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Review

# Are basin and reservoir tillage effective techniques to reduce runoff under sprinkler irrigation in Mediterranean conditions?

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ABSTRACT

The increasing use of low pressure moving sprinklers irrigation systems, like center-pivot irrigation systems, has increased surface runoff problems. Runoff decreases the irrigation system application efficiency, increasing the operational costs. It can also be responsible for environmental problems, such as soil erosion and the contamination of surface waters. Basin tillage and reservoir tillage have proved to be an effective practice to prevent runoff in many situations and can be an option to reduce surface runoff under moving sprinkler irrigation systems operating in Mediterranean conditions. However, even though it is a common practice in some Mediterranean regions, there are very few studies quantifying the effect of these tillage practices under moving sprinkler irrigation systems in Mediterranean countries. Many farmers are still not convinced that this is the best practice to prevent runoff. Some of them are converting to conservation agriculture, using no-till or minimum tillage, but the results of these tillage systems in the prevention of runoff are not always consistent. The industry is also creating new implements used to create the basins and reservoirs that apparently have some advantages over the old ones. But more studies are still required in order to be able to identify the better solutions for different soil, crop and irrigation management situations.



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## 1. Introduction

Sprinkler irrigation is one of the most common irrigation systems used worldwide. They can be used to irrigate almost all annual crops and are easy to adapt to different topography and soil situations, thus being one of the preferred options for farmers. The increase in the price of energy required by sprinkler irrigation systems has stimulated the use of low-pressure operating systems to achieve lower operational costs. Additionally, whenever it's possible the farmer's primary option is to use large sprinkler irrigation machines, like center-pivots or linear moving laterals, because of their higher degree of automation, thus being easier to operate, a higher water application efficiency compared to other sprinkler irrigation systems (Keller and Bliesner, 1990) and because they allow a lower investment cost per hectare in equipment as the irrigated area increases.

However, the decrease of operating pressure causes a decrease of sprinklers wetted diameter (Keller and Bliesner, 1990) which leads to an increase in water application rate (DeBoer et al., 1992). In many cases the use of low pressure irrigation systems and small irrigation times implies the use of application rates that exceed 100 mm $h^{-1}$ at the outer end of the center-pivot lateral (e.g., Valadas, 1997; Fernandez et al., 2004). According to Addink et al.

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(1983) the water application rate of a 400-m low pressure center-pivot irrigation system can achieve values of 150–300 mm $h^{-1}$ at its outer end. These application rates are excessive for many soil types and often lead to severe runoff problems (Undersander et al., 1985; Gilley et al., 1986; DeBoer et al., 1992; Silva, 2006).

In Southern European countries, with a Mediterranean Climate, characterized by hot dry summers where water availability is low, irrigation is the only way to grow many of the annual spring sown crops, and the use of sprinkler irrigation systems is increasing significantly. According to the EUROSTAT (2016) statistics, in 2010, the percentage of farm holdings using sprinkler irrigation was 23.9% in Portugal, near 15% in Spain, 39.4% in Italy and 29.4% in Greece. The number of farmers and sprinkler irrigated areas, namely with the use of moving sprinkler irrigation systems, continues to increase. For example, in Spain the use of moving sprinkler systems increased by 12.4% since 2005, and in some Spanish districts its use represents nowadays more than 26–46% of the total irrigated area (MAGRAMA, 2015).

In many cases, however, soil and topography present significant constrains to the proper use of these systems, leading to severe runoff problems (Silva, 2010) and to significant yield variability (Marques da Silva and Alexandre, 2005 ; Marques da Silva and Silva, 2006). Surface runoff can also cause soil erosion problems and the contamination of surface waters by transporting sediments and applied fertilizers or other agrochemicals washed-out from the cultivated field.

To minimize runoff problems farmers tend to manage the systems in order to apply small irrigation depths with high frequency. In the case of center-pivots or linear moving systems, with high water application intensities, the usual values of applied water are from 5 to 15 mm (Silva, 2006). This means that in many cases, at the peak of plant water requirements, farmers often irrigate every day, applying only enough water to satisfy plant daily evapotranspiration. Soil water content must be high along the irrigation season to avoid plant water stress, in the case of any sudden temperature increase or any problem with the irrigation system. In this context, and with low infiltrability soils and steeper topographies, common in many Mediterranean conditions, it is very difficult to avoid runoff problems.

Tillage practices can affect soil porosity (Horne et al., 1992) influencing soil water storage capacity (Mahboubi et al., 1993) and infiltration rate (Alegre et al., 1991; Horne et al., 1992). They can also affect soil surface roughness and soil surface storage capacity (Burwell and Larson, 1969), thus affecting irrigation runoff.

