

RESEARCH PROGRESS AND NEEDS CONSERVATION TILLAGE

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A North Central Region, Agricultural Research Service, U.S. Department of Agriculture soil tillage research workshop was held in Council Bluffs, Iowa, January 6-7, 1976. As a result of the discussions, the enclosed state of the art papers were prepared.

The purpose of this publication is to present an account of research needs in the field of soil tillage in the North Central Region.

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Chairman of the workshop and coordinator of this report:

W. E. Larson
ARS-USDA-NCR
201 Soil Science Building
University of Minnesota
1529 Gortner Avenue
St. Paul, Minnesota 55108

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NATURE AND SCOPE

Hydrology is the study of the occurrence and movement of water in and on the earth's crust. A major control on the various hydrologic mechanisms is the earth's surface. The soil surface, that is, the soil-atmosphere interface, is essentially a divider. The hydrologic mechanism of infiltration operates at this surface and determines what portion of precipitation is directed into the soil for future evaporation, transpiration, and accrual to ground water.

Precipitation in excess of infiltration runs off. Restrictions on its movement over the surface are few, and flowing water tends to concentrate in channels and reaches relatively high velocities. The potential is high for various sorts of damage, the most prevalent of which is erosion.

The soil surface and materials residing upon it also influence the rate at which soil water evaporates and is thus lost from the soil water reservoir.

Man's manipulation and treatment of the soil surface influences infiltration and evaporation and therefore other parts of the hydrologic mechanism. Let us define tillage as the manipulation of the upper few inches or feet of soil for agricultural purposes. Such manipulation can range from that accomplished with deep plows and chisels to compaction by tractor tire during broadcast seeding. On the microscale, tillage or the lack of it increases or decreases local infiltration. On the macroscale, however, tillage is only one part of a farming or land treatment system or practice. Other parts of the practice such as direction of tillage, surface cover, and use of such water control devices as terraces or meadow strips may reduce or magnify the effects of tillage. Increasing the scale still further, the downstream effect of a particular field subjected to a given agricultural practice will depend upon the position of that field in relation to other farmed or unfarmed areas in the same drainage basin and upon the hydraulic characteristics of the drainage system to which it contributes.

Time is a factor influencing the magnitude of tillage effects. As soon as the tillage operation is finished, the disturbed soil zone starts to return to the untilled state.

Antecedent moisture conditions influence infiltration also. To consider the extreme, when the whole soil system is near saturation as may happen in late winter and early spring or after prolonged rainfall in any season, the soil has little room to store more water, and the hydraulic gradients are such that the speed with which water can move downward through soil is low. During

^{1/} Hydraulic engineer, Agricultural Research Service, U.S. Department of Agriculture, Columbia, Mo.; in cooperation with the Missouri Agricultural Experiment Station, University of Missouri, Columbia.

such times, infiltration is likely to be low regardless of soil surface treatments.

PAST AND PRESENT RESEARCH

A wide variety of tillage methods and other surface treatments has been tested on runoff plots and small watersheds. In recent years, much interest has focused on various forms of minimum tillage, including no tillage. Bertrand and Mønnering (1963) used a sprinkling infiltrometer on plots somewhat larger than 1 m² in area to show that minimum tillage results in higher infiltration rates than conventional tillage if a crust is now allowed to form. Crust formation reduced infiltration rates by 50 percent. Sloneker and Burwell (1976) also used a sprinkling infiltrometer to test several tillage methods. They observed that tillage increased infiltration and also observed that soil cover, which retards crust formation, increases infiltration even more.

Free and Bay (1969) reported a nine-year plot study of conventional, mulch, and plow plant tillage. There was little difference in the total runoff from the several treatments during the dormant season. During the growing season, the rough surface resulting from plow-planting yielded less runoff than the other treatments. Differences were statistically significant at a level unspecified by the authors. Using a large rainfall simulator, Meyer and Mønnering (1961) had shown essentially similar results for the periods immediately following planting and cultivation. Moldenhauer and others (1971), using a large rotating boom rainfall simulator in early June, found that runoff varied from lowest to highest in the order row plant, conventional tillage, and ridge tillage. The differences were not significant at the 5 percent level.

