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The Depth of Rainfall-Runoff-Soil Interaction as Determined by ^{32}P

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This study dealt with the extent and dynamics of a thin zone of soil that interacts with rainfall and overland flow in releasing soil chemicals to runoff. A relatively immobile tracer, ^{32}P, was applied at 0.0 (soil surface), 0.5, 1.0, 1.5, or 2.0 cm depths in duplicate soil boxes of three different soils. Simulated rainfall of 6.5 cm/h was applied to each soil box for two separate 30-min periods. The degree of interaction decreased very rapidly, more or less exponentially, with depth below the surface. An effective average depth or zone of interaction, within which the degree of interaction equals that of the soil surface, was assumed to exist. The effective average depth calculated from the data ranged between 0.2 and 0.3 cm, depending more upon the period of rainfall than upon the type of soil. These average depths were used, along with values of total desorbable P and the fractions of the ^{32}P applied on the soil surface that appeared in runoff, to predict the P concentrations in runoff, which agreed rather well with the measured values. The assumption of an effective average depth was thus valid for P. Transient changes in the effective average depth of interaction during a rainfall period were calculated by using simultaneous P and ^{32}P concentrations in runoff, where the ^{32}P was applied at the soil surface. The effective average depth increased somewhat with time during a rainfall period, especially during the first 30-min rain. The 30-min mean effective average depth of interaction calculated by this method agreed well with that obtained by the first method described above.

INTRODUCTION

The quality of surface waters is of major concern at the present time. The transport of agricultural chemicals with overland flow of runoff water is an important factor. While it is recognized that a certain thin zone of soil at the surface interacts with rainfall and overland flow [*Bailey et al.*, 1974; *Frere et al.*, 1975; *Donigian et al.*, 1977], the extent and dynamics of this zone are not well understood.

Huff and Kruger [1967], in describing the transport of radioactive aerosols in a watershed, assumed that the soil mass interacting with water was the 'effective' mass at the soil surface (related to surface area of the soil particles) and the mass suspended in flow. *Frere et al.* [1975], in developing their agricultural chemical transport model, avoided the problem by assuming that the concentration of chemicals in runoff water equals that in the soil pore water at the soil surface. The latter was calculated for a given situation and time by using soil water movement and dispersion theories. *Donigian et al.* [1977] used a surface layer thickness of 0.2–0.6 cm in their agricultural runoff management model.

In line with earlier thinking of *Bruce et al.* [1975] and the work of *Sharpley et al.* [1978], *Leonard et al.* [1979] adopted an empirical statistical correlation between herbicide concentrations in the 0- to 1-cm soil layer and in runoff for practical applications. This approach has been incorporated in a recent version of the U.S. Department of Agriculture chemical and sediment transport model for agricultural management systems [*Knisel*, 1980]. The work of *Ponce* [1975] on total soluble salts indicated that their concentration in runoff was correlated highly with their concentration in 0- to 0.25-cm soil layer and poorly with that in 0- to 3.0-cm layer. *Ingram* [1979], using $CaSO_4$ in soil boxes under simulated rainfall, estimated the depth of soil involved to be from nearly 1 to 3 cm, depending upon the kinetic energy and intensity of rainfall and the slope. The soil surface conditions and the soil properties of texture, structure, strength, and permeability would also be expected to influence the depth of interaction. The degree of this interaction may be at a maximum right at the soil surface and decrease with depth. It may also be a function of time during a rainstorm or a series of rainstorms.

The purpose of this study was (1) to determine how the degree of interaction of soil with rainfall and overland flow might vary with depth of soil and time, (2) to test the assumption of an effective average depth within which the degree of interaction is uniform, and (3) to obtain some directly determined values of this depth for different soils under selected conditions. To achieve these objectives we placed ^{32}P as a tracer at the soil surface and at different depths in packed soil boxes and monitored its concentration in runoff water stemming from application of a simulated rainfall.

