REDUCING RUNOFF LOSSES OR IRRIGATION WATER BY IMPROVING CULTURAL PRACTICES

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Abstract

Wetting agents are mainly used to manage water repellency in soils but they do provide other benefits like increase in water retention and reduction in physiological moisture stress in plants. Experiments were conducted at the California State Polytechnic University, Pomona on a loamy sand soil situated on an 8% slope with an established turfgrass maintained under golf course fairway management conditions. The effect of cultural practices like core aerification followed by sand topdressing and application of a wetting agent in reducing runoff of irrigation water was evaluated. Runoff events after the cultural practices and the wetting agent treatment (Dispatch applied at 877 ml/ha) was repeated four times over a time period when the matric potential ranged from 15–40 kPa. An empirical formula based on Horton's equation was used to predict maximum runtime of sprinklers to prevent runoff from turf on slopes. Total irrigation runoff was calculated based on overspray, surface runoff and percolation or seepage over a specified period of time. When Dispatch was added to the irrigation water vertical movement of water was more pronounced than the control (water alone). The least runoff occurred when the soil had the highest matric potential. Dispatch treatments resulted in 43% and 55% higher total wetting surface area at 30 minutes and 60 minutes respectively compared to the water alone treatment. Cultural practices like core aerification, topdressing with sand and using a wetting agent reduced

the volume of surface runoff by increasing the infiltration rate and the time period when visible surface runoff was first observed since the start of the irrigation event.

Key words: infiltration, runoff, wetting agent, aerification, topdressing

Introduction

The rate at which a particular soil can absorb water is called the infiltration rate (IR). The infiltration rate depends on the soil texture, organic matter content, soil moisture content, compaction and other cultural practices which can affect soil physical properties. The rate at which an over-head sprinkler system applies water is called the precipitation rate (PR) of the sprinkler. The PR is calculated based on the total volume of water applied over a period of time at a specified pressure using a particular type of nozzle. If the PR is more than the IR for a particular soil some of the applied irrigation water will collect on the surface creating a potential for runoff. Runoff of irrigation water is not only a wastage of water but also leads to soil erosion and is a source of pollution since it can carry excess fertilizer, pesticides and other contaminants. Since runoff is closely related to IR several researchers have developed mathematical models to predict the infiltration capacity into the soil as a function of time. The most popular equation was developed by Horton (HORTON, 1939) which can be used to predict cumulative infiltration:

$$f_p(t) = f_c + (f_o - f_c)e^{-kt} \tag{1}$$

where, f_p (t) is infiltration rate in a given time (t), f_c is final equilibrium infiltration rate, f_0 = initial infiltration rate at time t = 0, t is elapsed time, and k is decay coefficient.

Horton's equation assumes an infinite water supply rate at the surface, that is, it assumes saturated conditions at the soil surface. Hence the cumulative infiltration that would occur under conditions of unlimited water supply at the surface could be predicted using a modified form of Horton's equation (HORTON, 1940):

$$F(t) = f_c t + \frac{f_o - f_c}{k}(1 - e^{-kt}) \quad (2)$$

where, $F(t)$ is the cumulative infiltration over time (t) since the start of infiltration. The actual infiltration rate is less than water supply rate when the sprinklers are turned on and the actual infiltration rate does not decay as predicted by Horton's equation. This is because Horton's equation assumes that the supply rate exceeds the infiltration rate from the start of infiltration. Therefore, in order to determine the true infiltration rate at a given time we need to solve the following equation to first determine the time t_p, the time at which water is starting to accumulate at the soil surface - (ponding time) and then evaluate $f_p(t_p)$;

$$F(t) = \int_0^t i(t)dt = f_c t_p + \frac{f_o - f_c}{k}(1 - e^{-kt_p}) \quad (3)$$

where, $F(t)$ is the cumulative infiltration over time (t) since the start of infiltration and $i(t)$ is the infiltration rate. Equation 3 represents the accumulated volume of actually infiltrated water; up to time t_p (ponding time) if the actual rate of infiltration had been equal to the infiltration capacity.

