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DRIP IRRIGATION ENERGY EFFICIENCY FOR TOMATO PRODUCTION IN NORTH FLORIDA

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Abstract. **A field study was conducted to evaluate the energy efficiency of irrigation pumping for drip-irrigated tomato production (*Lycopersicon esculentum* Mill.) in north Florida, and to estimate energy savings that could result from improvements in system design and maintenance. Eight farms believed to be representative of the industry were selected for in-depth study. Site visits were conducted to obtain detailed descriptions of the irrigation systems, to measure system performance, and to interview growers concerning normal operating procedures. Inefficiencies in pumping system operation were classified as those due to the irrigation pump, power unit, and friction head losses in pipelines and filters. Potential energy savings of 41% of current use rates were identified. Of these, 5% was due to pump inefficiency, 14% was due to power unit misapplication, and remainder was due to excessive friction losses. For the annual 5,000 acre drip-irrigated tomato crop in north Florida, the potential annual energy savings was demonstrated to be equivalent to approximately 58,000 gal of diesel fuel with a value of $64,000 per year.**

Introduction

Approximately 5,000 acres of tomatoes are grown annually in the Gadsden county area of north Florida (Freie and Young, 1993). Because of limited water supplies and the production benefits of drip irrigation, the majority of this acreage is drip-irrigated. Production benefits include high fruit quality, increased yield per unit of water applied, and reduced energy use per acre as compared to conventional irrigation systems.

The potential energy efficiency of drip irrigation is high when systems are well-designed, properly installed, and well-managed. A project conducted to improve drip irrigation management for tomatoes in the Telogia Creek basin in this region (Florida Governor's Energy Office, 1992) reported that the average energy use was 421 kilowatt-hours (KWH) per acre for fall, 1991 and spring, 1992 crops. This low energy use per acre was due to the low pressure required for drip irrigation and reduced water applied as compared to conventional irrigation systems.

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Despite the relatively low energy requirement per acre, a large variation was observed in energy required per acre-inch of water applied. The average fuel use (in equivalent gallons of diesel fuel) was 2.9 gal/acre-inch, with a coefficient of variation of 24% and a range from 1.4 to 3.9 gal/acre-inch. This wide variation in the rate of energy use was the basis for this field study of the energy requirements for irrigation pumping.

The objectives of this study were to evaluate the energy efficiency of irrigation pumping for drip-irrigated tomato production in north Florida, and to estimate energy savings that could result from improvements in system design, installation and management. Specific objectives were to (1) conduct an energy analysis of drip irrigation systems under field conditions, (2) categorize causes of any low efficiencies observed, and (3) calculate potential energy savings that would result from improving efficiencies to standard values.

Theory

The energy required per unit of irrigation water applied depends on the total head that the pump is operating against (total dynamic head) and on the efficiency of the pumping system (Longenbaugh and Duke, 1980; Pair, 1983). The total head that a pump operates against is defined as the total dynamic head:

$$TDH = EH + PH + FH \tag{1}$$

where
TDH = total dynamic head (ft),
EH = elevation head (ft),
PH = pressure head (ft), and
FH = friction head (ft).

EH is the vertical distance that water is lifted, PH is a function of the pressure required to operate the drip emitters, and FH is the friction losses that must be overcome as water is pumped from its source to the emitters. Of these components, potential energy savings are limited to reductions in FH because pumping lift is fixed due to topography and location of the water source, and PH is inherently small with drip irrigation. Friction losses are a function of the square of water velocity, thus FH increases rapidly as velocities increase. FH can be maintained at acceptable levels by limiting velocities of flow to a maximum of 5 ft/sec.

The brake power required to operate an irrigation pump is calculated from:

$$BHP = (Q \cdot TDH) / (39.6\ EFF) \tag{2}$$

where BHP = brake power (hp),
Q = pump flow or discharge rate (gpm), and
EFF = pump efficiency (%).

The overall efficiency of a pumping system is the multiple of the 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 efficiencies should normally be in the range of 75 percent, and drive efficiencies should be at least 90 percent. Power units should produce 14.75

hp-hr per gallon of diesel fuel or 1.18 hp-hr per kilowatt hour for electric motors (Smajstrla et al., 1985). These are the standards that were used for calculations made in this study.