EXPERIMENTAL PROCEDURE

Experiments were conducted with samples taken from the 0- to 20-cm depth of three different soil types: Ruston fine sandy loam (Typic Paleudults), Bernow fine sandy loam (Glossic Paleudalfs), and Houston black clay (Udic Pellusterts). All the soil samples were sieved through a 4.0 mm screen, air dried, and thoroughly mixed together before use.

The major experimental treatments were to apply small amounts of ^{32}P at 0.0 (soil surface), 0.5, or 1.0 cm soil depths. For one of the soils (Ruston), 1.5- and 2.0-cm depth treatments were also tested. Ordinary P in the form of calcium phosphate was uniformly mixed in the soil both below and above the levels of ^{32}P application. This was done to relate the release of uniformly mixed P in runoff to the release of ^{32}P from different placement depths. The purpose also was to provide no concentration gradients in the soil in order to minimize diffusion of ^{32}P. The soil was provided with adequate moisture and time to dissolve this P. Each treatment was replicated twice.

The advantage of using ^{32}P as a tracer is that it is relatively immobile in soils during a period of a day or so [*Mokady and Zaslavsky*, 1966]. *Cho et al.* [1970] showed that diffusion and bulk movement of ^{32}P is retarded by a strong adsorption capac-

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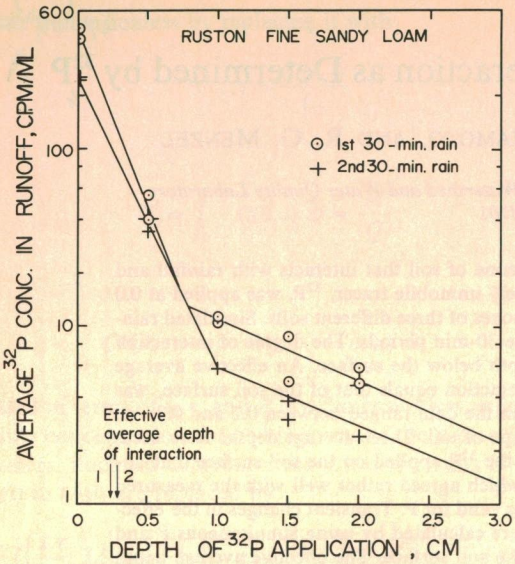

Fig. 1. The adjusted average ^{32}P concentrations in runoff as a function of the depth of ^{32}P application for the two 30-min rainfall periods on Ruston soil. The two exponential lines drawn through the data for each period were used to compute the indicated effective average depth of interaction.

ity of soils for P as well as by the presence of isotopically exchangeable phosphate (^{31}P) initially in the soil. In our experiments we were interested in equilibrating ^{32}P with the desorbable ^{31}P by isotopic exchange at the site of ^{32}P placement, but we wanted to minimize diffusional spread of the tracer. For this reason, based on literature and preliminary experimental measurements on some of our soils, we allowed a period of 18 hours between the time of ^{32}P placement and the start of simulated rainfall.

The soil boxes, made of plywood covered with black polyethylene sheet and with open bottoms made of nylon screen, were 100 cm long, 30 cm wide, and 10 cm deep. One end wall was provided with a V shaped funnel to catch runoff. The two side walls extended 20 cm above the top of the box to prevent the soil from splashing out during the rainfall. A detachable extension was also provided at the upper end wall for this purpose. The screen bottoms were covered with a 2.5 cm layer of dry gravel, thus leaving nearly 7.5 cm depth for packing the soil. The air-dried soil was mixed uniformly with a predetermined quantity of $Ca(H_2PO_4)_2\ H_2O$ in 3-kg increments and firmly packed into the box to the desired level of ^{32}P application.

The rates of calcium phosphate addition, taken from earlier studies, were 0.033, 0.0387, and 0.037% by weight (82, 95, and 90 μgP/g) for the Ruston, Bernow, and Houston soils, respectively. These P additions are equivalent to applying 50 kg P/ha under field conditions, allowing for differences in soil bulk densities. The soils were packed to bulk densities of 1.60, 1.73, and 1.33 g/cm^3 (4.8, 5.2, and 4.0 kg/cm depth of the box) for the Ruston, Bernow, and Houston black soils, respectively. Based on these densities, we set aside appropriate quantities of soil (mixed with P) for later packing above the level at which ^{32}P was applied, for the case of subsurface tracer treatments.

