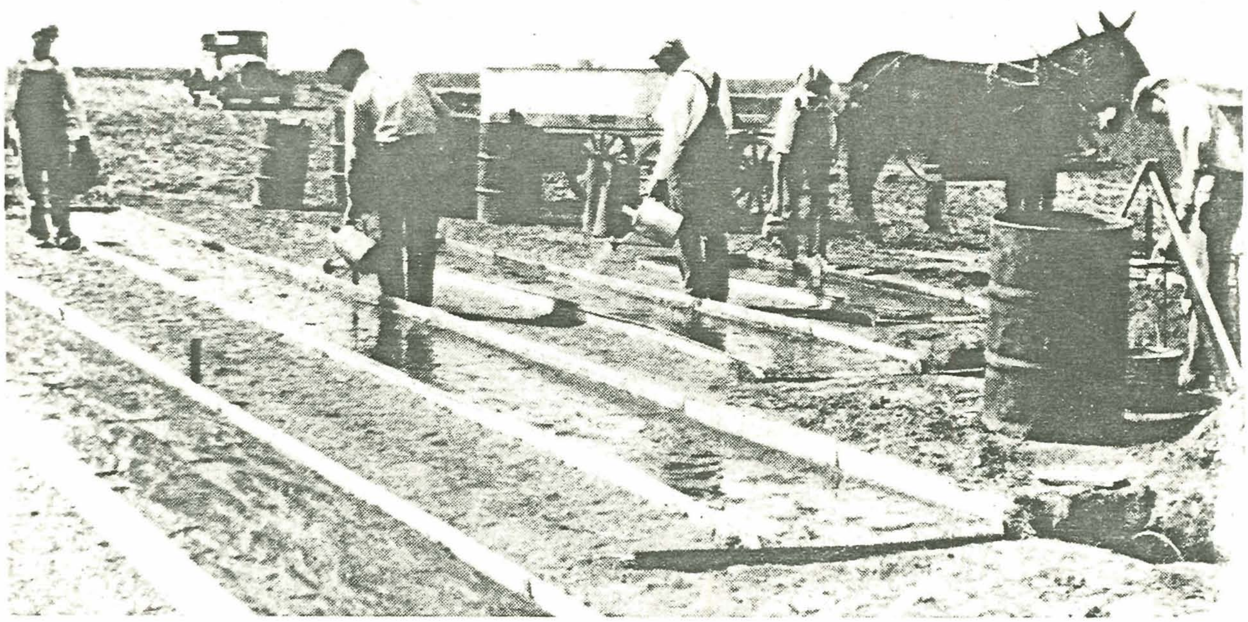
Proceedings of the Rainfall Simulator Workshop

Tucson, Arizona
March 7-9, 1979



U.S. Department of Agriculture
Science and Education Administration
Agricultural Reviews and Manuals • ARM-W-10/July 1979

Proceedings of the
Rainfall Simulator Workshop
Tucson, Arizona
March 7-9, 1979

C. R. Amerman
W. H. Blackburn
J. C. Brown
G. D. Bubenzer
R. M. Dixon
F. P. Eppert
G. R. Foster
G. F. Gifford
P. D. Green
W. R. Hamon
R. H. Hawkins
C. W. Johnson
R. S. Johnston
J. M. Laflen
L. J. Lane
D. K. McCool
K. C. McGregor
M. Martinez
L. D. Meyer
W. C. Moldenhauer
M. Molnau
C. K. Mutchler
E. L. Neff
J. B. Pate
K. G. Renard
A. R. Robinson
M. J. M. Romkens
R. E. Smith
E. Sundberg
N. P. Swanson
R. A. Young

U.S. Department of Agriculture
Science and Education Administration
Agricultural Reviews and Manuals • ARM-W-10/July 1979

RAINFALL SIMULATION AS A RESEARCH TOOL IN INFILTRATION

C. R. Amerman, SEA Research Hydraulic Engineer[1]

INTRODUCTION

The classical concept of infiltration in the hydrologic context is that of the passage of precipitation across the interface between atmosphere and soil. The underlying soil receiving infiltrated water profoundly affects the infiltration process, and most modern work embodies a broadened concept of water moving into and through soil.

Under the latter concept, the hydraulics of infiltration are based on Darcy's law which states that the velocity of water moving in porous media is proportional to the negative of the hydraulic head gradient. In non-saline soils, the effective components of hydraulic head are the pressure head of the soil water and the gravity head due to elevation. Pressure head in unsaturated soil is negative in sign, is a function of water content, and may range over several orders of magnitude as the soil wets or drys.

Hydraulic conductivity is the proportionality coefficient for Darcy's law. It, too, is a function of soil water content and typically varies over several orders of magnitude, being for a given soil, greatest at saturation.

