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Sprinkler Droplet Energy Effects on Infiltration and Near-Surface, Unsaturated Hydraulic Conductivity

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Reducing the impact energy of sprinkler droplets through irrigation management should minimize surface soil aggregate breakdown and seal formation while maintaining infiltration rates. From 1997 through 1999 in southern Idaho, we quantified sprinkler droplet energy effects on infiltration and near-surface hydraulic conductivity measured under tension after crop stand establishment. The treatments were droplet energies: 0 or 7 J kg⁻¹ (0 or 7 J m⁻² mm⁻¹), produced with a low-pressure, lateral-move irrigation system. After planting sugarbeet (*Beta vulgaris* L.) into a Portneuf silt loam (*Durinodic Xeric Haplocalcid*) and irrigating 2-3 times, we used tension infiltrometers to measure unconfined (three-dimensional) infiltration rates through undisturbed soil surfaces at three supply potentials. Reducing droplet energy significantly increased steady-state infiltration, averaged across years, at supply potentials of -20 and -40 mm and kept soil surfaces rougher with less aggregate breakdown. Pores with diameters between 0.75 and 1.5 mm were most affected by droplet energy.

Keywords. Droplet Impact, Sprinkler Irrigation, Infiltration, Hydraulic Conductivity, Surface Sealing

Introduction

Seedling emergence is inhibited by soil crusts. To help seedlings emerge through crusted soil, agricultural producers often apply one or more post-plant, pre-emergent irrigations with moving-lateral sprinkler systems. If too much water is applied at too high droplet energy, however, the crust can be thickened and strengthened, hindering rather than helping seedlings emerge. To minimize the risk of crust thickening, center pivots or other moving laterals could be nozzled to apply 5 mm (or less) of water at a low rate and low droplet energy at each pass until crop seedlings emerge, then re-nozzled to apply more water (at necessarily greater droplet energy) per pass for the remainder of the growing season. Reducing the impact energy of droplets from center pivot spray heads, particularly from planting to emergence, should minimize surface soil aggregate breakdown, seal formation, and subsequent crust development. Even slight crop stand increases from less-crusted soil can be economically significant. For example, increasing sugarbeet seedling emergence by as little as 11% can increase a producer's economic return by \$130 ha⁻¹.

Although the effects of irrigation on soil physical and chemical properties have been studied (e.g., Agassi et al., 1994; Roth and Helming, 1992), droplet energy effects on infiltration rates, especially at water potentials of -20 mm or less, or unsaturated hydraulic conductivities have received comparatively little attention. The objective of our three-year field study was to quantify the effects of sprinkler droplet impact energy on steady-state infiltration and near-surface, unsaturated hydraulic conductivity measured after sugarbeet stand establishment.

Methods and Materials

The experiment was on Portneuf silt loam (coarse silty, mixed, superactive, mesic *Durinodic Xeric Haplocalcid*) at 42° 32' N latitude and 114° 26' W longitude, about 2.3 km southwest of Kimberly, ID. Soil in Portneuf Ap horizons commonly has a cation exchange capacity of 190 mmol kg⁻¹, pH (saturated paste) of 7.7, an EC of 1.1 dS m⁻¹, and SAR of 0.87. Its organic C content is approximately 9.3 g kg⁻¹ and it contains 66% silt and 20% clay. Soil structure was weak at our site; surface aggregates fractured easily, readily forming surface seals that dried to form crusts. Other soil and site properties were given by McDole and Maxwell (1987).

The experimental design was a randomized complete block, with four replications in 1997 and 1998 and eight in 1999. We measured soil hydraulic properties of three subsamples per replication. Treatments were droplet energies: 0 and 7 J kg⁻¹ (0 and 7 J m⁻² mm⁻¹ applied water). A low-pressure, lateral-move irrigation system was modified to produce droplets that impacted the soil surface with nominal energies of 7 J kg⁻¹ by equipping sprinkler

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heads with Nelson² smooth spray plates (Kincaid, 1996). A 104-kPa (15-psi) pressure regulator was immediately upstream of each sprinkler head. The 0 J kg⁻¹-plots were covered with two layers of 20-mesh nylon screen, suspended about 50 mm above the soil on a coarse grid of 6-mm metal bar. Droplet impact energy was dissipated on the nylon screen above these plots.