The soil in the boxes was slowly wetted by drip tubing to retention capacity of the box and then equilibrated for 3 days. This period of 3 days was provided to ensure complete dissolution of applied solid P and to achieve a degree of uniformity in the distribution of both the soil water and the P on microscale. The additional soil that was set aside for later packing above the subsurface tracer applications was wetted by spraying it with small amounts of water with an atomizer. Enough water was added to dissolve the P but still keep the soil friable enough for packing. This moistened soil was then tamped, wrapped with a polyethylene sheet, and allowed to equilibrate for 3 days, like the soil packed in the boxes. After 3 days a small measured amount of ^{32}P solution was applied with an atomizer to the surface of packed soil in the boxes as uniformly as possible, avoiding any spray on the side walls. For the subsurface tracer applications the additional pretreated soil was then packed above the level of tracer application and sprayed with just enough water to bring it near retention capacity. The dosage of ^{32}P applied per box ranged from 8.0×10^7 to 1.9×10^9 counts/min (as determined by a Hamner counter) in a 50-ml solution; the dosage increased with the depth of application. The tracer was allowed to equilibrate in this condition for about 18 hours, as discussed earlier.

The boxes were held at room temperature of 18 ± 2°C. Evaporation from the soil boxes under these conditions was negligible. In a related study involving different periods of exposure under these conditions, there was no experimentally detectable movement of P to the soil surface.

Two 30-min rainfalls of 6.5 cm/hr intensity, with an interval of about three hours, were applied on each box, which was supported at a 4% slope. The rainfall was simulated by a capillary tube type simulator (as described by *Munn and Huntington* [1976]), which gave drops of about 3.0 mm in diameter falling from a height of 2.5 m. The drop formers were spaced 2.5 cm apart in a triangular pattern. The drop impact appeared to be random. During each 30-min rainstorm we sampled the surface runoff for analysis at the time of runoff initiation and after 6–8, 15, and 30 min and collected the rest of runoff in a container. A sample was also taken from this container at the end of the rainfall period to determine the aver-

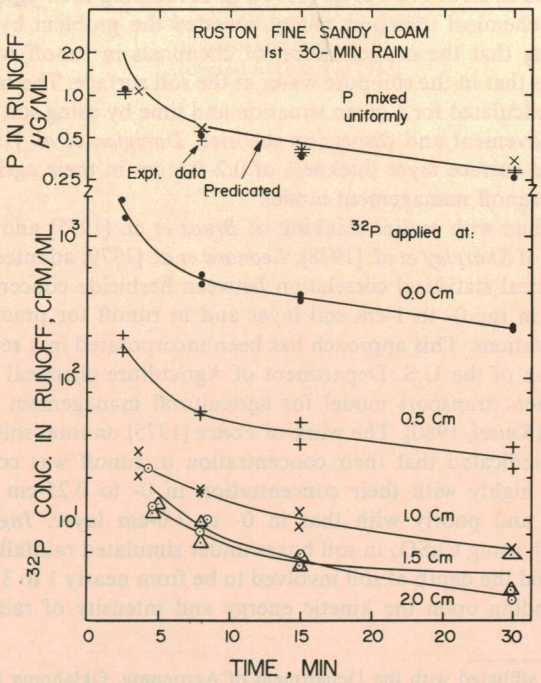

Fig. 2. Transient experimental data for P and ^{32}P concentrations in runoff and the P in runoff predicted by using the effective average depth of interaction for Ruston soil during the first rain period.

age ^{32}P and P concentrations in the 30-min runoff. All runoff samples were immediately centrifuged (15,000 rpm for 7 min) to facilitate Millipore filtration (<0.45 μm). The centrifuge tubes or the filter paper did not selectively adsorb P or ^{32}P. Eight to 24 ml of this filtered sample, the amount depending upon the sample's radioactive count, was dried on duplicate planchets to determine ^{32}P concentration by a Hamner scaler-counter. The concentration of soluble inorganic P in the remaining filtrate was determined by the method of *Murphey and Riley* [1962], with adsorbance being measured at 712 nm.

