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Simplified Forms of Surface Runoff Estimation Method for Silt-Loam Soils

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Surface runoff, the amount of water that runs off a field after precipitation or irrigation, can occur from irrigated, rain-fed, or dryland fields. Because it depends on numerous factors, runoff is a difficult variable to measure and/or quantify. However, when using a soil-water balance approach to estimate crop water use or evapotranspiration (ET) and/or crop irrigation requirements (IR), this variable needs to be taken into account. In many cases, runoff is assumed to be negligible or zero because of difficulties in quantifying it. When surface runoff is assumed to be negligible, any error or uncertainty in this variable could be lumped into the ET category and/or IR calculations, which can result in erroneous ET and IR estimates. This Extension Circular, which presents a simplified method to estimate surface runoff, can provide reasonable estimates of this variable for practical applications.

Among the many factors that influence the amount of water that runs off of the field are:

- Soil physical characteristics, including soil type (particle size distribution)
- Irrigation management and irrigation method
- Surface roughness, surface residue cover; precipitation intensity and duration
- Field slope
- Antecedent (initial) soil moisture before the precipitation and/or irrigation event
- Crop growth stage/canopy cover
- Soil management (tillage) practices

Coarse-textured soils (e.g., sandy, sandy-loam soils) usually have high infiltration rates and low water-holding capacity, which can result in lower surface runoff compared with fine-textured soils. Fine-textured soils generally have lower infiltration rates, resulting in more overland water flow, which in turn, creates greater surface runoff compared with coarse-textured soils. Surface runoff can be a particular concern in humid and subhumid climates where potential for runoff is greater due to greater precipitation and increased soil moisture, in general, in the soil profile.

Another factor is lower evaporation and evapotranspiration rates from the surface compared with arid and semiarid climates where the potential for runoff is usually lower. However, depending on soil and other terrain characteristics, irrigation management, and other factors, runoff can still occur in irrigated crop production systems in arid and semiarid climates. Subsurface drip and center pivot irrigation methods result in lower runoff compared with surface (gravity) irrigation.

In many cases, the terms "overland flow" and "surface runoff" are used interchangeably. Runoff occurs primarily when the precipitation rate exceeds the soil infiltration rate (the rate in which water enters into the soil). Once the infiltration process is completed, the remaining precipitation and/or irrigation water starts filling the depressions on the soil surface. After the depressions are fully filled, the overland (surface) flow process begins. The overland flow from different parts of the field converges and initiates the surface runoff process with which the excess precipitation and/or irrigation water starts to flow over the soil surface and flows off of the field.

The water that runs off the field may end up in a pond, lake, creek, river, ditch, water re-use pit, etc., which can transport diseases, nutrients, and other chemicals to another field and/or water bodies. Even with a properly designed, operated, managed, and maintained irrigation system, and soil and crop production system, it may be impossible to completely eliminate surface runoff due to the aforementioned reasons that influence this variable. However, properly designed and managed systems can minimize runoff.

Options for estimating surface runoff are limited. The existing methods are complex and require parameters, variables, and/or coefficients that are difficult to obtain. While those parameters may be possible to measure or quantify in research settings, they are difficult to quantify by practitioners in practical applications, which can make these runoff estimation procedures less applicable in practice. Therefore, more practical and simplified methods can be useful to quantify surface runoff when conducting soil-water balance analyses.

Simplified Method for Estimating Surface Runoff

The author has been conducting extensive field research projects with center pivot and subsurface drip irrigation systems to measure ET, irrigation requirements, hydrologic balances, and related variables for many cropping and natural systems in different parts of Nebraska since 2004. During this research, surface runoff amounts have been quantified for different cropping systems, and these long-term research datasets have been used to develop a simplified method to quantify surface runoff. To develop this method, the runoff values that have been measured and/or quantified using the USDA-NRCS (1972, 1985) curve number method were correlated to the total amount of water (precipitation + irrigation) supplied to the field. The USDA-NRCS curve number method estimates surface runoff as a function of field slope, initial abstraction losses, soil infiltration rate, potential maximum soil-water retention after runoff begins, surface residue cover, and soil moisture.