Procedure

Eight farms believed to be representative of the north Florida tomato industry were selected for an in-depth analysis of irrigation pumping energy requirements. All irrigation systems used centrifugal pumps and surface water from ponds or streams. Five electric motor powered and three diesel engine powered systems were selected. All pumps were direct-connected to the power units, thus drive efficiencies were 100%.

Site visits were conducted to obtain detailed descriptions of the systems, to measure system performances, and to interview growers concerning normal operating procedures. Detailed system descriptions were obtained in order to evaluate energy use in each of the system components and to help identify causes for any low efficiencies observed. Information was obtained to characterize the water source, pump, suction pipeline, power unit, mainline pipe, filtration system, and field water distribution system. Sizes of all pipe, valves, and fittings were obtained so that friction losses could be calculated for each component. Growers provided information on field sizes, number and size of irrigation zones, average irrigation time per zone, and average number of irrigations per day.

System performances were determined by measuring water flow rates and pressures during normal system operation. Characteristic curves were obtained from pump manufacturer's data to evaluate whether pumps were properly selected for each specific application. Sizes of power units were compared to sizes required for optimum pump operation and to calculate energy waste due to misapplication of pumps and power units. These data were then used to calculate irrigation system performance and to estimate potential energy savings if performance was lower than standard values.

Results and Discussion

General characteristics of the eight drip irrigation systems studied are shown in Table 1. These characteristics demonstrate that all systems were designed with sufficient capacity to meet the crop irrigation requirements. Based on the average farm size of 35.8 acres and flow rate of 539 gpm, the average system has the capacity to provide about 3/4 inch of water per acre per day. This is sufficient to allow irrigation applications to be made in relatively few hours per day, thus system capacity would not be expected to limit production at any time during the growing season, even with time allowances for normal maintenance and repairs.

The average pump efficiency in Table 1 was 74.4%, which compares very favorably with the 75% typically assumed for well-designed irrigation systems. All individual pump efficiencies were near the peaks for the pumps selected. Even the lowest efficiency of 65% (Farm No. 4) was within 1% of the peak efficiency for the specific pump used. These results demonstrate that the pumps used in these systems were well-selected for their specific applications, and that little energy savings would be obtainable from improvements in pump efficiency.

Power unit ratings in Table 1 were obtained from the nameplate ratings of the electric motors and from the power unit performance curves of the diesel engines. Diesel power unit ratings are the continuous engine ratings at the normal pump operating speed (rpm). In general, power units were much larger than required for proper pump operation. The average power unit rating (61.6 hp) was 1.6 times the average pump brake power required (38.3 hp). This demonstrates that energy savings could be realized by using smaller power units since power units waste energy if they are not fully loaded.

The total dynamic head (TDH) varied more than 3-fold, from 99 to 333 ft, with an average of 204 ft. This wide variation suggested the need to study the components of TDH to determine whether energy savings could result from component modification to reduce TDH. Table 2 shows the components of TDH: elevation head (EH), pressure head (PH), and friction head (FH). EH ranged widely, from 22 to 94 ft, with an average of 60 ft. However, EH is a function of topography and the location of the water supply with respect to the field site, thus energy requirements to lift water to these heights are unavoidable.

For line-source drip irrigation systems used in tomato production, PH is relatively low, normally approximately 10 psi (23 ft). For the systems studied in this project, PH was small (average PH = 27 ft), and further reductions are not feasible because this pressure is required to operate the drip emitters. Thus, energy savings could not result from reductions in PH because growers are already using a very efficient type of irrigation system with respect to its pressure requirements.

Table 1. General characteristics of the farm irrigation systems studied.