All ^{32}P count data for the runoff samples were adjusted to the time of application in order to account for the natural decay of the radioactivity. Since the rate of ^{32}P application was not the same for different depths of application, the data were further adjusted so that counts corresponded to the average application rate of 10^9 counts/min/box in all cases. The data were analyzed to obtain spatial and temporal change in the degree of rainfall-runoff-soil interaction. We determined an effective average depth of interaction by two different methods.

We considered the overall release of P from soil to solution form in runoff water without considering the specific modes of desorption: whether the P was desorbed from stationery soil mass in the box, from liquid-liquid diffusive and turbulent transfer, from soil aggregates that rolled along the soil surface with overland flow, or from sediments that eventually were dislodged and washed away with runoff [*Bailey et al.*, 1974]. It would be very difficult to separate contributions from different modes, since the physical factors that influence one mode also influence the other in a similar way. For the time periods between sampling and filtration, the effect of sediment content of runoff on solution P concentration was negligible in our studies.

RESULTS AND DISCUSSION

The adjusted average ^{32}P concentrations in runoff from the two 30-min rainfall periods on the Ruston soil are plotted in

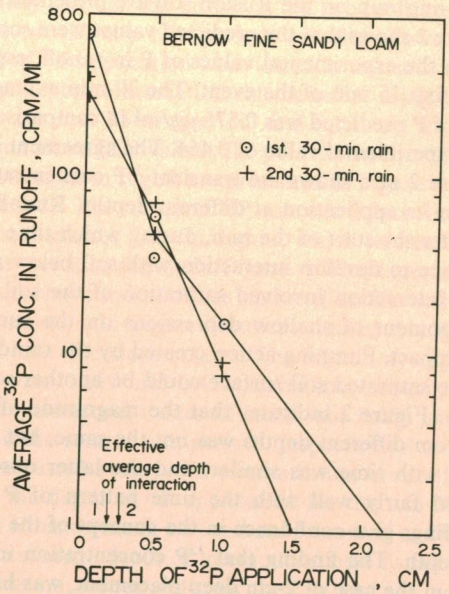

Fig. 3. The adjusted average ^{32}P concentrations in runoff as a function of the depth of ^{32}P application for the two 30-min rain periods on Bernow soil. The exponential lines drawn through the data points were used to calculate the indicated effective depth of interactions.

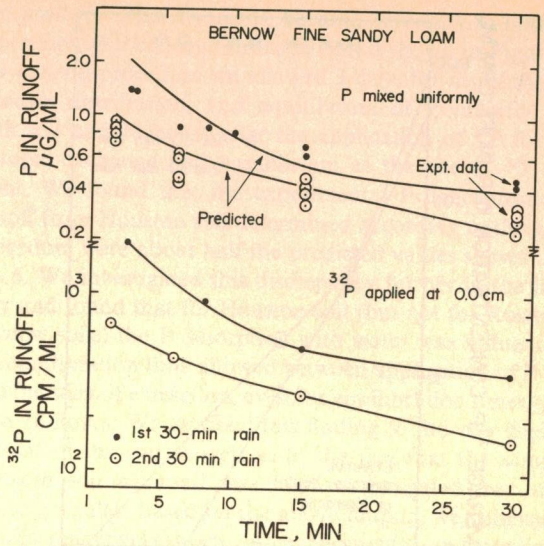

Fig. 4. Transient experimental data for P and ^{32}P concentrations in runoff (the latter just for soil surface application) and the P concentrations in runoff predicted by using the effective average depth of interaction for Bernow soil during the two rain periods.

