E3A: Irrigation Efficiency

Daran R. Rudnick, Assistant Professor Biological Systems Engineering, University of Nebraska-Lincoln
Suat Irmak, Professor Biological Systems Engineering, University of Nebraska-Lincoln
Edited by Milton Geiger, Assistant Extension Educator, University of Wyoming

OVERVIEW

Steps in the Irrigation Series

Should I Be Concerned About Irrigation Efficiency?

Water is heavy and moving it any direction, except downhill, takes substantial energy inputs. Irrigation is a leading use of energy on many agricultural operations in the central and western United States. This Exploring Energy Efficiency and Alternatives (E3A) series focuses on reducing energy consumption through conservation (behavior changes) and efficiency (improved technology).

The series is designed to help natural resource and agricultural professionals assist irrigators in reducing energy consumption and improving profitability. The module also seeks to reduce risk by limiting agricultural producer exposure to energy price increases and water supply curtailments.

Ron Nichols, Washington, http://photogallery.nrcs.usda.gov/netpub/server.np?find&catalog=catalog&template=detail.np&field=itemid&op=matches&value=73918&site=PhotoGallery

Canola field under pivot irrigation.

This series of publications addresses different perspectives for introducing and evaluating various irrigation efficiency terms, how these aspects are interrelated, and suggestions to consider when designing and improving an irrigation system. The series will primarily focus on energy and water efficiency under center pivot irrigation.

There are several critical questions that help determine your suitability to explore energy efficiency related to irrigation efficiency.

Are your irrigation systems gravity fed (e.g., no pumps or motors)?

If already using hydropower (water flowing downhill) to deliver water to fields, with no purchased energy (e.g., electricity, diesel, propane), then this module is not for you. If you reduce excessive head through pressure-reducing valves or other techniques, then explore the E3A micro-hydropower for home, farm, and ranch series.

Are your systems in need of updates, regardless of energy consumption?

Energy and water efficiency improvements can be cost-effective regardless of the system's age, but equipment at the end of its functional life presents a uniquely cost-effective opportunity.

Are you facing reduced water availability?

More effectively applying water to fields can result in less energy needed for irrigation (e.g., less water delivered means fewer energy inputs). If reducing water use has a financial value, it can drive improvements that would not be cost-effective solely on the basis of energy savings.

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How expensive is your energy source?

The differences in the price of fuel sources, such as electricity, diesel, gasoline, propane, natural gas, or ethanol, impacts the feasibility of energy enhancements. Higher-cost energy means more energy efficiency improvements will be profitable. Carefully consider the cost of service, particularly demand charges when evaluating the benefits of improvements.

Are you willing to utilize incentives from state, federal, and utility sources?

Various state, federal, and utility-sponsored programs are available to producers seeking to reduce energy and water inputs. Improvements are more likely to be cost-effective if you are willing to utilize these programs.

The irrigation efficiency module is well worth your time and attention if these critical questions indicate you should proceed. Please remember your local Cooperative Extension office can likely provide further information if you have additional questions beyond the scope of this module.

Notes

E3A: Understanding Irrigation Efficiency

Daran R. Rudnick, Assistant Professor Biological Systems Engineering, University of Nebraska-Lincoln
Suat Irmak, Professor Biological Systems Engineering, University of Nebraska-Lincoln
Edited by Milton Geiger, Assistant Extension Educator, University of Wyoming

STEP 1

Steps in the Irrigation Series

Supplemental irrigation is required when effective rainfall and soil water storage in the crop root zone cannot supply the root system with enough water to meet crop evapotranspiration (ET) demand. Without irrigation, practicing poor irrigation management, and/or using an inefficient irrigation system, can result in crop water stress, which can lead to reductions in biomass, grain yield, and grain quality. Whereas excessive irrigation can result in runoff, deep percolation, soil erosion, and/or anaerobic soil conditions, which can drive up operational costs and lead to environmental degradation. With local and global concerns for future water availability and environmental and financial sustainability, greater attention has been focused on efficiently using water and energy in the agricultural sector. Enhancing irrigation efficiency will result in water and energy reduction input and improved crop water use efficiency.

Caleb Carter. CC-BY-NC-4.0. http://uwyoextension.smugmug.com/Irrigation-Efficiency/i-ghmCWtD/0/O/P1010394.jpg

Gated pipe can improve irrigation efficiency by providing more control over the amount of water applied and in increased uniformity."

Irrigation Efficiency "Point-of-View"

Irrigation efficiency can be evaluated by various perspectives or metrics, including water, energy, economic, environment, water quality, crop response, operation, and management of the irrigation system. Unfortunately, being efficient in one manner does not necessarily translate to another. An irrigation system can be more energy efficient than another; however, depending on fuel type and cost, a less-energy efficient system can be more economical. The "scale" used should also be considered when evaluating the impact(s) of enhancing efficiency on water resources and crop productivity. One can evaluate a single irrigation event or cumulative irrigation events over a growing season as well as a single field as compared to an irrigation district. Irrigation system efficiency enhanced on a field scale may result in water conservation, but the impact on overall water balance of the watershed or a basin may not be affected to the same or similar magnitude as those on a field scale. Establish an irrigation efficiency "point-of-view" by outlining what metric on which the irrigation system will be evaluated, the objective or purpose of irrigating, and the time and spatial scale of interest. A flow diagram for establishing an irrigation efficiency "point-of-view" along with proceeding steps to evaluate and potentially improve irrigation efficiency is presented in Figure 1.

Several terms or indices used to explain and/or quantify the efficiency of an irrigation system have resulted in confusion and often misrepresentation of a system's performance.

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Corn under the linear move sprinkler at the Powell Research and Extension Center, Powell, WY.

One can more readily select the correct terms or indices to quantify their existing efficiency by establishing an irrigation efficiency "point-of-view." Several terms will be addressed in this series. One can identify controllable factors that can be adjusted to improve the performance of the system after evaluating the current efficiency of a system.

