# RECENT PROGRESS IN SOIL PHYSICS

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A number of general themes characterize the research in soil physics in the United States in recent years. This brief account does not attempt to describe all of them, being restricted to a few of those areas in which we at the University of Wisconsin-Madison have shared an interest with colleagues from a significant number of other research institutions. During the decades of the 1950's and 1960's there were carried out a large number of laboratory studies, particularly on water movement in unsaturated soils. With the increasing availability of high-speed digital computers many complex mathematical problems in unsaturated flow received attention. Along with an increased understanding of flow, both saturated and unsaturated, came an increased interest in and study of solute movement in soils.

Unsaturated flow of water has always been of interest in irrigated areas in the United States and in the Western regions salinity problems have engendered interest in solute movement, e.g. leaching of chlorides and sulfates. With the countrywide concern for water quality which expanded greatly during the 1970's, the need to understand water and solute movement under field situations became compelling nationwide. The nation's water quality standards were largely set by an Act of Congress in 1972, which specified as national policy the virtual elimination of all discharge of pollutants into the nations surface waters by 1985. This elimination of point discharge dictates that almost all wastes must be disposed of on land, since burning would tend to violate previously enacted air quality laws. Although soil physicists have felt confident that their laboratory studies have elucidated the proper physical and mathematical laws describing water and solute movement in the field, the application of these laws to field situations has proven very difficult and soil physicists and engineers across the country are now actively pursuing a large number of field studies.

Our Department has been involved in experiments on the disposal of sludge and other substances such as whey on agricultural land and has carried out the usual type of empirical field plot trials. However, the studies which I wish to describe in more detail are those designed to improve the efficiency of nitrogen fertilization under our irrigated conditions. Some of the hydrological aspects of our researches have been summarized in the SEFMIA paper (Gardner, 1977). Wisconsin has about 20,000 ha of land in potatoes, mostly on sandy soils with a very low water holding capacity (about 15mm in a 25-cm root zone). Large acreages are planted to other vegetable crops. This low water holding capacity requires that the normal rainfall be supplemented by irrigation, usually supplied by overhead sprinklers. Our water balance studies on beans (Black et al., 1970) indicated that most crops in this region were being irrigated much more than strictly necessary. Research also has shown that N applications

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in excess of 220 kg/N/ha do not increase yields of tubers. These facts inferred that substantial leaching losses of N were occurring, with the potential for nitrate pollution of groundwater, as well as the economic losses due to inefficient fertilizer use.

Therefore, our soil physicists joined forces with our soil chemists to verify these presumed leaching losses and to determine if more efficient irrigation and fertilization schedules could be developed. As described in the SEFMIA paper, the hydrological cycle for this sandy soil has been worked out with some precision, with the individual elements of the water budget for the soil profile capable of prediction with quite good precision. Unlike most irrigated regions in the Western United States, farmers in the Midwest must take precipitation during the growing season into account if they are to improve the efficiency of their irrigation and fertilization; although it has been the usual practice to ignore rainfall in scheduling irrigation. Details of the experiments are given by Saffigna and Keeney (1977) and by Saffigna et al. (1977) and will not be repeated here. The significant finding was that by reducing the irrigation according to the precipitation and by going to smaller and more frequent irrigations and fertilizer applications than the conventional practice, nitrate leaching could be reduced significantly. Figure 1 illustrates the reduced leaching accompanying the reduced drainage. Since there are fewer uncertainties in the chloride balance than in the nitrogen balance of a soil profile chloride as well as nitrate was followed. The data shown were obtained from the effluent from weighing lysimeters fitted with a suction drainage system. It has earlier been established that the drainage from the lysimeters was virtually identical with that from the surrounding field. It can be seen from Figure 1 that about a 25 percent decrease