Runoff from Combined Center Pivot and Subsurface Drip Irrigated Fields

The resulting simplified relationship between surface growing season precipitation + irrigation versus surface runoff for a Hastings silt-loam soil developed from research projects conducted at Clay Center, Nebraska, and elsewhere in the state. It is presented in *Figure 1*, in which data from center pivot and subsurface drip irrigated cropping systems are combined. In *Figures 2* and *3*, data were separated for center pivot and subsurface drip irrigated fields individually. The author has been conducting research under the center pivot irrigation system (40 acres) primarily with corn and soybean from 2005 to 2016. The subsurface drip irrigation system-1 (SDI-1; 34 acres) and subsurface drip irrigation system-2 (SDI-2; 11 acres) were researched with corn, soybean, winter wheat, sweet corn, watermelon, and sorghum from 2004 to 2016. Figures *1*, *2*, and *3* present the relationships in English units and *Figures 4*, *5*, and *6* present the same data and relationships in international standard (metric) units.

The combined data from both center pivot and subsurface drip irrigation fields presented in *Figure 1* indicates a strong correlation between precipitation + irrigation and surface runoff. A coefficient of determination (R^2) of 0.70 indicates that 70 percent of the variability in surface runoff was explained by precipitation + irrigation amounts alone for these experimental conditions. The other 30 percent of variation in surface runoff is due to other aforementioned factors that affect surface runoff. As the precipitation + irrigation increased, the surface runoff increased and the relationship was explained with a linear function.

The surface runoff may not be a linear function of precipitation + irrigation, but it should be noted that this is a simplified method that does not account for all other variables that runoff depends on. There is scatter in the data (large scatter in some cases), but overall the relationship presented in *Figure 1* [RO = 0.0291•(P+IR)-0.1892; RO = amount of runoff in inches; P = precipitation in inches; IR = irrigation amount in inches] is strong and can be valuable to estimate average runoff only as a function of two relatively easily obtainable variables from combined center pivot and subsurface drip irrigated row crop systems.

Depending on the precipitation timing and amount as well as the irrigation water applied to different treatments and cropping systems over the years, in *Figure 1*, as expected, runoff varied for the same amount of water supplied (precipitation + irrigation). Some of the precipitation + irrigation amounts had runoff, but for some other cases, runoff did not occur for the same or similar amount of water supplied. This is due to a variety of reasons, including initial soil moisture of the topsoil as well as in the crop root zone just before and at the time of irrigation and/or precipitation events, the treatment's irrigation level, precipitation and/or irrigation timing and amount during the growing season, irrigation method, and other factors.

Runoff from Only Subsurface Drip Irrigated Fields

The correlation between precipitation + irrigation and runoff for only subsurface drip irrigated fields (*Figure 2*) is not as strong (R^2 = 0.50) as that of the pooled center pivot and subsurface drip irrigated fields data (*Figure 1*). This is because there is one data point with 16.8 inches of precipitation + irrigation water supply that resulted in a very small amount of runoff, causing the low R^2 value. While the number of observations in *Figure 2* is rather high (n = 40), not all of these data points are visible because there are many data points with different precipitation + irrigation amounts that had the same runoff values. These data points fell on top

