TEKA Kom. Mot. Energ. Roln. – OL PAN, 2008, 8a, 79–85

MODELLING FUNCTIONING PARAMETERS OF RAIN KINETIC ENERGY INDICATOR

Ryszard Konieczny

Institute for Land Reclamation and Grassland Farming (ILRGF) at Falenty,
Western Pomeranian Research Centre in Szczecin, Czesława Str. 9, 71-504 Szczecin, Poland,
e-mail: rkoniecz@poczta.onet.pl

Summary. The paper includes the structure and functioning principle of a new type of device to indicate the energy and measurement of rainfalls and outline information on the purpose of application of the technical solution in forecasting the phenomena of water erosion intensity of farming soils. The method of mathematical modelling of the functioning parameters was presented and kinetic energy of rainfall waters determined for specific farmland area with known slope of soil. Basing on relevant research it was assumed that the mathematical modelling of rainfall indicator functioning parameters and ability to determine the kinetic energy of rainfall water jet over farmland will enable effective agricultural engineering measures to be taken against the negative effects of water erosion of soils.

Key words: rainfall water parameter indicator, modelling, water erosion, farm soils.

INTRODUCTION

In the natural conditions of Poland the highest losses in the soils are caused by erosion [Licznar 1995]. The intensity of erosions depends on several factors [Nowocień 2008; Kowalczyk 2007; Patro 2005], of which rainfall deserves particular attention in terms of range, effects and length of reaction. It is estimated that rainfall is one of the immediate factors causing water erosion of soils and fading of aggregation [Grigoriev et al. 2008; Patro 2008; Owczarzak et al. 2006; Prokop 2005; Brodowski, Rejman 2004; Witkowska-Walczak et al. 2004], therefore, all the erosion preventing measures [Patro et al. 2008; Koreleski 2005; Józefaciuk et al. 2005] in agricultural conditions with regard to rainfall seem to be particularly justified. For 30% farmland and 1,4% forest areas [Jała, Cieślakiewicz 2004] the average annual values of soil losses are on the level of 76 $Mg \cdot km^{-2} \cdot year^{-1}$ [Wawer, Nowocień 2006; Juzefaciuk Cz., Juzefaciuk A. 1995]. The knowledge of rainfall parameters, including its kinetic energy constitutes the basis for modelling the complicated processes of water erosion of soils [Licznar 2008; 2007]. Thus, the development of measuring techniques of rainfall phenomena is the necessary element of further progress in recognition, description as well as modelling and forecasting of water erosion [Licznar et al. 2005], because no model has been developed so far to enable definition of the size of the soil drift in the natural conditions [Rejman 2006], and the dependencies established so far had arisen in virtue of tests with rainfall simulators only [Nowocień et al. 2002; Rejman et al. 1994] and had not been verified. A device called rainfall parameter indicator was developed at the Western Pomeranian Research Centre of the Institute for Land Reclamation and Grassland Farming in Szczecin, in order to meet such expectations [Konieczny 2008], the device was designed to record the strength of rainfalls and determine the kinetic energy of rain. The solution (Fig. 1) is a set of standard elements with a cylinder-shaped chamber open from the top, solidly integrated with the bottom. A dynamometer with LV conductors is mounted to the cylinder bottom, constituting a connector with measuring data recorder, while from the top the dynamometer has a working element in the form of a hollow hemisphere fixed by screw joint, situated with its convexity towards the rainfall vector. Start of the device and recording the strength of the rainfall takes place in the recorder with the use of relevant software.