What Impacts Irrigation Efficiency

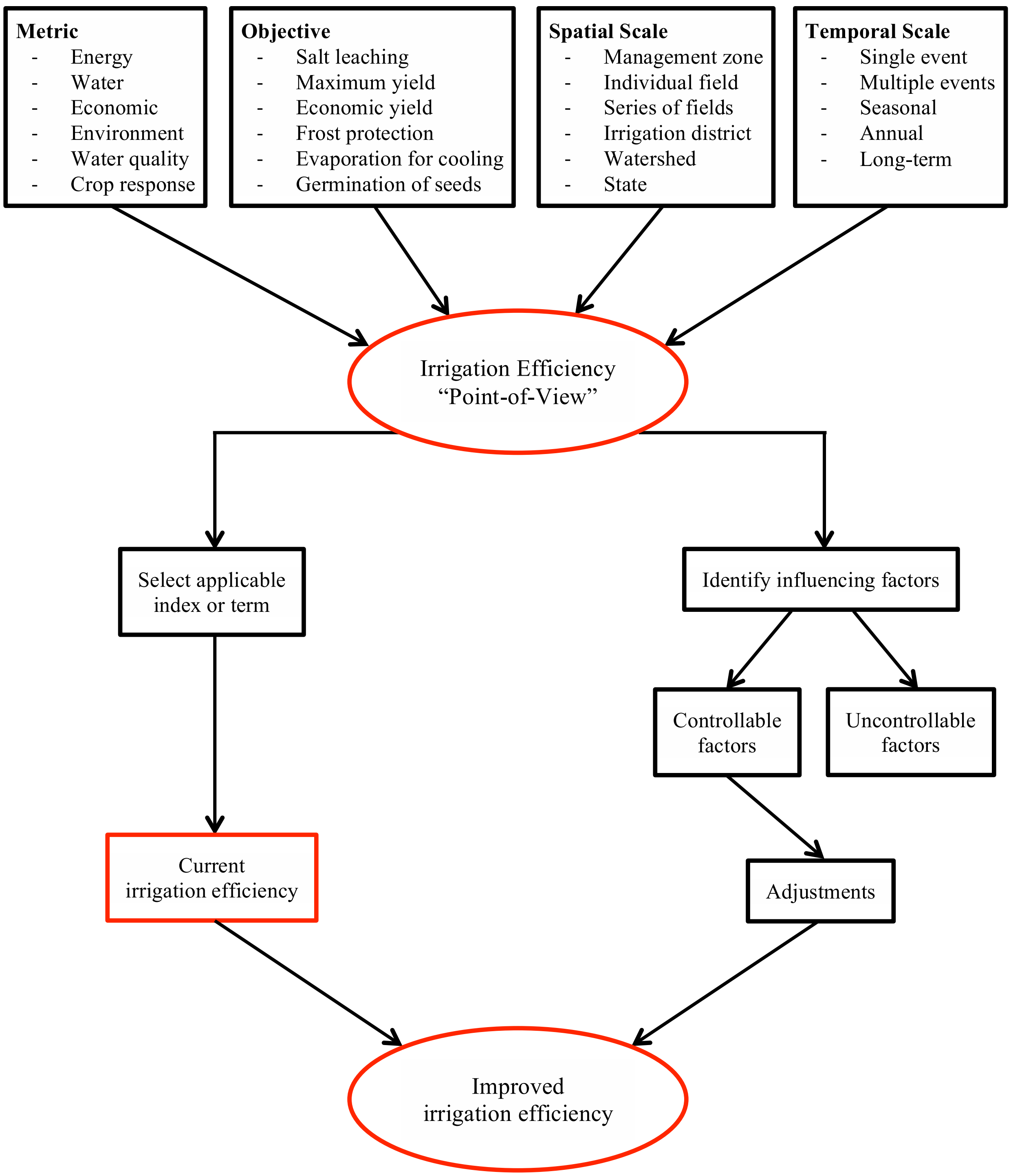
Depending on the "point-of-view," irrigation efficiency can be influenced by a number of factors, including pump efficiency, engine, irrigation system type and capacity, management practices, crop type and development, climate, soil physical and chemical properties, and fuel price, among others. These influencing factors can be divided into two categories: controllable and uncontrollable. Controllable factors can be adjusted or influenced by the producer to improve irrigation efficiency, and uncontrollable factors cannot be adjusted. Table 1 lists various controllable and uncontrollable factors that can impact irrigation efficiency.

Certain controllable factors are more easily modified than others, and in some cases adjusting factors to improve efficiency is not economical. We recommend consulting an irrigation equipment expert prior to major adjustments or upgrades.

Table 1. Primary controllable and uncontrollable factors that can impact irrigation efficiency.

Controllable Factors	Uncontrollable Factors
Irrigation system	Climate and weather
Irrigation uniformity	Soil properties
Irrigation scheduling	Field size and geometry
Pump	Fuel price
Pumping pressure	Pumping lift
Engine and fuel type	Water availability
Crop type	
Land and crop management	

Figure 1. Diagram for establishing an irrigation efficiency "point-of-view" and proceeding steps to further improve irrigation efficiency.



Notes

E3A: Pumping Plant Performance

Daran R. Rudnick, Assistant Professor Biological Systems Engineering, University of Nebraska-Lincoln
Suat Irmak, Professor Biological Systems Engineering, University of Nebraska-Lincoln
Edited by Milton Geiger, Assistant Extension Educator, University of Wyoming

Found at: http://www.nrcs.usda.gov/wps/portal/nrcs/main/nv/newsroom/stories/

Evaluating your pumping plant can help to identify efficiency issues and areas that can be improved, possibly identifying money saving improvements.

The pumping plant is tasked with transferring water from a source (e.g., groundwater) to a field for irrigation. A typical pumping plant consists of a pump, engine (or electric motor), and gear drive and can be powered by several different energy sources. A more efficient pumping plant requires less energy to transfer water between the source and the field. Several factors can impact pumping plant efficiency. Kranz et al. (2010) listed the following as common causes for a pumping plant to operate inefficiently:

1. The pipeline is valved back at the well to meet pressure requirements
2. Increase in pumping lift due to mineral incrustation and/or iron bacteria clogging the well screen
3. Wear and tear on pump impeller over time or due to pumping sand
4. Improper impeller adjustment on deep-well turbine pumps
5. Modifying irrigation system without redesigning pumping plant
6. Mismatched system components (e.g., power unit is too large)
7. Power source is not operating at most efficient speed
8. Engine needs a tune-up
9. Improperly sized discharge column

Nebraska Pumping Plant Performance Criteria

The Nebraska Pumping Plant Performance Criteria (NPPPC) was developed to provide an estimate of the amount of work available per unit of energy consumed for a well-designed and managed water pumping plant. The amount of work accomplished by the pumping plant is referred to as water horsepower (WHP) and is calculated as:

$$WHP = \frac{Flow\ Rate \times [(Pressure \times 2.31) + Lift]}{3960} \quad \text{(Equation 1)}$$

