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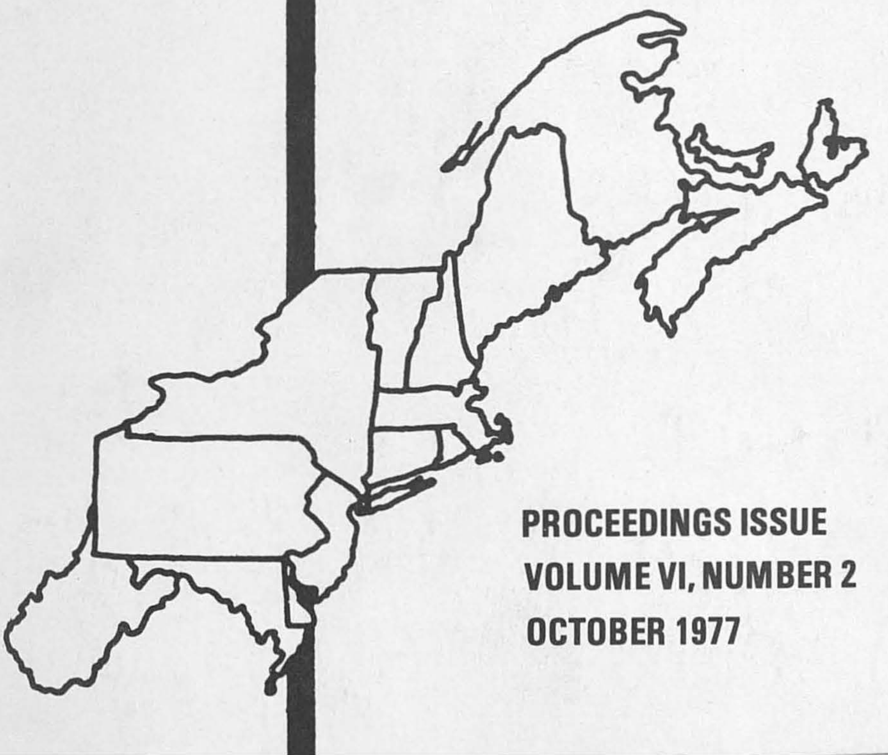

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CONSERVING IRRIGATION ENERGY IN THE NORTHEAST

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Introduction

While there has been some irrigated agriculture in each of the 11 States in the Northeast farm production region for a number of years, irrigation has never been widely practiced in this region. The latest available data indicate that only about 2 percent of the cropland in the Northeast is irrigated [7], while 12 percent of the cropland in the nation is under irrigation [6], largely in the more arid West. During the past year, ERS has investigated why supplemental irrigation is not practiced by more farmers in the East. The one example of extensive supplemental irrigation in a humid State is Florida, which contains over half of the irrigated acreage in the 26 States east of the Mississippi River although it has the second highest average annual rainfall in the nation. Although discussed in the last section, the main purpose here is not the potential for expanding supplemental irrigation, but to discuss ways of conserving energy with the irrigation already practiced in the Northeast.

Irrigation Efficiency

Irrigation pumping energy requirements are a function of:

1. The volume of irrigation water pumped.

2. The feet of lift, which is the difference in elevation between the source of water and the field being irrigated.

3. The efficiency of the irrigation system; that is, the portion of the irrigation water stored in the root zone expressed as a percent of the total water pumped.

Another efficiency term associated with irrigation is pumping efficiency. This is the energy that operates the pumping unit, net of the energy lost to heat or friction, expressed as a percentage of total energy expended.

Everything else being constant, pumping energy can be conserved by reducing the volume of irrigation water and the energy saved is roughly proportional to water saved. Using the lowest possible lift and employing an irrigation system that utilizes the lowest pumping pressure to achieve a given level of irrigation efficiency are the two other fundamental measures for conserving irrigation energy.

Since surface water requires a lower lift than groundwater in most cases, it will usually be preferred as an irrigation water source because of the lower pumping cost. However, in the East surface water is generally available only to landowners with riparian rights to streams and lakes. Therefore, irrigators without such rights must use groundwater. According to a preliminary report by Gordon Sloggett, ERS irrigation energy specialist, 53 percent of the irrigated acreage in the Northeast is serviced by surface water and 47 percent by groundwater [5]. Sloggett's data indicate that the Northeast Region's irrigation groundwater lift ranges from 50 to 175 feet while the surface water lift ranges from only 15 to 35 feet.

