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RESIDUE DECAY EQUATION FOR USE IN EVALUATING SOIL CONSERVATION SYSTEMS

by

J. M. Gregory, Assistant Professor
T. R. McCarty, Assistant Professor
F. Ghidey, Graduate Research Assistant
Agricultural Engineering Department
University of Missouri-Columbia

and

E. E. Alberts, Soil Scientist
USDA ARS, Columbia, Missouri

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SUMMARY: Two residue decay equations were developed. A simple exponential decay equation was developed by curve-fitting published data. A second equation was derived based on changing surface area. Both equations are relatively simple to use and are thus suitable in analyzing residue decay for soil conservation work.

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ABSTRACT

Two residue decay equations were developed. Both equations are relatively simple to use and are thus suitable in analyzing residue decay for the evaluation of residue management systems for soil conservation.

The first equation is a simple exponential decay equation using a time variable weighted for variations in temperature, rainfall, and initial carbon-nitrogen ratio of the residue. This equation was developed by fitting various published data sets.

The second equation was derived based on changes in surface area of the residue. The same collection of variables was used to adjust for effects of temperature, moisture, and residue type. Both equations fit the published data reasonably well.

INTRODUCTION

Residue decay is an important process which affects soil cover, nutrient release, insect populations, and disease outbreaks. With the development of chemicals for weed and insect control and conservation tillage equipment, it is presently possible to produce crops when the soil is covered with residue. A residue decay equation is one of the basic relationships needed to fully evaluate the various alternatives for soil and water conservation.

Various studies (Alberts and Shrader, 1980; Brown and Dickey, 1970; Miller and Johnson, 1964; Nyhan, 1975; Nyhan, 1976; Pal and Broadbent, 1975; Parker, 1962; Sain and Broadbent, 1977; Smith and Douglas, 1968; Volk, 1973; and Waksman and Gerretsen, 1931) have been performed to evaluate the decay process. It has been determined that a variety of microorganisms over a wide range of temperature and moisture conditions affect decomposition.

The objective of the present study was to develop a simple equation to describe residue decay which would be suitable for soil and water conservation evaluations. Previous models typically assume a first order reaction with time. The equation which results is an exponential decay equation. The problem with this form of equation is that the decay coefficient is not constant with time (Reddy et al., 1980). Reddy et al. (1980) have developed procedures to modify the simple exponential decay equation with time, but these procedures require data which are not easy to measure or estimate.

DEVELOPMENT OF SIMPLE MODEL

Two equations will be developed. The first equation is a modified exponential decay equation based on analysis of various data sets. The second equation is derived based on the assumption that decay varies directly with the surface area of the residue.

Development of First Model

Data from Parker (1962) was used first to develop an exponential decay equation with time. An exponential decay equation fits Parker's data reasonably well for both surface and buried residue (Fig. 1). This data was collected during the corn growing season in Iowa.

The same form of equation was tried for wheat decay data reported by Smith and Douglas (1968). This data set included more than one full year of decay with both winter and summer conditions. An exponential decay equation using time only was not adequate in fitting this data. It was then assumed that decay losses in residue might vary with the product of time and temperature similar to the degree growing concept for plant growth. Temperatures less then $0^{o}C$ were assumed to have zero effect. In other words, each day has a weighted effect depending on temperature. An exponential decay equation using the product of time and temperature gave a good fit (Fig. 2).

The data from Parker's work was rechecked using the product of time and temperature. The results were still satisfactory. His data was collected during a period of relatively small changes in air temperature.

Two exponential decay equations now existed using the product of time and temperature: one for corn data and one for wheat data. A variable was needed to explain the difference due to residue type. The initial carbon-nitrogen ratio of the residue was found to be a satisfactory variable to explain the effect of residue type (Fig. 3). This was somewhat surprising since the wheat data and the corn data experiments were performed in different locations as well as with different types of residue.

An exponential decay equation using the product of time and temperature divided by the initial carbon-nitrogen ratio seemed to be both simple and adequate except for one other study. This combination of variables was used with data from Alberts and Shrader (1980) with the results shown in Fig. 4. The problem with this data set was that dry weather occurred during the mid part of the study. During the dry weather, the decay essentially stopped. To circumvent this problem, the previous collection of variables was multiplied by a rainfall index used by Ligon and Johnson (1960) to estimate the anticident rainfall effect on infiltration. Rainfall data was not collected during the winter so a complete analysis was not possible. Only the data from the second point forward in the decay study could be used. The relationship is shown in Fig. 5. With the exception of one data point, the moisture index seems to be adequate to predict moisture effects on residue decay. Like the temperature effect, each day also has a weighted effect due to the rainfall index.

