EVAPOTRANSPIRATION and IRRIGATION CAPACITY [1]

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INTRODUCTION

Irrigation capacity is defined as the system flow rate (in gpm or L/s) per unit land area (ac or m^2). It is a rate constraint and not a volume constraint on irrigation design and management. Many irrigation districts or resource conservation districts have institutional controls on either irrigation capacity or irrigation volume. Irrigation well sizing and location regulations are examples of irrigation capacity constraints. Regulations that control water pumping volume (ac-ft or L) per unit land area (ac or m^2) are examples of volumetric constraints. The volumetric constraint is critical in long-range (strategic) irrigation planning while the irrigation capacity constraint is more important in day-to-day (tactical) irrigation management decisions. Both types of irrigation constraints have inherent economic consequences -- 1) irrigation capacity largely determines pipe sizes, well sizes, pump sizes and motor and engine sizes and any demand charges imposed by the utilities supplying power (these are often called the fixed irrigation costs), and 2) irrigation volume determines seasonal (annual, etc.) irrigation costs per unit land area (these are often called the variable irrigation costs).

This brief review will focus on irrigation capacity and its consequences for day-to-day irrigation management options for sprinkler irrigation of corn in the Southern Great Plains. Irrigation capacity can be expressed directly in terms of an equivalent water application rate such as in/d or mm/d. [Note: 1 gpm/ac = 0.053 in/d; 1 gpm/ac = 1.35 mm/d]. Irrigation capacity controls the gross irrigation amount that can be applied to a unit area in a certain time interval. For center pivot sprinklers, irrigation capacity determines the maximum application rate (which occurs at the outer-most end of the system), which is unaffected by irrigation amount. This maximum application rate can influence sprinkler application package selections, soil physical conditions during and after irrigation (droplet size interactions), runoff from the field, and many other factors. For center pivot sprinklers, it is important to use the minimum irrigation capacity to meet the crop needs within some specified probability or likelihood level to avoid problems caused by high application rates.

As irrigation capacity is reduced, the ability of the irrigation system and the irrigation management to meet *full* crop irrigation needs is sacrificed. Irrigation capacity in excess of the minimum capacity necessary to meet crop needs in *all* years (and conditions) requires excessive capital investment for irrigation equipment. The optimum irrigation capacity is somewhat difficult to precisely determine since the acceptable risk level associated with reduced crop yields resulting from soil water deficits depends on the philosophies and financial resources of the individual grower.

Irrigation capacity necessary to meet the *full* irrigation needs of a crop is largely based on 1) the maximum crop evapotranspiration rate over some specified planning interval, 2) the *plant available soil water* that can be extracted by the crop without any serious yield effects, and 3) *effective precipitation* during the planning interval. The first factor is well defined in many sources (see Jensen et al., 1990) while the second factor is more difficult to precisely characterize for particular crops and soils. The simple soil water budget equation for a time period (I of t days duration) is given as

$$\int_{0}^{R_{(I)}} SW_{(I)}\, dz = \int_{0}^{R_{(I-1)}} SW_{(I-1)}\, dz + \sum_{0}^{t} [P + I_r - ET - D_R - Q] \qquad ...[1]$$

where SW is the volumetric soil water content in $m^3(H_2O)/m^3$(soil), R is the rooting depth in m, dz is a soil profile increment in m, P is the total precipitation in mm, I_r is the total irrigation application in mm, ET is the evapotranspiration in mm, D_R is the drainage in mm below the root-zone, and Q is the runoff in mm. At some soil water content level (SW_c), the crop can not extract water from the soil at a rate sufficient to meet the atmospheric demand rate for transpiration, and the crop will develop a crop water deficit which will reduce growth (and ultimately yield) and evapotranspiration through both feed-back and feed-forward mechanisms that regulate the stomatal opening and biochemical processes in the leaves. This *critical* soil water content is not necessarily the same for these two processes -- normally growth (photosynthesis) will be reduced before evapotranspiration is greatly affected -- and may even vary with several environmental conditions. In addition, if the soil water content is too large, exceeding some value SW_u, then water more easily moves through the profile resulting in water losses to D_R with its associated nutrient leaching losses and rainfall losses to Q will increase. The irrigation management goal is therefore to maintain SW within the SW_u - SW_c range while minimizing irrigation application losses to D_R and Q with $\Sigma I_r/t$ constrained to be $\leq$ the irrigation capacity. The maximum irrigation capacity can be estimated as $\Sigma ET/t$ when no soil water ($SW_{(I-1)} = SW_c$) can be extracted without reducing crop growth and yield. As the soil water content increases above SW_c, available soil water can be extracted by the crop to meet its evapotranspiration demand without reducing crop growth and yield; thereby, reducing the irrigation amount (ΣI_r) and irrigation capacity ($\Sigma I_r/t$) required to meet the crop water needs. Likewise precipitation directly offsets ET reducing irrigation needs and irrigation capacity.

