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SOIL AIR PRESSURE UNDER SUCCESSIVE BORDER IRRIGATIONS AND SIMULATED RAIN[1]

D. R. LINDEN, R. M. DIXON, AND J. C. GUITJENS

Agricultural Research Service, USDA, St. Paul, Minnesota, Agricultural Research Service, USDA, Tuscon, Arizona, and Department of Irrigation Engineering, University of Nevada, Reno, Nevada

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ABSTRACT

Soil air pressure and surface water head were measured at a single field site during eight irrigations of alfalfa during the 1972 growing season. Soil air pressure h_a and surface water head h_w are presented as functions of elapsed irrigation time to illustrate the short-term and seasonal variation of these parameters. It is shown that h_a varies directly with h_w, and that the head imbalance $h_a - h_w$ increased at a decreasing rate during each irrigation, until it reached a plateau ranging between 4 and 7 cm, and, thereafter, it remained nearly constant until headgate closure. Small differences in $h_a - h_w$ between irrigations may have had a significant effect on infiltration because total field application decreased as $h_a - h_w$ increased. Soil air pressure increased under simulated rain when ponding began where airflow was restricted by an impermeable barrier at a 20-cm depth. This air pressure increase had little apparent effect on infiltration. Soil air pressure created and maintained from the onset of infiltration reduced infiltration by about 20 percent.

INTRODUCTION

Soil air pressures (>1 atm) have been shown to reduce infiltration during flooded border irrigations on soils with shallow water tables (Dixon and Linden, 1972; Linden and Dixon, 1973). Air pressures at any point were reported to increase as flooding began, and to rise at a decreasing rate until headgate closure. Air pressures at any instant of time were maximum near the central upslope end of the border strip, and decreased in the direction of the advancing surface water front and the unwetted border edge (Dixon and Linden, 1972). Infiltration was reduced by about a third at central upslope locations (Dixon and Linden, 1972; Linden and Dixon, 1973). Soil air pressure differences at the onset of infiltration and during the first 10 min of simulated border irrigation were shown to greatly influence infiltration (Linden and Dixon, 1973). Constant air pressure reduced infiltration below the zero pressure control, whereas slow pressure increases had little effect (Linden and Dixon, 1973). Relatively high initial air pressures apparently disrupt the water phase continuity within the macroporosity; i.e., the macropores become or remain air-logged. Subsequent surface water heads are insufficient to purge air from the macropores to establish water phase continuity. Seasonal changes in air permeability, air volume, temperature, infiltration, and other variables would be expected to produce soil air pressure differences (Free and Palmer, 1940; McWhorter, 1971; Peck, 1965; Wilson and Luthin, 1963). This manuscript describes a season-long study to measure the net effect of these variables on soil air pressure and infiltration. Soil air pressures, surface water heads, and irrigation amounts were measured during border irrigation. Infiltration was also measured with a sprinkling infiltrometer under different early air-pressure treatments.

MATERIALS AND METHODS

Soil air pressure h_a and surface water head h_w were continuously recorded at a site 50 m downslope from the head ditch and midway between two adjacent border dikes (with a 65-m spacing) during eight irrigations in 1972. This site is in the same border check where previous

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spatial and single irrigation time variations of soil air pressure were observed earlier (Dixon and Linden, 1972). Soil air pressure head h_a (in excess of atmospheric) was measured with a bellows-type pressure recorder connected to a 2.5-cm-diameter, 2-m-long, perforated access tube (Dixon and Linden, 1972; Linden and Dixon, 1973). The surface water head h_w (depth of ponded water) was measured with a bellows-type pressure recorder connected to a bubbling tube submerged in a 3-cm-deep container of water set in the soil with the container lip flush with the soil surface. Irrigation amounts were determined with a totalizing meter at the upper end of the head ditch.