Based on the above analysis, the following equation was developed to predict residue decay

$$\frac{M}{M_o} = e^{-k\tau} \tag{1}$$

where,

M = present mass of residue,
M_o = initial mass of residue,
k = a calibration coefficient, and
τ = a time variable adjusted for temperature, and moisture conditions and the initial carbon-nitrogen ratio of the residue.

The variable τ is calculated with the next equation

$$\tau = \frac{TtA_m}{C/N} \tag{2}$$

where,

T = time (days),
t = temperature (^oC above zero),
C/N = initial carbon-nitrogen ratio, and

$$A_m = \sum_{i=1}^{5} \frac{I}{i} \tag{3}$$

where,

I = depth of rainfall on a given day, and
i = the day number with the present day being 1, the previous day being 2, etc.

All of the variables in this equation are either constants for a given residue type or are relatively easy to measure. Based on the data analyzed, this equation seems to be adequate for modeling residue decay for soil and water conservation work. The decay coefficient k seems to be nearly constant across residue types based on the buried corn and wheat residue analyzed. From the study of Parker (1962), it is obvious that the decay of surface residue is slower than that of buried residue. Thus k will vary depending on the placement of the residue.

Development of a Theoretical Equation

In the development of the next equation, two assumptions will be made:

1. Crop residue is considered to consist of solid stems of uniform length and diameter, and

2. Decay is assumed to start from outside the material and proceeds inward linearly with a weighted time variable τ as shown in Fig. 6.

Using the first assumption the decay or change of residue mass can be expressed as

$$dM = 2\pi RL\rho NdR \qquad (4)$$

where,

dM = change in mass of residue,
R = radius of one stem,
L = length of stem,
ρ = density of stem, and
N = number of stems per unit area.

From the second assumption, dR can be written as

$$dR = -ud\tau \qquad (5)$$

where,

τ = a weighted time variable as defined earlier, and
u = a constant.

Replacing dR in equation 4 with the value from equation 5 gives

$$dM = 2(\pi RL\rho N)ud\tau \qquad (6)$$

The mass per unit area can be expressed as

$$M = \pi R^2 L\rho N \qquad (7)$$

Dividing equation 6 by 7 we get

$$\frac{dM}{M} = \frac{-2}{R}ud\tau \qquad (8)$$

From equation 5 we know that R varies with τ. If the left side of equation 5 is integrated from the initial radius R to the final radius R_o and the right side is integrated from 0 (because at time t = 0, τ is equal to 0) to τ, the following function for R is obtained:

$$R = R_o - u\tau \qquad (9)$$

Equation 8 can now be written as

$$\frac{dM}{M} = \frac{-2ud\tau}{R_o - u\tau} \qquad (10)$$

Both sides of equation 10 can now be integrated. The initial limits of integration will be M_o for mass and 0 for τ. The final limits will be the present amount of mass M and the final weighted time value τ. This integration gives

$$\ln \frac{M}{Mo} = 2 \ln \left(1 - \frac{u\tau}{Ro}\right) \quad (11)$$

Taking the exponential of both sides and simplifying gives the following relatively simple equation for residue decay

$$\left[\frac{M}{Mo}\right]^{1/2} = 1 - \frac{u\tau}{R_o} \quad (12)$$

The first assumption is not entirely valid for all crop residues. The assumption was made to keep the math simple. To describe more complex geometry, the use of the ratio of solid area divided by perimeter (concept of hydraulic radius) can be used to replace R_o. This gives the ability to describe a range of conditions from round stems to flat paper-like leaves. In the case of wheat stems, only the solid cross sectional area would be used; thus R_o would be smaller than the R_o for a solid stem of the same diameter.

As a check on equation 12, the data from Parker (1962) and Smith and Douglas (1968) is shown in Fig. 7. Since rainfall data was not available the value for A_m was set at unity. The slope of the line in Fig. 7 is the value for u/R_o. From this comparison, the derived equation appears to fit the data reasonably well.