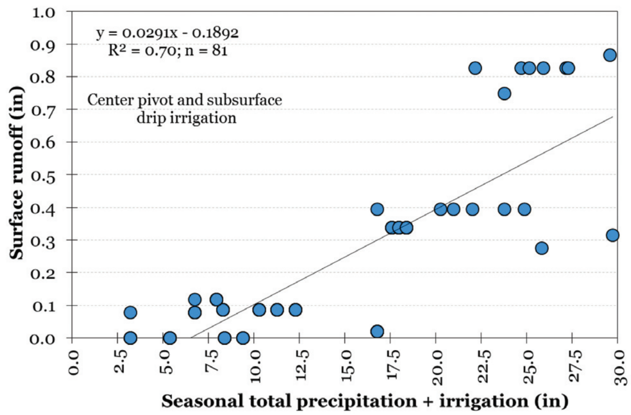

Figure 1. Relationship (in English units) between surface runoff and growing season precipitation + irrigation. The relationship is developed from long-term data measured for row crops (e.g., corn, soybean, winter wheat) under silt-loam soils at Clay Center, Nebraska, from 2004 to 2016.

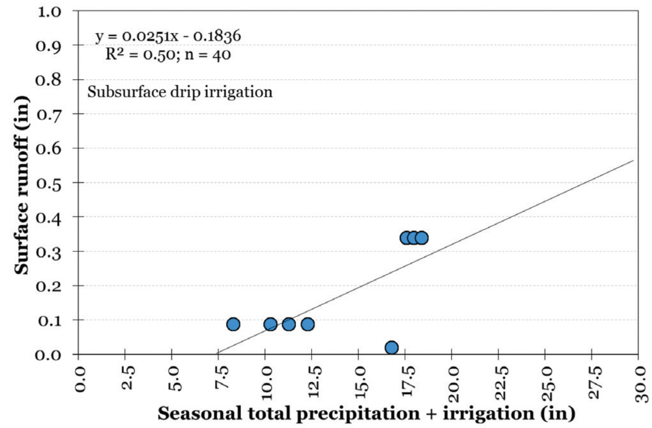

Figure 2. Relationship (in English units) between surface runoff and growing season precipitation + irrigation for subsurface drip irrigated row crops. The relationship is developed from long-term data measured for row crops (e.g., corn, soybean, winter wheat) under silt-loam soils at Clay Center, Nebraska, from 2004 to 2016.

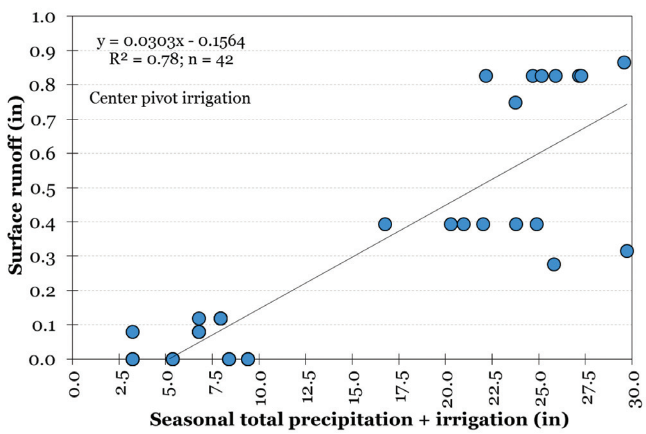

Figure 3. Relationship (in English units) between surface runoff and growing season precipitation + irrigation for center pivot irrigated row crops. The relationship is developed from long-term data measured for row crops (e.g., corn, soybean) under silt-loam soils at Clay Center, Nebraska, from 2005 to 2016.

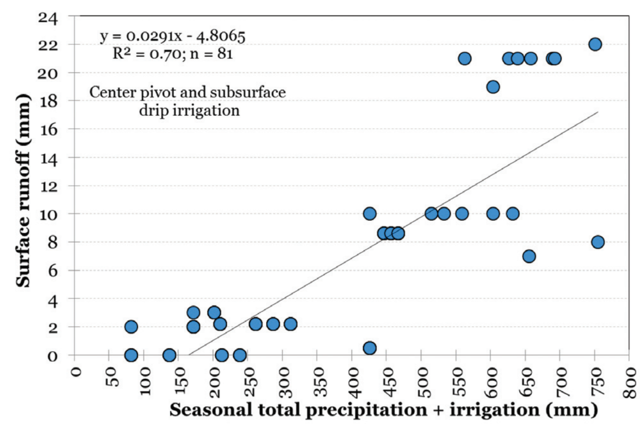

Figure 4. Relationship (in metric units) between surface runoff and growing season precipitation + irrigation. The relationship is developed from long-term data measured for row crops (e.g., corn, soybean, winter wheat) under silt-loam soils at Clay Center, Nebraska, from 2004 to 2016.