These equations were modified by researchers to develop a practical equation based on a series of maximum sprinkler irrigation runtime curves for different sprinkler precipitation rates vs. soil types to maximize the sprinkler application efficiency and conserve water (HUNG & KRINIK, 1995). However, it is necessary to develop different infiltration capacity data for various types of soil so that the equation can be applied in the field. The United States Department of Agriculture-National Resource Conservation Service (USDA-NRCS) published a series of infiltration data for several soil families (CUENCA, 1989). An equation for determining the maximum sprinkler irrigation runtime in order to reduce runoff was developed by HUNG & KRINIK (1995). The following equation can be used to calculate maximum irrigation runtime:

$$t_{max} = \frac{\{f_o - P + f_c [\ln (f_o - f_c)/(P - f_c)]\}}{Pb} \qquad (4)$$

where, t_{max} is maximum irrigation runtime without runoff (hours), P is average sprinkler precipitation rate, b is Horton's constant, f_o is initial infiltration rate at time $t = 0$, and f_c is final equilibrium infiltration rate. In equation 4, the Horton constant b can be obtained by solving Horton's equation using the infiltration rate curves for the particular soil textural class. The infiltration data obtained from the USDA-NRCS were based on 50% available soil water depletion which has been used in irrigation applications in the United States for almost a century. The relationship between infiltration rate and elapsed time in different soils has been reported by researchers (KOSTIAKOV, 1932; KUTILEK & NIELSEN, 1994.

Wetting agents can wet hydrophobic surfaces and help carry or keep water available for turfgrass (RUITER, 2005). Furthermore, wetting agents reduce the surface tension of water and increase infiltration and percolation rates of root zones, which helps water to penetrate into soil and decreases moisture stress on turfgrasses (LEINAUER, 2002). Moreover, soil wetting agents are considered as a tool in turf management to improve irrigation efficiency and water conservation (KOSTKA et al., 2000). The objective of this research was to evaluate the effect of a wetting agent application on the wetting pattern, infiltration rate and runoff of irrigation water.

Materials and methods

Runoff collection

Experiments were conducted at the California State Polytechnic University, Pomona on a loamy sand soil with established hybrid bermudagrass (GN-1) turf maintained under fairway management conditions. The plot size was 0.03 hectare situated on an 8% slope. Runoff experiments were conducted over a matric potential range of 15–40 kPa in the soil to study the relationship between irrigation water runoff and matric potential. Based on the runoff experiment a matric potential range of 15–25 kPa was selected to further investigate the effect of the various treatments in reducing irrigation runoff. The treatments (cultural practice of aerification followed by topdressing with sand and the use of a wetting agent) were designed in a randomized block design with four replicates which were repeated over time under similar soil moisture conditions (15–25 kPa). Soil moisture sensors (Watermark, Irrometer Co, Riverside, CA, U.S.A.) were buried in the soil at 10 and 20 cm from the soil surface. The sensors measured the matric potential every 5 minutes before and after the irrigation event till 24 hrs after each irrigation event. The maximum irrigation runtime was calculated using the modified Horton's equation (equation 4, HUNG & KRINK, 1995). Extended irrigation runtimes were calculated to create runoff. Total runoff was monitored through surface runoff and subsurface seepage. The sum of surface runoff and surface flow or seepage of water till 1 h after the start of the irrigation event was reported as total runoff. Surface runoff was measured by installing rain gutters which drained into a collection pit with a tipping bucket. The subsurface seepage was monitored through a collection bucket placed at the bottom of the collection pit. Horton's constant for loamy sand soil was used to calculate the maximum runtime for sprinklers based on their precipitation rate (PR).

Cultural practice

Cultural practices like core aerification and top dressing with sand were done before and after a set of runoff experiments. Core aerification is a process of removing soil cores from the soil to reduce compaction due to traffic on an established turfgrass surface in golf courses, sports fields and landscapes to increase air and water movement in the soil profile. Aerification can be done with a solid tine when the soil cores are not removed from the soil or by using hollow tines where the soil cores are removed after the operation. The pore spaces created by the solid tine after aerification can be filled in with sand to increase the porosity of the soil. Core aerification was done with a 10 cm hollow tine using a walk behind aerifier (John Deere Co, Moline, Illinois, U.S.A.). The cores were picked up with a turf-vac and the turf was top dressed with sand.

