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COMPARISON OF RILL EROSION MODELING ACCORDING ULSE EQUATION AND MITAŠOVÁ METHODOLOGY AND PARAMETERS IN GIS USING VARIOUS CROP MANAGEMENT

PORÓWNANIE MODELOWANIA EROZJI STRUMYKA NA PODSTAWIE PROGRAMU USLE, METODOLOGII MITAŠOVEJ I PARAMETRÓW W GIS PRZY RÓŻNYM UŻYTKOWANIU

Lenka Grešová, Elena Kondrlová, Jozef Streďanský, Tomáš Urban, Anna Streďanská

Slovak University of Agriculture, Nitra

Abstract. Water erosion is considered as one of the major factors causing physical soil degradation in Slovakia. The moderate up to the extreme potential erosion risk was assessed about 65% of Slovak agricultural soil fund. Most studies concentrated on the application of empirical formulae, such as the Universal Soil Loss Equation (USLE), which is not always the appropriate tool for erosion studies. It was designed as a method to predict average annual soil loss caused by sheet and rill erosion, the USLE is often criticized for its lack of applications. While it can estimate long-term annual soil loss, it can not be applied to a specific year or a specific storm. To incorporate the impact of flow convergence, the hill slope length factor was replaced by upslope contributing area [Moore and Burch 1986, Mitašová et al. 1995, 1996, Desmet and Govers 1996]. The modified equation for computation of the LS factor is finite difference form in a grid cell representing a hillslope segment was derived by Desmet and Govers [1996]. Geographic information system is modern tool that enable the various equation for water erosion calculation to have a spatial variability. The final model locates potential erosion areas which need control and preventive measures according degree of erosion focused on rill the hill erosion.

Streszczenie. Erozja wodna jest uważana za jeden z głównych czynników powodujących fizyczną degradację gleby na Słowacji. Oceniono, że około 65% słowackiego areału rolnego zagrożonych jest erozją w stopniu od umiarkowanego do skrajnego. Większość

Corresponding author – Adres do korespondencji: Ing. Lenka Grešová, PhD., Faculty of Horticulture and Landscape Engineering, Department of Landscape Planning and Ground Design Slovak University of Agriculture, Hospodárska 7, 949 76 Nitra, Slovak Republic, e-mail: lenka.gresova@gmail.com.

badań koncentruje się na zastosowaniu formuł empirycznych, takich jak Universal Soil Loss Equation (USLE), który nie zawsze jest właściwym narzędziem do badań erozji. Zaprojektowany jako metoda przewidywania średnich rocznych strat gleby powodowanych przez erozję strumyka USLE bywa często krytykowany za brak aplikacji. Chociaż można za jego pomocą oszacować straty gleby dla długiego okresu, to jednak nie może być on zastosowany dla specyficznego roku lub zjawiska. Aby uwzględnić wpływ zbieżności przebiegu, współczynnik nachylenia i długości stoku został zastąpiony przez powierzchnię zasilającą [Moore i Burch 1986, Mitašová i in. 1995, 1996, Desmet i Govers 1996]. Zmodyfikowane równanie do obliczania współczynnika LS jest formą pokazującą różnicę w komórce siatki reprezentującej segment stoku zbocza, która została wyprowadzona przez Desmet i Govers (1996). System Informacji Geograficznej to nowoczesne narzędzie, które umożliwia wprowadzanie różnych równań do obliczeń erozji wodnej uwzględniających zmienność przestrzenną. Ostateczny model lokalizuje potencjalne obszary erozji, które wymagają kontroli i środków zapobiegawczych, według stopnia erozji skupiając się na erozji strumyka.