Figure 1 as a function of the depth of ^{32}P application. The plot is of logarithm of the counts per minute per milliliter (cpm/ml) versus the depth of ^{32}P placement. The two data points at each depth are from the two replicate boxes. For each rainfall event, two straight lines were drawn through the data points to represent the functional change of the ^{32}P concentration with the depth of tracer application. The fitted function passed exactly through the mean of the two replicate data points for the 0.0-, 0.5-, and 1.0-cm depths of application but allowed for some random scatter in the means for the 1.5 and 2.0 cm depths, where the counts became smaller (and greater random scatter of the data was expected).

The results in Figure 1 indicated that the interaction of soil with rainfall and runoff that results in the movement of ^{32}P to runoff water decreases exponentially with depth, much more rapidly from 0.0- to 1.0-cm than from 1.0- to 2.0-cm depths. One may intuitively feel that the interaction below 1.0-cm depth would continue to decrease at least at the same rate as between 0 and 1.0 cm. We do not understand the physical reasons for this observed behavior. Of course, we must recognize that using a semilog plot and the fitting of two exponential lines is just a convenient way of plotting. The choice is arbitrary. Another suitable function could be found, so that all the data points would fall along a single straight line. We will show later in this paper, however, that the contribution of 1.5- and 2.0-cm depths to the overall interaction is small and negligible. The exponential function representing the first three depths is therefore the important one.

The graphs in Figure 1 show that the maximum depth of soil interacting with rainfall and runoff may exceed 2.0 cm, but the degree of interaction below the soil surface decreases rapidly. For practical purposes we can assume an effective average depth of interaction such that all the soil volume above this assumed depth has the same degree of interaction with rainfall and runoff as does the soil surface (0.0-cm depth), but the total interaction is the same as that in the real case. This average depth can be obtained by finding the area under the exponential functions, representing the data in Figure 1, from zero depth to infinity (or the maximum depth of interaction suggested by the data) and then dividing this area by the

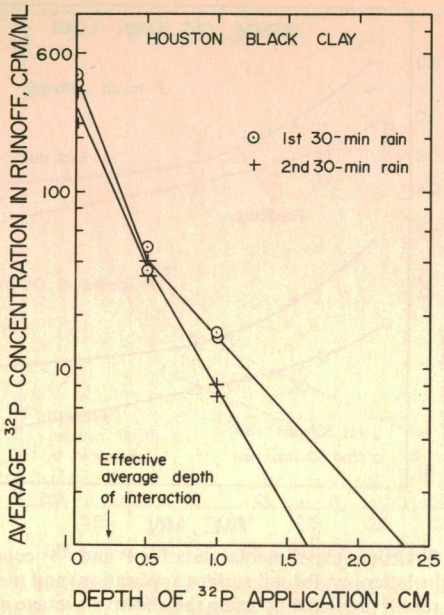

Fig. 5. The adjusted average ^{32}P concentration in runoff as a function of the depth of ^{32}P application for the two 30-min rain periods on Houston soil. The exponential lines drawn through the data were used to calculate the indicated effective average depth of interactions.

value of the function at zero depth. The effective depth of interaction, denoted by the symbol EDI, is given by

$$\mathrm{EDI} = \left[\int_0^{x_1} a_1 e^{-b_1 x}\,dx + \int_{x_1}^{\infty} a_2 e^{-b_2 x}\,dx\right] \Big/ a_1 \qquad (1)$$

where a_1 is the ^{32}P concentration in runoff from application of ^{32}P at the soil surface (0.0-cm depth), b_1 is the slope of the first straight line (0- to 0.8-cm depth range) in Figure 1, b_2 is the slope of the second straight line (for depths >0.8 cm), x is the depth of application variable, x_1 is the value of x at which the two straight lines intersect, and a_2 is the intercept of the second straight line on the vertical axis. The EDI values calculated this way for the individual 30-min rainfall events on Ruston soil are shown in Figure 1. These values were 0.249 and 0.291 cm for the first and second rainfall events, respectively.