The fall before each study year, the site was moldboard-plowed to a depth of 0.18 m. Generally in early spring, a seedbed was prepared by tilling the site with an offset disk (to 0.10 m), then roller-harrowing twice (to 65 mm). Sugarbeet (Hilleshog-MonoHy² cv. PM-9) was planted at a depth of about 18 mm every 0.15 m in 0.56-m rows using a four-row, Milton² planter, traveling at about 4 km h⁻¹. Plots were 2.2 m wide and about 13.1 m long, with the long axis parallel to the system's lateral. Just after planting, plots were reservoir-tilled to form 0.16-m deep reservoirs every 0.76 m in every furrow to increase surface depression storage and reduce runoff. To intercept sediment-laden runoff from upslope, a diversion ditch was formed at the upslope plot edge.

The site was irrigated 2-3 times in the 3-4 weeks between planting and final stand establishment each year. We applied 18-20 mm of water, in gross, at the first post-plant irrigation and 11-13 mm at each subsequent irrigation, always with an application intensity of about 37 mm h⁻¹. We irrigated with Snake River water, that commonly has a pH of 8.2, an EC of 0.5 dS m⁻¹, and an SAR of 0.65.

After all seedlings had emerged and final plant populations were determined, the plants were killed by spraying with glyphosate in mid-June. Each year, about 4 (±2) weeks (± standard error) elapsed between spraying and completing the infiltration measurements. In that time, plot surfaces changed little: they were neither tilled nor irrigated and received only 8 (±8) mm of natural precipitation. We used tension infiltrometers to measure unconfined (three-dimensional) infiltration rates at three in-the-row locations in each plot using the procedure of Ankeny (1992), though slightly modified. Infiltration was measured through each location's undisturbed surface at supply potentials of -60, then -40, then -20 mm of water. Measurements were taken at a potential of -40 mm, and one larger and smaller, to adequately characterize soil hydraulic properties most affected by management and biological activity (Murphy et al., 1993; White et al., 1992). Tension infiltrometers are well suited for studying soil structural changes induced by tillage, water droplet impact, and biological activity (White et al., 1992). At a potential of -20 mm, flow occurs through pores with diameters ≤ 1.5 mm, at -40 through ≤ 0.75 mm, and at -60 through ≤ 0.5 mm. We did not use potentials lower than -60 mm because the method of Ankeny (1992) may underestimate hydraulic conductivity at lower supply potentials (Logsdon and Jaynes, 1993). After the infiltration rate at each potential had stabilized, we manually recorded reservoir water levels at 30- to 60-s intervals for an additional 5-15 min. After infiltration into all plots had been measured, the site was kept fallow by disking when needed until fall.

We determined steady-state infiltration rates at each potential and, with them, calculated unsaturated hydraulic conductivities using software described by Ankeny et al. (1993). In brief, one uses infiltration rates at two adjacent potentials as data to simultaneously solve three equations with three unknowns. Their solution yields the hydraulic conductivity at each potential and α , hydraulic conductivity divided by matric flux potential, for the input potential range (Ankeny et al., 1993).

After initially identifying heterogeneous variances among blocks for the year-by-treatment combinations for each response variable, we transformed the data to common logarithms to stabilize the year-by-treatment variances. Thereafter, Bartlett's analyses revealed homogeneous variances for the year-by-treatment combinations for steady-state infiltration rates and unsaturated hydraulic conductivities at each potential. After averaging the data across subsamples, we performed a multi-year analysis of variance using mixed model procedures with replication and year as random factors (SAS Institute Inc., 1997)². Least-squares treatment means were declared statistically different whenever the treatment *F*-ratio's significance was less than 0.05. Means and 95% confidence limits on the mean were back-transformed into original units for presentation.

Results and Discussion

At every supply potential, droplet energy of 7 J kg⁻¹ decreased steady-state infiltration rates, compared to controls (Table 1). In general, the infiltration rates decreased by about 22%, revealing the substantial effects of even moderate amounts of droplet energy on infiltration rates under tension. A seal may have formed, reducing infiltration rates. If so, structural breakdown from droplet impact was the likely cause. The stability of soil surface aggregates influences soil hydraulic properties (Murphy et al., 1993). Soil hydraulic properties measured at potentials ≤ -40 mm were thought to be unaffected by environmental processes or management (Murphy et al.,

²Mention of trade names is for the reader's benefit and does not imply endorsement of the product by the USDA.