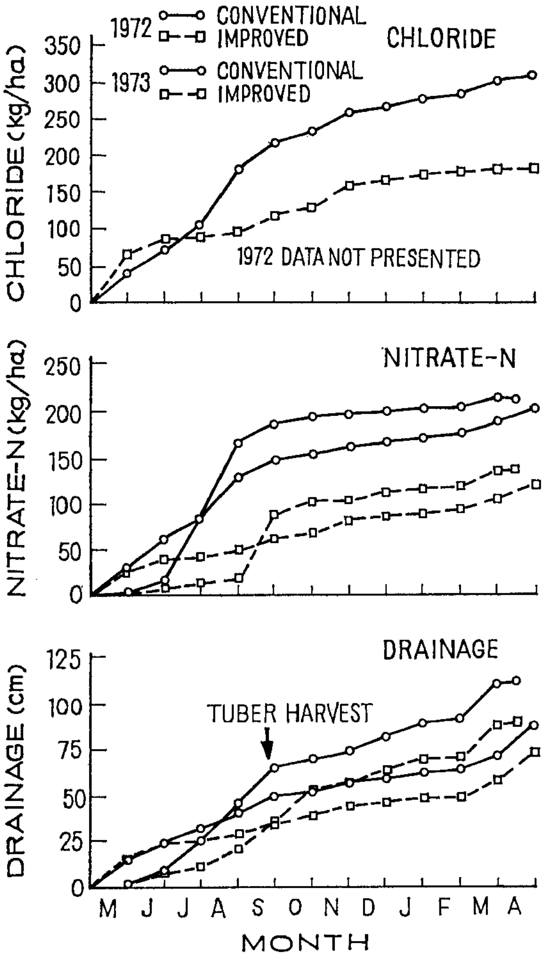


**Figure 1** Cumulative drainage, nitrate and chloride leachingunder irrigated potatoes. The Conventional treatment represents present farmer practices and the Improved smaller and more frequent irrigations and fertilizer applications.

in the amount of drainage water was achieved by the reduced irrigation schedule. When this is coupled with more frequent application of nitrate an even greater reduction in the leaching of nitrate is achieved. For details of the actual treatments, the reader is referred to the papers cited.

One important finding of Saffigna's experiments was that, at least for potatoes, was that there was a very non-uniform infiltration of water into the soil profile (Saffigna et al., 1976). The potato plants were found to channel water down their stems and into the soil above the

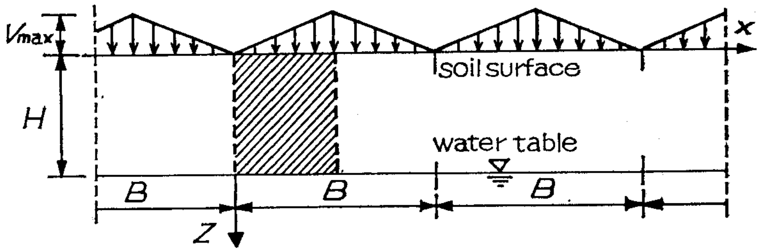


**Figure 2** Schematic diagram of non-uniform infiltration problem.

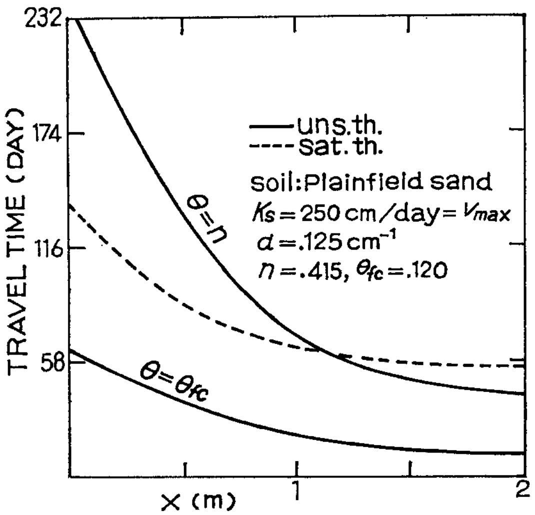


**Figure 3** Travel times as a function of lateral postion for special case of problem illustrated in Figure 2. n=0.415 represents saturated water content and $\theta_{fc}$=0.12 is the approximate value of the field capacity water content. The maximum infiltration is 250 cm/day which is also equal to the saturated permeability. The parameter a characterizes the soil structure.

tubers. Water running off the leaves tended to infiltrate in the furrow with very little water entering the soil on the shoulders of the ridges. This non-uniform infiltraton lead to a very nonuniform leaching of the root zone, and it was found that estimation of leaching losses from field cores tended to give biased estimates. A weighted sampling scheme taking into account the non-uniform infiltration improved the estimates (Jury et al., 1976), but did not completely solve the problem. The field data suggested that there was every little lateral dispersion of transport of solute in this soil.