Onstad (1972) compared several tillage requirements on 0.01-ha plots and found that growing season runoff varied from high to low in the following order: fallow, conventional, mulch, till plant up- and down-hill, and till plant across the slope. There was statistical significance at the 1 percent level only between conventional tillage and till planting across the slope.

Comparisons between no-tillage and various types of tillage treatments have resulted in differing conclusions regarding runoff influences. For a single storm in early June, Harrold and Edwards (1972), observing small watersheds of near 0.6 ha in size, found slightly more runoff from no-till as compared to clean till when both were on the contour. Over a three-year period, however, Harrold and others (1967) observed that no-till runoff on small watersheds was only about one-third that of conventional tillage. This was a dry period, however, and runoff for both practices was quite small. Shanholtz and Lillard (1969) observed from 3 to 4 times more runoff from conventionally tilled 6-m square plots than from no-till plots of the same size. McGregor and others (1975) observed that, on plots and small watersheds, no-till corn after beans yielded more runoff than conventionally tilled beans. In both these comparisons, the rows ran up- and downhill.

Shanholtz and Lillard (1969) also observed that soil water content persisted at higher levels longer under no-till than under conventional tillage,

but eventually dropped to a lower level than conventional tillage during a prolonged drought period.

Ehlers and van der Ploeg (1976) observed soil water conditions for four years under conventional tillage and no-till conditions. They noted that unsaturated but wet (suction < 100 cm water) hydraulic conductivity was higher in untilled than tilled soil. They concluded that large pores are broken up in tilled soil but remain continuous in untilled soil. However, they did not detect a significant difference in the treatments as regards rates of evaporation and drainage.

Greb and others (1970) observed that increasing amounts of soil water storage occurred under increasing depths of mulch with stubble mulch tillage. Army and others (1961) showed that chemical weed control is also effective in improving soil water conditions but that this effectiveness does not extend below 1.0 cm. Unger and others (1971) compared a variety of tillage-mulch-herbicide combinations and found that cultivation without herbicide limited profile water additions to the upper 75 cm, but herbicide treatment with or without cultivation resulted in profile water additions on down to about 120 cm.

Musick and Dusek (1975) studied the effects of deep tillage on Pullman clay loam under irrigation. Increasing tillage depth to 40 cm increased infiltration rate, but deeper tillage caused no further increase. Deeper tillage led to greater deep percolation losses than 40-cm tillage, however. Tillage to 40 cm resulted in higher infiltration rates in subsequent years when normal tillage to 20 cm was practiced. Sandoval and others (1972) investigated tillage depth effects on a sodic claypan soil and found that 30- to 60-cm tillage depths when compared to 15-cm normal depth of tillage resulted in greater water storage at the end of a fallow period, particularly in the 60- to 90-cm depth. The differences, however, were quite small.

The above papers and many others of a similar vein present essentially microscale results. These results are quite important from an agronomic standpoint and give insights on the development of surface treatments for efficient utilization of precipitation and irrigation water for crop production. However, one cannot generalize from the microscale to the macroscale, from small plots to watersheds. Edwards and others (1973) studied a 28-year record for watersheds in the size range 0.7 to 3.2 ha. These watersheds were in corn, wheat, meadow, meadow rotations under either conservation (contour and contour strip cropping) or nonconservation (rectangular fields without contouring or strip cropping) management. Conservation practices reduced growing season runoff by about 50 percent and peak rates of flow by about 33 percent. McGuinness and others (1971) commented that downstream effects of any treatment on any given area are likely to be well masked by the hydrologic activity of other areas (meadows, woodlands, or other treatments) within the same watershed. For watersheds from 12 to 120 ha in size, Harrold and others (1962) could not detect statistically significant differences in either volumes or peak rates of runoff when comparing conservation and nonconservation watersheds. Even reforestation of a 17.2-ha watershed did not cause an apparent reduction in peak flows during major storms, although annual and seasonal runoff volumes were considerably reduced. These watersheds, in contrast to

the single cover watersheds studied by Edwards and others (1973), had considerable areas in permanent pasture and woodland and, in general, were characterized by incised channels and base flow.