Wetting agent application

A wetting agent (Dispatch applied at 877 ml/ha) was applied to the plots before each of the four irrigation events. The cultural practice of aerification followed by topdressing with sand and the incorporation of a wetting agent were two treatments in the experimental design which were repeated four times over a time period when the matric potential was 15-25 kPa. Runoff was monitored after each treatment for all the four repeated irrigation events at the same site.

Distribution uniformity (DU)

Fourty nine plastic cone shaped cans were placed on the plots in a grid pattern. Ring can-holders were used to place catch cans in upright position to avoid any can movement. The four cans in the corner of the plot were placed 1 m away from the sprinkler heads, while the others were placed approximately 2 m apart in a uniform grid pattern throughout the plots. All the cans had a diameter of 11.5 cm, and a height of 15 cm. The sprinklers were run for a total of 10 minutes for each plot, and the collected water in each catch can was recorded in milliliter (ml). Distribution uniformity (DU) was calculated based on the low quartile distribution uniformity (LQDU). The collected water reading in catch-cans was re-ordered from low to high. The lowest 25 percent of catch-can readings were averaged, and divided by the average of the overall can reading, and expressed in percentage.

Percent of LQDU = Average catch in the low quartile x 100/Average catch overall (8)

Infiltration rate

The infiltration rate in the experimental area was measured with a double ring infiltrometer (Turf-Tec International, Coral Springs, Florida, U.S.A.) at specified matric potential of 15–40 kPa. Raw data of soil infiltration rates in a loamy sand soil was obtained from the USDA-NRCS and was compared to the infiltration tests in the experimental sites. The change in infiltration rate over a matric potential range of 15-25 kPa was plotted against the elapsed time (Fig. 1).

Wetting area

Experiments were conducted to study the wetting pattern of water with and without an added wetting agent in a plexiglass soil bin using the same soil as the field runoff experiment. The soil was loamy sand with a pH of 6.6, electrical conductivity (EC) of 1.8 dS/m and an organic matter content of 0.13%. Dispatch was added to the irrigation water at a rate of 877 ml/ha. Separate experiments were conducted using two drip emitters, one rated as 3.8 l/h and another at 1.9 l/h. The experiments were repeated four times. Actual flow rates were within 5% of the rated flow rates at the operation pressure (210 kPa). A micro tube of 45 cm length was attached to each emitter to facilitate the location of the emission point in the soil bin. The system was run for 30 minutes. A dye was not used in the experiment since the dry soil and the wet soil had contrasting colors which could be easily seen through the plexiglass. Lines were drawn with a marker on the plexiglass to indicate the wetting pattern. Wetted areas measurements were taken at 15 and 30 minutes. The 60 minute measurement was taken 30 minutes after the end of the run time (a total of 60 minutes from the beginning of the run time). Approximately 180 minutes after the beginning of the run time a cross section was made in the soil directly under the location of the emission point and perpendicular to the plexiglass in the front of the bin. The wetted areas were given in cm^2 and were calculated based on the shape of the wetted area or were measured with a planimeter.

Statistical analysis

The data was subjected to analysis of variance (ANOVA) program of SAS (SAS, 1988). Regression models were used to study the relationship for continuous variables while mean separation techniques like protected least significant difference (LSD) test and Duncan New Multiple Range Test (DNMRT) ($p = 0.05$) were used to separate the means of discontinuous variables. Data for treatments and interactions that were not significant at the $p = 0.05$ level were pooled to conduct an overall ANOVA analysis. The interactions that were significant were split and analyzed further using the proc glm program of SAS (SAS, 1988).

Results and discussion

Distribution uniformity (DU)

The low quartile distribution uniformity (LQDU) ranged from 56% to 68% and the precipitation rate (PR) varied from 2 cm/h to 3 cm/h depending upon the wind direction and velocity during the runoff experiments. The mean matric potential between the different moisture sensors ranged from 15–40 kPa. Least surface runoff occurred when the soil had the highest matric potential (Fig. 2). The wind direction and speed also influenced surface runoff; hence experiments were conducted at similar wind speeds. Wind speeds ranged form 4 to 6 km/h during the runoff experiments.

