Erosion and Sediment Transport Measurement (Proceedings of the Florence Symposium, June 1981). IAHS Publ. no. 133.

Instrumentation for studies of the erosive power of rainfall

N. W. HUDSON
National College of Agricultural Engineering, Silsoe, Bedford MK45 4DT, UK

ABSTRACT There is a need for both a worldwide study of the erosivity of rainfall, and also for detailed localized studies. Previous studies, which are reviewed, have used different techniques, and this complicates the comparison of results. The alternatives are (a) direct measurements of erosion, which are only effective for splash erosion; (b) computations from measurements of raindrop size, which is an established but laborious technique even with modern scanners and signal analysers; (c) direct measurement of rainfall properties such as impact stress, momentum, or energy. It is suggested that this last method is most appropriate because of developments in pressure transducers and microprocessors. The proposed route to standardization is first a comparative study of pressure transducers and acoustic or piezo-electric sensors, followed by development of an instrument suitable for cheap mass production, which could then be adopted and used by an international network.

Equipement pour l'étude du pouvoir érosif de la pluie
RESUME Il existe un besoin pour une étude à l'échelle mondiale de l'érosivité de la pluie et également pour des études locales de détails. Des études antérieures ont utilisé des techniques disparates et cela complique l'analyse des résultats. On peut envisager (a) de déterminer l'érosion par mesure directe, ce qui n'est possible que pour l'érosion des gouttes; (b) de calculer celle ci à partir des mesures de la taille des gouttes de pluie, technique déja bien au point mais qui exige un travail laborieux même avec la technologie moderne comme celle des analyseurs de signaux; (c) de mesurer directement les propriétés de la pluie par exemple la force d'impact, le moment, ou l'énergie. On prétend que cette dernière méthode est la mieux appropriée en raison des progrès de la technologie des transducteurs à magnétostriction. La méthode proposée pour standardiser la mesure du pouvoir érosif est d'abord une étude comparative des transducteurs de pression, suivie par la mise au point d'un instrument convenable en vue d'une production en masse importante donc économique. Il pourra alors être adopté et utilisé par un réseau international.

THE NEED AND THE PURPOSE

A worldwide assessment of the erosive power of rainfall would serve a number of purposes. In particular it would enable research workers and planners of soil conservation activities to compare relative erosion hazard in the same way that it is possible to compare mean annual rainfall or other climatic parameters which affect agricultural production. A secondary advantage would be that research workers would be able to quantify the effect of rainfall and thereby eliminate one variable when studying the complicated interactive effect of the factors which influence soil erosion.

While on a worldwide basis a fairly crude estimate of erosivity would be sufficient, there is also a need for more detailed studies applicable to a particular region or climatic zone. A parallel is the study of rainfall. A general picture may be obtained from isohyets of mean annual rainfall mapped at national or continental scale, but there is also the need for more detailed studies of more specific or more localized application.

INSTRUMENTATION SPECIFICATION

When comparing the results of previous studies a major difficulty is that each research worker has developed his own technique and so it is not possible to compare them directly. Even when the same basic principle is used, e.g. the flour pellet method or the dyestain method, there is no generally accepted technique. This is illustrated in Fig. 1 which shows the relationship between kinetic energy and intensity. The five studies were scattered across the world, and if the results were comparable they would provide useful information on the variation in rainfall; but there is no way of determining whether the differences are real variations in the rainfall characteristics or the result of different techniques.

There is a powerful argument for the adoption of standard instrumentation and methodology. It is likely that two levels of instrumentation are required. The specification for obtaining a relatively coarse assessment on a worldwide scale would be that the method should be cheap, simple, robust, and capable of producing a large quantity of information even at the expense of accuracy or sensitivity. Again, the parallel is the collection of rainfall data. The reliability and accuracy of monthly and annual rainfall data are often low. However, the sheer volume of data available means that comparisons and evaluations on a world-wide scale or continental scale are possible.