Farm no.	Farm size (ac)	Pump flow rate (gpm)	Total dynamic head (ft)	Pump efficiency (%)	Pump brake power (hp)	Type of power unit	Power unit rating (hp)
1	17.5	400	225	66	34.5	Diesel	74
2	49.8	500	191	75[z]	32.2	Electric	40
3	67.0	700	218	74	52.0	Electric	75
4	24.0	400	156	65	24.2	Diesel	67
5	23.6	469	99	72	16.2	Diesel	67
6	68.0	693	333	81	72.0	Electric	80
7	14.3	550	174	81	29.8	Electric	40
8	22.0	602	241	81	45.2	Electric	50
Avg.	35.8	539	204	74.4	38.3	—	61.6

[z]Pump efficiency was estimated for Farm No. 2.

Table 2. Hydraulic characteristics of the irrigation systems studied.

Farm no.	Elevation head (ft)	Pressure head (ft)	Friction head				
			Suction (ft)	Mainline (ft)	Filter (ft)	Minor (ft)	Total (ft)
1	78	35	6	34	69	4	113
2	90	28	9	36	23	6	73
3	56	23	4	26	101	7	139
4	53	28	4	46	23	2	75
5	22	28	8	16	20	6	49
6	94	17	5	153	49	16	222
7	34	28	11	73	23	6	112
8	57	28	7	118	23	8	156
Avg.	60	27	7	63	41	7	117

FH was highly variable for the systems studied, ranging from 49 to 222 ft with an average of 117 ft. In this analysis, friction head losses were categorized as suction pipeline, main pipeline, filtration system, and minor (valve, fitting, and component) losses. Mainline friction losses were the largest and most variable, ranging from 16 to 153 ft with an average of 63 ft. The higher losses were the result of excessive velocities of water flow and long pipeline lengths. Long pipeline lengths cause unavoidable energy losses because lengths are a function of the location of the water supply with respect to the irrigated field, however, friction losses can be minimized by reducing velocities to the standard of 5 ft/sec. Velocity reductions can occur by reducing flow rates or increasing pipe sizes.

Filtration system losses were the second-largest category with an average of 41 ft and a range from 20 to 101 ft. Filter losses should be limited to approximately 10 psi (23 ft) for well-designed, well-maintained filters (FIS, 1991). Thus, the opportunity for energy savings exists for Farms No. 1, 3 and 6 by improving filter system design or maintenance.

Suction pipeline and minor friction losses were both small, averaging 7 ft each. Thus, there is little opportunity for significant energy savings as a result of system modifications in these categories.

In Table 3, fuel use rates and fuel costs for irrigation pumping are shown based on the evaluations made of system flow rate, TDH, pump efficiency and power unit loading efficiency. Unit costs were calculated per hour of pumping and per acre-inch of water applied. Costs were also estimated per acre and per farm for a crop growing season. These estimates were based on 12 inches of irrigation per crop season as reported for both fall and spring crops by the Florida Governor's Energy Office (1992), although actual amounts might be 2-3 inches more per season because that report did not measure water requirements for land preparation and plant establishment.

In Table 4, the potential fuel cost savings per acre per crop season are shown. These savings could be realized by improving pump efficiency, properly matching the size of the pump and power unit, and by reducing friction losses in those system components where excessive friction losses were observed. Potential savings from pump efficiency improvements were calculated by assuming that efficiencies could be improved to 75% by proper pump selection. This resulted in only moderate potential savings for four farms because pump efficiencies were generally high.

Potential savings from properly matching power units to pumps were low for electric motors but significantly higher for diesel engines. For all three of the diesel-powered systems studied, the power requirements could have been provided by smaller 4-cylinder diesel engines as compared to the 6-cylinder engines used. The average potential savings from down-sizing diesel power units was $10.24/acre per crop.

Reducing excessive friction losses would result in large energy reductions as shown in Fig. 1 as a percentage of the current fuel use rate. The average potential fuel savings due to reductions in friction losses was 23.9%, however, four systems studied had potential savings of nearly 40%, and only Farm No. 4 had no potential savings. From Table 4, energy losses and potential savings were very small from suction pipelines and minor components. Four systems had excessive mainline friction losses, and three systems had excessive filter losses.

The overall potential fuel and energy savings is summarized in Fig. 2 as a percentage of the current fuel use

Table 3. Fuel use rates and fuel costs for irrigation pumping.