Batty, Hamad and Keller in a 1975 article gave the comparative energy requirements per acre for nine different irrigation systems [1]. Two of those systems were gravity systems in which water runs down furrows or spreads inside field borders by gravity flow. The other seven were sprinkler systems in which water is forced by pump pressure through pipes and distributed by nozzles attached to the pipes. Total annual energy requirements were calculated assuming 36 acre-inches net irrigation water with zero pumping lift and were expressed in thousand kilocalories of energy.

The analysis assumed that the volume of irrigation water required is independent of the type of irrigation system used, but gross volume of water pumped or delivered is a function of the efficiency of the irrigation system. The efficiency of simple gravity systems generally varies between 30 and 70 percent with 50 percent as an average value. However, efficiency of about 85 percent could be obtained by using an irrigation runoff recovery system. Sprinkler irrigation efficiencies vary from 60 to 90 percent with the average being 70 percent.

Annual energy requirements of each system were determined for installation, pumping, labor, and total as shown in Table 1 ranked upward. (The accounting of human-labor inputs assumed a man expends approximately 3,000 kilocalories during a 10-hour working day.) As expected the simple gravity system uses the lowest amount of energy followed by the gravity with irrigation runoff recovery system. The hand-moved sprinkler has the lowest energy requirements of the seven sprinkler systems shown although its requirements are sharply above the gravity irrigation systems. The energy requirements of the remaining sprinkler systems ranged upward rather gradually except for big gun, the highest energy consumer of all systems. Its pumping energy requirements alone are greater than total energy requirements of the others.

Table 1
Total Annual Energy Inputs per Acre Irrigated for Nine Different Irrigation Systems a/

Irrigation System	Installation b/	Pumping	Labor	Total
	Thousand Kilocalories			
1. Gravity without irrigation runoff recovery system	103.2	35.2	0.50	138.9
2. Gravity with irrigation runoff recovery system	179.9	48.0	0.30	228.2
3. Hand-moved sprinkle	159.7	804.0	4.80	968.5
4. Trickle or drip	530.5	468.0	0.10	998.6
5. Side-roll sprinkle	200.3	804.0	2.40	1,006.7
6. Center-pivot sprinkle	388.5	864.0	0.10	1,252.6
7. Permanent sprinkle	493.6	770.0	0.40	1,263.7
8. Solid-set sprinkle	614.1	770.0	0.40	1,384.5
9. Big gun sprinkle	288.9	1,569.0	0.40	1,858.3

a/ Based on 36 ac.-in. net irrigation requirement and zero pumping lift.

b/ Includes energy used in manufacturing all materials, machinery, and a pro rata share of excavation machinery used, and the energy required to operate excavation machinery. Energy required to transport materials, machinery, or labor was not included.

Source: Batty, J. Clair, Safa N. Hamad, and Jack Keller [1].

The 1969 Census of Agriculture data show that 91 percent of the acreage irrigated in the Northeast is by sprinklers and only 9 percent by gravity irrigation [8]. Among the sprinkler systems, 62 percent of the acreage in the Northeast is irrigated by hand-moved, 10 percent by big gun, 6 percent each by solid set, center pivot, and side roll, and the remaining 10 percent is scattered among the other less used sprinkler systems [4].

Irrigation scheduling, timing of irrigation, as practiced in the Northeast is largely by what might be called the "eye ball" method. That is, farmers decide when to irrigate by observing the stress conditions of their crops or by picking up a handful of soil and applying the "squeeze test" to determine the moisture content of the soil. While such methods have served the farmers well, they could conserve both water and energy by employing one of the soil moisture monitoring devices in fairly common use throughout irrigated regions of the West. The two most widely used methods are gypsum blocks and tensionmeters that are buried at various depths in the soil to make soil moisture readings. From the readings, irrigation is scheduled for the optimum use of both water and pumping energy.

Energy Types

Among the types of irrigation energy, gasoline is used to pump water on 60 percent of the irrigated acreage in the Northeast, diesel fuel on 23 percent, electricity on 11 percent, and liquid propane on the remaining 6 percent [5]. No natural gas is used because the production fields are so distant that transportation costs make the price too high for irrigation in the Northeast. On a cost per acre basis, gasoline is the most expensive irrigation energy source in this region. For pumping groundwater the gasoline cost is $26.28 per acre, liquid propane is next highest at $23.74, diesel ranks third at $14.11, and electricity is lowest at $11.12 per acre. Surface water pumping costs are generally about one-half of groundwater pumping costs because of the corresponding lower lift. Liquid propane is highest at $12.44, gasoline ranks second at $11.93, diesel is third at $8.06, and electricity is lowest again at $5.86 per acre. The reason gasoline is predominantly used as the energy source for irrigation despite its high cost is that many farmers use their tractor engines or old gasoline engines installed many years ago. If these farmers could convert to electricity or diesel they would reduce their energy pumping cost by approximately 50 percent. Since the total energy crunch seems to involve gasoline more than these latter two energy types, such conversion would probably benefit the overall energy situation.