For detailed studies the specification would be for more sophisticated technology. It would probably be used primarily by research workers and would produce more detailed information with a higher degree of accuracy. Again the comparison with precipitation measurements is valid. A study of precipitation measurements for localized research purposes will contain instruments of greater complexity, producing more detailed information than the national network of standard raingauges.

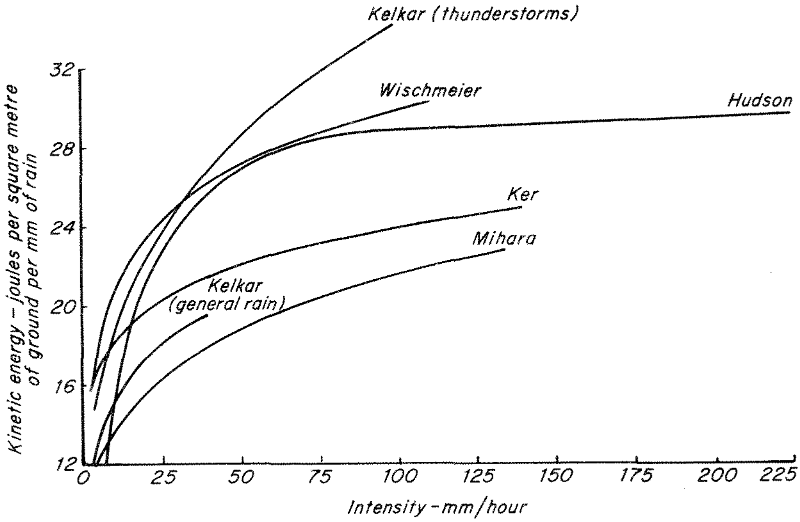

Fig. 1 The relation between kinetic energy of rainfall and intensity. Kelkar was working in India, Wischmeier in America, Hudson in Zimbabwe, Ker in Trinidad, and Mihara in Japan.

REVIEW OF AVAILABLE METHODS

Direct measurement of erosion

The simplest way of measuring the capacity of rain to cause erosion is to measure how much erosion is actually caused. For the measurement of splash erosion this is fairly straightforward and the Ellison splash cup has been widely used as a standard for nearly 40 years (Ellison, 1944). This method is extremely useful when the detachment phase of the erosion process is the limiting factor, and a measurement of splash, even under artificial conditions, will give a useful indication of the total soil movement. Attempts to extend the direct measurement of splash erosion to the field situation are less reliable and satisfactory as pointed out by Morgan (1981).

In summary, the use of Ellison type splash cups using a standard sand under controlled conditions is a useful, precise, and reliable technique for the direct measurement of splash, but the extension of this result to assessments of erosivity is only valid when detachment by splash is the dominant factor.

Assessment of erosivity from rainfall

Rainfall quantity There will obviously be some degree of correlation between erosive power and the amount of rainfall. A number of correlations have been established in localized conditions, e.g. in Malaysia Morgan (1974) established a correlation between erosivity and the 10-year daily rainfall amounts. In Rhodesia, Elwell & Stocking (1975) obtained reasonable agreement with rainfall based on the concept of selecting only rainfalls within defined limitations of amount and duration. However, the large variations in rainfall, both temporal and spatial, mean that this approach can only yield empirical results of limited local application.

The attraction of using readily available data on amounts of rainfall has also led to a search for a method which will allow worldwide application, and the method developed by Fournier some years ago has recently attracted interest (Fournier, 1960). Originally the Fournier index was intended as a guide to the potential for geological erosion on a large scale, and was based on correlating rainfall with sediment load measured in the major rivers of Africa. Since the only data required are mean monthly rainfall totals the method has great appeal for worldwide surveys, and a modified version was introduced for the FAO study of soil degradation (Arnoldus, 1980). A first approximation of a worldwide map of erosivity using this modified Fournier principle has been produced (Kingu, 1980). From the crude nature of the input such models can naturally only give a first approximation of erosivity and more accurate estimations must depend on more detailed inputs.