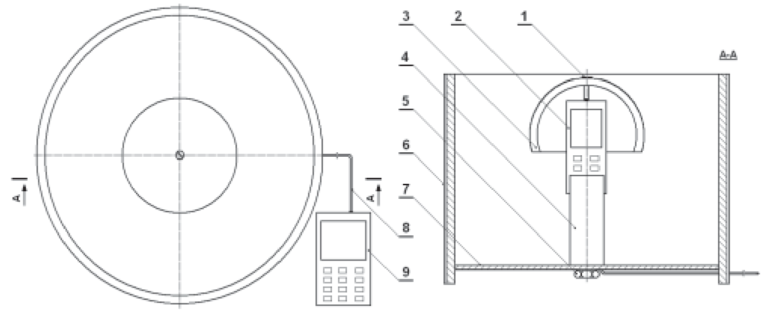

Fig. 1. Rainfall water parameter indicator developed at the Western Pomeranian Research Centre of the Institute for Land Reclamation and Grassland Farming in Szczecin: 1-top screw joint, 2-dynamometer, 3-hollow hemisphere, 4-dynamometer cantilever, 5-bottom screw-joint, 6-cylinder, 7-cylinder bottom, 8-LV conductors, 9-measuring data recorder

The purpose of this paper is to present the method of mathematical modelling of rainfall functioning parameter indicator and to determine the kinetic energy of rainfall water jet weight for farmland with known slope and area. It was assumed that the ability of mathematical modelling and appropriate parametrisation of rainfall waters in rural areas, based on scientific recognition of the soil drift, run-off and rainwash phenomena would enable the development of knowledge in the scope of water erosion of farming soils and bring about efficient agricultural engineering measures preventing erosion.

METHODS OF STUDY

The working element and cylinder of the rainfall parameter indicator was assumed as the modelling area. Basing on the open cylinder with inner diameter d=0,248m, base perforated with ř=0,001m holes in l=0,015m intervals and m_1=0,5kg water weight poured from the graduated cylinder to the open cylinder, the dynamic force F (N) of water drops falling during the time t=15s was recorded by means of measuring data recorder. The electronic recording of measuring data with recording transfer frequency f=10Hz was carried out with the use of dynamometer type FGC-0.5-B from Alluris GmbH & Co. KG [FMI... 2008] and Fmi Connect software Version 2.03 (EU) [Fmi Connect... 2008]. For the largest transverse plane of the working element (hollow hemisphere) covering the area A=0,0113m^2 the following formula was considered in modelling:

$$F_x = c_x \cdot A \cdot \frac{\rho \cdot v^2}{2} \qquad N, \tag{1}$$

for the dynamic force F_x in which the particular elements of equation (1) constitute:

c – head resistance coefficient, -

A – body plane area [m^2],

ρ – liquid density [$kg \cdot m^{-3}$],

v – fall speed [$m \cdot s^{-1}$],

x – marker corresponding to the direction of liquid jet weight.

The following were assumed as input data: c_1=1,33 of hollow hemisphere and c_2=1,11 of flat pulley; density ρ=1kg·m^{-3} and volume V=0,0005m^3 liquid; d=0,12m diameter of the hollow hemisphere; d_1=0,248m diameter of the cylinder; d_2=0,051m of the dynamometer cantilever. From the mathematical relations characterising the environment's effect on the working element of the rainfall parameter indicator, the input parameter, rainfall water kinetic energy E_k (J) was determined, with vector perpendicular to the surface S=10m^2 of the farmland defined by slope $\alpha=9^o$.

RESULTS

For drops of water of density ρ ($kg \cdot m^{-3}$), falling from the open cylinder with v ($m \cdot s^{-1}$) speed during the t (s) time of measurement, the following equation determined the weight m (kg) of the jet theoretically moving in plane of A (m^2) area of the largest cross-section of the hollow hemisphere of the rainfall parameter indicator:

$$m = \int \rho \cdot A \cdot v(dt) \qquad [kg], \tag{2}$$

where: index A in the form:

$$A = 0.25 \cdot \pi \cdot d^2 \qquad [m^2]. \tag{3}$$

is at the same time the cross-section of the column of liquid corresponding to d (m) diameter. Due to the fact that the rainfall water jet weight (2) in the particular transverse planes of the circular cross-section is equal to the sum of all the material points, the formula for the kinetic energy was determined by the following dependency:

$$E_k = \sum_{i=1}^{n} \frac{m_i \cdot v_i^2}{2} \qquad [J,], \tag{4}$$

where: upon consideration to expressions (2), (3) and t (s) time of force (1) measuring duration, based on equation:

