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Energy Requirements for Drip Irrigation of Tomatoes in North Florida [1]

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INTRODUCTION

The energy required to pump irrigation water for crop production is measured in terms of fuel use or electric power use. Energy use depends on the amount of water pumped and on the fuel or electric power required to pump each unit of water.

For example, if an irrigation system is used to apply 20 acre-inches (ac-in) per acre per year and uses 2 gallons (gal) of diesel fuel per ac-in, then the annual energy use per acre is the energy contained in 40 gal of diesel fuel. Likewise, if an electric-powered irrigation pump is used to apply 10 ac-in per acre per year and uses 25 kilowatt-hrs (kwh) per ac-in, then its annual energy requirement is 250 kwh per acre.

This publication discusses the factors that affect energy requirements for irrigation pumping. It emphasizes ways that irrigation systems can be designed and managed to minimize energy requirements for drip irrigation of tomatoes in north Florida.

AMOUNT OF WATER PUMPED

The amount of irrigation water pumped depends on several irrigation system factors, and on crop, climate, and management factors that are independent of the irrigation system.

Irrigation System Factors

Potential Irrigation System Efficiency

An important irrigation system factor is the potential irrigation system efficiency. Efficiency is a measure of the fraction of the water pumped that is available for plants to use. The potential irrigation system efficiency is the maximum efficiency that can be obtained with an irrigation system, assuming perfect management. It depends on the type of irrigation system and how well the system is designed.

Microirrigation systems, including drip irrigation systems, have high potential application efficiencies. Because water is applied very near or directly into the crop root zone, evaporation and wind drift losses are minimized. Water applications

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can be limited to the amounts that are needed by the crop, and efficiencies can be as high as 85 percent. Conversely, seepage (subirrigation) systems apply water to establish and maintain a water table just below the crop root zone. Larger fractions of the water pumped are not used by the crop, thus application efficiencies are lower, typically in the range of 50 percent. Efficiencies of sprinkler and surface irrigation systems are normally greater than seepage efficiencies but less than microirrigation efficiencies.

System Design

To achieve high efficiencies, the irrigation distribution system must be well-designed. Good design means that pipe diameters, lengths, and flow rates are compatible so that water can be uniformly applied. If uniformity is poor, water will be wasted and crop production may decline because excess water will be applied in some areas, while too little will be applied in other areas.

Area of Coverage

For many agricultural crops, plants are very closely spaced. Their roots overlap and extend throughout the production area. These crops can be very efficiently irrigated with sprinkler systems because sprinklers distribute water over the entire production area. An example is the use of center pivot systems to irrigate field crops such as corn in north Florida.

For many other crops, plants are widely spaced and roots are concentrated near the individual plants. There may be areas between plants where no roots grow. Examples are mulched-bed vegetable production systems such as tomatoes where roots are primarily located in the beds and few roots extend to the row middles. In these systems, water use can be reduced if water is not applied to the row middles, but is limited to the production bed. Drip irrigation systems minimize water use by avoiding applications to row middles where losses would occur due to deep percolation, evaporation from bare soil, and weed growth.

Crop Factors

The crop production system is the type of crop and the associated production practices such as row spacing and the use of plastic mulch. Crop water use depends on the type of plants, size of plants, and number of plants per acre. It also depends strongly on climate factors as discussed under the following heading of this publication.

In Florida, the irrigation requirement for most crops depends heavily on rainfall because a large part of the crop water use is supplied by rainfall. It also depends on soil water-holding capacity and root distributions because these factors affect the amount of rain that can be held in the soil and extracted by plant roots. For tomatoes and other crops grown on plastic mulched beds, the irrigation requirement is a large fraction of the crop water use because much of the rainfall runs off of the mulched beds.

Climate Factors

Climate factors affect the amount of water required by a crop. Climatic demand depends on solar radiation, temperature, humidity and wind speed. Climatic demand is high on hot, dry, clear sky days, and it is low on cool, humid, overcast days.

Management Factors

Management practices greatly affect the amount of irrigation applied. If well-designed and well-installed systems are poorly managed, both water and energy will be wasted. Drip-irrigated tomatoes require small, frequent water applications, normally daily or more than once a day, except when interrupted by significant rainfall. Smaller irrigation durations (amounts) are required early in the growing season when plants are small. Larger amounts are required as plants and fruit develop and grow to maturity.