Other rainfall properties There is now a great deal of evidence showing that the erosive power of rainfall is dependent not only on the amount of rainfall but also on the physical characteristics of the rain. The dominant characteristics appear to be drop size which is related to terminal velocity, and combinations of mass and velocity into energy or momentum. It seems highly probable therefore that the key to erosivity lies in an analysis of the physical characteristics of rainfall and this approach has attracted the attention of many research workers.

A general review of rainfall properties is given by Mason (1971). There is now a substantial body of information on the shape and the fall velocity of raindrops, and interest now centres on drop size and size distribution. A detailed review of the large range of possible methods is given by Hudson (1964a).

The two methods most popular for studies related to erosivity are the dyestain method and the flour pellet method. The flour pellet method is simple to operate and is attractive in situations where the high labour input is not a disadvantage (Hudson, 1964b). The dyestain method, reviewed by Hall (1970), is increasingly attractive because the previously tedious job of counting the images can now be accomplished by the use of electronic scanners and image analysers (Attle *et al.*, 1980).

Empirical indexes from rainfall Empirical methods have in my view received a disproportionate amount of attention and this probably stems largely from the success of the EI_{30} index of Wischmeier (1958). Unfortunately the success and attraction of the method has led to over-enthusiastic extrapolation (Wischmeier, 1977). The danger of extending empirical methods beyond the area of their validity is shown by the recent changes in the method of calculating EI_{30} (Wischmeier & Smith, 1978). Many previous studies in high intensity rainfall using the old EI_{30} are now meaningless until re-calculated.

The need therefore is to collect basic data on the physical characteristics of rainfall so that these may be combined into either locally valid empirical indices of erosivity, or into physically meaningful parameters such as kinetic energy which can be universally if crudely approximated to erosivity.

Direct measurement of energy

Even if detailed and accurate information on drop size and drop size distribution has been collected, there still remains the problem of combining these data with terminal velocity into momentum, kinetic energy, or some similar function, and so it is not surprising that many attempts have been made to record energy or momentum directly. The small magnitude of the forces make it difficult to separate the signal from the noise in any device which depends upon moving parts. It is probable therefore that attention will increasingly focus on the use of three possible methods:

(a) The acoustic principle in which the energy of rain is translated into sound and then into an electrical signal.

(b) Pressure transducers which measure the strain induced in a sensor by the impact of the rain.

(c) Sensors which depend upon the direct conversion of impact into an electrical signal through the use of a piezoelectric crystal.

Acoustic methods In this method the noise of the rain falling on a diaphragm is picked up by a microphone which gives out a measurable signal. The advantage is that the sound signal is integrated across the whole of the raindrop spectrum (Kinnell, 1972). Also by tuning the circuit this method can be adjusted to measure intensity, or momentum, or kinetic energy (Hudson, 1965). The sensor can be quite large so that a representative sample of rainfall can be measured. It has been suggested that the physical effect of drops striking the diaphragm is the best physical representation of the effect of raindrop impact (de Wulf & Gabriels, 1980). This may link with recent theories of the effect of raindrop impact stress (Ghadiri & Payne, 1977).

The disadvantage of the acoustic method is that a drop striking the centre of the diaphragm may produce a different effect compared with a drop striking the edge of the diaphragm. This can be partially overcome by shielding all but the centre portion. Another disadvantage is that it is possible to make an individual instrument for a special purpose, e.g. calibrating the energy values of simulated rain (Hill, 1970), but much more difficult to manufacture uniform diaphragms which do not require individual calibrations.

Pressure transducers Several instruments have been developed to measure momentum by recording the physical displacement of a target sensor against an elastic spring (Neal & Baver, 1937), or against gravity (Rose, 1958; Hudson, 1965). The same principle is more elegantly used nowadays by the use of bonded strain gauges (Webster, 1980). Another application of the physical deflection of a target has been the measurement of irrigation drops (Schleusener, 1967).

Alternatively the target sensor could be a diaphragm pressure transducer and it would seem feasible to use the unbonded strain-gauge type, or the linear variable displacement type, or capacitance, or semi-conductors (Bass, 1971; Henry, 1975). These could all be classed as high-inertia pressure transducers and are fairly sophisticated, and at the present time expensive. They are probably more suitable for research instruments than meeting the requirements for a cheap, simple, robust instrument for widespread use in the field.