$$E_k = \int_0^t \frac{\rho \cdot A \cdot v^3}{2}(dt) \; [J,], \tag{5}$$

the theoretical kinetic energy value was determined. As speed v ($m \cdot s^{-1}$) of weight m (kg) in expression (2) depends on the parameters of drops and causes problems with its estimation in natural conditions, therefore formula (4) and dependency (1) for dynamic force were used for determination of the actual value of rainfall water kinetic energy. For the t (s) time of measuring duration the following formula was obtained:

$$\Delta E_k = \frac{\sum_i^n m_i \cdot F_{xi}}{c_x \cdot A \cdot \rho} \quad [J,], \tag{6}$$

for kinetic energy increment. As the above dependency concerns the rainfall kinetic energy for F_x forces determined in relation to the hollow hemisphere with shape c_x=$c_1$coefficient only, thus the F_x parameter was established in the mathematical considerations of the device's functioning parameters, in the plane of the largest cross-section of the hollow hemisphere, corresponding to the surface of a flat pulley with c_x=c_2 shape coefficient. Based on the vectorial dependencies (1) for the hollow hemisphere and flat pullet, the F_x parameter value was determined in plane A by the following equation:

$$F_x = \frac{c_2}{c_1} \cdot \overline{F}_x \quad [N,], \tag{7}$$

where: the $\overline{F}_x$ (N) index is the arithmetic average dynamic force, estimated for each unit of (t=1s) time of duration of the experiment out of 10 measuring data of the rainfall water parameter indicator. Considering the determination of weight (2) theoretically moving through the surface of cross-section A, the following formula was determined:

$$V_c = \frac{\pi \cdot h_c \cdot (d_1^2 - d_2^2)}{4} \quad [m^3], \tag{8}$$

for V_c volume of water stored in the cylinder of rainfall water parameter indicator, where, upon consideration of the parameters:
d_1 – cylinder diameter, m;
d_2 – dynamometer cantilever diameter, m,

the actual h_c=0,011m height of the water column was calculated basing on the equation:

$$h_A = \frac{h_c \cdot (d_1^2 - d_2^2)}{d_1^2} \quad [m], \tag{9}$$

the theoretical h_A height of water column moving through the surface A of the circular cross-section of the hollow hemisphere during (t=15s) time of the experiment's duration was determined. Upon application of equation (9) for the h_A height of water column with base A to the formula:

$$V_A = A \cdot h_A \quad [m^3], \tag{10}$$

volume V_A=0,0001m^3 was calculated. Considering expressions (8), (10) and proportion based on m_1 weight of water stored in the cylinder of rainfall water parameter indicator, the actual value of parameter m=0,117kg was presented for equation (6). Regarding the slope α of soil in relation to weight (2) of rainfall water jet with circular cross-section (3), from the dependency:

$$A_1 = \frac{A}{\cos\alpha} \quad [m^2], \tag{11}$$

a fragment of surface A_1=0,0114m^2 of farmland for the considered S (m^2) area, and upon vectorial distribution of forces (7) from the formula:

$$F_{1x} = \frac{c_2}{c_1} \cdot \overline{F}_x \cdot \cos\alpha \quad [N], \tag{12}$$

the numerical value of the unit perpendicular dynamic forces in relation to dependencies (11) was estimated. Basing on equation (6), where c_x=c_2 parameter, dependency (12) and formula:

$$S = \sum_{n}^{i} A_1 \qquad [\mathrm{m}^2], \tag{13}$$

of which S based on (11) is the sum of partial farmland areas, the expression:

$$\Delta E_k = \frac{\sum_{i}^{n} m_i \cdot \left(\frac{\overline{F}_x \cdot \cos\alpha}{c_1}\right)_i}{S \cdot \rho} J, \tag{14}$$

determined the total value of E_k=0,0029J rainfall water kinetic energy. The dependency (14) presented in virtue of the practical use of rainfall water parameter indicator in rural areas, allows for efficient measures aimed at monitoring and determining the value of rainfall water kinetic energy and determination of water erosion of farming soils caused by rainfalls.