Soil air pressure and infiltration were measured under three test conditions using a sprinkling infiltrometer on an East Fork loam soil. A modified, Purdue-type infiltrometer with a 1-m-square frame and a vacuum runoff accumulation system was used (Dixon and Peterson, 1968). Air pressures were measured with a 1-cm-diameter, perforated access tube connected to a bellows-type recorder. Duplicate infiltration runs were conducted for each of the three conditions. First, soil air downflow was prevented by placing a steel barrier at a 20-cm depth along the bottom of the infiltration frame. The infiltration frame was driven 20 cm into the soil, a pit was dug next to one side of the frame, and a steel plate was hydraulically forced into the soil along the bottom of the frame. The plate was then sealed to the frame with silicone rubber. The second treatment was to pump air into the soil without a bottom barrier, and thereby control the pressure (Linden and Dixon, 1973) at a constant level equal to the soil air pressure as measured in the bottom barrier treatment near the end of the 30-min infiltration period. The principal differnece between this treatment and the first was that the soil air pressure was imposed before water began infiltrating and then was maintained at a constant level throughout the infiltration run. In the third treatment (control), air was neither pumped into nor trapped within the soil.

RESULTS AND DISCUSSION

Soil air pressure h_a, surface water head h_w, and the head imbalance, $h_a - h_w$, for the first 5 hr of eight successive irrigations in 1972 are shown in Fig. 1, wherein at zero time the surface water front reached the sensors. For each of the first three irrigations, h_w was very similar with a maximum at about 18 cm, whereas maximum h_w for the remaining five irrigations was about 9 cm. Soil air pressure varies directly with h_w, and exceeds it by similar amounts whether the maximum h_w was 18 cm (first three irrigations) or 9 cm (last five irrigations). The importance of the imbalance between the two counterbalancing heads, h_a and h_w, was discussed earlier (Dixon and Linden, 1972; Linden and Dixon, 1973). The imbalance, $h_a - h_w$, may also be identified with the effective bubbling pressure h_b (Dixon and Linden, 1972), whereas the negative of this imbalance $[-(h_a - h_w)]$ may be identified with the effective surface head (Dixon, 1975).

Some consistent patterns and minor variations of this imbalance ($h_a - h_w$) can be seen in Fig. 1. Shortly before the surface water reached the sensing point in the field, soil air pressure started to increase, and, thus, the condition $h_a > h_w$ prevailed at the onset of infiltration. Relative rates of increase of h_a and h_w varied from irrigation to irrigation, so that $h_a - h_w$ also varied. At 10 min of elapsed time, $h_a - h_w$ varied between 0.4 cm for the first irrigation and 4.7 cm for the sixth. At larger elapsed irrigation times, when h_a and h_w were approaching plateau values, the differences between irrigations of $h_a - h_w$ became less. The difference between the 0 to 180-min average h_a and h_w varied between 3.6 cm for the first irrigation and 6.4 cm for the sixth.

Soil air pressure measurements may be interpreted by the ideal gas law (Dixon and Linden, 1972). Solving the gas law for the pressure increase in a closed system due to a change in volume and temperature results in $h_a = P_a \{[(T_2/T_1) V_1 - V_1]/V_2\}$ wherein h_a is $P_2 - P_a$, P_a is prevailing atmospheric pressure and the initial pressure within the soil, V is soil air volume, T is the temperature, and subscripts 1 and 2 denote initial and final conditions, respectively. This equation can be adapted to a leaky soil system by correcting V_1 for the soil air volume V_v that is vented laterally beneath the wetting front and vertically through the soil surface, and by replacing V_2 with V_1 minus the infiltration volume i_v (Dixon and Linden, 1972). The pressure increase equation then becomes $h_a = P_a \{[(T_2/T_1) V_1 + i_v - V_v]/(V_1 - i_v)\}$. Atmospheric pressure, temperature, initial air