Considering relatively small watersheds of less than 80 ha, Baird (1946) showed that a conservation farming method yielded less runoff than a nonconservation method. He found that peak rates were reduced by a nearly constant amount, regardless of size of storm.

Sharp and others (1966) attempted to determine the effects of land treatments on large river basins (hundreds of square kilometers in size). They tried several statistical techniques of greater or lesser sophistication and could not detect, among other things, even the influence of a number of reservoirs. Kennon (1966), however, was able to detect a 20 percent reduction of streamflow for a 221 km² basin, 75 percent of which was controlled by reservoirs. Kuzin (1965) strenuously objected to the extrapolation of plot and small watershed data to river basins when L'vovich (1960) attributed reduced flows in the Don River to increased cultivation within its basin.

In summary, the literature indicates that the detection of tillage effects on hydrology is largely a matter of scale. Even on the scale of small plots, researchers are having difficulty measuring rather small differences in runoff and agreeing on whether the differences are positive or negative. As larger areas are considered, a multitude of such other factors as field position, drainage system hydraulics, and so forth, apparently overpower not only tillage influences, but also farming practice effects.

RESEARCH NEEDS AND APPROACHES

Considering the circumstance that hydrologic effects of cultural practices can hardly be detected on large, mixed cover watersheds, the practical significance of tillage effects on hydrology per se seems to be limited to the field or small watershed scale, at most. This observation does not necessarily extend to the detection of such waterborne substances as sediments and dissolved chemicals.

On the smaller scale, hydrologic effects of tillage may be quite important, particularly as regards its influence on the efficient use of irrigation water or precipitation by crops, maintenance of an adequate rooting depth of soil, and the management of fertilizers and pesticides.

After a brief review of only a sampling of the tillage literature relating to infiltrometers, runoff plots, and small watersheds, one is struck by the heterogeneity in results and the seeming impossibility of drawing clear-cut conclusions on the basis of the data alone. This may in part be due to the "lumped system" nature of most plot and infiltrometer studies of runoff response to tillage and to the uniqueness in experimental design for each tillage study. Runoff from a plot is a function of many factors besides tillage. Slope, aspect, subsurface physical and hydraulic conditions, soil and vegetation characteristics, plot borders and observational equipment, and climatic factors all interact with the particular tillage treatment to

influence runoff. To begin to get a handle on hydrologic influences, the problem must be broken down into a number of parts and a research approach developed for each part.

From a hydrologic standpoint, a soil surface may be characterized by its infiltration properties and by its microtopography. Below the surface the soil is hydrologically characterized by its soil water pressure head and hydraulic conductivity properties as functions of water content. Other characteristics, such as slope, the presence of impeding layers below the tilled zone, mulches, and crop canopies are environmental or boundary conditions. The hydrologic impact of tillage is really the impact on hydrologic properties of the interaction of tillage with a soil of given initial character and with given boundary and environmental conditions.

Definitive study of the characteristics discussed may require even further subdivision of the problem. Consider infiltration, for example. Skaggs and others (1969) present infiltration equations due to Green and Ampt (1911), Philip (1969), Horton (1940), and Holtan (1961). The bases for these equations range from empirical to physical. Each equation contains terms relating to internal soil properties or to internal soil water conditions. Each equation also contains one or more parameters whose values must be obtained by fitting the equations to observed infiltration data. Without this fitting or calibration procedure, none of the equations can be applied to a field situation.

Considerable effort has in recent years been expended upon developing sophisticated numerical models to depict infiltration (Rubin, 1966; Whisler and Klute, 1967). These models suffer the same shortcomings as the infiltration equations in that they cannot depict soil surface conditions, and thus there is no way to differentiate between a cornfield and a forest.