A similar check was made for the data of Alberts and Shrader (1980) shown in Fig. 8. Again the equation gave a reasonable explanation of the data.

SUMMARY AND CONCLUSIONS

Data sets from Parker (1962), Smith and Douglas (1968) and Alberts and Shrader (1980) were used to develop two residue equations. One equation was developed by curve fitting the data. The other equation was derived based on surface area changes. Both equations gave an adequate fit of the data. More work is needed to further verify the equations for other residue types. Field verification of these equations will be given by Ghidey et al. (1983).

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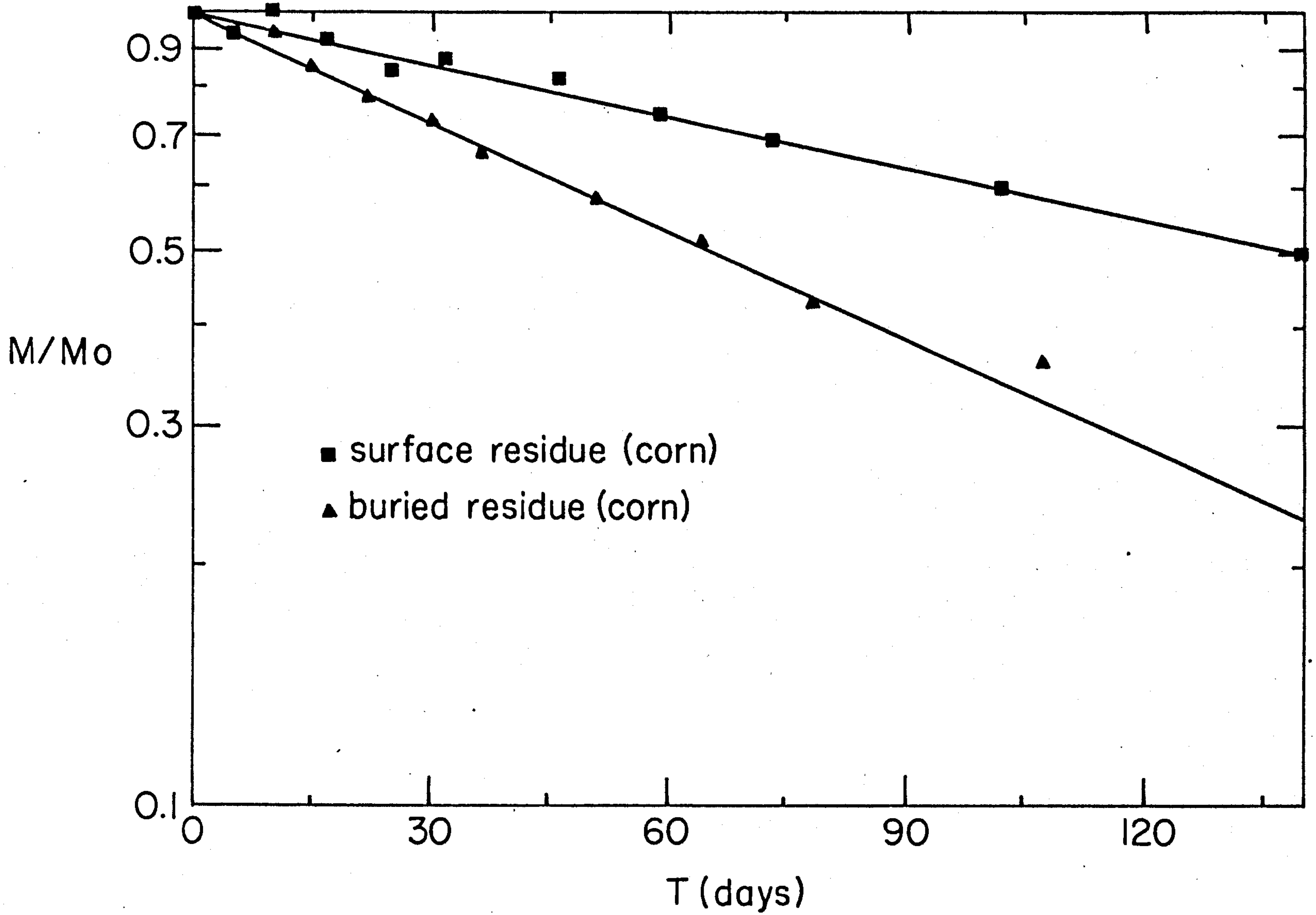

Fig. 1. Prediction of residue decay using an exponential equation of time. Data from Parker (1962).