Key words: rill erosion, USLE, Mitašová methodology

Słowa kluczowe: erozja strumyka, USLE, metodologia Mitašovej

INTRODUCTION

Soil erosion is the most important form of physical degradation of soils in Slovakia. Due to the action of erosion factors, it comes to topsoil layer eroding, the loosened soil particles are further transported and accumulated in other positions down slope or they reach water bodies. Dealing with the degradation of soil and water quality is not straightforward because the agriculture contribution to diffuse pollution varies widely as a complex function of soil type, climate, topography, hydrology, land use and management. Soil together with water, air, rocks and organisms is a fundamental component of the biosphere [Halva and Kliment 2004]. In order the soil could persistently or permanently carry out its irreplaceable functions, the society must ensure the protection of its quality and quantity. Recently, soil degradation processes have reached such intensity and extent that they are classified as the most serious environmental problems and therefore the issue of soil protection belongs to the latest environmental issues. In Slovakia, about 50% of agricultural land is threatened by water erosion [Jambor et al. 2005]. Despite of the availability of many simulation models, because of its simplicity and worldwide use, USLE is still applied in Slovakia, e.g. in the ongoing land consolidation projects. The USLE, developed by ARS scientists W. Wischmeier and D. Smith, has been the most widely accepted and utilized soil loss equation for over 30 years. The USLE is mature technology and enhancements to it are limited by the simple equation structure. To incorporate the impact of flow convergence, the hillslope length factor was replaced by upslope contributing area [Moore and Burch 1986, Mitasova et al. 1995, 1996, Desmet and Govers 1996, Tárnik and Šinka 2012]. The modified equation for computation of the LS factor is finite difference form in a grid cell representing a hillslope segment was derived by Desmet and Govers [1996]. Geographic information system is powerful set of tools used to collect, store, retrieve, transform and display spatial data from the real world for a particular purpose [Borrough 1986]. The limit values for total soil loss caused by water erosion are set in Slovak Technical Norm 75 4501 and in Law no. 220/2004.

Table 1. Comparison of acceptable total erosion
Tabela 1. Porównanie dopuszczalnej całkowitej erozji

The depth of soil Miąższość gleby m	Total erosion, t · ha^{-1} · year^{-1} Całkowita erozja, t · ha^{-1} · rok^{-1} STN 75 4501	Total erosion, t · ha^{-1}·year^{-1} Całkowita erozja, t · ha^{-1} · rok^{-1} Law nr 220/2004
< 0.30	1.0	4.0
0.30–0.60	4.0	10.0
0.6–0.9	10.0	30.0
> 0.9	10.0	40.0

The aim of this paper was to compare the USLE equation and its LS factor calculation with the methodology by Mitašová, 1995 using various crops. The area we selected is one field in the watershed of small river Jasenok.

MATERIAL AND METHODS

The selected area is one field in the watershed of small river Jasenok. The river is situated in the cadastral area of Plavnica in Stará Ľubovňa district, north-east Slovakia. We choose one field, which is the most endangered by rill erosion, which regularly occurs there. Soil conditions are created with predominant soil unit cambisoil pseudogley.

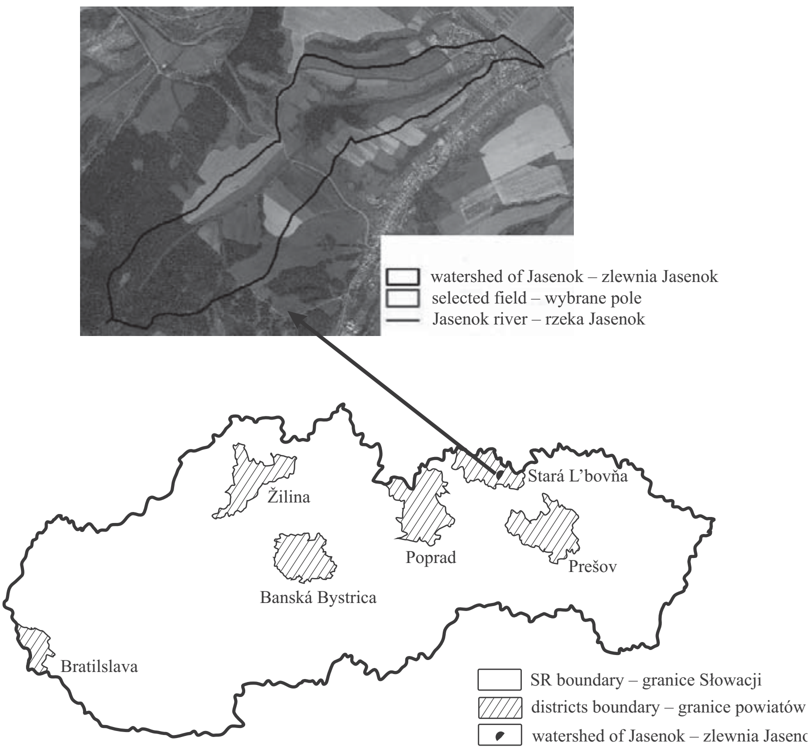

Fig. 1. Watershed of Jasenok – selected field, localization within Slovakia
Rys. 1. Zlewnia Jasenok – usytuowanie wybranych pól na Słowacji

The Universal Soil Loss Equation (USLE) predicts the long term average annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system and management practices. Water erosion is mostly expressed in the Universal Soil Loss Equation [Wischmeier and Smith 1978].