The small values of the effective average depth of interaction would indicate that the contribution of deeper depths, such as the 1.5 and 2.0 cm, is relatively very small. It was useful for our further work to find out whether we could obtain a good value of the effective depth from data points for the 0.0-, 0.5- and 1.0-cm ^{32}P applications in Figure 1. We represented these data points for each rainfall event by a single exponential line and extrapolated it to the x axis. The EDI computed from these functions using (1) were 0.246 and 0.266 cm for the first and second rain, respectively. These values are fairly close to those found by using the data from five depths of ^{32}P application given above.

We tested the validity of the assumed effective average depth of interaction by using the EDI values calculated above, in conjunction with the fractions of the ^{32}P applied at the soil surface (0.0 cm depth) that came off in runoff, to predict the concentration of ordinary P in the runoff at different times. The procedure was to find the total P present in the soil mass above the calculated effective average depth of interaction, which was in equilibrium with the applied ^{32}P. Then the fraction of this P that came out in runoff at any given time would be equal to the corresponding fraction of ^{32}P. This total P above the effective depth was taken to be equal to the amount of P added as $Ca(H_2PO_4)_2\ H_2O$ plus a part of the native soil P which was as effective as the applied P in contributing solution P to runoff water. We determined the latter values (native soil P) based on our laboratory study on the kinetics of P desorption in several different soils (including Bernow and Houston) [*Sharpley et al.*, 1981*b*] and on the release of P to runoff in soil boxes similar to those in the present study [*Sharpley et al.*, 1981*a*]. In the laboratory study we found that mean concentration of solution P for a fixed time of desorption and a fixed water to soil ratio was linearly related to amount of P added to soil within the range of 0–190 μg/g rates of P application. In the soil box studies we found a similar linear relationship between mean solution P concentration in a 30-min runoff and different levels of P applied, including the native P level where no P was added. The work of *Romkens and Nelson* [1974] also indicated such linear relations for a variety of soils. In order to determine the contribution of native P on this basis, we made an additional measurement of the amount of solution P in runoff from a soil box with no P addition. A straight line drawn through two points (0 and 82 μgP/g soil additions) on a plot of mean solution P concentration in runoff versus the amount of P applied was back-extrapolated to the point where mean concentration value was equal to 0. Absolute values of intercept on the P-applied axis gave the desired amount of native P. For Ruston soil the value was found to be 0.0164 μgP/g of soil, nearly 27% of the P applied in this study. With this value of native P the equation to predict concentration of ordinary P in runoff water at any given time during the rainfall event can be written as

$$\text{P in runoff } (\mu\text{g/ml}) = \frac{^{32}\text{P in runoff (CPM/ml)}}{^{32}\text{P applied at soil surface (CPM/box)}} \times 1.27 \times \text{P applied in EDI } (\mu\text{g/box}) \qquad (2)$$

The predictions made this way for the transient data during the first 30-min rain on the Ruston soil are presented in Figure 2. Figure 2 shows that the predicted values were somewhat higher than the experimental values of P in runoff, especially during the first 15 min of the event. The 30-min average concentration of P predicted was 0.575 μg/ml in comparison with the mean experimental value of 0.464. The agreement is fairly close. Figure 2 also shows the transient ^{32}P concentrations in runoff from its application at different depths. Runoff began 2–4 min after the start of the rain, during which time rainfall had a chance to develop interaction with soil below the surface. This interaction involved saturation of the soil surface and development of shallow depressions on the surface by raindrop impact. Pumping action created by the raindrop impact on the saturated soil surface could be another source of interaction. Figure 2 indicates that the magnitude of the ^{32}P released from different depths was not the same, but the rate of change with time was similar, and the latter observation also agreed fairly well with the time pattern of P release. These findings give confidence in the concept of the effective average depth. The finding that ^{32}P concentration in runoff, especially in the case of 2-cm deep placement, was highest at first sampling of runoff and decreased thereafter indicated that the soil-rainfall part of the total interaction had developed to considerable extent within a short time. As indicated earlier, however, the amounts of ^{32}P coming off the 1.5- and