Infiltration rate

The infiltration rate in a loamy sand soil was calculated based on raw data obtained from USDA-NRCS and then compared to the infiltration tests using a double ring infiltrometer. Cumulative infiltration for the particular soil texture was obtained by the integration of the equation (3) for a total elapsed time of 400 min. The infiltration rate for a loamy sand soil was plotted in a graph against the elapsed time when the matric potential was 15-25 kPa (Fig 1). The infiltration rate in the loamy sand soil increased when a wetting agent (Dispatch) was applied on the turfgrass before the runoff event compared to the untreated control plots. Highest infiltration rate was observed after the core aerification and topdressing program (Fig 3).

Runoff

A normal runtime for the loamy sand soil for a 15 cm root zone was 25 minutes to bring the root zone from 50% depletion to field capacity. A runtime of 60 minutes was used to ensure that runoff was observed for the study; however the runtime had to be reduced to 40 minutes for several of the tests because the volume of runoff exceeded the runoff collection device capacity. The time from the beginning of the irrigation to the time for surface water to be visible was recorded to compare with the T_{max} as determined by equation 4. HUNG & KRINIK (1995) had reported a maximum runtime approximately of 100 minutes using a Horton constant of 2.48 for a loamy sand soil on 6–8% slope (Table 1). The results from our infiltration tests using a double ring infiltrometer on the experimental area was used to calculate Horton's constant (Fig. 1). Horton's constant was found to be 5.89 in the loamy sand soil with an 8% slope. Modifying equation (4) with this Horton's constant resulted in a maximum irrigation runtime for loamy sand soil as 42 minutes. The actual times for surface water to be visible ranged from 15 to 29 minutes with a mean of 20 minutes in the untreated plots.

On an average overall the wetting agent treated plots did not have any appreciable runoff till 45 minutes of irrigation runtime while it took 60 minutes since initiating the irrigation event to observe any surface runoff after the aerficiation and topdressing with sand treatment was performed. The application of a wetting agent significantly reduced surface runoff of irrigation water compared to the untreated check. The aerification followed by topdressing treatment resulted in the least surface runoff between all the treatments but the seepage losses were higher than the wetting agent treatments. Hence there was no statistical difference in the volume of total runoff between the wetting agent and aerification treatment (Fig. 4). The aerification program significantly reduced total runoff compared to the untreated control. The initial soil moisture levels affect the infiltration rate in soils and hence soil moisture would influence the length of time when first surface runoff would be observed (Fig. 2). These results from this research study would suggest that the Horton's equation over estimates the time before runoff would begin.

Wetting area

Addition of a wetting agent (Dispatch) to water increased the vertical movement of water compared to the water alone treatment in a loamy sand soil. The wetted soil surface area was determined by the contrast in color between dry soil and wet soil. The wetted soil area in the horizontal direction between the wetting agent treatment and water was not significantly different (Table 2). Dispatch treatments resulted in 43% and 55% higher total wetted surface area at 30 minutes and 60 minutes respectively compared to the water alone treatment (Table 2). Incorporation of the wetting agent with water increased the vertical movement of water in the soil profile and the difference in wetted vertical soil surface between the wetting agent and the water alone treatment was more pronounced under unsaturated condition when the soil was dry. This difference during unsaturated condition may be pronounced since the moisture in soils is held at a higher tension or matric potential in a dry soil and the wetting agent may help in reducing the matric potential. Hence the addition of a wetting agent may facilitate movement of water in the vertical direction and increase the retention capacity of soil.

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Table 1. Horton's constant (b) for the different soil textural classes (HUNG & KRINIK,1995).

Soil Textural class	Horton's Constant
Sandy	2.76
Loamy sand	2.48
Loam	2.57
Clay loam	2.60
Clay	2.81

Table 2. Mean wetting pattern of water with and without an added wetting agent (Dispatch 877 ml/ha) in a loamy sand soil using a 1.9 l/hr emitter.