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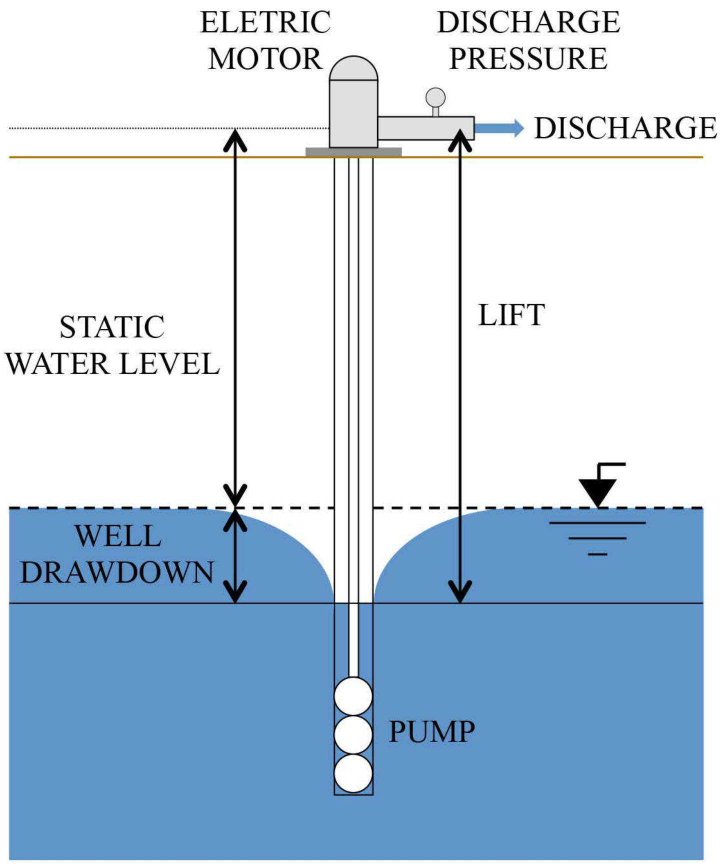

Figure 2. Diagram of a pumping plant and critical parameters needed to assess pumping plant efficiency.

where:

- WHP – Water horsepower produced by pumping plant
- Flow Rate – Discharge flow rate, gallons per minute (GPM)
- Pressure – Pump outlet pressure, pounds per square inch (psi)
- Lift – Distance between drawdown and outlet point, feet (ft)

These parameters are shown in relation to the pumping plant in Figure 2. As shown in Figure 2, lift is the vertical distance between the discharge point and the drawdown point and not between the discharge point and the static water table level or the location of the pump bowls. Lift can change over time if the drawdown level changes. Schroeder and Fischbach (1982) explained the necessary procedures to correctly measure pumping lift, discharge pressure, discharge flow rate, and the energy consumption of any particular pumping unit.

The energy performance (WHP-hr/unit) is obtained by dividing WHP by the energy use rate (unit/hr). The WHP-hr/unit values reported by the NPPPC for different energy sources, along with the average work available per unit of energy (HP-hr/unit) and the work accomplished by the power unit, including drive losses, per unit of energy (BHP-hr/unit) are shown in Table 2. Calculate pumping plant efficiency by dividing WHP-hr/unit by HP-hr/unit. For example, the NPPPC acceptable pumping plant efficiency (Epp) is 66% (Epp = 0.885 ÷ 1.34 = 0.66) for electricity and 23% (Epp = 12.5 ÷ 54.5 = 0.23) for diesel.

Performance Rating

The energy performance (WHP-hr/unit) values reported by NPPPC (Table 2) represent well-designed and managed/operated pumping plants and serve as a reference to evaluate existing pumping plants. The pumping plant's performance rating (PR) is the ratio of the existing and NPPPC WHP-hr/unit values and is calculated as:

$$PR(\%) = \left(\frac{Existing\ WHP-hr/unit}{NPPPC\ WHP-hr/unit}\right) \times 100\%$$

(Equation 2)

Table 2. Nebraska Pumping Plant Performance Criteria (NPPPC). Adapted from Martin et al. (2011) and Kranz (2010).

Energy source	Energy unit	[1]Horsepower-hr per unit	[2]Brake horsepower-hr per unit	[3,4]Water horsepower-hr per unit
Diesel	Gallon	54.5	16.7	12.5
LPG	Gallon	37.5	9.2	6.89
Gasoline	Gallon	49.1	11.5	8.66
Natural gas[5]	1,000 cu ft	393	88.9	66.7
Electricity	Kilowatt-hour	1.34	1.18[6]	0.885

[1]Average work available for different power sources per unit of energy
[2]Work accomplished by the power unit, including drive losses, per unit of energy
[3]Work produced by the pumping plant per unit of energy
[4]Based on 75% pump efficiency
[5]Assumes energy content of 1,000 BTU per cubic foot
[6]Assumes 88% electric motor efficiency

If the performance rating is at or greater than 100%, the system is operating at or above the expected performance level set by NPPPC; if it is below 100%, the system is using more energy than required. The pumping plant should be investigated to improve system performance and save energy and reduce unnecessary pumping costs. Morris and Lynne (2006) addressed and explained how to properly maintain irrigation pumps, motors, and engines for maximum efficiency. They also include descriptions and diagrams of recommended installations, checklists for maintenance tasks, and a troubleshooting guide.

Excess Energy Use

Determine the amount of excess energy used for pumping irrigation water with respect to the NPPPC by using the performance rating and total fuel consumed over a test period, calculated as:

$$Excess\ Energy = \left[\frac{(100\% - PR\%)}{100\%}\right] \times Amount\ of\ Fuel\ Used$$

(Equation 3)

Example:

- Performance rating = 89% (i.e., system is operating at 89% of the NPPPC)
- Fuel consumed = 3,500 gallons of diesel
- Test period = 1 year

$$Excess\ Energy = \left[\frac{(100\% - 89\%)}{100\%}\right] \times 3{,}500\ gallons\ per\ year$$

$$= 0.11 \times 3{,}500\ gallons\ per\ year$$

$$= 385\ gallons\ per\ year$$

The potential savings is the amount of excess energy consumed multiplied by the cost per unit of energy. For the above example, if diesel cost was $3.10 per gallon, the financial savings would be 385 gallons per year x $3.10 per gallon = $1,193.50 per year.

Economic Consideration

The potential financial savings can be thought of as the amount of money per year that can be invested to improve the performance of the pumping plant with the assumption of a fixed cost per unit of energy over the repayment period. The series present worth factor (SPWF) can be used to determine the present worth (i.e., total investment) of a series of equal annual payments (i.e., annual savings) for upgrades and repairs and is calculated as:

$$SPWF = \frac{(1+i)^n - 1}{i(1+i)^n}$$

(Equation 4)

where, i is the interest rate compounded annually (as decimal) and n is the number of equal annual payments. Table 3 provides SPWF values for various interest rates and repayment periods. The total investment is calculated by multiplying the financial savings (i.e., annual payment) by the SPWF.