Other Factors

Since irrigation in the Northeast is largely by sprinkler systems utilizing considerable quantities of pipes, increasing pipe size would reduce friction losses and thereby conserve energy. However, trade-offs are involved because of the higher initial cost and added weight of larger pipes.

High pumping efficiency can be maintained by proper maintenance and lubrication of all irrigation machinery--with a saving of energy.

Energy conservation can be achieved by proper pumping plant adjustments to match the pump with the lift. Matching pump impellers, pulleys (RPM), and motors to reflect lift and system pressure can increase pumping efficiency as much as 20 to 30 percent [1].

Where gravity irrigation is practiced water and energy requirements can be reduced by land leveling and also by lining canals and ditches to reduce water losses.

Conclusions on Energy

Since energy saved in irrigation is roughly proportional to water saved, any measure that will conserve water will in turn conserve energy when everything else is constant. Thus, perhaps the most important factor from this standpoint is the efficiency of the irrigation system used. Also, the lower the pump pressure of the irrigation system employed, the greater will be the saving of energy. Irrigators in the Northeast could save additional energy by utilizing soil moisture monitoring devices to better schedule irrigation that would result in more efficient use of both water and energy. Most farmers who irrigate in the Northeast could reduce their irrigation energy cost if not their energy requirements, by approximately one-half by converting from gasoline to electricity or diesel power. Additional ways of conserving energy are proper maintenance and adjustments of irrigation machinery, and water conservation measures such as land leveling and lining of canals and ditches.

Water Response Function

In an effort to show the potential for supplemental irrigation in the Northeast, a general production function is used that was developed by Hogg and Vieth [3] which in turn was adapted from a similar function developed by Hargreaves and Christiansen [2].

In these equations, production is considered as a function of available moisture. Hargreaves and Christiansen present a summary of recent experimental results and developed an average relationship that they believe can be generally used. This function is given in Equation (1).

$$\frac{Y_a}{Y_p} = 0.8W + 1.3W^2 - 1.1W^3 \ldots (1)$$

in which Y_a = actual yield; Y_p = potential yield; and W = composite water variable for measuring moisture adequacy. Y_a is observed yield under conditions of E (actual evapotranspiration) and Y_p occurs when $E_a = E_p$ (potential evapotranspiration). W is also the ratio of E_a to E_p. Evapotranspiration rates are those developed by the Palmer Weather Index for given conditions of climate, soil, temperature, and moisture availability. Potential evapotranspiration is the combined total amount of water that can be evaporated from the soil and transpired through the plants.

The alternative production function developed by Hogg and Vieth is given in Equation (2).

$$\frac{Y_a}{Y_p} = -.7326 + 3.4652W - 1.7326W^2 \ldots (2)$$

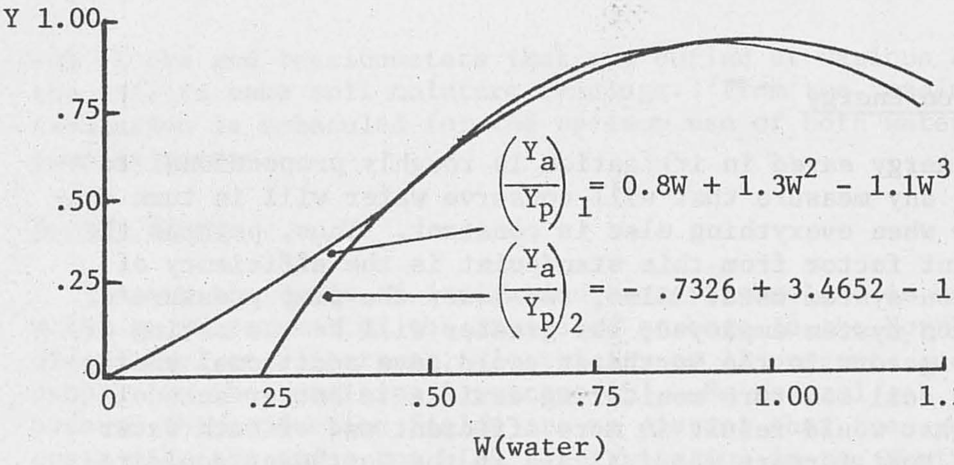

Figure 1. Water Response Production Functions

The above two production functions are shown graphically in Figure 1 indicating that yield reaches a maximum at W=1.