Farm no.	Actual fuel use rate Electric (kw) Diesel (gph)	Fuel cost ($/hr)^z	($/acre-inch)	($/acre /crop)^y	($/farm /crop)^y
1	3.03 gph	3.34	3.78	45.36	794
2	28.1 kw	2.25	2.04	24.44	1217
3	46.9 kw	3.75	2.43	29.14	1952
4	2.45 gph	2.70	3.05	36.67	880
5	2.00 gph	2.20	2.13	25.50	602
6	61.6 kw	4.93	3.22	38.66	2629
7	26.3 kw	2.10	1.73	20.80	297
8	38.7 kw	3.10	2.33	27.96	615
Avg.	27.1 kw^x 2.17 gph	3.05	2.59	31.06	1123

^{z}Based on diesel fuel cost = $1.10/gal and electricity cost = $0.08/kwh.
^{y}Based on 12 inches of irrigation per crop season. To calculate annual costs, double these values if 2 crops are grown per year.
^{x}Equivalent fuel use rates based on 1 gal/hr diesel = 12.5 kwh/hr.

Table 4. Potential fuel cost savings due to improved pump efficiency, properly matched power unit, and reduced friction losses.

	Potential fuel cost savings ($/acre/crop)^z						
			Friction losses				
Farm no.	Pump	Power unit	Suction	Main	Filter	Minor	Total
1	5.44	9.24	0.00	0.00	9.31	0.00	23.99
2	0.00	0.76	0.51	2.96	0.00	0.28	4.50
3	0.39	1.71	0.00	0.00	10.51	0.00	12.60
4	4.89	10.46	0.00	0.00	0.00	0.00	15.36
5	1.04	11.01	0.90	0.00	0.00	0.00	12.96
6	0.00	0.39	0.00	11.70	2.95	0.83	15.87
7	0.00	0.99	0.55	6.99	0.00	0.33	8.86
8	0.00	0.27	0.00	10.27	0.00	0.43	10.97
Avg.	1.47	4.35	0.25	3.99	2.85	0.23	13.14

^{z}Based on 12 inches of irrigation per crop season. To calculate annual costs, double these values if 2 crops are grown per year.

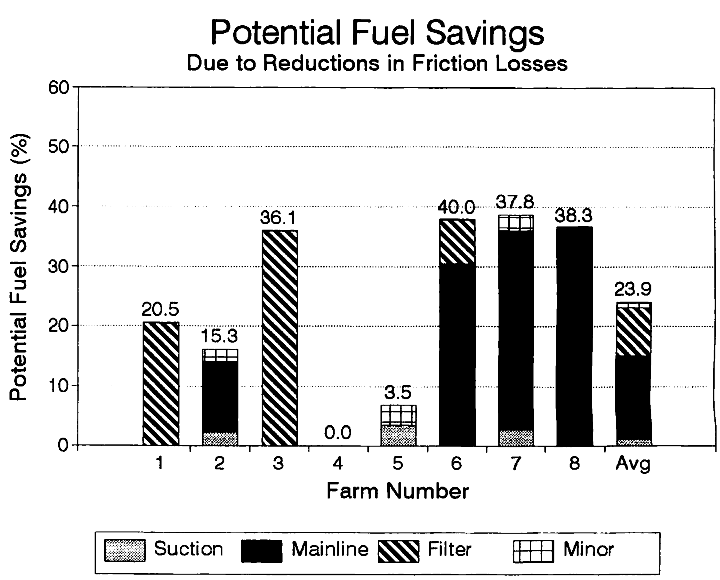

Figure 1. Potential fuel savings due to reductions in friction losses as a percentage of current fuel use rates.

