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Irrigation Tailwater Loss and Utilization Equations
by Arland D. Schneider 461

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Irrigation Tailwater Loss and Utilization Equations

By Arland D. Schneider,[1] M. ASCE

Allowing irrigation tailwater runoff is the commonly accepted practice for fully irrigating the lower end of graded furrows or borders. Irrigation-system water losses are minimized by proper balance between tailwater losses and deep percolation losses. Criddle, et al. (3) recommended an irrigation advance time equal to one-fourth of the application time. To reduce tailwater losses, they recommended a "cutback" furrow stream during the latter part of the irrigation set. Irrigation tailwater recovery systems can reduce the water losses that occur without a cutback furrow stream. Bondurant (2) presented design criteria for tailwater recovery systems and recommended operating the systems to achieve a reduced furrow stream input.

A knowledge of the relative importance of design variables and the ability to place bounds on tailwater loss and recovery aids the engineer with limited design information. This paper develops equations that show the relative importance of the variables affecting tailwater loss and utilization.

Analysis

Input to an irrigation border or furrow is divided into three fractions: Plant root zone storage s; deep percolation p; and tailwater runoff r. The sum of the three fractions is unity, i.e.

$$s + p + r = 1 \qquad (1)$$

When tailwater is recovered, a fraction of the runoff is lost in collection ditches and storage pits, and the remainder is returned to the irrigation distribution system. Let l be the fraction of the tailwater runoff lost in the recovery process. Then, lr is the tailwater runoff lost to evaporation and seepage, and $(1 - l)r$ is the tailwater runoff returned to the irrigation system.

Assume that the tailwater runoff is recycled indefinitely through additional irrigation sets and that s, p, r, and l, are constant. The total tailwater loss and utilization can be expressed as infinite series. Total tailwater loss L is $L = l(1 - s - p) + l(1 - l)(1 - s - p)^2 + l(1 - l)^2 (1 - s - p)^3 + \ldots + l(1 - l)^n (1 - s - p)^{n+1} + \ldots$, in which n = the number of times the tailwater runoff has been returned to the next irrigation set. Since the common

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ratio $(1 - l)(1 - s - p)$, is less than one, the sum of the infinite geometric series is easily obtained. The summation for L is

$$L = \frac{l(1 - s - p)}{l(1 - s - p) + s + p} \quad \ldots \ldots \quad (2)$$

Since $(s + p)$ is constant and does not affect tailwater loss, it can be replaced by $(1 - r)$. Then equation for the total tailwater loss becomes

$$L = \frac{lr}{1 - r + lr} \quad \ldots \ldots \quad (3)$$

Eq. 3 is a simple expression for the total tailwater loss as a function of the tailwater runoff and loss fractions. In Fig. 1, values of L are plotted for $0 \leq l \leq 0.6$ and $0 \leq r \leq 0.6$. The significance of the equal loss curves will be considered later.

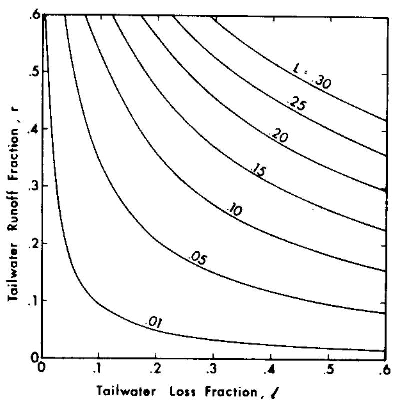

FIG. 1.—Total Tailwater Loss as Function of Tailwater Runoff and Loss Fractions

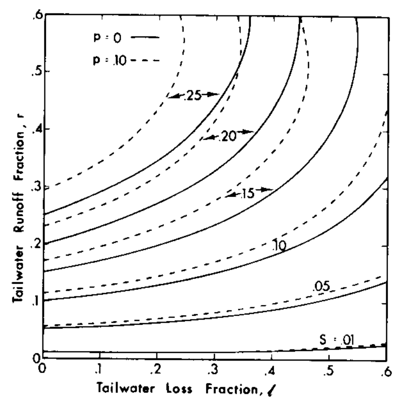

FIG. 2.—Total Tailwater Utilization as Function of Tailwater Runoff and Loss Fractions