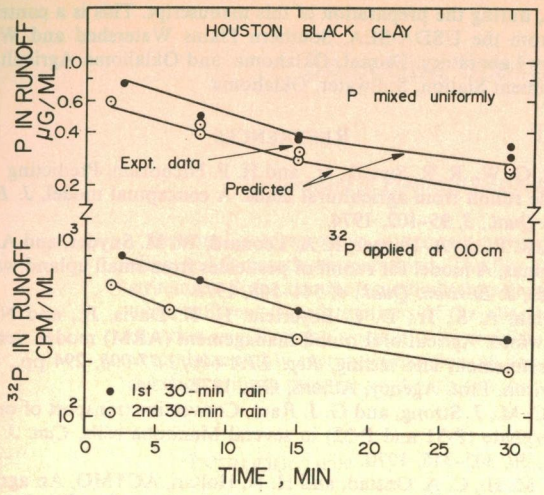

Fig. 6. Transient experimental data for P and ^{32}P concentrations in runoff (the latter just for soil surface application) and the P concentrations in runoff predicted by using the effective average depth of interaction for Houston Black soil during the two rainfall periods.

2.0-cm ^{32}P placements were relatively much smaller (and could be neglected) in comparison with the contribution from soil surface and shallower placements.

The transient data for P and ^{32}P and the predictions made for P concentrations in runoff during the second 30-min rainfall on Ruston soil were very similar to those for the first rainfall event (Figure 2). The predictions for P in runoff were somewhat higher during the first half and somewhat lower during the second half of this rain period. The 30-min average concentration of P predicted was 0.362 μg/ml compared to the mean experimental value of 0.416. The average P concentration was somewhat underpredicted in this case, while it was overpredicted in the case of first 30-min rain period.

The plots of the average ^{32}P concentrations in runoff versus the depth of ^{32}P application for the Bernow fine sandy loam are shown in Figure 3. The exponential straight lines drawn separately through the means of the two replicate data points for the two 30-min rain periods are also shown. Only three depths of ^{32}P application were tested in this soil. The effective average depth of interaction calculated by using (1) was 0.207 cm for the first 30-min period, and 0.291 cm for the second. Based on these EDI values, the predictions for the transient P concentrations in runoff are presented in Figure 4 for both the rain periods. The transient ^{32}P concentrations for ^{32}P applied at the soil surface (0.0-cm depth), which we used in the predictions, are also shown in Figure 4. The experimentally determined contribution of the native P in this soil was nearly 4%. The results in Figure 4 indicate reasonably good predictions for the P concentrations. The 30-min average predicted values were 0.659 and 0.439 μg/ml in comparison with the mean experimental values of 0.685 and 0.456 μg/ml for the first and the second rain periods, respectively.

The adjusted average ^{32}P concentration in runoff as a function of the depth of ^{32}P application for the two 30-min rainfalls on Houston black clay soil are presented in Figure 5. The effective average depth of interactions were found to be 0.243 and 0.248 cm, respectively, for the first and second rain periods. The predictions for the transient P concentrations in runoff and the transient ^{32}P concentrations for surface (0.0 cm) application of this tracer are shown in Figure 6. A modification in the general P–^{32}P equilibration procedure, given earlier and used for other two soils, became necessary to obtain the experimental P concentrations in runoff shown in Figure 6. In our general procedure we allowed 3 days for dissolution, microscale distribution, and equilibrium of P initially mixed with soil and 18 hours after the application of ^{32}P for P–^{32}P isotopic exchange and equilibrium at the site of ^{32}P placement. We found that the experimental P concentrations in runoff from Houston soil determined according to the general procedure were about half the predicted values shown in Figure 6. We investigated this discrepancy further in the laboratory and found that for Houston soil (but not for Ruston and Bernow soils) the P desorption with water was influenced by the equilibration time allowed between application of P to soil and the start of extraction, even for equilibration times greater than 18 hours. We ascribed this finding to the very high clay content of the soil as well as to the fact that the sample of Houston soil we used was highly aggregated into mainly coarse granules. Based on the above finding, we believed that the discrepancy between our experimental and predicted P concentration in runoff was due to the fact that we allowed 72 hours for P equilibration with soil, but only 18 hours for P–^{32}P exchange and equilibration. For this reason we prepared two additional soil boxes with P added, allowing just 18 hours between wetting and rainfall simulation. The experimental data for P concentrations shown in Figure 6 are from these two boxes. The contribution of the native P in this soil was 10.8%. With the correction the agreement between the predicted and the experimental values is fairly good. The 30-min average P concentrations predicted were 0.417 and 0.299 μg/ml as compared with the experimental values of 0.426 and 0.391 for the first and second rain periods, respectively.