Infiltration is classically defined as the movement of water across a surface. The physically based equations referred to above (Green and Ampt, Philip) and the numerical approaches model infiltration by considering the physics of water flow in the soil below the surface, that is, they indirectly approach infiltration by modeling one of the boundary conditions to infiltration.

From the preceding, the reader realizes that no one, hydrologists, soil physicists, or tillage investigators, really understands infiltration. The same is true to greater or lesser extent of the formation of microtopography, and the in-soil establishment of the relation between soil water content and hydraulic conductivity and soil water pressure head. No one understands how a soil's physical constituents and chemistry interact with water, air, and organic life to give a particular dynamic expression of these characteristics.

There will be argument over how fundamental we have to get in seeking understanding. I submit that we have to go deeply enough to develop mathematical expressions for the characteristics in which we are interested. With mathematical expressions as building blocks, we can construct simulation models and with good simulation models we can study tillage-soil impacts on hydrology at the desk with a minimum of field experimentation.

If simulation capabilities are not developed, then each new idea and combination of tillage methods will have to be tested by large numbers of plots. For the same reasons that they now produce conflicting results, they will continue to do so. Furthermore, plot experiments take years, and farmers won't wait. A multiyear field experiment begun today runs a risk of producing information no longer needed by the time it is concluded. That risk will become larger as the rapidity of change in the agricultural sector continues to accelerate.

Based on the preceding observations of this section, I conclude that a portion of our hydrologic and tillage research effort should be devoted to development of knowledge leading toward the capability to simulate the hydrologic impact of tillage and/or of tillage-cropping-management systems on soils of given physical, chemical, and organic character. With the capability of soil-specific simulation, site or environmental and boundary conditions can be added to expand the capability to simulation of the hydrologic impact of tillage on given plots, fields, and watersheds. These capabilities would be a boon not only to the development of tillage-cropping-management systems, but also to increasing hydrologic simulation capabilities in general.

A possible approach is to assign a team consisting of a soil physicist, a soil chemist, and a microbiologist to perform an in-depth survey of the literature of their fields and of such allied fields as petroleum extraction technology, filtering technology, and so on. Their aim should be to pool their assembled knowledge in the development of a research plan with three objectives: (1) determine the physics of water movement across the soil-air interface and thus identify the pertinent hydraulic characteristics of such an interface, (2) determine how these surface hydraulic characteristics are established and controlled, and (3) determine how the hydraulic conductivity-soil water pressure head and the soil water content-soil water pressure head relations are controlled in soils.

At the end of an 18-month or 2-year period, the team should report their plan of research and be prepared to discuss experimental techniques, likelihood of success, and its probable cost in terms of dollars, facilities, and personnel. Feasibility of the plan can then be assessed and a decision made on whether to proceed in full, in part, or not at all.

Further outlining of the approach toward eventual simulation capability must await at least the aforementioned plan of fundamental research and assessment of its feasibility.

EXPECTED BENEFITS

Long-term benefits, as indicated in the preceding section, would accrue to tillage system development and assessment efforts and to the general field of hydrologic simulation. Tillage research and application would benefit primarily in terms of increased timeliness of the release of experimental results if a simulation capability is eventually obtained. The anticipated simulation capability would be a direct contribution to hydrologic simulation in general and would contribute to an increased capability for predicting downstream influence of various land use and land management plans.

POTENTIAL FOR INTERREGIONAL EXTRAPOLATION OF NEW TECHNOLOGY
IN A PREDICTIVE SENSE

Simulation based on fundamental physical understanding will have no geographic limitations.

RESOURCES REQUIRED TO ACHIEVE RESEARCH OBJECTIVES AND GOALS

The most important resources are three team members well grounded in their own fields and in analytical mathematics. The team should be located at a university capable of offering extensive library facilities and technical backup in physics, mathematics, and chemistry.

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