INTRINSIC LIMITATIONS OF THE USLE MODEL

- The model applies only to sheet erosion since the source of energy is rain; so it never applies to linear or mass erosion.
- The model applies only for average data over 20 years and is not valid for individual storms [Williams 1975].

To calculate water erosion we used Universal Soil Loss Equation Wischmeier-Smith [Wischmeier and Smith1978], known as USLE

$$S_p = R \cdot K \cdot L \cdot S \cdot C \cdot P$$

R is the rainfall and runoff factor by geographic location. The grater the intensity and duration of the storm is, the higher is the erosion potential.

K is the soil erodibility factor. It is the average soil loss in tons/acre per area for a particular soil in cultivated, continuous fallow with an arbitrarily selected slope length of 72.6 ft and slope steepness of 9%. *K* is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff.

C is the cover-management factor. The *C*-factor is used to reflect the effect of cropping and management practices on erosion rates. It is the factor used most often to compare the relative impacts of management options on conservation plans. The *C*-factor indicates how the conservation plan will affect the average annual soil loss and how that soil loss potential will be distributed in time during construction activities, crop rotations or other management schemes.

P is a factor that takes account of specific erosion control practices such as contour tilling or mounding, or contour ridging. It varies from 1 on bare soil with no erosion control to about 1/10 with tied ridging on a gentle slope.

LS is the slope length-gradient factor. It represents a ration of soil loss under given conditions to that at a site with the „standard" slope steepened of 9% and the slope length of 72.6 feet. The stepper and longer the slope, the higher is the risk for erosion.

$$LS = l_d^{0,5} \cdot (0.0138 + 0.0097 \cdot s + 0.00138 \cdot s^2)$$

LS factor modified for complex terrain

To incorporate the impact of flow convergence, the hillslope length factor was replaced by upslope contributing area A [Moore and Burch 1986, Mitašová et al. 1995, 1996, Desmet and Govers 1996]. The modified equation for computation of the *LS* factor is finite difference form in a grid cell representing a hillslope segment was derived by Desmet and Govers [1996]. A simples form of the equation for computation of *LS* factor at a point $r = (y, x)$ on a hillslope [Mitašová et al. 1996] is

$$LS(r) = (m+1) \cdot \left[\frac{A(r)}{a_0} \right]^m \cdot \left[\frac{\sin b(r)}{b_0} \right]^n$$

where:

A	– unslope contributing area per unit contour width, m,
b	– the slope, deg,
m and n	– parameters,
$a_0 = 22.1$ m = 72.6 ft	– the length,
$b_0 = 0.09 = 9\% = 5.16$ deg	– the slope of the standard USLE plot.

Choosing exponent parameters

The typical values for $m = 0.4–0.6$ and $n = 1.0–1.4$ depending on the prevailing type of flow (higher values are for more rilling). Lower values for m and n should be used for areas with prevailing dispersed flow, such as areas well covered with vegetation. Higher values should be used for areas with a more turbulent type of flow caused by existing rills or disturbed areas [Mitasova et al. 1999].

RESULTS

R factor was equal for the entire field, set to value 18.89.

Texture is principal factor affecting *K* factor, but structure, organic matter and permeability also contribute. To set the *K* factor in our area we used the values of the main soil unit of evaluated soil ecological units (Table 1).