Piezoelectric sensors This device is used in gramophone record players, where changes of pressure on a quartz crystal generate an electric signal. Several instruments for measuring raindrop size using this concept have been used, and the best known being the Joss-Waldvogel distrometer which is commercially available (Joss & Waldvogel, 1967; Kinnell, 1976). Apart from the question of the cost of the commercial instrument, the technical problems are (a) achieving the right balance between sensitivity and damping the echoes, and (b) the possibility of interference between drops which arrive at the sensor in rapid succession.

A piezoelectric sensor used with unsophisticated sorting and storage equipment gave important results in Nigeria (Kowal & Hassam, 1977). Another simple but effective application of the method is that of Heuveldop & Kruse (1978) whose instrument, developed in Germany, has been used to good effect in Venezuela (Capriles-Paez, 1978). Several other similar applications are currently being developed, and at the moment this appears to be the most promising line of instrumentation for further development.

There remains the question of how to filter, grade, sort, and store the data generated by the sensor. There are plenty of possibilities to investigate. Direct printout might be useful in research situations, or storage on tape or disc. The whirlwind pace of development in microprocessors suggests that the solution which will be most suitable in 2 years' time, is today still on the drawing board, but it would seem probable that a solid-state "black box" will soon be available to meet the requirements of a robust instrument which can be mass produced cheaply.

CONCLUSIONS AND PROPOSALS

Standardization of methods is desirable, but it should be directed towards equipment which will provide basic data on drop size distribution or energy, and not towards a search for a universal index of erosivity. The first phase, materially helped by this conference, is to collect information on all current and recent studies. The next phase is to make a comparative study of the alternative methods. This should be followed by the development of one or more prototypes for testing, and eventually the adoption and use by an international network.

An application has been submitted to WMO for assistance to accelerate the research programme in this subject which is currently being followed at the National College of Agricultural Engineering. Another possibility is that the International Society of Soil Science is currently proposing the establishment of an international organization to coordinate studies of soil erosion and soil conservation. The objectives and method of operation have not been finalized but it is quite likely that studies of rainfall erosivity might be supported by this organization. In 1982 there will be an international conference on soil conservation in Hawaii which will be primarily concerned with the establishment of international networks and organizations to work cooperatively on soil erosion and conservation.

There is a clearly defined need for standardization of instrumentation and methodology to study the erosivity of rainfall. There is also an excellent foundation of knowledge upon which to build, and there are opportunities in sight which could lead to a major breakthrough, and the achievement of the objectives.

REFERENCES

Arnoldus, H. M. J. (1980) An approximation of the rainfall factor in the USLE. In: *Assessment of Erosion* (ed. by M. de Boodt & D. Gabriels). Wiley, Chichester, UK.

Attle, J. R., Oney, D. & Swenson, R. A. (1980) Applications of image analysis. *American Laboratory*, April 1980.

Bass, H. G. (1971) *Introduction to Engineering Measurements*. McGraw-Hill, Maidenhead, UK.

Capriles-Paez, M. L. (1978) Algunos valores de energia alcanzada en lluvias simuladas (Some measured values of energy in simulated rainfall). MSc Thesis, Universidad Central de Venezuela.

de Wulf, F. & Gabriels, D. (1980) A device for analysing the energy load of rainstorms. In: *Assessment of Erosion* (ed. by M. de Boodt & D. Gabriels). Wiley, Chichester, UK.

Ellison, W. D. (1944) Studies of raindrop erosion. *Agric. Engng* 25, 131-136, 181-182.

Elwell, H. A. & Stocking, M. A. (1975) Parameters for estimating annual runoff and soil loss from agricultural lands in Rhodesia. *Wat. Resour. Res.* 11 (4), 601-605.

Fournier, F. (1960) *Climat et Erosion, la Relation entre l'Erosion du Sol par l'Eau et les Précipitations Atmosphériques*. Presses Universitaires de France, Paris.