We determined the transient change in the effective average depth of interaction during a rainfall period by a method which consisted of essentially reversing the prediction procedure of (2) described above. The method also provided another estimate of the 30-min average effective depth of interaction for the whole rainfall period. The calculation involved dividing the experimental concentrations of P in runoff at any given time during the rainfall period by the measured fraction of the applied ^{32}P in runoff at the same time to obtain the total amount of P contributing to the measured release of P in runoff. Then, with the known P concentration in soil, we found the mass of soil that contained that total P. Assuming that the

TABLE 1. Transient Changes in the Effective Depth of Interaction During Two 30-min Rainfall Periods of 6.5 cm/h Intensity

Time, min	Depth of Interaction for Soil Samples, cm		
	Rustin	Bernow	Houston Black
Storm Number 1			
2.55, 2.6, 2.7	0.134	0.137	0.235
8.0	0.207	0.185	0.207
15.0	0.206	0.175	0.230
30.0	0.236	0.172	0.269
(30-min average)	0.201	0.215	0.248
(average, method 1)	0.249	0.207	0.240
Storm Number 2			
1.67, 1.5, 1.75	0.254	0.229	0.268
6.0	0.229	0.202	0.260
15.0	0.288	0.243	0.270
30.0	0.365	0.335	0.337
(30-min average)	0.335	0.248	0.323
(average, method 1)	0.290	0.291	0.250

initial bulk density of unpacked soil did not change during rainfall, we determined the effective depth of interaction at any given time during the rainfall period. The computations made this way for the transient changes in the effective depth of interaction during each of two rain periods and the 30-min average effective depth for the periods for all the three soils are presented in Table 1. The first time of sampling the runoff was somewhat different in different soils. The 30-min average values given in Table 1 were computed from the experimentally measured P concentration in the whole 30-min runoff; it is not the mean of the transient values. The values marked as '(average, method 1)' are the values computed earlier from the plots of ^{32}P concentration versus depth of ^{32}P application. There is some experimental variability reflected in the data, but in general the results indicated that the depth of interaction increases somewhat with time during a rainfall period. This change could be explained by the time that it takes to build overland flow patterns to a steady level. The average values calculated by the two methods agreed acceptably.

Integrating all the results presented above, we can conclude that the assumption of an effective average depth of interaction is valid for P. The actual degree of interaction between the soil and the rainfall and runoff decreases very rapidly, more or less exponentially, with depth below the soil surface. During a rainstorm, it takes some time for the interaction to build up to a full level. For the three soils investigated in this study under a 6.5 cm/h simulated rainfall the effective depth of interaction ranged between 0.2 and 0.3 cm, depending more upon the period of rainfall than upon the type of soil.

Knowledge of the above facts, combined with the kinetics of P release [*Sharpley et al.*, 1981*b*], should help improve modeling of P loading in runoff. Further work is, however, needed to know how soil properties, surface conditions, surface microrelief, degree and length of slope, and rainfall and runoff characteristics might influence the depth of interaction and kinetics. Some of these factors are dealt with in another paper [*Sharpley et al.*, 1981*a*]. The effective depth of interaction, as defined and estimated above for P, can also be used for other adsorbed chemicals uniformly distributed within the surface 2 cm. However, using this effective depth will underpredict runoff concentrations for a fairly mobile chemical which has moved down just below this effective depth but is still within the zone of interaction as shown by Figure 1 This discrepancy may not be important, or it may require a small correction, depending upon the relative rates of infiltration and runoff.

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