Example continued:

Annual financial savings = $1,193.50

Interest rate = 6%

Repayment Period = 5 years

$$Investment = Annual\ Payment \times SPWF$$

$$= \$1{,}193.50 \times 4.21$$

$$= \$5{,}027$$

If the performance of the pumping plant can be improved to the NPPPC level with an investment of $5,027 or less, it is advised; if the cost of repairs exceeds $5,027, further investigation is needed to identify economically feasible means of improving the pumping plant.

Table 3. Series Present Worth Factor (SPWF) for equal annual payments.

Repayment	Annual Interest Rate (i)						
Period (n)	4%	5%	6%	7%	8%	9%	10%
3	2.78	2.72	2.67	2.62	2.58	2.53	2.49
4	3.63	3.55	3.47	3.39	3.31	3.24	3.17
5	4.45	4.33	4.21	4.10	3.99	3.89	3.79
6	5.24	5.08	4.92	4.77	4.62	4.49	4.36
7	6.00	5.79	5.58	5.39	5.21	5.03	4.87
8	6.73	6.46	6.21	5.97	5.75	5.53	5.33
9	7.44	7.11	6.80	6.52	6.25	6.00	5.76
10	8.11	7.72	7.36	7.02	6.71	6.42	6.14
11	8.76	8.31	7.89	7.50	7.14	6.81	6.50
12	9.39	8.86	8.38	7.94	7.54	7.16	6.81
13	9.99	9.39	8.85	8.36	7.90	7.49	7.10
14	10.56	9.90	9.29	8.75	8.24	7.79	7.37
15	11.12	10.38	9.71	9.11	8.56	8.06	7.61

Table 4. Estimated expected life (years) of various pumping plant components. Adapted from Duke (2007).

	Annual Hours of Operation			
Component	500	1000	2000	3000
Well	25	25	25	25
Pump	15	15	15	10
Gearhead	15	15	15	10
Drive shaft	15	15	7	5
Engine (heavy duty)	15	15	10	7
Engine (automotive)	5	3	2	1
Gas pipeline	25	25	25	25
Engine foundation	25	25	25	25
Electric motor	25	25	25	25
Electric controls and wiring	25	25	25	25

One should consider the expected life of the component(s) being updated or repaired when determining the repayment period length. In some cases, the manufacturer will provide an estimated expected life; however, if not, it should be estimated. Table 4 provides estimated life expectancy (years) for different components of a pumping plant under various annual hours of operation. Note the life expectancy of any component is also a function of the level and frequency of maintenance, quality of parts, and exposure to environmental conditions (e.g., shelter vs. no shelter).

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Notes

E³A: Energy Source Selection

Daran R. Rudnick, Assistant Professor Biological Systems Engineering, University of Nebraska-Lincoln
Suat Irmak, Professor Biological Systems Engineering, University of Nebraska-Lincoln
Edited by Milton Geiger, Assistant Extension Educator, University of Wyoming

STEP 3

Steps in the Irrigation Series

Irrigation pumps can be powered using various energy sources, including electricity, diesel, natural gas, liquefied petroleum gas (LPG), gasoline, and ethanol. Diesel and electricity are the primary sources of energy for irrigation, with minimal use of gasoline and ethanol. Each energy source has a different energy content per unit as shown in Table 5. In addition, the ability of a motor or engine to convert energy content to productive work to pump water depends on the energy source. In terms of energy, electricity is the most efficient power source ranging between low 80% for small horsepower motors to over 90% for large horsepower motors; internal combustion diesel engine efficiencies range between 25% and 37% and gasoline engines between 20% and 26% (Evans et al., 1996). However, certain factors may prevent or limit the use of different energy sources in particular areas. For example, electric lines as well as three-phase service may be limited in rural areas and in areas near water sources.

Alex Garcia y Garcia. CC-BY-NC-4.0. http://uwyoextension.smugmug.com/Irrigation-Efficiency/i-XcbQTtB/0/O/LAteral10%20-%20Beets%20-%20PREC%202014.jpg

A diesel powered linear move sprinkler at the Powell Research and Extension Center, Powell, WY.

Table 5. Approximate energy content per unit of fuel for commonly used energy sources.

Energy Source	Energy Unit	Approximate Energy Content per unit	
		BTU	Horsepower-hour
Diesel	Gallon	138,690	54.5
LPG	Gallon	95,475	37.5
Gasoline	Gallon	125,000	49.1
Natural Gas	1,000 cu ft	1,000,000	393
Electricity	Kilowatt-hour	3,412	1.34

Conversions: 1 Kilowatt-hour = 3,412 BTU, 1 Horsepower-hour = 2,544 BTU, 1 Horsepower = 0.746 kilowatts

Different energy sources may be more economical than electricity depending on energy cost per unit. Martin et al. (2011) compared diesel and electricity as energy sources for a typical center pivot system. Their results showed electricity was preferred except when diesel was less than $2.25 per gallon and electrical rates exceeded 8¢ per

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kilowatt-hour based on the fuel costs at the time of their evaluations. They also concluded results were representative, and agricultural producers should analyze their unique situation to better account for additional expenses, such as bringing three-phase service to the motor. The detailed analysis used was developed by Tom Dorn, extension educator, University of Nebraska-Lincoln Institute of Agriculture and Natural Resources (UNL-IANR) Lancaster County, NE, and can be found at: http://lancaster.unl.edu/ag/crops/irrigate.shtml.

Historical Energy Prices

Historical energy prices can be used to infer which energy source may be the most economic over time when designing and/or upgrading the power unit of a pumping plant. Figure 3 shows average long-term energy prices (1970-2012) of natural gas, diesel, LPG, gasoline, and electricity for Nebraska, Wyoming, Montana, and the United States. In general, energy prices have increased over time for all states and the United States; however, the rate of growth has varied among energy sources. The most prominent example of this is how electricity was on average the most expensive energy source between 1980 and 2000 and then became one of the cheapest, second to natural gas, between 2000 and 2012 among the states. In addition, energy prices have varied between states. In 2012, electricity was $20.54, $17.64, and $14.96 per million BTU in Nebraska, Wyoming, and Montana, respectively; whereas, natural gas was $4.26, $4.71, and $7.36 per million BTU, respectively. Geographical location can also influence energy prices due to the availability of different energy sources in the state. One observation worth noting is diesel, LPG, and gasoline have had a rapid increase in energy price since 2000 and electricity has had a positive increase but less than the aforementioned; natural gas had a similar increase in electricity up to 2006 and has then shown a decreasing trend for all states. Natural gas may prove to become a primary source of energy for irrigation depending on future projections. However, the overall selection of a power source will depend not only on price, but also efficiency.