CONCLUSIONS

1. It was necessary to know the rainfall force value, head resistance coefficients for the hollow hemisphere and flat pulley, column height of water stored in the parameter indicator's cylinder and soil slope, in order to carry out mathematical modelling of rainfall water parameter indicator and to determine rainfall kinetic energy for farmland with known areas.
2. The determined value of rainfall water kinetic energy with water jet weight vector perpendicular to S=10m^2 farmland area represents E_k=0,0029J, basing on measuring data and mathematical considerations recorded by rainfall water parameter indicator.
3. The purposefulness of mathematical modelling of rainfall energy measuring device functioning parameters results from the ability to determine and monitor rainfall kinetic energy in all rural areas, i.e., upon prior scientific recognition of the drift, run-off and rainwash phenomena of soil under rainfall conditions – from agricultural engineering measures restricting the effects of water erosion of farming soils.

REFERENCES

Brodowski R., Rejman J., 2004. Określenie wpływu wilgotności i stanu powierzchni gleby wytworzonej z piasku gliniastego na spływ powierzchniowy i zmyw gleby. Acta Agrophysica, No 4 (3), pp. 619-624.

Fmi Connect, Version 2.03 (EU), 2008. Hans Schmidt & Co. GmbH. Waldkraiburg, Germany.

FMI Force Gauge, 2008. Alluris GmbH & Co. KG. Freiburg, Germany.

Grigoriev V., Piechnik L., Podsiadłowski S., 2008. Simplifi ed technique for the determination of soil aggregation in assessing the resistance of soils to erosion and defl ation. Ann. Warsaw Univ. of Life Sci. – SGGW. Land Reclamation No 39, pp. 151-158.

Jała Z., Cieślakiewicz D., 2004. Potencjalna erozja gleb w Karkonoskim Parku Narodowym. [In:] Štursa J., Mazurski K. R., Palucki A., Potocka J. (eds.), Geoekologické problémy Krkonoš. Sborn. Mez. Věd. Konf., Listopad 2003, Szklarska Poręba. Opera Corcontica, nr 41, s. 66-73.

Józefaciuk Cz., Nowocień E., Podolski B., 2005. Ocena melioracji przeciwerozyjnych w wybranych obiektach badawczo-wdrożeniowych. Acta Agrophysica, No 5 (2), pp. 291-305.

Juzefaciuk Cz., Juzefaciuk A., 1995. Erozja agroekosystemów. Biblioteka Monitorinku Środowiska, 186 str..

Konieczny R., 2008. Parametryzator wód opadowych. Patent application P-385568. Urząd Patentowy RP, 6 pp..

Koreleski K., 2005. Wybrane zagadnienia przeciwerozyjnej ochrony gleb w świetle wymogów zrównoważonego rozwoju. Acta Agrophysica, No. 5 (1), pp. 49-55

Kowalczyk A., 2007. Obliczanie wielkości erozji wodnej gleb na obszarach górskich. [In:] Woda-Środowisko-Obszary Wiejskie. Wyd. IMUZ Falenty, t. 7, z. 1 (19), s. 91-103.

Licznar M. 1995: Erozja gleb w Polsce. [In:] Środowisko glebowe – degradacja i zagospodarowanie. Cz. I. Zesz. Post. Nauk Roln., z. 418, s. 91-100.

Licznar P., 2007. Wstępna propozycja związku energii kinetycznej deszczu i warstwy opadu w warunkach polskich. Inżynieria ekologiczna, nr 18. Konferencja naukowa: „Rola Melioracji wodnych w inżynierii, kształtowaniu i ochronie środowiska". Wrocław-Polanica Zdrój, 19-21.09.2007. Wyd. Polskie Towarzystwo Inżynierii Ekologicznej, s. 43-44.

Licznar P., 2008. Nowa formuła związku pomiędzy warstwą opadu deszczu a jego energią kinetyczną. [In:] Rola melioracji wodnych w ochronie środowiska przyrodniczego. Zesz. Post. Nauk Roln., z. 526, s. 99-104.