When rainfall begins on a relatively dry soil, a steep hydraulic head gradient is established immediately beneath the soil surface. This leads to an initial hydraulic gradient approaching infinity so that during the early part of a rainfall period, infiltration rate is equal to rainfall intensity - is precipitation controlled. If rain continues to occur at an intensity at least higher than saturated hydraulic conductivity for a long period of time, near-surface hydraulic gradients decrease as the "wetting front" moves deeper and ponding occurs at the soil surface; infiltration from that time is controlled by subsurface hydraulic properties and gradients. During the post-ponding period, the near-surface hydraulic gradient continues to decrease (tends toward unity as soil water content, hence, soil water pressure head, tends towards constancy with depth) and does so more rapidly than hydraulic conductivity increases, with the overall result that infiltration rate decreases with time.

Numerous investigators have attempted to model both the time to ponding and the shape of the post-ponding decay curve. Brakensiek (1979) at a SEA-AR infiltration workshop presented a brief summary of approaches and discussed a few models. With his permission, I have appended his list of references as a fairly comprehensive guide to infiltration model development over the years.

---

[1]USDA, Science and Education Administration, Columbia, MO 65201, in cooperation with the Missouri Agricultural Experiment Station, Columbia, MO

RAINFALL SIMULATION AND INFILTRATION

Rainfall-simulating or sprinkling infiltrometers are often used to obtain representative infiltration curves for various combinations of land surface treatments and soil types.

Sprinkling infiltrometers may also be used to determine the values of parameters used by some infiltration equations. Brakensiek et al. (1977) illustrate the use of an infiltrometer (Hamon, 1979) in obtaining three parameters for the Green and Ampt infiltration equation. Smith and Parlange (1978) present a new two-parameter infiltration equation and indicate how its parameters may be obtained through infiltrometer tests. These are just two of the many examples that could be given.

What are the important points in rainfall simulation in the context of infiltration? Judging from the number of different types of simulators available, and from the fact that ponded water infiltrometers also continue in use, one may conclude that this is a question without a universally accepted answer.

This is probably because, the existence of several fairly successful infiltration models notwithstanding, some details of the infiltration mechanism are poorly understood. For example, there is no way in present models to account for differences in surface condition, except to assume the presence of a thin surface layer of material having a different hydraulic conductivity relation than the underlying soil. So the various investigators may have different opinions as to which precipitation characteristics are significant to infiltration.

One use of infiltrometers, as noted above, is to obtain infiltration model parameters. Unless an infiltration model can account for crusting, or unless its parameters can be conceived as "effective" parameters that reflect surface condition (i.e., an "effective" hydraulic conductivity), there seems little point in attempting to emulate much more than precipitation intensity. Jeppson (1970) constructed a theoretically well-founded infiltration model specificially for use with infiltrometers. This is essentially a state of the art (air flow not considered) model developed around current porous media flow theory and viewing infiltration as either a flux or a zero pressure head (post-ponding) boundary condition on the flow system. Application rate is the only pertinent infiltrometer parameter required by this model.

Brakensiek et al. (1977) used a highly sophisticated sprinkling infiltrometer (Hamon, 1979) to estimate the Green and Ampt equation parameters. Infiltrometer application rates and plot runoff rates were the only parameters of direct interest. The role of precipitation energy in the analyses were not clear, although the authors stressed the ability of the infiltrometer to produce 83% natural rainfall energy. On the other hand, Brakensiek and Onstad (1977) estimated the Green and Ampt parameters from flood infiltrometer data in which neither application rate nor energy plays any part at all. Unfortunately, the two infiltrometers were applied to different soils.

To obtain the Smith and Parlange (1978) equations parameters, one apparently analyzes the infiltration curve obtained by comparing application and runoff rates. Again, the role of precipitation energy is unclear.

The infiltration curve otained from sprinkling infiltrometer data reflects the combined effects of the interactions between precipitation, ground cover, and soil characteristics. Therefore, values of hydraulic conductivity and other parameters obtained from analysis of these curves must also reflect these interactions.

Without detailed knowledge of the above-mentioned interactions, authoritative discussion of precipitation simulation for infiltration studies is not possible. One may discuss extremes with reasonable certainty, but the variation in importance of such a parameter as precipitation energy from one extreme to the other is another matter.

For example, a bare soil tends to puddle and crust, so drop size distribution and velocity in both time and space are probably as important as intensity of application. As energy-dissipating cover becomes more dense, the importance of emulating precipitation energy diminishes until for such conditions as heavy mulches, dense grasses, litter-covered woodland soils, etc., intensity and duration may well be the only important precipitation characteristics.

To be on the safe side, one may simply state that the "best" sprinkling infiltrometer is the one that most nearly emulates natural precipitation - drop size, kinetic energy, average intensity or intensity pattern, duration, temperature, etc. (Incidentally, one seldom sees temperature discussed, and hydraulic conductivity is influenced by temperature. I suspect that for many field infiltrometer tests, neither water nor soil is at temperatures representative of storm conditions.) Of course, in order to be on the safe side, one runs the risk of spending more time and money than is necessary.

The preceding discussion has been slanted toward infiltration model parameter estimation, but the reasoning regarding the relation between soil and cover and which sprinkling infiltrometer characteristics are important applies equally to situations where one wants to empirically compare infiltration curves for different soil-cover-tillage and other conditions.