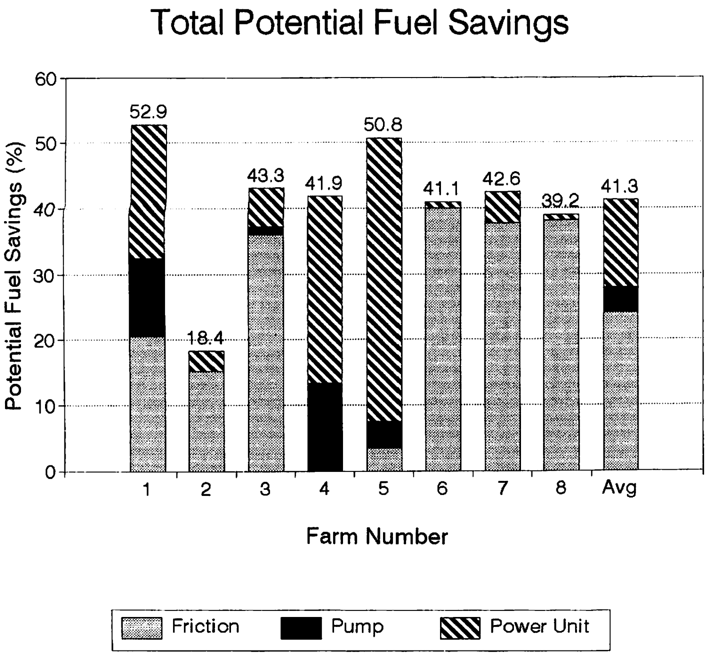

Figure 2. Total potential fuel savings as a percentage of current fuel use rates.

rate. From Fig. 2, the average potential fuel savings from all causes studied was 41.3%, however two systems had potential savings over 50%, and even the most efficient system (Farm No. 2) had a potential savings of 18.4%. These potential fuel and energy savings are believed to be representative of the annual 5,000 acre drip-irrigated tomato crop in north Florida. From the average fuel use data in Table 3, the annual energy usage is the equivalent of about 141,000 gal of diesel fuel at a cost of about $155,000 per year. Thus, the potential savings is demonstrated to be about 58,000 gal of diesel fuel with a value of about $64,000 per year.

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PAN EVAPORATION SCHEDULING FOR DRIP-IRRIGATION TOMATO

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Abstract. **Tomatoes (*Lycopersicon esculentum* Mill.) were grown with polyethylene mulch and drip irrigation on a fine sandy soil to evaluate the effects of water quantity scheduled by pan evaporation. Water was applied at 0, 0.25, 0.50, 0.75 and 1.0 times pan evaporation in one irrigation per day during the 1990 season. In this extremely dry season, fruit yields were doubled by irrigation. Total fruit yield were highest with irrigation quantities of 0.75 and 1.0 pan and significantly lower with 0.25 and 0.50 pan. Fruit yields were similar with 0.75 pan, 1.0 pan, and with the soil maintained at 10 cb. As compared with tensiometer (10 cb) controlled treatment, water applications were higher early in the season with the 0.75 pan treatment but were similar later in the season. Total water use was higher with the 0.75 pan schedule than with the 10 cb treatment. Tomato leaf N concentrations were reduced with an increase in water quantity.**

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Introduction

Tomato is the highest valued vegetable grown in Florida. During the 1991-92 season, the crop was grown on 20,760 ha with an on-farm value of $728.6 million (Freie and Young, 1993). Most of the crop is grown from transplants with polyethylene mulch and must be irrigated to prevent water stress. The most common forms of irrigation are subsurface with the application of about 115 to 150 $cm \cdot ha^{-1}$ and sprinkler with 38 to 50 $cm \cdot ha^{-1}$ (Locascio et al., 1989). In 1974, Locascio and Myers reported that tomato yields similar to those produced with sprinkler irrigation could be produced with less than one-half as much water applied by drip irrigation provided that N-K were injected with the irrigation water.

Drip irrigation has been slow to be used by commercial growers where water was abundant because of the increase in cost and the intensity of management required to use drip irrigation (Prevatt et al., 1984). In recent years, the need to conserve water has increased along with the use of drip irrigation. Currently 4700 ha of tomatoes are grown with drip in Florida (Hochmuth et al., 1993).

Water application scheduling is important since overwatering or underwatering may result in a reduction in yield. A convenient method to schedule drip irrigation water quantity is to apply water as a factor of evaporation from a U.S. Weather Service Class A evaporation pan (pan). On a sandy soil, tomato water requirements were reported to be more than 0.50 pan (Locascio and Smajstrla, 1992) and below 1.0 pan (Locascio et al., 1989). The study reported