References and Further Readings

Duke, H.R. 2007. Pumping systems. In: Design and operation of farm irrigation systems 2nd Edition. *American Society of Agricultural and Biological Engineers.* pp. 392-435.

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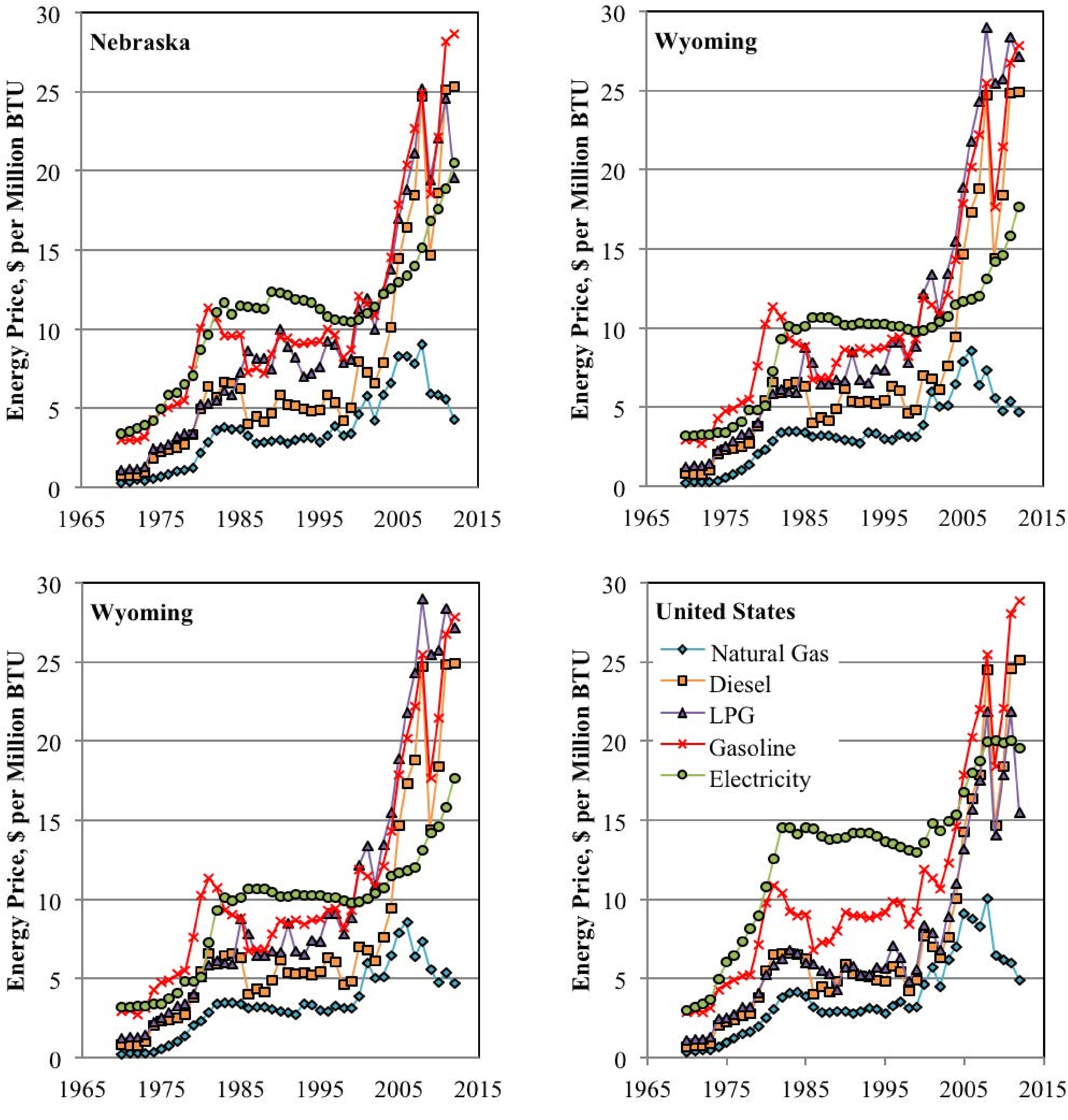

Figure 3. Long-term (1970 – 2012) energy prices for Nebraska, Wyoming, Montana, and the United States. Source: www.eia.gov. Adapted from Martin et al. (2011).

Notes

E3A: System Performance and Efficiency

Daran R. Rudnick, Assistant Professor Biological Systems Engineering, University of Nebraska-Lincoln
Suat Irmak, Professor Biological Systems Engineering, University of Nebraska-Lincoln
Edited by Milton Geiger, Assistant Extension Educator, University of Wyoming

STEP 4

Steps in the Irrigation Series

How effective the system delivers water to a field from a water source is a major contributor to the performance of an irrigation system. Several terms, including water conveyance efficiency, water application efficiency, soil water storage efficiency, overall irrigation efficiency, and effective irrigation efficiency, have been used to assess the performance of a system (Irmak et al., 2011). Less-efficient systems usually require greater irrigation amounts to meet crop evapotranspiration (ET) demands due to water loss between the source and the crop as compared to more efficient systems. This results in increased energy use and operational cost for the producer. Several efficiency terms will be described; however, the reader is directed to the references below for further information regarding different efficiency terms.

Top mounted sprinklers on a pivot can be less effective due to evaporation and wind affecting uniformity.

Pivot sprinkler system in Idaho. NRCS photo – photographer: Howard Johnson. For more info: http://photogallery.nrcs.usda.gov/netpub/server.np?find&catalog=catalog&template=detail.np&field=itemid&op=matches&value=4003&site=PhotoGallery

Water Application Efficiency

Water application efficiency evaluates how well an irrigation system delivers water from the conveyance system to the crop and is calculated as:

$$E_a = \left(\frac{V_s}{V_f}\right) \times 100\% \qquad \text{(Equation 5)}$$

where, E_a is application efficiency (%), V_s is volume of irrigation water stored in the crop root zone (acre-inch), and V_f is the volume of irrigation water delivered to the farm or field (acre-inch). In terms of irrigation efficiency "point-of-view," E_a is used to evaluate crop yield response. Water application efficiency is always less than 100% due to water loss from various pathways. Figure 4 illustrates the water cycle for a center pivot-irrigated field. The contributing factors that reduce E_a are runoff, deep percolation below the crop root zone, wind drift, and evaporation from droplets, crop canopy, and the soil surface; however, if runoff is captured and reused, then V_f should be adjusted to account for the recovered water.