ON INFILTROMETER APPLICABILITY

Assuming that we have a perfect infiltrometer from the standpoint of emulating all precipitation characteristics except areal coverage, what is the meaning of the infiltration curve that we obtain? Of necessity, a sprinkling infiltrometer of any type applies water to a very small area in comparison to the size of a field or a watershed. The porous media boundary condition imposed by the sprinkling infiltrometer results in an essentially one-dimensional, vertically downward flow system. Even if there is soil layering, the negative of all gradients is essentially away from the infiltrating surface in a psuedo one-dimensional manner. Under natural storm conditions, particularly those producing amounts of water applied in many sprinkling infiltrometer tests, subsurface flow systems develop that are characterized by hydraulic gradients that are vertical at only a limited number of points. About the only exceptions to this would be very flat areas or such undeveloped profiles as are prevalent in the deep loess areas of southwest Iowa or the central sands of Wisconsin. Klute et al. (1965) illustrate the principle involved. Because infiltration rate is a function of both soil hydraulic conductivity and of soil hydraulic gradient, a sprinkling infiltrometer test must yield a measure of the maximum infiltration rates (curve) to be expected at a given point. During initial periods under actual storm conditions, the hydraulic gradients may be essentially vertical at all locations. As a storm progresses, however, the subsurface flow system develops gradients inclining from the vertical, the infiltration curve probably steepens and drops under the curve obtained with an infiltrometer. In crude "natural infiltrometer" tests on a claypan site in Missouri, I have obtained data that show that for heavy storms, some sites, generally low on a slope, produce more runoff than rainfall, i.e., the subsurface gradients are upward toward the surface. Some of these sites continue to produce runoff (seepage flow) for hours after cessation of precipitation. For the same storms, generally upslope sites produce less runoff than rainfall, and, for lesser storms, all sites infiltrate precipitation throughout the event. Sprinkling infiltrometer tests (modified Purdue type, Dixon and Peterson, 1964, 1968) on all sites produced essentially the same infiltration curves regardless of slope position.

CONCLUDING REMARKS

Rainfall simulation for infiltrometer purposes is not easily prescribed if one wishes to make the most efficient use of resources.

Considering that an infiltrometer-produced infiltration curve is probably a "maximum possible" and that topographic and soil layering effects may obviate its application (in a lumped sense) to a watershed surface, we might conclude that its main utility in comparing different soil-cover-tillage complexes is that of an index rather than that of an absolute quantity. If such be the case, then we might find it most useful to select or develop a standard infiltrometer and operational technique than to dwell on obtaining the best possible simultaneous emulation of all natural precipitation characteristics.

Infiltrometers used in estimating infiltration model parameters must be selected on the basis of the inputs needed by the models.

Infiltrometers used in investigating infiltration mechanisms should themselves be researched. An attempt should be made to assess the nature, or at least the relative importance, of precipitation characteristic-soil-cover interactions. With this type of information, we should be well equipped to design laboratory and/or field infiltrometers for the purpose of isolating the effects upon infiltration of such factors as residue incorporated in surface soil, type of tillage tools, types of vegetation, and so on.

REFERENCES

Brakensiek, D. L.
1979. In C. R. Amerman (ed.) Empirical and simplified infiltration of the Research Planning Workshop. I. State of the Art Reports. SEA-NC Series. (In Press)

Brakensiek, D. L., and C. A. Onstad.
1977. Parameter estimation of the Green and Ampt infiltration equation. Water Resources Res. 13(6):1009-1012.

Brakensiek, D. L., W. J. Rawls, and W. R. Hamon.
1979. Application of an infiltrometer system for describing infiltration into soils. Paper No. 77-2553 presented at 1977 Winter Meeting of American Society of Agricultural Engineers at Chicago, Illinois. Accepted for publication in Am. Soc. Am. Engr.

Dixon, R. M., and A. E. Peterson.
1964. Construction and operation of a modified spray infiltrometer and a flood infiltrometer. University of Wisconsin Res. Report 15. July.

Dixon, R. M., and A. E. Peterson.
1968. Vacuum system for accumulating runoff from infiltrometers. Soil Sci. Soc. Am. Proc. 32(1):123-124.

Hamon, W. R.
1979. Infiltrometer using simulated rainfall for infiltration research. In C. R. Amerman (ed.) Infiltration Research Planning Workshop. I. State of the Art Reports. SEA-NC. (In press)

Jeppson, Roland W.
1970. Transient flow of water from infiltrometers - formulation of mathematical model and preliminary numerical solutions and analyses of results. Utah Water Research Laboratory PRWG-59c-2, Utah State University, Logan. 50 p.

Klute, A., E. J. Scott, and F. D. Whisler.
1965. Steady state water flow on a saturated inclined soil slab. Water Resources Research 1(2):287-294.

Smith, R. E., and J.-Y. Parlange.
1978. A parameter-efficient hydrologic infiltration model. Water Resources Research 14(3):533-538.