Table 1. *K* factor values based on Main Soil Unit (HPJ)
Tabela 1. Wartość współczynnika *K* opartego na jednostce głównej gleby (HPJ)

Code – Kod HPJ	*K* factor – Współczynnik *K*
63	0.30
69	0.25
78	0.40
82	0.40

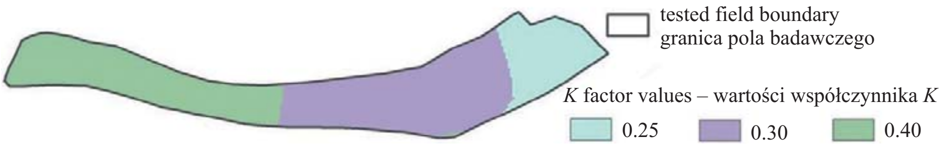

Fig. 2. *K* factor values based on HPJ in the selected field
Rys. 2. Wartość współczynnika *K* opartego na HPJ na wybranym polu

The *C* factor resulting is a generalized *C* factor value for a specific crop that does not account for crop rotations or climate and annual rainfall distribution for the different agricultural regions of the country. This generalized *C* factor, however, provides relative numbers for the different cropping and tillage systems.

Table 2. *C* factor values
Tabela 2. Wartość współczynnika *C*

Crop – Uprawa	*C* factor value Wartość współczynnika *C*
Winter wheat (*Triticum aestivum*) Pszenica ozima	0.12
Sunflower (*Helianthus annuus*) Słonecznik	0.22
Sugar beet (*Beta vulgaris*) Burak cukrowy	0.6
Permanent grass cover Trwały użytek zielony	0.005

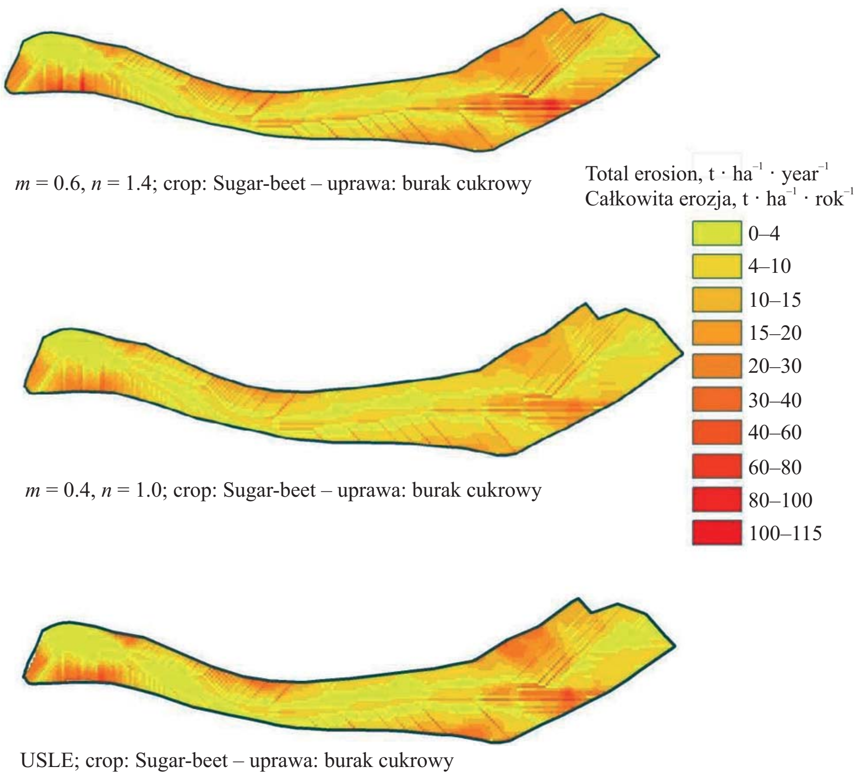

Fig. 3. The comparison of total erosion soil loss ($t \cdot ha^{-1} \cdot year^{-1}$) using different parameters in *LS* factor by Mitašová and USLE

Rys. 3. Porównanie strat gleby przy całkowitej erozji ($t \cdot ha^{-1} \cdot rok^{-1}$) przy użyciu różnych parametrów, współczynnika *LS* Mitašovej i USLE

Fig. 4. Rill erosion in the selected field
Rys. 4. Erozja strumyka w wybranych polach

We tried to compare the minimum and maximum *m* and *n* values (0.4 and 0.6 for *m* and 1.0 and 1.4 for *n* values). Lower values for *m* and *n* should be used for areas with prevailing dispersed flow, such as areas well covered with vegetation. Higher values should be used for areas with a more turbulent type of flow caused by existing rills or disturbed areas [Mitašová et al. 1999].