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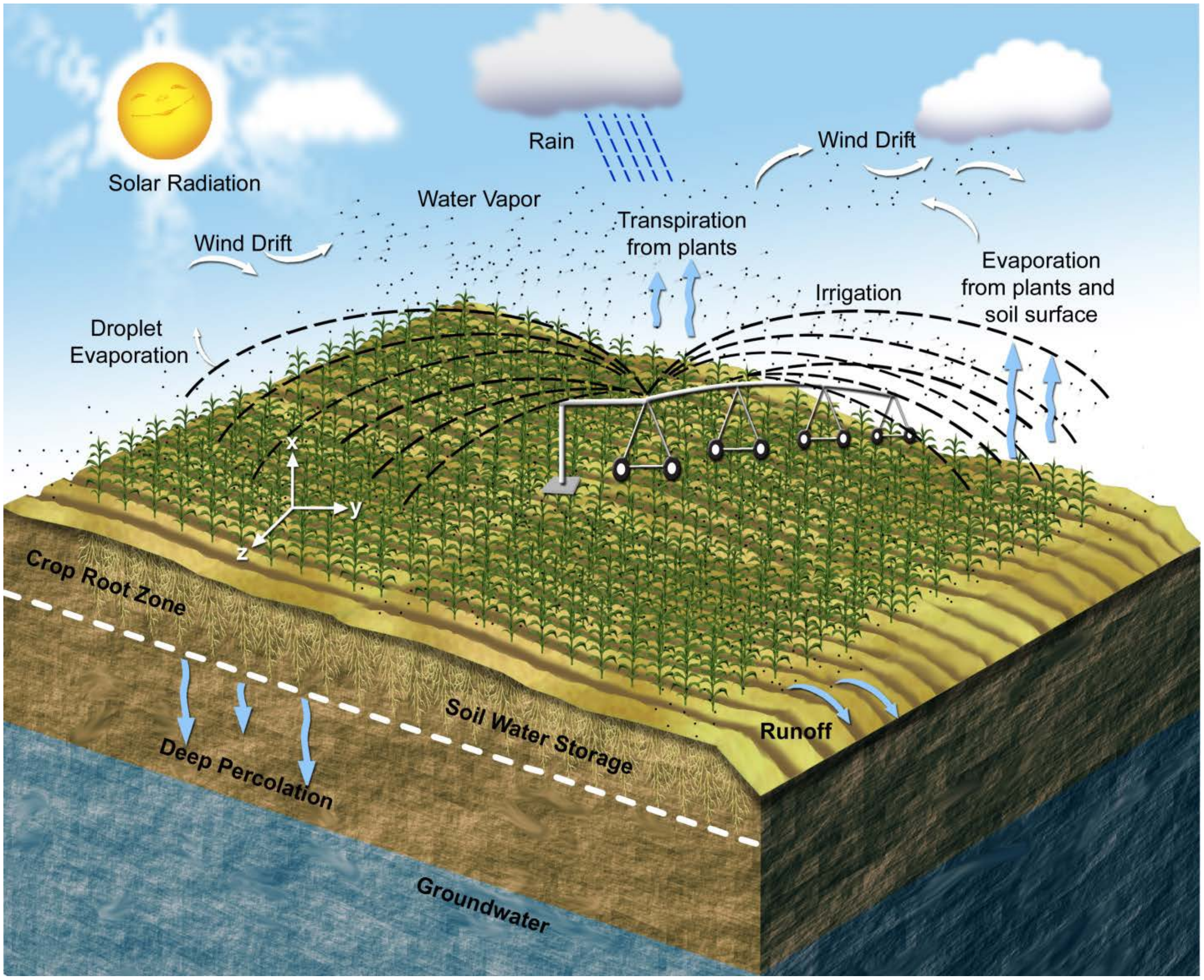

Figure 4. Components of the water cycle for a center pivot irrigated field as it relates to water application efficiency (E_a) [Adapted from Irmak (2009)].

Water application efficiency is affected, in part, by irrigation management. Table 6 provides typical E_a values for well-designed and managed irrigation systems. It is possible to have high E_a values yet unsatisfactory system performance if the irrigation system does not meet crop ET demands. A small amount of irrigation under low atmospheric evaporative demand can result in minimal water loss (i.e., high E_a), yet not meet crop ET demand, resulting in crop water stress. Table 6 provides a good estimate of the upper limit achievable for different system types under well-managed conditions in which crop ET demands are met. Other factors to consider when calculating and assessing E_a are the accuracy of measuring stored irrigation water, effective crop rooting depth, and spatial variability in E_a. Spatial variability in E_a can be, in part, attributed to poor water distribution of an irrigation system. Reporting both E_a and water distribution uniformity provides a better indication of overall irrigation system performance. Additional readings, listed below, will provide further information on factors impacting E_a.

Irrigation Efficiency

Irrigation water may be applied to satisfy other objectives than meeting crop ET. Table 7 presents different uses of irrigation water between beneficial and non-beneficial as well as between consumptive and non-consumptive. Irrigation efficiency (E_i) is commonly used to assess the effectiveness of the irrigation system in delivering water for beneficial uses. It is defined as the ratio of the volume of water beneficially used (V_b, acre-inch) to the volume of irrigation applied (V_f, acre-inch) and is expressed as:

$$E_i = \left(\frac{V_b}{V_f}\right) \times 100\% \quad \text{(Equation 6)}$$

Similar to E_a, irrigation management decisions can also impact E_i. In addition, E_i is subjected to personal biases in the term beneficial water use. We recommend one explicitly defines their interpretation of the beneficial use of irrigation, when using E_i to evaluate the irrigation system performance.

Table 6. Potential water application efficiencies (E_a, %) for well-designed and managed irrigation systems. Adapted from Irmak et al. (2011).