Licznar P., Łomotowski J., Rojek M., 2005. Zintegrowany system pomiarów opadów atmosferycznych dla potrzeb badań nad erozją wodną. Acta Agrophysica, No. 5 (2), pp. 335-344.

Nowocień E., 2008. Wybrane zagadnienia erozji gleb w Polsce. Ocena zagrożenia gleb erozją [In:] Problem erozji gleb w procesie przemian strukturalnych na obszarach wiejskich, Studia i Raporty IUNG-PIB, Puławy, z. 10, s. 9-38.

Nowocień E., Podolski B., Wawer R., 2002. Badania ilościowe podatności różnych gatunków gleb na erozję wodną w warunkach symulowanego deszczu. Zesz. Probl. Post. Nauk Roln., nr 487, s. 175-180.

Owczarzak W., Kaczmarek Z., Szukała J., 2006. The influence of stockosorb hydrogel on selected structureforming properties of gray-brown podzolic soil and black earth. Journal of Research and Applications in Agricultural Engineering, Vol. 51 (3), pp. 55-61.

Patro M., 2005. Skutki ulewnych deszczów w zlewni lessowej zabudowanej małymi zbiornikami retencyjnymi. Acta Agrophysica, No. 5 (2), pp. 377-385.

Patro M., 2008. Infl uence of in-fi eld retention reservoirs on soil outfl ow from a catchment. Ann. Warsaw Univ. of Life Sci. – SGGW. Land Reclamation No. 39, pp. 103-109.

Patro M., Węgorek T., Zubala T., 2008. Ploughed-on terraces in loess landscape of strongly developed high plains. Ann. Warsaw Univ. of Life Sci. – SGGW. Land Reclamation No. 39, pp. 95-101.

Prokop P., 2005. Modelowanie erozji wodnej w klimacie monsunowym o najwyższych na świecie opadach (zlewnia Umiew, wyżyna Meghalaya, Indie). Acta Agrophysica, No. 5 (1), pp. 121-128.

Rejman J. Link M., Dębicki R. 1994. Podatność na erozję gleby lessowej w badaniach z symulowanym opadem deszczu. Rocz. AR w Poznaniu, nr 266 (14), s. 227-232.

Rejman J., 2006. Wpływ erozji wodnej i uprawowej na przekształcenie gleb i stoków lessowych. Rozprawy i Monografie Instytutu Agrofizyki PAN, Lublin, nr 136, ss. 91.

Wawer R., Nowocień E. 2006. Mapa erozji wodnej aktualnej w oparciu o Corine Land Cover 2000. Pamiętnik Puławski, z. 142, s. 537-546.

Witkowska-Walczak B., Turski M., Lipiec J., 2004. Analiza jakości agregacji gleb płowych wytworzonych z utworu piaszczysto-pyłowego i lessu. Acta Agrophysica, No. 4 (1), pp. 221-233.

MODELOWANIE PARAMETRÓW PRACY URZĄDZENIA DO WYZNACZANIA ENERGII KINETYCZNEJ DESZCZU

Streszczenie. W artykule przedstawiono budowę i zasadę działania urządzenia nowego typu do wyznaczania energii i pomiaru siły opadu wód atmosferycznych oraz w zarysie zapoznano z celowością stosowania technicznego rozwiązania w prognozowaniu zjawisk natężenia erozji wodnej gleb rolniczych. Zaprezentowano sposób matematycznego modelowania parametrów pracy urządzenia i wyznaczono dla określonej powierzchni gruntu rolniczego o znanym skłonie gleby energię kinetyczną wód opadowych. W oparciu o naukowe rozważania założono, że matematyczne modelowanie parametrów pracy parametryzatora wód opadowych oraz umiejętność wyznaczania energii kinetycznej strumienia deszczu atmosferycznego nad gruntami użytkowanymi rolniczo umożliwi skuteczne agrotechniczne działania przed negatywnym skutkiem erozji wodnej gleb.

Słowa kluczowe: parametryzator wód opadowych, modelowanie, erozja wodna, gleby rolnicze.