PREVIOUS STUDIES

Stegman and Shah (1971) analyzed 37 years of climatic data for Oakes, ND and determined that a net irrigation capacity of at least 0.18 in/d to 0.25 in/d (4.6

mm/d to 6.4 mm/d) was necessary to avoid yield reductions for corn for a soil type with 4.5 in (114 mm) of available soil water. They suggested that the irrigation capacity would increase for soils with much less available soil water holding capacity.

Heermann et al. (1974) analyzed the irrigation capacity change ($\Sigma I_r/t$) as the allowable soil water depletion [approximately defined as $\int (SW_u - SW_c)\,dz$ over R] increased for a 60-yr time period at Akron, CO. The median irrigation capacity ($P_e = 0.50$, where P_e is the exceedence probability) declined from 0.23 in/d (5.8 mm/d) at a 1 in (25 mm) allowable soil water depletion level to 0.10 in/d (2.5 mm/d) with 6 in (152 mm) allowable soil water depletion; however, the maximum irrigation capacity ($P_e \leq 0.01$) declined from 0.32 in/d (8 mm/d) to 0.21 in/d (5.3 mm/d) over the same range in allowable soil water depletion. Daily maximum alfalfa evapotranspiration rate during 1971 was 0.47 in/d (12 mm/d) and the maximum corn evapotranspiration rate ($P_e \leq 0.01$) was estimated to be 0.39 in/d (10 mm/d) at Akron, CO for the 60-yr period. The maximum irrigation capacity ($P_e \leq 0.01$) at Akron, CO was 0.34 in/d (8.6 mm/d) even for 15-day averaging and did not decline further even for an averaging period extending to 30 days.

Von Bernuth et al. (1984) simulated soil water contents and corn yields for four locations in Nebraska for differing record lengths of 14-30 years as affected by irrigation capacity, irrigation management, and soil water holding capacity. For Southwest Nebraska, they reported that a maximum net irrigation capacity of 0.30 in/d (7.6 mm/d) was necessary to limit corn yield reductions to less than 5% for 99% of the time ($P_e \leq 0.01$) for *available* soil water holding capacities exceeding 12% by volume (1.4 in/ft). For the same conditions, the net irrigation capacity would vary from 0.26-0.24 in/d (6.6-6.1 mm/d), 0.24-0.22 in/d (6.1-5.6 mm/d), and 0.20-0.18 in/d (5.1-4.6 mm/d) for probabilities of 90, 75, and 50% ($P_e \leq$ 0.10, 0.25, and 0.50), respectively.

Howell et al. (1989) simulated corn yields at Bushland, TX for a 28-yr record for varying net irrigation capacities and irrigation management for the Pullman clay loam soil (13.5% volumetric water holding capacity; 1.62 in/ft). Net irrigation capacities greater than 0.32 in/d (8 mm/d) did not increase yields; net capacities less than 0.32 in/d, even as low as 0.16 in/d (4 mm/d), reduced mean corn yields only slightly; however, the risk for greater yield reductions (even up to 60% yield reductions) increased dramatically with net capacities below 0.32 in/d.

RECOMMENDATIONS

Irrigation capacities that are too high or too low both result in inappropriate irrigation systems. Maximum daily ET for corn in this region is unlikely to exceed 0.5 in/d (13 mm/d) even under rather extreme advective conditions which sets an upper bound on *net* irrigation capacity necessary to fully irrigate corn without the occurrence of significant yield reducing crop water deficits. Center pivot sprinkler design with this maximum irrigation capacity may result in excessive application rates with operational problems controlling runoff, particularly if field slopes exceed 2% or with heavier textured soils. Minimum *net* irrigation capacity for fully irrigated corn without major yield reductions in this region may approach 0.25 in/d (6.3

mm/d); however, time needed for equipment maintenance and repairs and for greater flexibility in irrigation management may dictate irrigation capacities above this *minimum* value. *Optimum* irrigation capacity will need to be determined on a grower-by-grower and almost on a field-by-field basis. As the irrigation capacity increases above this minimum value, risk of reduced crop yields due to insufficient irrigation capacity decline; however, irrigation water use may increase without an increase in net profit. As irrigation capacity approaches this lower limit, irrigation management options are severely restricted.

Irrigation amount should be the maximum [up to approximately 1.0-1.5 in (25-38 mm)] that can be practically and efficiently stored within the root-zone without losses to runoff and deep percolation. This irrigation amount will depend on the irrigation capacity which determines the peak application rate as well as the method of application (sprinkler, spray, LEPA, etc.). English et al. (1990) discuss irrigation management options for deficit irrigation capacities. Irrigations with a developing canopy should be avoided unless necessary to prevent critical crop water deficits. Irrigations with bare soil and developing crop canopies can result in water losses to rainfall runoff and soil water evaporation. However, crop water deficits develop quickly in some soils, and critical crop water deficits should be avoided even during vegetative development. Even a small crop water deficit at critical early crop development stages of corn (particularly differentiation) can greatly reduce potential kernel numbers. Later critical periods are tassel emergence through pollination. Soil water reserves should be increased during the early season, when crop ET needs are not as great, to near *field capacity* at tassel emergence stage of growth. The soil water reserve can then be *mined* during the maturation stages, when crop ET needs are near maximum, while avoiding severe levels of crop water deficits.

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