Treatment	Horizontal surface area (cm^2)			Vertical surface area (cm^2)			Total surface area (cm^2)			Vertical cross section area (cm^2)
Minutes	15	30	60	15	30	60	15	30	60	180
Water alone	283	374	503	0	13	26	283	387	529	147
Water + wetting agent	302	412	555	45	142	264	347	554	819	287
LSD (p = 0.05)	22.6	34.8	29.0	16.5	55	67.4	55.8	66.8	75.8	80.6

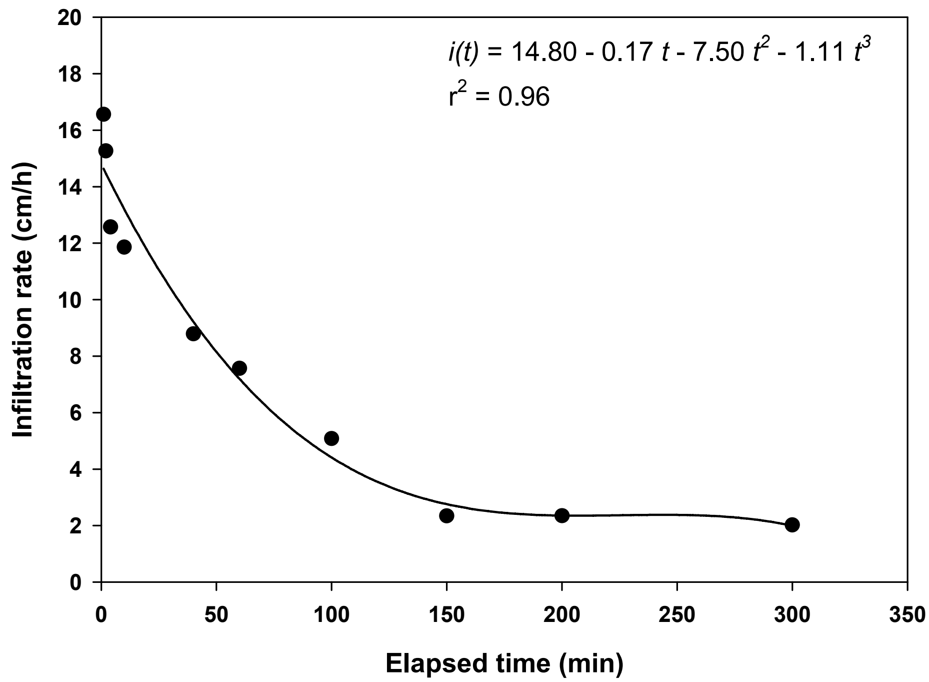

Fig. 1. Infiltration rate [$i(t)$] (cm/h) in a loamy sand soil as observed over a period of time since the start of infiltration (t). The matric potential was 15-25 kPa during the infiltration experiment.

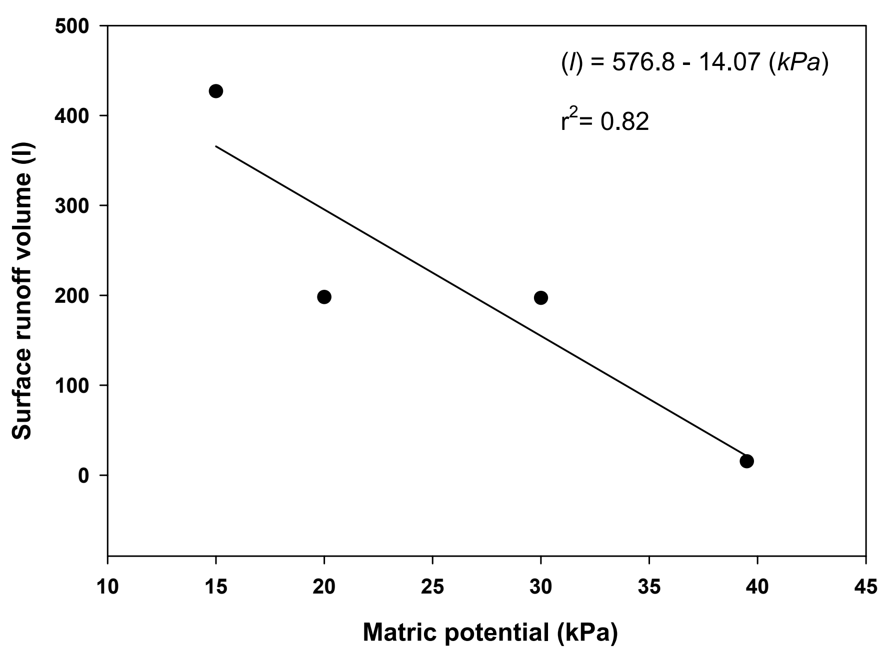

Fig. 2. Effect of matric potential on surface runoff (l) of irrigation water from a bermudagrass turf surface maintained under normal fairway management conditions on a loamy sand soil. Matric potential range was 15-40 kPa.