Irrigation System	*"Potential" Application Efficiency (%)*
Sprinkler Irrigation System	
LEPA	80 – 90
Linear move	75 – 85
Center pivot	75 – 85
Traveling gun	65 – 75
Side roll	65 – 85
Hand move	65 – 85
Solid set	70 – 85
Surface Irrigation Systems	
Furrow (conventional)	45 – 65
Furrow (surge)	55 – 75
Furrow (with tailwater reuse)	60 – 80
Basin (with or without furrow)	60 – 75
Basin (paddy)	40 – 60
Precision level basin	65 – 80
Micro-Irrigation Systems	
Bubbler (low head)	80 – 90
Micro-spray	85 – 90
Micro-point source	85 – 90
Micro-line source	85 – 90
Subsurface drip	> 95
Surface drip	85 – 95

Note: LEPA (Low energy precision application)

Overall Irrigation Efficiency

The overall irrigation efficiency (E_o) represents the efficiency of the entire system to deliver water from a water source to a crop. It can be calculated by multiplying either water application efficiency (E_a, as decimal) or irrigation efficiency (E_i, as decimal) by the water conveyance efficiency (E_c, as decimal) calculated as:

$$E_c = \left(\frac{V_f}{V_t}\right) \times 100\%$$

(Equation 7)

where, E_c is conveyance efficiency (%), V_f is the volume of irrigation water that reaches the farm or field (acre-inch), and V_t is the total volume of water diverted from the water source (acre-inch). The conveyance efficiency will decrease as a result of water losses, including canal seepage, canal spills, evaporation from canals, and leaks in pipelines. For center pivot irrigation, E_c can be as high as 100% since there is minimal water loss in closed/pressurized conveyance systems. The selection between E_a and E_i to calculate E_o will depend on the purpose or objective of irrigation, and the equation to calculate E_o is:

$$E_o = [(E_a \; or \; E_i) \times E_c] \times 100\%$$

(Equation 8)

Table 7. Partition of irrigation water use between beneficial and non-beneficial as well as consumptive and non-consumptive.

	Consumptive Use	Non-Consumptive Use
Beneficial	Crop evapotranspiration Plant evapotranspiration for windbreaks Germination of seeds	Water for leaching Softening soil crust for emergence Evaporation for cooling Evaporation for frost protection
Non-Beneficial	Phreatophyte evapotranspiration Weed evapotranspiration	Wind drift and droplet evaporation Evaporation from soil and plant surfaces Reservoir and canal evaporation Deep percolation Surface runoff Operational spill

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Notes

E³A: Irrigation Application Uniformity

Daran R. Rudnick, Assistant Professor Biological Systems Engineering, University of Nebraska-Lincoln
Suat Irmak, Professor Biological Systems Engineering, University of Nebraska-Lincoln
Edited by Milton Geiger, Assistant Extension Educator, University of Wyoming

STEP 5

Steps in the Irrigation Series

The overall performance of an irrigation system also relies on water application uniformity. Irrigation application uniformity is a statistical property describing the distribution of water applied from an irrigation system. Irrigation systems are designed and managed to apply water as uniformly as possible to enhance crop production by providing equal access of water to crops. Poor water distribution can result in over- and under-irrigated areas. Under-irrigated areas can experience water stress and reduce crop growth and grain development; over-irrigated areas can experience surface runoff, deep percolation of water along with nutrients, and waterlogging, which can cause plant oxygen stress and ultimately reduce crop growth and grain development. Irrigation systems with low uniformity are often managed to prevent the under-irrigated areas from experiencing water stress, which results in over-irrigation for most of the field and increases energy use and operational costs.

Caleb Carter. CC-BY-NC-4.0. http://uwyoextension.smugmug.com/Irrigation-Efficiency/i-brkd2Xm/0/O/P1010406.jpg

Barley under sprinkler irrigation in the Big Horn Basin, WY.

Idaho. http://photogallery.nrcs.usda.gov/netpub/server.np?find&catalog=catalog&template=detail.np&field=itemid&op=matches&value=4059&site=PhotoGallery

A side roll, or wheel line, irrigation system in alfalfa.

Factors Impacting Uniformity

Factors that can impact application uniformity depend on the irrigation method and system characteristics (e.g., pressure and flow rate) as well as topography and soil properties, among others. Table 8 lists several factors that affect uniformity for sprinkler, surface, and micro-irrigation methods. Poor management practices can affect application uniformity for all system types.

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Table 8. Factors impacting irrigation application uniformity for sprinkler, surface, and micro-irrigation methods. Adapted from Irmak et al. (2011).

Irrigation Method	*Factors Influencing Uniformity*
Sprinkler irrigation	☐ Improper selection of delivery pipe diameters ☐ Incorrect operating pressure ☐ Improper selection of sprinkler heads and nozzles ☐ Inadequate sprinkler overlap ☐ Wind drift ☐ Wear and tear on system components over time ☐ Nozzle clogging
Surface irrigation	☐ Differences in opportunity time caused by advance and recession ☐ Spatial variability of soil-infiltration properties ☐ Non-uniform grades
Micro-irrigation	☐ Variations in pressure caused by pipe friction and topography ☐ Variations in hydraulic properties of emitters or emission points ☐ Variations in soil wetting from emission points ☐ Variations in application timings

Irrigation Uniformity Measures

Several procedures and equations evaluate application uniformity for various irrigation systems. Application uniformity is typically evaluated based on the depth of water applied; however, emitter discharge is used for micro-irrigation since the area is not entirely wetted (Howell, 2003). Sprinkler irrigation often uses catch cans to determine the distribution of applied water; surface irrigation uses intake opportunity time and infiltration rate to estimate applied depth due to challenges in measuring applied depth along the furrow. The conventional uniformity measures are Christiansen's uniformity coefficient for sprinkler irrigation, adjusted Christiansen's uniformity coefficient for center pivot sprinkler irrigation, low-quarter distribution uniformity for surface irrigation, and emission uniformity and coefficient of design uniformity for micro-irrigation. Further details of the uniformity measures are in the references and further readings section.

Improving Application Uniformity

Improving application uniformity requires (i) estimating current uniformity, (ii) identifying major influencing factors, and (iii) determining if improving application uniformity is economically justifiable. The previous section listed commonly used uniformity measures to estimate current application uniformity for various irrigation methods. With several sources of error when collecting data to determine uniformity, Heermann and Solomon (2007) recommend the following American Society of Agricultural and Biological Engineers (ASABE – formerly ASAE) standards and engineering practices be reviewed prior to evaluating and/or designing an irrigation system.

☐ ASAE S436.1. Test Procedure for Determining the Uniformity of Water Distribution of Center Pivot and Lateral Move Irrigation Machines Equipped with Spray or Sprinkler Devices.