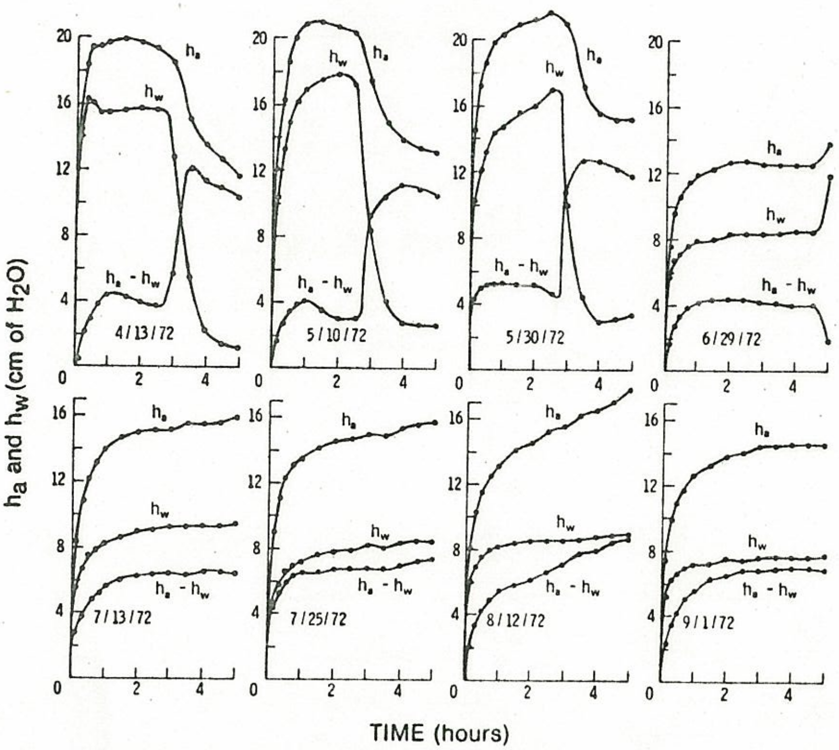

FIG. 1. Surface water head, h_w, and soil air pressure, h_a, as a function of time for eight irrigations of the 1972 season. Zero time is the time surface water reached the sensors.

volume, infiltration, and air venting will all affect soil air pressure.

Initial atmospheric pressure varied as much as 15 cm throughout the season, and would, thus, affect h_a by about 0.1 cm over the season. Atmospheric pressure also varied from 1 to 2 cm during the irrigations, which could account for some of the short-term variability in the h_a data that are independent of h_w as shown in Fig. 1. Small variations in T_2/T_1, V_1, and V_v would cause much larger effects on h_a, if isolated and studied independently. In this dynamically balanced, multivariable system, the effect of any variable on h_a is somewhat modified by the change in other variables. For example, during an early spring irrigation, soil air temperature increased as warm irrigation water entered a cool soil, thus causing an air pressure increase due to temperature. During a subsequent midsummer irrigation, water cooled the soil, thus producing the opposite effects on the soil air pressure. Yet, these opposite effects produced little difference in h_a, because the lateral and vertical venting of soil air probably tended to be more during the spring irrigation and less during the midsummer irrigation to offset the effects of temperature. Air venting may be viewed as a relief of excess pressure in this dynamically balanced system.

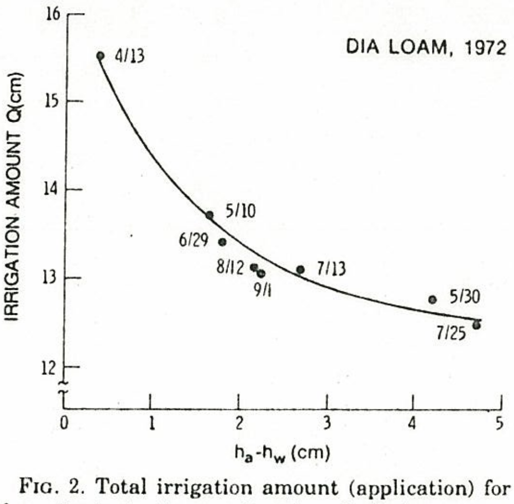

FIG. 2. Total irrigation amount (application) for the entire irrigation as a function of soil air pressure minus surface water head ($h_a - h_w$) at 10 min of elapsed irrigation time.

The venting rates are a function of lateral and vertical air permeability, and will, thus, be affected by soil water content and porosity. Porosity of the surface soil layer was decreased somewhat during each harvest by tractor and trailer traffic, and, thus, could have had some effect on soil air pressures. The alfalfa forage crop was harvested on June 23 and August 1.