of each other and are seen as one data point. The equation developed in *Figure 2* [RO = 0.0251•(P+IR)-0.1836; RO = amount of runoff in inches; P = precipitation in inches; IR = irrigation amount in inches] can be used for estimating surface runoff specifically from subsurface drip irrigated fields for practical purposes.

Since subsurface drip and center pivot are two different irrigation methods, the amount of surface runoff expected from these two fields can vary due to several reasons, which also causes scatter in the data in *Figure 1*. One of the reasons is the surface soil wetness. With the center pivot irrigation system, the entire soil surface is wetted during an irrigation event, whereas the topsoil (approximately the top 6 to 8 inches) in the subsurface drip irrigated field remains very dry even during and after an irrigation event (in the absence of precipitation). Thus, for the same irrigation and/or precipitation amount, the amount of water that can be stored in the soil profile is different between the two systems, which results in different runoff amounts for the two different irrigation methods under the same or similar total amount of water supplied.

Runoff from Only Center Pivot Irrigated Fields

When only center pivot irrigation systems are considered, the relationship between precipitation + irrigation and runoff is also very strong (*Figure 3*) with an R^2 of 0.78 with 42 data points. As mentioned earlier, there is some scatter in the data distribution, but this is expected because of dif-

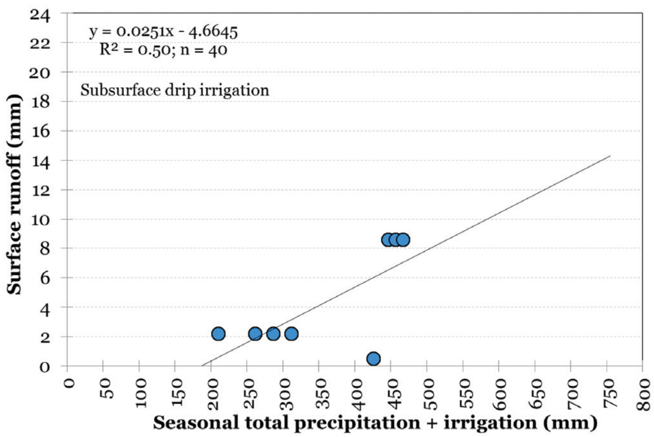

Figure 5. Relationship (in metric units) between surface runoff and growing season precipitation + irrigation for subsurface drip irrigated row crops. The relationship is developed from long-term data measured for row crops (e.g., corn, soybean, winter wheat) under silt-loam soils at Clay Center, Nebraska, from 2004 to 2016.

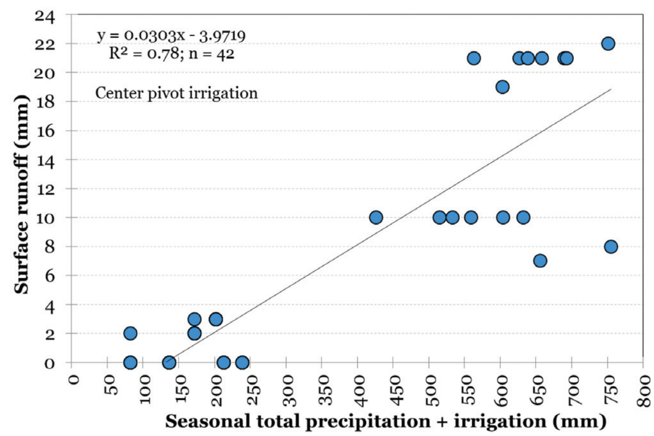

Figure 6. Relationship (in metric units) between surface runoff and growing season precipitation + irrigation for center pivot irrigated row crops. The relationship is developed from long-term data measured for row crops (e.g., corn, soybean) under silt-loam soils at Clay Center, Nebraska, from 2005 to 2016.

