a pH of 6.0 or less and a subsoil pH of less than 6.4.



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