The value of $h_a - h_w$ at 10 min elapsed time for irrigations on April 13, June 29, and August 12 were 0.4, 1.8, and 2.1 cm, respectively. These are the season's first irrigation and the first irrigation after each harvest. The $h_a - h_w$ imbalance tends to increase after each harvest; because the variables were not isolated, and surface porosities were not measured, however, all such conclusions are tentative. Initial air volumes varied somewhat during the season; however, because of the narrow range encountered, and because it was not an isolated variable, no conclusions can be drawn.

Soil air pressure and the head imbalance under border irrigation varied little during the season and were, thus, primarily determined by the soil and the existing border irrigation practice. Combined variations in depth of ponded water, initial moisture content, surface water advance rate, barometric pressure, and temperature resulted in little change in the imbalance; each of these variables could have a marked effect, however, if isolated and measured independently. Although the differences between irrigations found under field conditions were small, they would be expected to have some effect on infiltration, because infiltration rates are very sensitive to small soil air pressure changes near zero imbalance between the surface water head and soil air pressure (Dixon, 1975). One indication of this effect is shown in Fig. 2 wherein the total volume of water applied to the field is plotted against $h_a - h_w$ at the 10-min elapsed irrigation time. These data are not conclusive evidence of a cause-and-effect relationship, because total application is a measure of area-wide infiltration, rather than point infiltration. However, if soil air pressure differences between irrigations caused infiltration effects that are consistent over a major portion of the field, total infiltration (application) will decrease as $h_a - h_w$ increases between irrigations. Stated inversely, as $h_a - h_w$ increases between irrigations, causing infiltration rates to decrease, decreasing amounts of water would be required to irrigate the field. The irrigation water requirement (application) on July 25 was 20 percent less than the first irrigation of the season with $h_a - h_w$ (at 10 min) about 4 cm greater than the first irrigation.

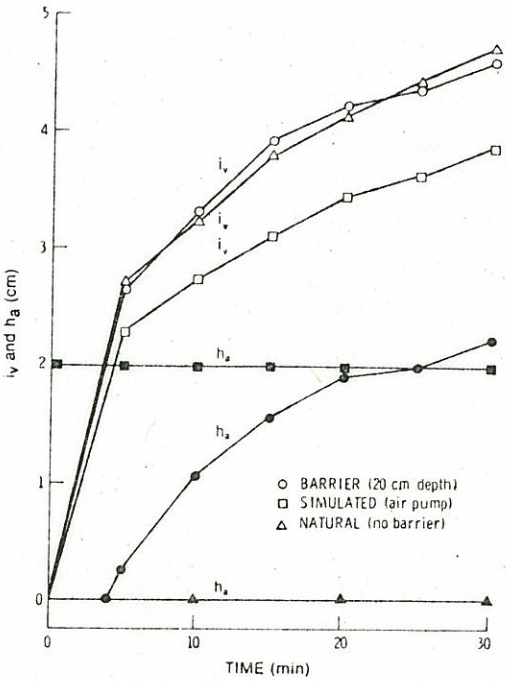

FIG. 3. Infiltration volume, i_v, and soil air pressure, h_a, as functions of time under simulated rain for various air pressure treatments.

Further evidence of the importance of small soil air pressure, especially at the beginning of infiltration, is shown in Fig. 3, wherein accumulative infiltration volume, measured with a sprinkling infiltrometer, and corresponding soil air pressures are plotted as a function of time for three air pressure treatments. Infiltration is reduced below the zero soil air pressure control only under the artificial condition of continuous soil air pressure. Soil air pressure increased in the shallow barrier condition as ponding began, but it had no measurable effect on infiltration.

Small soil air pressures (less than 30 cm) and even smaller $h_a - h_w$ imbalances (less than 7 cm) have been shown to influence infiltration (Dixon, 1975). The magnitude of these imbalances in natural-structured soils under border irrigation never exceeded 7 cm, and under simulated rain it was even less. These imbalances have largely been ignored in infiltration theory and would certainly not be reflected in the data from common infiltrometer equipment. They have been shown to be important to a flooded-border irrigation system, but their importance to other infiltrating systems, such as natural rainfall systems, will require further study.

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