This publication emphasizes irrigation system characteristics which minimize energy requirements for drip-irrigated tomato production. For detailed discussions of irrigation system management and irrigation scheduling, see IFAS Extension Bulletin 245, *Microirrigation on Mulched Bed Systems: Components, System Capacities, and Management* and IFAS Extension Circular 872, *Irrigation Scheduling and Management of Micro-Irrigated Tomatoes.*

ENERGY REQUIRED PER UNIT OF WATER

The energy required per unit of irrigation water pumped depends on the total dynamic head that the pump is operating against and the efficiency of the pumping system. The total dynamic head depends on:

- the vertical distance that the water is lifted,
- the pressure required to operate the drip emitters, and
- the friction losses that must be overcome as water is pumped from its source through filters, valves, and pipelines to the emitters.

The efficiency of the pumping system depends on the efficiencies of the pump, power unit, and connecting drive units.

Total Dynamic Head

The total dynamic head is the sum of the pumping lift, operating pressure, and friction losses within the irrigation system. The total dynamic head is defined for each of the irrigation subunits. In a well-designed irrigation system, flow rate and total dynamic head should be approximately the same for each subunit so that the pumping system can operate as efficiently as possible.

Pumping Lift

The pumping lift is the vertical distance from the water source to the entrance to the subunits. This is the height that water must be lifted to deliver it from its source to the irrigation distribution system. Energy is required to lift the water, and the amount of energy required is the same for each unit of water: 1 foot-pound (ft-lb) of energy must be expended to lift each pound of water a vertical distance of 1 foot. This is equivalent to 1 horsepower (hp) to lift 30 gpm a distance of 100 feet. It is not possible to avoid this energy use, because it depends on the location of the water source and the field elevation and slope.

Because the elevation of the water source may change during the irrigation season, a pumping system should have sufficient capacity to lift water from its lowest anticipated level. In wells, drawdown during pumping reduces the water level below the static (non-pumping) level, and a greater amount of energy is required to lift water from this lower level.

Operating Pressure

The operating pressure is the pressure required at the entrance to each subunit for the emitters to operate effectively and water to be uniformly distributed. The required pressure is defined by the choice of emitter and the subunit pipe network design. Pipelines are designed to distribute water to the emitters with controlled pressure losses so that water can be uniformly applied throughout the subunit.

Operating pressures can be minimized by selecting emitters that operate at low pressures. Drip systems for tomato production typically use drip tape laterals that operate at about 10 psi. It is not feasible to reduce operating pressures much below this level. Only about 0.8 hp is required to pump 100 gpm at 10 psi.

Friction Losses

Friction losses must be minimized in order to minimize the energy requirements for irrigation pumping. Energy must be provided to overcome friction losses which occur as water flows through all components from the water source and throughout the irrigation system. Some friction losses are unavoidable, even in well-designed, well-constructed, and properly-maintained irrigation systems. However, excessive losses waste energy and should not be tolerated.

Proper selection of irrigation system components requires that the cost of energy lost to friction be compared against the cost of larger components with lower friction losses. Then components with the overall lowest cost throughout the expected life of the irrigation system should be selected.

In general, friction losses can be minimized by selecting pipe sizes to limit the velocity of flow to 5 feet per second (fps) in all mainlines and submains, and selecting valves and fittings compatible with the pipe sizes. Proper maintenance is essential to prevent excessive friction losses as water flows through an irrigation system, especially at points where large pressure losses can easily occur, such as filters and intake strainers on pumps.

For a detailed discussion of component selection, installation, and maintenance to minimize friction losses in irrigation systems, see Agricultural Engineering Department Extension Report 93-7, *Improving Energy Efficiency for Drip-Irrigated Tomato Production: II. Conserving Energy by Reducing Friction Losses.*

Pumping System Efficiency

The overall efficiency of the pumping system is the multiple of the individual efficiencies of the pump, power unit, and connecting drive units. Energy losses can be minimized by properly selecting, installing, and maintaining each of these components.