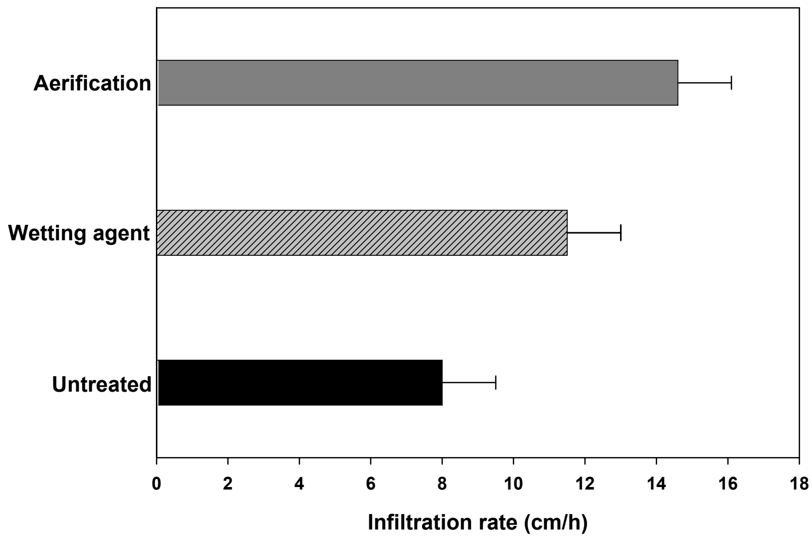

Fig. 3. Mean infiltration rate in a loamy sand soil on an 8% slope with an established turf stand as affected by cultural practices like core aerification and topdressing with sand or application of a wetting agent (Dispatch applied at 877 ml/ha) every time before the four repeated irrigation events. The matric potential in soil was 15-25 kPa during the infiltration experiment. The error bars indicate the standard deviation.

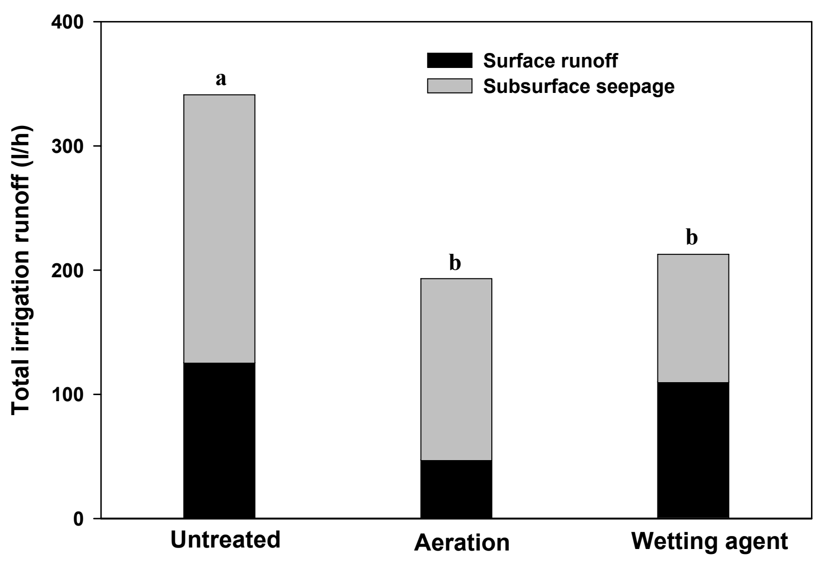

Fig. 4. Mean irrigation runoff volume collected as surface runoff and subsurface seepage into the collection pit. The aeration and topdressing was done a week prior to the runoff event. The wetting agent (Dispatch) was applied at 877 ml/ha rate 7 days before the each of the four runoff events The means were separated with Duncan's New Multiple Range Test (DNMRT) at p = 0.05 level. Bars with the same letter were not statistically different.