Table 3. The comparison of total soil loss ($t \cdot ha^{-1} \cdot year^{-1}$) according various crops and *m, n* parameters
Tabela 3. Porównanie całkowitej utraty gleby ($t \cdot ha^{-1} \cdot rok^{-1}$) w różnych uprawach, parametry *m, n*

m/n	Total erosion, $t \cdot ha^{-1} \cdot year^{-1}$ Całkowita erozja, $t \cdot ha^{-1} \cdot rok^{-1}$			
	Helianthus annuus	*Triticum aestivum* L.	Permanent grass cover Trwały użytek zielony	*Beta vulgaris*
0.6/1.4	38.29	20.88	0.87	114.9
0.6/1.0	28.82	15.72	0.65	86.47
0.4/1.4	18.91	10.31	0.42	56.74
0.4/1.0	13.40	7.31	0.30	40.22
USLE	18.00	9.82	0.40	54.01

The highest soil loss was modeled by using *LS* factor by Mitašová, with highest parameters $m = 0.6$ and $n = 1.4$ as we supposed as lower values for *m* and *n* should be used for areas with prevailing dispersed flow, such as areas well covered with vegetation. Higher values should be used for areas with a more turbulent type of flow caused by existing rills or disturbed areas. The USLE calculation is comparable with Mitašová *LS* (parameters $m = 0.4$ and $n = 1.4$) where the results of total erosion were similar. According the terrain

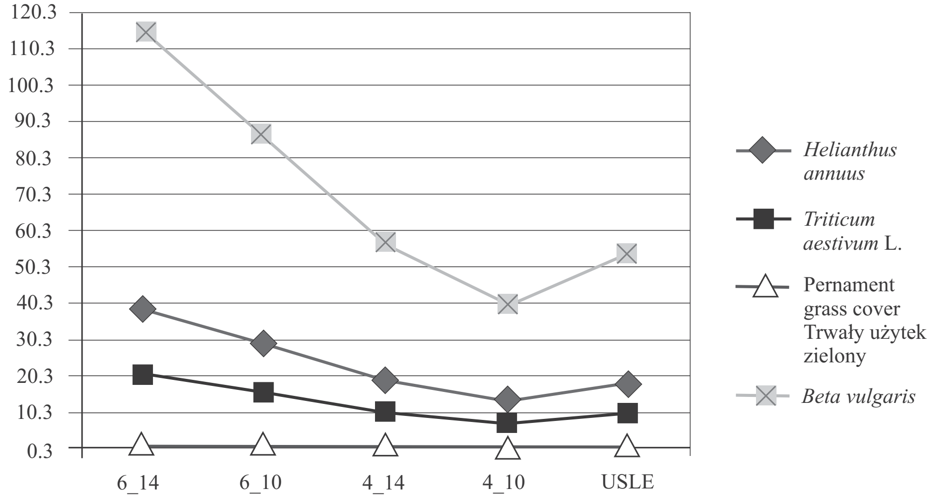

Fig. 5. The comparison of total soil loss (t · ha^{-1} · year^{-1}) according various crops and m,n parameters and USLE calculation

Rys. 5. Porównanie całkowitej utraty gleby (t · ha^{-1} · rok^{-1}) w różnych uprawach, parametry *m, n* i obliczenia USLE

measurements and observance we suppose and can admit that in the areas disturbed by visually seen rill erosion it is better to use the parameters of m = 0.6 and n = 1.4. USLE equation calculation has no potential to model rill erosion as it is.

Unreasonable interventions to landscape lead to irreversible changes and degradation. The most notable it is in surface-runoff and water erosion increase [Muchová and Konc 2010].

The eroded material, as the result of the water erosion phenomena, is silted in the water basins as the part of the water basin sediments. Fuska [2011] states the methodology for the measurement of the sediment quantity in the water basins with the usage of the sonar mapping of the water basins.

CONCLUSION

Universal Soil Loss Equation (USLE), which is not always the appropriate tool for erosion studies. It was designed as a method to predict average annual soil loss caused by sheet and rill erosion, the USLE is often criticized for its lack of applications. To incorporate the impact of flow convergence, the hillslope length factor was replaced by upslope contributing area A [Moore and Burch 1986, Mitašová et al. 1995, 1996, Desmet and Govers 1996]. The modified equation for computation of the *LS* factor is finite difference form in a grid cell representing a hillslope segment was derived by Desmet and Govers [1996]. We choose one field, which is the most endangered by rill erosion, which regularly occurs there. The aim of this paper was to compare the USLE equation and its *LS* factor calculation with the methodology by Mitašová [1995] using various crops. The area we selected is one field in the watershed of small river Jasenok.