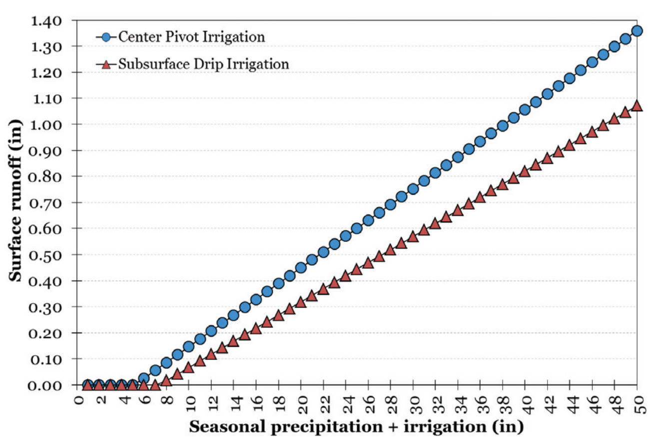

Figure 7. Comparison of surface runoff (in English units) between subsurface drip and center pivot irrigated fields. The equations presented in *Figure 2* for subsurface drip and *Figure 3* for center pivot irrigation systems were solved for different amounts of precipitation + irrigation to estimate surface runoff.

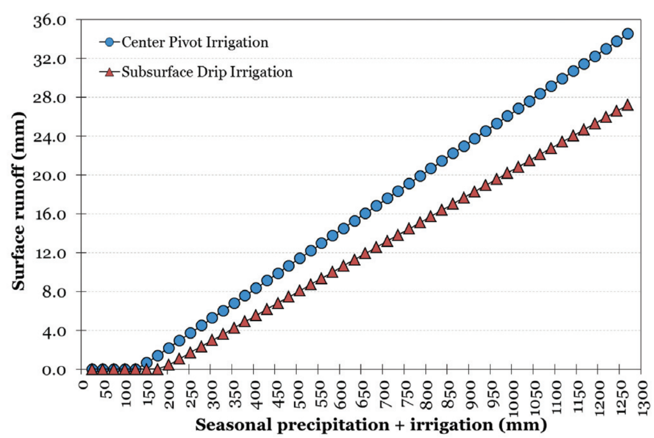

Figure 8. Comparison of surface runoff (in standard metric units) between subsurface drip and center pivot irrigated fields. The equations presented in *Figure 2* for subsurface drip and *Figure 3* for center pivot irrigation system were solved for different amounts of precipitation + irrigation to estimate surface RO.

ferent treatments with the same or similar precipitation + irrigation amounts. This resulted in different runoff values, as quantified from 2004 to 2016 under different cropping systems, treatments, and years that had different irrigation levels and very different precipitation timings and amounts. The amount of runoff ranged from 0 to 0.9 inch and the amount of precipitation + irrigation ranged from 3.2 inches to about 30 inches. The equation developed in *Figure 3* [RO = 0.0303•(P+IR)-0.1564; RO = amount of run-off in inches; P = precipitation in inches; IR = irrigation amount in inches] could be used for estimating surface runoff on a seasonal basis specifically from center pivot irrigated fields for practical purposes.

Comparison of Runoff from Center Pivot versus Subsurface Drip Irrigated Fields

While *Figures 2* and *3* were not developed or provided for comparison purposes, as mentioned earlier, the runoff amount that can occur from these two different irrigation methods can be different for the same or similar precipitation + irrigation amounts supplied to center pivot and subsurface drip irrigation fields. Since the topsoil in a subsurface drip irrigated field is not wetted during the irrigation events, and remains dry throughout the growing season (except when it is wetted with the precipitation), there is more soil water storage opportunity in a subsurface drip field than in a center pivot irrigated field in which the topsoil is wetted during every irrigation event. Thus, a center pivot field can be expected to have more runoff than a subsurface drip irrigation field under the same amount of precipitation + irrigation water supplied to both fields.