1993; White et al., 1992). Data in Table 1 reveal, however, that water drop impact energy can substantially decrease infiltration rates at potentials ≤ -40 mm.

Table 1. Droplet energy effects on steady-state infiltration rates measured at three water supply potentials. Data have been averaged across years (1997, 1998, and 1999).

Droplet energy	Infiltration rate [†]		
	Supply potential (mm H ₂ O)		
	-20	-40	-60
J kg ⁻¹	----- mm h ⁻¹ -----		
0	36.9	30.1	29.0
7	28.9	24.2	21.7

[†] Droplet energy effects were significant at $P=0.002$ for -20 mm, at $P=0.049$ for -40 mm, and at $P=0.055$ for -60 mm.

The increase in steady-state infiltration rate from -40 to -20 mm at 0 J kg^{-1} was 6.8 mm h^{-1} , nearly 45% greater than the increase at 7 J kg^{-1} (Table 1). This finding reveals that 45% more flow was occurring through 0.75–1.5 mm pores in plots protected, rather than not protected, from droplet energy. To put it differently, sprinkler droplet impact significantly reduced infiltration through pores with diameters between 0.75 and 1.5 mm. So, minimizing or eliminating droplet energy will allow more infiltration to occur through pores with diameters between 0.75 and 1.5 mm. Greater infiltration will reduce runoff, thereby decreasing both concentrated-flow detachment and transport, and could reduce water stress.

Droplet energy did not affect hydraulic conductivity at any potential when averaged across years ($P=0.20$ for -20 mm, $P=0.09$ for -40 mm, and $P=0.41$ for -60 mm) (data not shown). Much year-by-treatment variability made identifying treatment differences problematic. To eliminate this year-to-year variation, we examined each year's hydraulic conductivity separately. Droplet energy effects on hydraulic conductivity were not significant in 1997 or 1998 (data not shown) but in 1999 were significant at -20 mm ($P=0.03$) and nearly so at -40 mm ($P=0.06$) (Fig. 1).

Compared to controls, 7 J kg^{-1} of droplet energy decreased hydraulic conductivity by 40 to 55% at each potential in 1999. Droplet energy decreased hydraulic conductivity most at -20 mm potential, where management and biological influences upon soil pores would be greatest.

Since droplet energy decreased hydraulic conductivity at -20 mm but not significantly at -40 or -60 mm (Fig. 1), then droplet energy altered pores with diameters between 0.75 and 1.5 mm in the subsurface, as well as the surface (Table 1). Soil structural breakdown as a consequence of sprinkler droplet impact energy may have led, in turn, to soil being deposited in these pores. Also, pores < 1.5 mm may have collapsed due to soil reconsolidation from droplet energy.

Droplet energy fractured aggregates at the soil surface. As we conducted the field experiment, we clearly observed that eliminating droplet energy kept soil surfaces rougher with fewer aggregate fragments and primary particles being deposited in surface

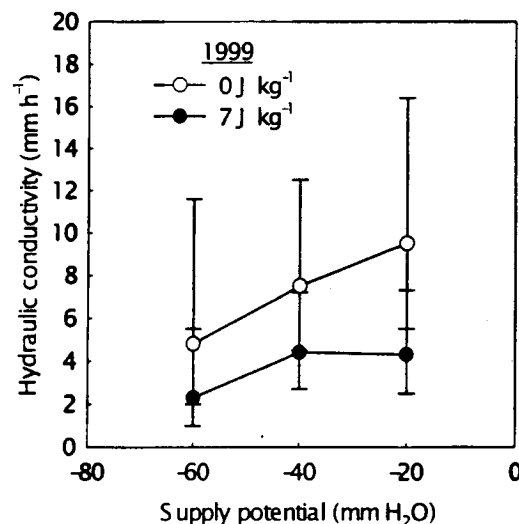


Figure 1 - Droplet energy effects on hydraulic conductivity measured at three water supply potentials in 1999. Each mean is shown with upper and lower 95% confidence limits.

depressions on the plots. On plots irrigated with water having droplet energy of 7 J kg^{-1} , water infiltrating through the soil surface likely transported aggregate fragments and/or sand into surface pores, reducing infiltration (Table 1). Droplet energy most affected pores with diameters between 0.75 and 1.5 mm, particularly those pores at the soil surface.

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