Pump Efficiency

The efficiency of irrigation pumps typically ranges from 60 to 90 percent, with values of 75 to 80 percent being very common. If a pump has an efficiency of 75 percent, this means that 75 percent of the energy that is delivered to the pump from the power unit is transmitted to the water being pumped, where it produces the flow rate and pressure delivered by the pump. The remaining 25 percent of the energy that was input into the pump is lost due to friction and turbulence in the pump.

Pump efficiencies can be much lower than 75 to 80 percent if a pump is not properly selected for a specific application, if it is not operated at the proper speed, or if the impellers or other components are worn or damaged.

Pump Selection

Irrigation pumps operate near peak efficiency over a fairly narrow range of discharge rates and pressures. If an irrigation system requires that a pump discharge 300 gpm at 50 psi, but the pump installed is too large, its peak efficiency will occur at another operating point, for example, 500 gpm and 80 psi. Then this large pump will operate at a low efficiency and waste energy because it is being applied at the wrong operating point, even though the pump may be in good repair.

When an irrigation pump is considered for a given application, its pump characteristic curves must be studied to verify that it can operate efficiently at the required discharge rate and pressure. If it cannot, another pump which is efficient at the required operating point should be selected. Pump characteristic curves should always be provided by the pump dealer and kept by the pump owner so that the pump operating characteristics will be known if operating conditions change.

Pump Speed

Irrigation pumps can be operated at a range of speeds, and the proper speed is required to obtain the required discharge rate and pressure. This is not a problem when the power unit is an electric motor, because the pump will be directly connected to the motor, and the pump speed will be the same as the speed of the electric motor.

When an irrigation pump is driven by an internal combustion engine, the proper engine speed must be set by throttling the engine to obtain the desired pump output at high efficiency. The engine should be equipped with a tachometer so that the engine and pump speeds can be accurately set.

Worn or Damaged Impellers

With age, pump impellers may become worn or damaged. Damage may occur due to the corrosive nature of some water supplies or due to physical damage by sand or gravel in the water. When this occurs, impeller adjustment, repair, or replacement may be needed. Adjustments should be made by qualified, experienced individuals because improper adjustment can damage a pump.

Pump characteristic curves should be used as a reference when pump tests are conducted to determine whether a loss in efficiency has occurred. This reference is needed to help determine when repairs should be scheduled. In general, repairs should be scheduled when pump efficiency has decreased to the point that the expected energy savings from the pump repair would be greater than the cost of the repairs.

Power Unit Efficiency

Power unit efficiency is the effectiveness of the power unit in converting electric power or engine fuel to mechanical power to drive an irrigation pump. A convenient way to express this is the performance standard for a specific type of power unit. Performance standards are expressed in units of horsepower-hours per kilowatt-hour (kwh) of electric power or gallon (gal) of fuel. The performance standards are:

- electric motors = 1.19 hp-hr/kwh
- diesel power units = 14.75 hp-hr/gal
- gasoline engines = 11.30 hp-hr/gal, and
- LP gas engines = 8.92 hp-hr/gal.

Consider the diesel performance standard data for example. The standard of 14.75 hp-hr/gal means that a 14.75 hp diesel engine would be expected to use 1 gal of diesel fuel per hour of operation. Likewise, a 60-hp diesel engine would be expected to use about 4 gal of diesel fuel per hour. If the measured fuel use rate for a diesel engine is higher than these standards, this could indicate problems with the power unit.

Power unit efficiencies will decline if the power units are not maintained, not properly loaded, or if they are worn with age. The solution to these problems might be routine maintenance such as a tune-up or adjustment, cleaning of fuel injectors, or change of partially plugged filters. To make best use of performance standard data, the pump owner should measure fuel use rates of their systems when they are in good repair, and record this information as a reference for later comparisons. As a minimum, comparisons should be made during equipment preparation for each irrigation season.

Performance standards will probably not be met if power units are either overloaded or underloaded. Overloading will occur if the power unit is too small for the power requirements of the pump. Also, running an internal combustion engine at a too-high speed can quickly overload the engine. Underloading will occur if the power unit is significantly larger than the power requirements of the pump. In this case, the large power unit will waste fuel as compared to a power unit of the proper size.

It is possible to exceed the previously given performance standards if high efficiency power units are used or if other innovations are used to reduce the loads on internal combustion engines. For example, the use of turbocharged diesel engines will increase the efficiency of fuel conversion to mechanical energy. Thus, a turbocharged diesel engine would be expected to exceed the performance standard of 14.75 hp-hr/gal. Likewise, many of the newer air-cooled internal combustion engines have fuel conversion efficiencies that exceed the performance standards described above.