Reservoir and basin tillage are among the tillage practices that had been used successfully, especially in the United States of America, to minimize runoff under sprinkler irrigation machines (e.g., Busch and Kincaid, 1987; Kincaid et al., 1990; Hasheminia, 1994; Schneider and Howell, 2000). These tillage practices consist of creating depressions in the soil surface to increase soil surface storage capacity and thus holding water that might otherwise be lost as surface runoff during the irrigation events. The question is, can they be the better solution to prevent runoff under sprinkler irrigation systems operating in Mediterranean conditions?.

## 2. Causes of surface runoff under sprinkler irrigation moving systems

Sprinkler irrigation systems apply water to the soil and crop surfaces with an application rate that depends upon the system operating characteristics. When the soil infiltrability (Hillel, 1980) is lower than the water application rate, the water does not infiltrate into the soil and ponds on the soil surface. In unlevelled fields, after filling soil surface depressions, non-infiltrated water flows down the field producing surface runoff.

The irrigation-runoff process is complex, since there are many factors that, directly or indirectly, influence it (Silva, 2010). The major factors influencing directly surface runoff are those related to the characteristics of the irrigation system and to the field characteristics. The irrigation system factors determine water application rate and depth, which if it is not compatible with the soil infiltration capacity can lead to runoff. The soil infiltration capacity will depend on different soil parameters and the characteristics of the irrigated field that determine its surface storage capacity. Other factors, such as meteorological factors (wind and air temperature) (Kohl et al., 1987; Silva, 2006) and crop canopy (DeBoer et al., 2001) will have an indirect effect in the process by influencing the amount of water that reaches the soil and its impact energy on the soil surface, which in some cases can produce surface sealing and crust formation affecting soil infiltrability and increasing runoff (Bradford et al., 1987; Mohammed and Kohl, 1987; Basahi et al., 1998; Silva, 2006).

The irrigation system water application rate is a major runoff affecting-factor due to the fact that soil infiltrability is limited. Water application rate depends mainly on water pressure, flow rate and sprinkler type. In long sprinkler moving irrigation systems, such as center-pivots, the water application rate increases along the machine length achieving at the machine outer end values that are much higher than soil infiltration capacity. As mentioned before, the decrease in the sprinklers operating pressure decreases the sprinklers wetted radius and thus increases water application rate. DeBoer et al. (1992) found that application rates increased almost twice and wetted diameters halved with a 50% decrease in sprinklers operating pressure. In order to reduce wind drift and evaporation losses, in semi-arid or windy regions, many center-pivot and linear moving lateral irrigation systems are equipped with spray sprinklers on drop tubes near the crop canopy or even in-canopy (Dechmi et al., 2003; Kincaid, 2005). Reducing the distance of the sprinklers to the soil surface reduces also the sprinkler wetted diameter, and consequently increases water application rates and runoff problems. An example of this is the low energy-precision application (LEPA) system (Lyle and Bordovsky, 1981). These systems are used in moving sprinkler irrigation systems and apply water at or near the soil surface, usually to alternate individual furrows opened in row crops. The system is designed to be independent of soil infiltration capacity (ASAE, 1999) and to use all soil surface storage capacity. However, when applied water exceeds the soil storage capacity there can be significant water runoff amounts. Schneider and Howell (2000), using a 117 m long linear moving lateral, found that two-years, seasonal average surface runoff from a LEPA system (52% of the applied water) was about four times higher compared to the runoff produced by a mid-elevation spray application (12% of the applied water), with spray head sprinklers positioned 1.5 m above the soil surface or about 0.3 m above the height of the mature grain sorghum crop, in a clay loam soil. The LEPA system water application near the soil surface increases substantially the water application rate compared to the water application with the mid-elevation spray sprinklers making it more difficult for the soil to infiltrate all applied water, which leads to more surface runoff.

Field topography can also have a significant influence on runoff due to its effect on water redistribution over the soil surface, influencing infiltration and soil water content (Hanna et al., 1982). Fields with variable topography will present different surface runoff situations over the entire field. Concave areas will concentrate water flow, increasing infiltration and reducing surface runoff, while convex areas will disperse water flow, reducing infiltration and increasing surface runoff (Daniels et al., 1987; Timlin et al., 1998). The increase in field slope has also been frequently found as a surface runoff increasing-factor (Hanna et al., 1983; Onstad, 1984). Increasing slope increases the rate of surface water flow and con-