In order to gain some insight into the lateral transport phenomenon, we have carried out two additional studies. In one of these we (Batu and Gardner, 1977) looked at the lateral movement of water in a profile due to non-uniform infiltration. Taking for simplicity a linearly-varying infiltration rate illustrated in **Figure 2**, we calculated the position of the streamlines and the travel times within the root zone. **Figure 3** shows the travel times as a function of position in a system two meters wide across which the infiltration rate varies linearly. Two different water contents were assumed, saturation at which $\theta=0.415$ and field capacity at which $\theta=0.12$. A saturated conductivity of 250 cm/day was assumed and the maximum infiltration rate at the peak was set equal to this rate. The conductivity was assumed to decrease exponentially with decreasing water potential. The soil is quite sandy so the result is more dramatic than it would be in a clay. What should be observed is that the time for a solute tracer to travel about one meter down through the profile is four times as long under the region where the infiltration is minimum compared with the region where it is maximum, and that the difference is much greater for the unsaturated case than were the soil saturated. The practical implication of this result is that the water tends to move downwards below where it enters the soil and that any surface effects which tend to result in non-uniform infiltration are propagated for considerable depth down through the unsaturated zone and do not average out readily.

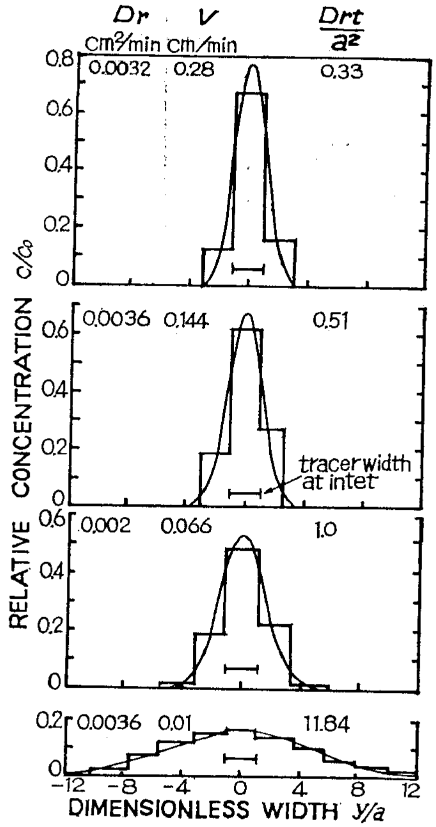


**Figure 4** Chloride concentration showing lateral dispersion for flow through Plainfield sand for different velocities. The corresponding dispersion coefficients are shown on the figure.

In a second study, we (Yule and Gardner, 1978) found from laboratory dispersion experiments that the lateral dispersion coefficient in this sandy soil is very small and independent of flow velocity. In **Figure 4** are plotted the concentration distribution of a chloride tracer as it passes through a 20cm soil sample. Four different flow velocities are represented. In each case, the driving force was approximately unity (gravitational) so that the decreasing flow rates are associated with decreasing soil water contents. The pore water velocities varied from 0.01 cm/min to 0.28 cm/min, represesting a water content variation from a low of 0.12 to a high of 0.28 (percent by volume). The concentration distribution obeys simple dispersion theory (Yule and Gardner, 1978) with a constant lateral dispersion coefficient of about 0.003 $cm^2$/min. Over this same range of water contents and velocities the longitudinal dispersion coefficient was found to be a linear function of the velocity according to the regression equation $D_L = 0.216v + 0.0032$ $cm^2$/min.

The significance of this very low and constant lateral dispersion coefficient is that in this sandy and poorly structured soil, there is very little lateral dispersion or spreading so that a solute which enters the soil as a narrow band or at a point will tend to move along a water flow streamline for great distances without much lateral displacement. Furthermore, the amount of displacement depends upon how slowly the solute moves. This explains why the infiltration pattern and nitrate leaching pattern found under our potato field persisted to the water table at a six or seven meter depth. It implies that small localized soil samples will reflect local effects even to considerable depth that a collection of individual samples will not necessarily represent a good average for a large field. We found that we could not determine the average water percolation rate and multiply it by the average concentration of the soil solution to get a good average for the leaching rate. It was necessary to multiply the local percolation rate by the local solution concentration and then average the product of the two. Even then this was not in exact agreement with the lysimeters. Field cores indicated that the profile was leached more rapidly than did the lysimeter. This implies that the less well-leached regions were not adequately represented in our field core sampling procedure, even though attempts were made to take into account the differences in fluxes below the furrows and the ridges.

Our results seem to be consistent with those found elsewhere in field studies in recent years. We find that we can predict the soil water budget quite well and that our flow theories are reasonably adequate in terms of averages over large areas so long as we have hydraulic conductivity data determined in the field. Our prediction and description of solute movement is much less satisfactory and we have much more to do on this problem before we have adequate predictive capability. When we add to the problem biological effects such as those involved in the nitrogen budget where mineralization and nitrification must be taken into account, our equations do not even cope with controlled laboratory situations. We are far from an adequate description of the field. Thus, we cannot predict the fate of nitrogen added in land disposal of wastewater and we still do not know why we must apply much more nitrogen than the plants need to get maximum crop production. Because the problems are so complex and the experiments so difficult and time-consuming, it is very important that we share information as widely as possible and seek to work together with colleagues everywhere. We in the United States have much to learn from our Japanese colleagues, particularly on the subject of soil nitrogen, and I hope that the future will see us working very closely together on many of these important problems.