The performance standards presented here were determined for internal combustion engines using standard accessories, including a water pump, fan, and radiator. If a heat exchanger is used, replacing the fan and radiator with cooling by the irrigation water pumped, then the energy used to power the fan would be saved. This could save 3 to 5 percent of the power unit horsepower.

Drive Unit Efficiency

Drive units are the drive shafts and right-angle gear drives or belt drives that are used to connect internal combustion engines to irrigation pumps. Normally, an electric motor does not require a gear or belt drive because it is directly connected to the pump or to the pump drive shaft.

Some energy is lost as power is transmitted through gear or belt drives. This may amount to 5 to 10 percent of the transmitted energy because the efficiency of these drive units typically ranges from 90 to 95 percent. However, energy losses can be greater than this if these drives are worn or not in good repair.

To ensure efficient operation, regularly check and maintain the lubricating fluid level in a gear drive. Change the fluid as recommended by the manufacturer or at least annually.

The fluid in some large gear drives is water cooled using a cooling coil that is connected to the irrigation water supply. Check that the required amount of water is flowing through the coil so that the lubricating fluid does not overheat.

Energy will be lost as gears and bearings wear. Check regularly for excess "play" in the gears, leakage around seals, or unusual noises and have these repaired when needed.

Belt drives should be routinely inspected for proper belt tightness and belt wear. Loose belts will slip, causing excess energy loss and premature belt failure. Worn belts may slip or fail during irrigation, possibly damaging mechanical components. Worn or damaged belts should be replaced. Belts should be replaced in matched sets so that all belts in a set will be uniformly loaded during use.

Some energy is required to spin a drive shaft and overcome friction losses from drive shaft bearings or universal joints. The energy required to spin a drive shaft is unavoidable because it is a function of the weight of the drive shaft. However, energy losses to bearings can be minimized by keeping bearings in good repair and properly lubricated.

Drive shaft bearings in wells may be either oil or water lubricated. Inspect the lubricating oil reservoir regularly and add oil as needed. Always pre-lubricate water-lubricated bearings before starting pumps. Prelubrication is done by pouring a few gallons of clean water into the column pipe along the drive shaft before pump start-up. This is very important for water lubricated bearings because they will heat up very quickly before the water flows through the column pipe to lubricate them.

Universal joints are used on drive shafts between internal combustion engines and gear drives or pumps. These U-joints should be inspected regularly for wear and proper lubrication. U-joints are used to allow efficient power transmission even though the drive shafts of the connected units are not in perfect alignment. Engines and drives should be closely aligned when installed to avoid excessive flexing of the joints during operation. Excessive flexing will lead to earlier failure and increased energy loss. Visually inspect the drive shaft and U-joints during operation. Excessive vibration indicates the need for repair. Excessive vibration can also indicate a serious safety problem, and thus should be repaired immediately.

SUMMARY

The energy required to pump irrigation water for crop production is measured in terms of fuel use or electric power use. Energy use depends on the amount of water applied and on the fuel or electric power required to apply each unit of water.

The amount of water applied depends on several irrigation system factors and on crop, climate, and management factors that are independent of the irrigation system. Irrigation system factors include specific system design factors, such as the potential irrigation system efficiency, the system design uniformity, and the relative area of coverage. Crop factors include type of crop, size of plants, plant density, and other production system factors such as the use of plastic mulch. Climate factors include solar radiation, temperature, humidity and wind speed. Management factors include irrigation scheduling decisions which affect irrigation frequencies and durations.

The energy required per unit of water delivered depends on the irrigation system design and on field site characteristics. These factors can be summarized as the total dynamic head that the pump is operating against and the efficiency of the pumping system. Total dynamic head depends on the vertical distance that the water is lifted, the pressure required to operate the drip emitters, and the friction losses that must be overcome as water is pumped from its source until it is delivered from the emitters. Efficiency of the pumping system depends on the efficiencies of the pump, power unit, and connecting drive units. Recommendations were made for selecting, installing, and maintaining components to minimize energy loss and maximize pumping efficiency.