Using Equation (2), and applying it to data for the State of Maryland for the ten-year period 1966-75, a table of values showing the gross return to irrigation under a range of moisture deficiency conditions was constructed. The three crops used were corn, potatoes, and tomatoes and the data are shown in Table 2. The moisture deficiencies (ratios of E_a:E_p) range downward in negative increments of .05 from 1.0 to .70. Y_p is the 1966-75 average yield under conditions of E_p. $Y_a = Y_p$ when the ratio of E_a:E_p = 1. Column 7 shows the total value of the loss without irrigation or the gross value of the irrigation water that would result in Y_p for each ratio of E_a:E_p. Column 8 indicates the value of irrigation water per acre-inch at the various ratios of E_a:E_p. As expected, there is negative correlation between this latter ratio and the value per acre-inch of water.

Among the individual crops, corn shows the lowest response to irrigation by far, especially from a value standpoint (the percents of maximum physical yield are the same for all three crops). At E_a:E_p ratio of .70, the lowest shown, the total gross return if Y_a of corn is increased to Y_p is only \$33.42 per acre, with the value of irrigation water being \$6.85 per acre-inch. Corresponding values for potatoes are \$145.45 and \$26.35. The values for tomatoes are considerably higher yet, being \$201.10 and \$36.43 respectively. In fact, potatoes and tomatoes both have higher gross returns from irrigation at E_a:E_p ratio of .85 than corn at ratio of .70.

Total irrigation cost data were not available for incorporation into this paper. However, the data in column 7 of Table 2, gross returns to irrigation, can be considered as funds available to cover irrigation costs at those various levels of moisture deficiency for the crops shown. If these data are considered as typical of the Northeast, the low gross irrigation return to corn means little or no potential for profitable irrigation in the region. However, the

Table 2

Amount and Value of Yield Response to Supplemental Irrigation Under Various Moisture Deficiencies for Corn, Potatoes, and Tomatoes in Maryland Using 1966-75 Average Potential Yield

E_a (ins.) a/	$E_p - E_a$ (ins.)	$\frac{E_a}{E_p}$	Percent of Maximum Yield	Y_a b/	$Y_p - Y_a$	Value at Normalized Price c/	Value per Ac.-in. of Irrigation Water
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
			Corn	(bu.)		($2.68)	(Dols.)
18.39	-	1.00	1.0000	80.00	-	-	-
17.47	.92	.95	.9957	79.66	.34	.91	.99
16.55	1.84	.90	.9827	78.62	1.38	3.70	2.01
15.63	2.76	.85	.9610	76.88	3.12	8.36	3.03
14.71	3.68	.80	.9307	74.46	5.54	14.85	4.04
13.79	4.60	.75	.8917	71.34	8.66	23.21	5.05
12.87	5.52	.70	.8441	67.53	12.47	33.42	6.85
			Potatoes	(cwt.)		($5.62)	
18.39	-	1.00	1.0000	166.00	-	-	-
17.47	.92	.95	.9957	165.29	.71	3.99	4.34
16.55	1.84	.90	.9827	163.13	2.87	16.13	8.77
15.63	2.76	.85	.9610	159.53	6.47	36.36	13.17
14.71	3.68	.80	.9307	154.50	11.50	64.63	17.56
13.79	4.60	.75	.8917	148.02	17.98	101.05	21.97
12.87	5.52	.70	.8441	140.12	25.88	145.45	26.35
			Tomatoes	(cwt.)		($10.00)	
18.39	-	1.00	1.0000	129.00	-	-	-
17.47	.92	.95	.9957	128.45	.55	5.50	5.98
16.55	1.84	.90	.9827	126.77	2.23	22.30	12.12
15.63	2.76	.85	.9610	123.97	5.03	50.30	18.22
14.71	3.68	.80	.9307	120.06	8.94	89.40	24.29
13.79	4.60	.75	.8917	115.03	13.97	139.70	30.37
12.87	5.52	.70	.8441	108.89	20.11	201.10	36.43

a/ National Oceanic and Atmospheric Administration, U.S. Dept. of Commerce, 1966-75.
b/ Agricultural Statistics, Statistical Reporting Service, U.S. Dept. of Agr., 1966-75 average yields.
c/ Agricultural Price Standards, U.S. Water Resources Council, July 1976.

Legend: E_p=potential evapotranspiration; E_a=actual evapotranspiration; Y_p=potential yield; Y_a=actual yield.

higher gross returns to both potatoes and tomatoes indicate high potentials for profitable irrigation, and additional research toward that end appears advisable. This is especially true of tomatoes because it indicates the highest potential return and is typical of other high value vegetable crops.

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