### References


1)Batu, V. and W.R. Gardner. 1978. Steady-state solute convection in two dimensions with non-uniform infiltration. Soil Sci. Soc. Am. J. 42: 18–22.

2)Black, T.A., W.R. Gardner and C. B. Tanner. 1970. Water storage and drainage under a row crop on a sandy soil. Agron. J. 62: 48–51.

3)Gardner, W.R. 1977. Control of irrigation and drainage for ntensively-managed soils. Trans. Seminar on Soil Environment and Fertility Management in Intensive Agriculture, Tokyo, Oct. 1977. p. 44–52.

4)Jury, W.A., W. R. Gardner, P.G. Saffigna and C. B. Tanner. 1976. Model for predicting simultaneous movement of nitrate and water through a loamy sand. Soil Sci. 122: 36–43.

5)Saffigna, P.G., C. B. Tanner and D.R. Keeney. 1976. Non-uniform infiltration under potato canopies caused by interception, stemflow, and hilling. Agron. J. 68: 337–342.

6)Saffigna, P.G. and D.R. Keeney. 1977. Nitrogen and chloride uptake by irrigated Russet Burbank potatoes. Agron J. 69:258–264.

7)Saffigna, P.G., D.R. Keeney and C. B. Tanner. 1977. Nitrogen chloride and water balance with irrigated Russet Burbank potatoes in a sandy soil. Agron. J. 69: 251–257.

8)Yule, D.F. and W.R. Gardner.1978. Longitudinal and transverse dispersion coefficients in unsaturated Plainfield sand. Water Resour. Res. (In press).


### Questions and Answers

**Yasutomi:** Profile of nitrate content have any peaks against depth. Is it because the irregularity of mechanical property of soil texture? Did you get mechanical texture of soil you use?

**Gardner:** We do have the mechanical texture. It is the fine sand. We think there are in a lysimeter in a slight separate two peaks for any individual input of fertilizer. But we don't know why.

It (is those are) two sets of channels, perhaps, but for specific uniform material, we don't know why these two sets of channels sit to exist. If there were well structured soil, we might be able to believe in a two-channel system, but in this we can't find the evidence for it. I don't know the answer to your question.

**Miyazaki:** You have programmed that you put a ceramic tube at bottom of lysimeter. What suction, I mean the negative tension, you put to that ceramic tube?

**Gardner:** About one-third the atmosphere. About 3 – 500 mb., it's initially with control quite precisely and it's found that this control with unnecessary, that it could be uncontrolled suction, but it's been measured about one third.

**Miyazaki:** What's the depth of the bottom of the lysimeter?

**Gardner:** 150 cm. The ceramic tubes are surrounded with the layer of special earth which give you better contact than the sand.

**Iwata:** You showed that the gradient of hydraulic head becomes often about unit in profile of the field. I also found this phenomina. Please tell me the reason.

**Gardner:** It takes a little bit of mathematics. But the reason is that profile drains almost uniform water content. And it only requires a very small increase in water content with that to give you enough increase in conductivity to take care of the diversion of the flux, or the increase flux. And so that if there is any major departure from unity, then you will have attendency for the lines straight up again. And in one of his papers, Philip goes soon argument as to why a propagation cannot grow why it must decrease. What is surprising a little bit is that at the surfaces of the soil, of course, cannot be true. Because there is no flux and gradient must be -1 to oppose gravity, but the surface zone turns out to be very short. And I can't prove why that should be. But it is.

**Tabuchi:** About the problem of nitrate intake. Are you studying under the cooperation with soil chemists or biologists?

**Gardner:** The study we did was with Dr. Keeney, soil microbiologist, and Dr. Kirkham who is a plant physiologist. So I myself would not do that alone. I don't want to take time to go and to study except that the conclusion convinced us that there was very little nitrate taking up in a lower part of the red zone until the water was taking up from the same region. And so we think that the water and nitrate cycles must be studied together. May I make one another comment? I have not included the references to publish papers here. If you would like them, please write to me. And if you would rather write your question and send to me, please do. I promise I'll answer if I can, and so if you would like to think about your question and write it down, and send it to me, then I'll be pleased to write your letter and if I can answer that well.

**Tabuchi:** Thank you.