☐ ASAE EP405.1. Design and Installation of Microirrigation Systems

☐ ASAE EP419.1. Evaluation of Irrigation Furrows

The ASABE standards also provide how to improve uniformity. For sprinkler irrigation, the catch can test can help identify areas along the system that are applying below-or-above average depths, which provides a starting point to identify the sources of non-uniformity. Faulty sprinkler nozzles as well as pressure differences along the lateral are a primary source of non-uniformity. Supplying equal pressure to individual nozzles can account for pressure differences. Kranz et al. (2007) reported pressure regulators to control sprinkler flow rate are desirable when:

1. Elevation differences exist between sprinklers
2. Pipeline friction loss causes large differences in pipeline pressure
3. Excessive pressure is supplied to small sprinklers on the first few spans of the center pivot
4. A constant pressure is required for installations where more than one set of sprinklers are supplied by the same pump

Figure 5. Aerial image of a center pivot irrigation system that has low application uniformity. (Courtesy UNL: Gary Zoubek)

Visual observations and aerial imagery can also identify areas experiencing poor uniformity. For example, as shown in Figure 5, aerial imagery can show distinct patterns in crop growth due to water stress caused by missing, clogged, or worn nozzles; stuck impact sprinklers; out-of-sequence nozzle packages; inadequate pressure to operate end gun; and other causes. Improving irrigation uniformity will require investment in system improvements and maintenance and/or labor cost for improved management. The source and magnitude of non-uniformity dictates whether promoting uniformity is economically justified. Duke et al. (1992) presents a method to determine the potential savings from improving center pivot irrigation uniformity.

Variable Rate Irrigation

Advancements in irrigation systems and controllers can now intentionally apply water non-uniformly to meet spatial differences in crop water needs. Variable rate irrigation (VRI) has the potential to conserve energy use by limiting areas that would normally get over-irrigated under uniform irrigation management; however, the success of VRI to conserve energy and water use depends on how accurate a producer can characterize a field (irrigation prescription) to account for spatial and temporal differences in crop water demand as well as the system's ability to accommodate the prescription. The notion that VRI can enhance irrigation efficiency is not a straightforward process. VRI may or may not reduce irrigation water requirements or enhance irrigation efficiency as compared to fixed irrigation application, depending on the variability of the field, how soil water status is monitored across the field, and most importantly, how VRI prescriptions are prepared and decisions are made. Kranz et al. (2014) explains different VRI methodologies along with benefits and shortcomings of VRI to conserve energy and water.

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Notes

STEP 6

Steps in the Irrigation Series

E3A: Irrigation Scheduling

Daran R. Rudnick, Assistant Professor Biological Systems Engineering, University of Nebraska-Lincoln

Suat Irmak, Professor Biological Systems Engineering, University of Nebraska-Lincoln

Edited by Milton Geiger, Assistant Extension Educator, University of Wyoming

A well-designed irrigation system can perform unsatisfactorily or operate inefficiently due to poor irrigation scheduling. Scheduling irrigation to prevent crop water stress requires detailed information of the irrigation system (e.g., application efficiency and system capacity) as well as frequent and accurate information on crop status and field characteristics, which includes current and forecasted crop water demands and plant soil water availability (i.e., current soil water status). The irrigation amount should be adequate to meet evapotranspiration demand but not excessive to prevent surface runoff and deep percolation of water below the crop root system. When scheduling an irrigation event, try to minimize operational costs by taking advantage of water available in the soil profile while at the same time starting the irrigation event early enough to ensure the last portion of the field being irrigated does not experience water stress. Using soil moisture monitoring sensors can enable irrigating the crops at the right time and apply adequate/sufficient amount of water to meet crop demand and minimize other water losses. There is a direct link between monitoring soil water status for irrigation scheduling and irrigation efficiency.

Axel Garcia y Garcia. CC-BY-NC-4.0. http://uwyoextension.smugmug.com/Irrigation-Efficiency/i-CrKLwM8/0/O/Lateral%20-%20WheelTrack%20-%20PREC%202013.jpg

Sprinkler wheel tracks through a corn field.

Although irrigation scheduling affects the performance and efficiency of an irrigation system, it is a vast topic that exceeds the scope of this publication. We direct the reader to a list of references for further information on properly scheduling irrigation. The University of Nebraska-Lincoln Institute of Agriculture and Natural Resources (UNL-IANR) has published several papers on irrigation design, management, and scheduling for various crops across different soils and climate gradients. A few of these publications are listed below, and further publications are at http://ianrpubs.unl.edu.

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Notes

E³A: Incentives and Technical Assistance

Daran R. Rudnick, Assistant Professor Biological Systems Engineering, University of Nebraska-Lincoln
Suat Irmak, Professor Biological Systems Engineering, University of Nebraska-Lincoln
Edited by Milton Geiger, Assistant Extension Educator, University of Wyoming

STEP 7

Steps in the Irrigation Series

Implementing the suggestions provided in the previous six steps will often require investment in equipment, controls, and monitoring. Often, improvements are cost-effective and practical without the assistance of government or utility programs, but accessing these funds can allow deeper efficiency improvement and/or reduce upfront expenditures. There are three principal sources of incentives: utility, state, and federal.

Linear move sprinkler in corn field.

Axel Garcia y Garcia. CC-BY-NC-4.0. http://uwyoextension.smugmug.com/Irrigation-Efficiency/i-gL4s2VL/0/O/Lateral8%20-%20Corn%20-%20PREC%202012.jpg

Utility – Although seemingly counterintuitive, electric utilities will often pay to reduce electrical consumption and demand. Many utilities, including investor-owned, publically owned, and rural electric cooperatives, offer incentives and technical assistance. Incentives range from pump and motor retrofits, such as variable frequency drives, to water-saving enhancements for center pivots and wheel lines.

State – Programs vary by state across the western and central region. Some states offer programs designed to save water, where the energy savings would be a secondary benefit.

Federal – The U.S. Department of Agriculture Natural Resources Conservation Service (NRCS) and Rural Development (RD) are particularly active in irrigation energy and water efficiency. Each opportunity is described in further detail.

The USDA NRCS Environmental Quality Incentive Program (EQIP) On-farm Energy Initiative offers energy audit assistance through the Agricultural Energy Management Plan program. Following an energy audit, the EQIP program can be used to cost-share irrigation improvements.

The USDA RD addresses irrigation energy through the Rural Energy for America Program (REAP). REAP offers 25% grants to agricultural producers for the purchase and installation of energy efficiency upgrades, including irrigation. Your state RD office will provide a contact for the program.

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Notes

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Steps in the Irrigation Series

STEP 8

E3A: Cumulative References

Daran R. Rudnick, Assistant Professor Biological Systems Engineering, University of Nebraska-Lincoln

Suat Irmak, Professor Biological Systems Engineering, University of Nebraska-Lincoln

Edited by Milton Geiger, Assistant Extension Educator, University of Wyoming

First irrigation of the season in furrow irrigated field.

Caleb Carter. CC-BY-NC-4.0. http://uwyoextension.smugmug.com/Irrigation-Efficiency/i-CqCCg5V/0/O/P1010400.jpg

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