We tried to compare the minimum and maximum *m* and *n* values (0.4, 0.6 for *m* and 1.0 and 1.4 for *n* values). Lower values for *m* and *n* should be used for areas with prevailing dispersed flow, such as areas well covered with vegetation. Higher values should be used for areas with a more turbulent type of flow caused by existing rills or disturbed areas [Mitašová et al. 1999]. According the terrain measurements and observance we suppose and can admit that in the areas disturbed by visually seen rill erosion it is better to use the parameters of $m = 0.6$ and $n = 1.4$. USLE equation calculation has no potential to model rill erosion as it is.

REFERENCES

Act No. 220/2004-Soil Protection Law.

Borrough P.A., 1986. Principles of Geographic Information System for Land resources assessment. Oxford University Press New York.

Desmet P., Grovers G.,1996. A GIS pro cedure for automatically calculating the USLE LS factor on topographically complex landscape units. J. Soil Water Conserv. 51(5), 427–433

Fuska J., 2011. The usage of Digital Terrain Model of the small water basin bottom for the quantification of the bottom sediments. Dissertation thesis. Slovenská poľnohospodárska univerzita Nitra.

Halva J., Kliment M., 2004. Porovnanie eróznej ohrozenosti územia z ortofotomáp a z univerzálnej rovnice straty pôdy. [In:] Bioklimatologické pracovné dni. Slovenská poľnohospodárska univerzita Nitra.

Jambor P., Ilavská B., Lazúr R., 2005. Identifikácia ohrozenia kvality pôdy vodnou a veternou eróziou a návrhy opatrení. VÚPOP Bratislava, pp. 52.

Kalúz K. et al., 2010. Poškodzovanie poľnohospodárskej výroby imisiami. Slovenská poľnohospodárska univerzita Nitra.

Mitasova H., Mitas L., Brown W.M., Gerdes D.P., Kosinovsky I., Baker T., 1995. Modeling spatially and temporally distributed phenomena: new methods and tools for GRASS GIS. Int. J. Geogr. Inform. Sci. 9(4), 433–446.

Mitasova H., Mitas L., Brown W.M., Gerdes D.P., Kosinovsky I., Baker T., 1996. Modeling topographic potential for erosion and deposition using GIS. Int. J. Geogr Inform. Sci. 10(5), 629–641 [reply to a comment to this paper appears in 1997 in Int. J. Geogr. Inform. Sci. 11(6)].

Mitasova H., Mitas L., Brown W.M., Gerdes D.P., Kosinovsky I., Baker T.,, 1999. Spatial modeling of soil detachment with RUSLE 3d. Engin. Res. Develop. Cent. http://skagit.meas.ncsu.edu/~helena/gmslab/reports/CerlErosionTutorial/denix/Models%20and%20Processes/RUSLE3d/RUSLE3d.htm (7.04.2012).

Moore I., Burch G.,1986. Physical basis of the length-slope factor in the Universal Soil Loss Equation. Soil Soc. Amer. J. 50, 1294–1298.

Muchová Z., Konc L., 2010. Pozemkové úpravy – postupy, prístupy a vysvetlenia. Vydavateľstvo SPU Nitra.

Slovak Technical Standard No. 75 4501 – Conservation of Agricultural Soils. Basic regulations.

Tárnik A., Šinka K., 2012. Vplyv topografického faktora na výpočet vodnej erózie pôdy. [In:] Študentská vedecká konferencia FZKI. Slovenská poľnohospodárska univerzita Nitra, 72–77.

Williams J.R., 1975. Sediment yield prediction with USLE using runoff energy factor. [In:] ARS-S-40. Agr. Res. Serv. USDA Washington DC, 244–252.

Wischmeier W.H., Smith D.D., 1978. Predicting rainfall erosion losses – a guide to conservation planning. Agriculture Handbook. U.S. Department of Agriculture Hyatsville, pp. 58.

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