Ghadiri, H. & Payne, D. (1977) Raindrop impact stress and the breakdown of soil crumbs. *J. Soil Sci.* 28, 247-258.

Hall, M. J. (1970) Use of the stain method in determining the drop-size distributions of coarse liquid sprays. *Trans. Am. Soc. Agric. Engrs* 30, 33-37, 41.

Henry, Z. A. (1975) *Instrumentation and Measurement for Environmental Sciences*. American Society of Agricultural Engineers, SP-0375.

Heuveldop, Von J. & Kruse, R. (1978) Ein Messgerat zur bestimmung kinetischer Energien in Regenniederschlagen bei forstökologischen Untersuchungen (An instrument for recording the kinetic energy of low intensity rain in studies of forest ecology). *Forstarchiv* 49 (10), 199-203.

Hill, R. J. A. (1970) An investigation into the energy levels produced in sprinkler irrigation storms for use in the measurement of soil final infiltration rates using disturbed soil samples. MSc Thesis (MS/70/15), National College of Agricultural Engineering, Silsoe.

Hudson, N. W. (1964a) A review of methods of measuring rainfall characteristics related to soil erosion. *Res. Bull. no. 1, Dept. of Conservation, Salisbury, Rhodesia.*

Hudson, N. W. (1964b) The flour pellet method for measuring the size of raindrops. *Res. Bull. no. 4, Dept. of Conservation, Salisbury, Rhodesia.*

Hudson, N. W. (1965) The influence of rainfall on the mechanics of soil erosion. MSc Thesis, University of Cape Town.

Joss, J. V. & Waldvogel, A. (1967) Ein Spectograph für Niederschlagstropher mit automatischer Auswertung (A spectograph for raindrop size measurement with automatic classification). *Pure and Appl. Geophys.* 68, 240-246.

Kingu, P. A. (1980) World map of erosivity. MSc Thesis (MS/80/190), National College of Agricultural Engineering, Silsoe.

Kinnell, P. I. A. (1972) The acoustic measurement of water drop impacts. *J. Appl. Met.* 11, 691-694.

Kinnell, P. I. A. (1976) Some observations of the Joss-Waldvogel rainfall distrometer. *J. Appl. Met.* 15, 499-502.

Kowal, J. M. & Hassam, A. H. (1977) Energy load and instantaneous intensity of rainstorms at Samaru, northern Nigeria. In: *Soil Conservation and Management in the Humid Tropics* (ed. by D. J. Greenland & R. Lal). Wiley, Chichester, UK.

Mason, B. J. (1971) *The Physics of Clouds*, 2nd edn. Oxford University Press.

Morgan, R. P. C. (1974) Estimating regional variations in soil erosion hazard in Peninsular Malaysia. *Malay. Nat. J.* 28 (2), 94-106.

Morgan, R. P. C. (1981) Field measurement of splash erosion. In: *Erosion and Sediment Transport Measurement* (Proc. Florence Symp., June 1981), . IAHS Publ. no. 133.

Neal, J. H. & Baver, L. D. (1937) Measuring the impact of raindrops. *J. Am. Soc. Agron.* 29, 708-709.

Rose, C. W. (1958) Effects of rainfall and soil factors on soil detachment. PhD Thesis, London University.

Schleusener, P. E. (1967) Drop size distribution and energy of falling raindrops from a medium pressure irrigation sprinkler. PhD Thesis, Michigan State University.

Webster, D. K. (1980) An investigation into the use of microprocessors for the measurement of rainfall intensity. BSc Dissertation (H/80/197), National College of Agricultural Engineering, Silsoe.

Wischmeier, W. H. (1977) Use and misuse of the USLE. In: *Soil Erosion Prediction and Control.* Soil Conserv. Soc. of Amer. Special Publ. 21.

Wischmeier, W. H., Smith, D. D. & Uhland, R. E. (1958) Evaluation of factors in the Soil-Loss Equation. *Agric. Engng* 39 (8), 458-462, 474.

Wischmeier, W. H. & Smith, D. D. (1978) Predicting rainfall erosion losses. *USDA Agric. Handbook 537.*