The tailwater runoff recovered and stored in the plant root zone during subsequent irrigation sets is the tailwater utilization, S: $S = s(1 - l)(1 - s - p) + s(1 - l)^2(1 - s - p)^2 + s(1 - l)^3(1 - s - p)^3 + \ldots + s(1 - l)^n(1 - s - p)^n + \ldots$. The sum of the infinite series for S is

$$S = \frac{s - sl(1 - s - p) - sp - s^2}{l(1 - s - p) + s + p} \quad \ldots \ldots \quad (4)$$

If deep percolation losses are negligible, $p = 0$, and Eq. 4 reduces to

$$S = \frac{(1 - l)(r - r^2)}{1 - r + lr} \quad \ldots \ldots \quad (5)$$

The tailwater utilization equation is plotted in Fig. 2 for $0 \leq l \leq 0.6$ and $0 \leq r \leq 0.6$. The solid curves are for $p = 0$, and the dashed ones are for $p = 0.10$.

The lower case symbols, l, p, r, and s, are fractions of input to or runoff from an individual border or furrow. The upper case symbols, L and S, are fractions of input to the entire irrigated field.

Review

The tailwater loss and utilization equations show the relative importance of the variables in Eq. 1. The analysis is an idealized one because tailwater will not be recycled indefinitely through an irrigation system. The total loss should be considered a minimum value, and the total utilization a maximum value. With the tailwater loss and utilization bounded, the important design variables in a tailwater recovery system can be delineated.

The tailwater loss curves of Fig. 1 illustrate two important considerations for system designers. For values of l and r ranging from 0.1-0.4, both variables have nearly the same effect on the total tailwater loss. If either l or r remains high, total tailwater loss will not be negligible, unless the other variable is quite small. The design of the irrigation and tailwater recovery systems have essentially equal importance in reducing tailwater loss.

The second important consideration is that tailwater losses can be large in systems considered well designed by present day standards. A tailwater recovery system is no substitute for a poorly designed and operated irrigation system. If a large fraction of the applied irrigation water becomes tailwater runoff, continual recovery of the water for irrigation simply subjects the water to continual loss. An example of a typical tailwater recovery system shows that these systems are no panacea. A tailwater runoff fraction of 0.2 is typical of many areas with good irrigation water supplies. Evaporation and seepage from extensive tailwater collection systems often make the tailwater loss fraction as high as 0.35. Substituting these values into Eq. 3 gives a total tailwater loss of 0.08. Without the tailwater recovery system, the loss would be 0.20. Thus, 40% of the initial tailwater runoff is lost even with the recovery system.

The quantity of tailwater recovered for crop use determines the economic feasibility of a tailwater recovery system. The curves of Fig. 2 show total tailwater utilization for combinations of the tailwater runoff and loss fractions. The amount of water actually utilized from small quantities of tailwater runoff may not justify the cost of a tailwater recovery system. Where a tailwater recovery system is to be installed, the curves show how much additional water will be available to the irrigator. Recycled water means either increased irrigated acreages or decreased water demand by the irrigator.

For the slowly permeable soils of the Southern High Plains, uniform irrigation water distribution can be achieved with tailwater runoff fractions of 0.10 or less (4). Deep percolation losses on Pullman clay loam, the most extensive soil in the area, are small enough to be neglected in the tailwater utilization Eq. 1. Extensive open ditch tailwater collection systems may cause the tailwater loss fraction to be as high as 0.3-0.5. Total tailwater utilization with a tailwater runoff fraction of 0.10, and a tailwater loss fraction of 0.40 is only 0.057. Thus, only 5.7% of the irrigation water supply would be recovered with a tailwater recovery system. By reducing the tailwater loss fraction to 0.10, the total tailwater utilization is increased to 9.1% of the irrigation water supply. Where pumps and return pipelines are major expenses, this large percentage increase in tailwater utilization may economically justify additional tailwater recovery systems.

Conclusions

1. The minimum tailwater loss and maximum tailwater utilization for an irrigation tailwater recovery system can be bounded with a relatively simple model.
2. The quantity of tailwater runoff and the tailwater recovery system losses are equally important in determining the total tailwater loss.
3. Tailwater utilization depends on the quantities of deep percolation, tailwater runoff, and tailwater recovery system losses.

Acknowledgment

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Appendix.—References

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