To demonstrate this, the equations in *Figures 2* and *3*, for subsurface drip and center pivot irrigation systems, respectively, were solved for different amounts of precipitation + irrigation and the estimated runoff values were graphed in *Figure 7* in English units and in *Figure 8* in standard metric units. Based on these estimations, surface runoff did not occur in the subsurface drip irrigation fields until 8 inches of precipitation + irrigation, and runoff did not occur until 6 inches of precipitation + irrigation in the center pivot field. Surface runoff increased linearly with increasing precipitation + irrigation for both systems, but runoff increased at a greater rate in the center pivot field than in the subsurface drip irrigation field. The amount of surface runoff in the center pivot field gets larger as precipitation + irrigation amounts are increased.

When a total of 20 inches of precipitation + irrigation water was supplied to both fields, the amount of runoff was estimated as 0.32 inch and 0.45 inch (0.13 inch greater runoff in the center pivot field) for the subsurface drip and center pivot irrigated fields, respectively. Again, this value increases in the higher precipitation + irrigation range. For example, when a total of 30 inches of precipitation + irrigation is supplied to both fields, the estimated surface runoff from the subsurface drip irrigated field increases to 0.57 inch, whereas runoff increases to 0.75 inch with the center pivot field (0.19 inch greater runoff in the center pivot field). On an overall average, based on these estimations, the center pivot field had 0.17 inch more surface runoff than the subsurface drip irrigated fields. These relationships are developed for growing season precipitation + irrigation amounts and do not consider off-season precipitation.

Summary

The data and relationships presented in this Extension Circular are developed for typical corn, soybean, and winter wheat cropping systems grown in silt-loam soils with a 0–1.5 percent slope and 30-inch row spacing (10-inch row spacing for winter wheat). The effective root density of these crops ranges from 3 to 4 feet. During the last 13 years of research, typical growing season total irrigation application amounts with the center pivot ranged from zero for rainfed treatments to 1.25–1.40 inches per revolution for fully irrigated treatments on a five-day or weekly basis. The irrigation application with the subsurface drip irrigation system ranged from zero for rainfed treatments to 1.00–1.25 inches per week for fully irrigated treatments.

The runoff data for both irrigation systems represent dry, average, and wet years encountered from 2004 to 2016. However, for the SDI precipitation + irrigation versus surface runoff data, most of the data points were quantified during very wet years (2007, 2008, 2011, and 2014), which resulted in greater runoff than might be expected during normal or dry years. The precipitation + irrigation versus runoff relationships presented in this Extension Circular represent a typical row crop production in Nebraska. These relationships can be used as simplified methods to estimate runoff on a seasonal (growing season) basis for center pivot and subsurface drip irrigated row crops.

While the relationships developed and presented in this study do not explicitly account for other variables that influence runoff, during the calculation of runoff values in various research projects from which the datasets were used to develop these relationships, the other variables that affect runoff were accounted for. Thus, the relationships developed in this study implicitly account for other runoff-influencing variables. The relationships presented in this Extension Circular can be useful tools in practice as they do not use complex formula and/or approaches and do not require additional variables or parameters that can be very difficult to obtain to estimate runoff. Extra attention to soil, crop, and irrigation management practices, soil type, as well as climatic conditions, must be taken into account when the data presented and the simplified method developed in this study are used or extrapolated beyond their boundaries to estimate surface runoff.

Reference

USDA-NRCS. 1985. National Engineering Handbook (NEH) Section 4, Hydrology. Soil Conservation Service, USDA, Washington, D.C.

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