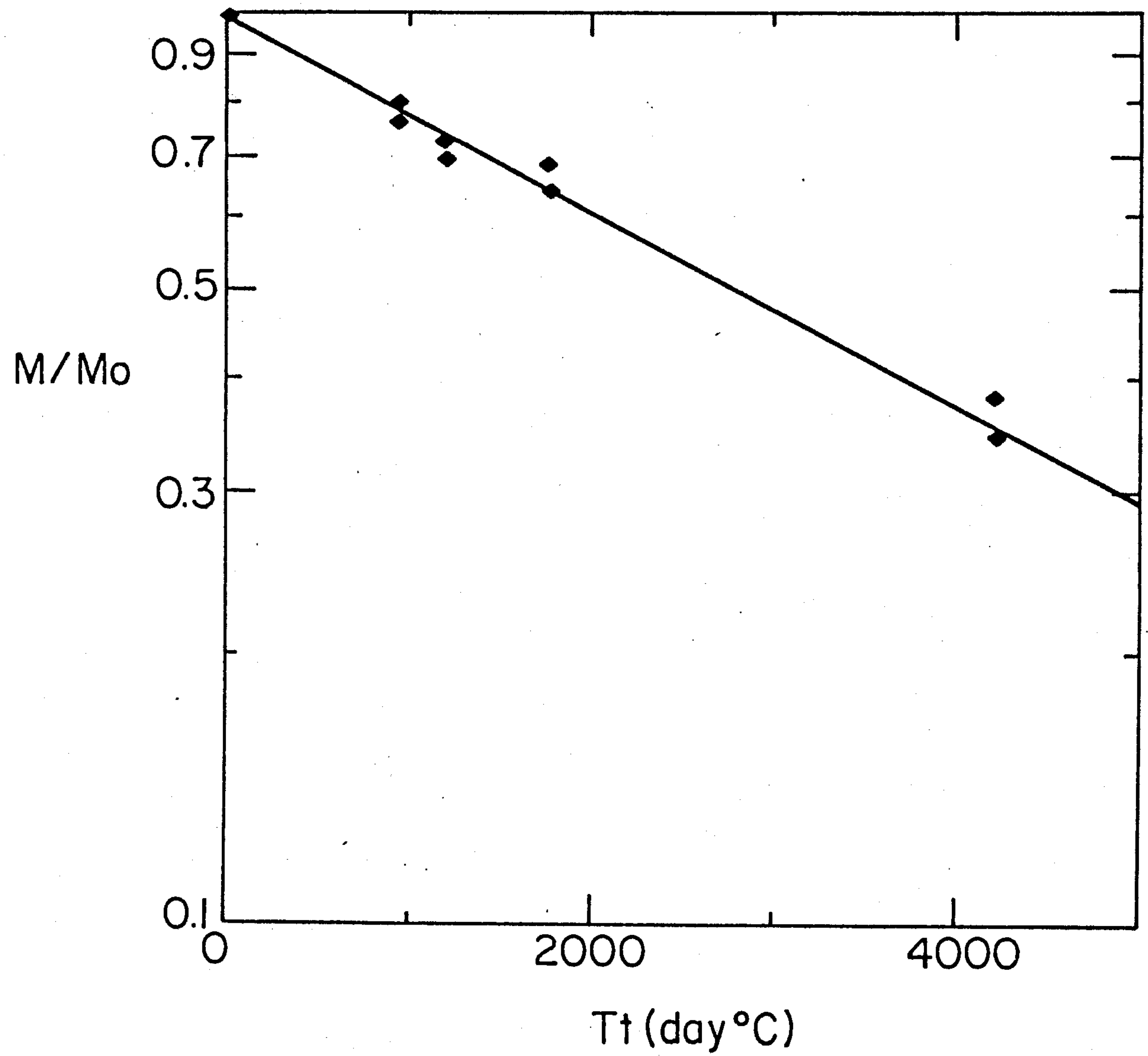

Fig. 2. Prediction of residue decay using an exponential equation of time weighted by air temperature above 0°C. Data from Smith and Douglas (1968).

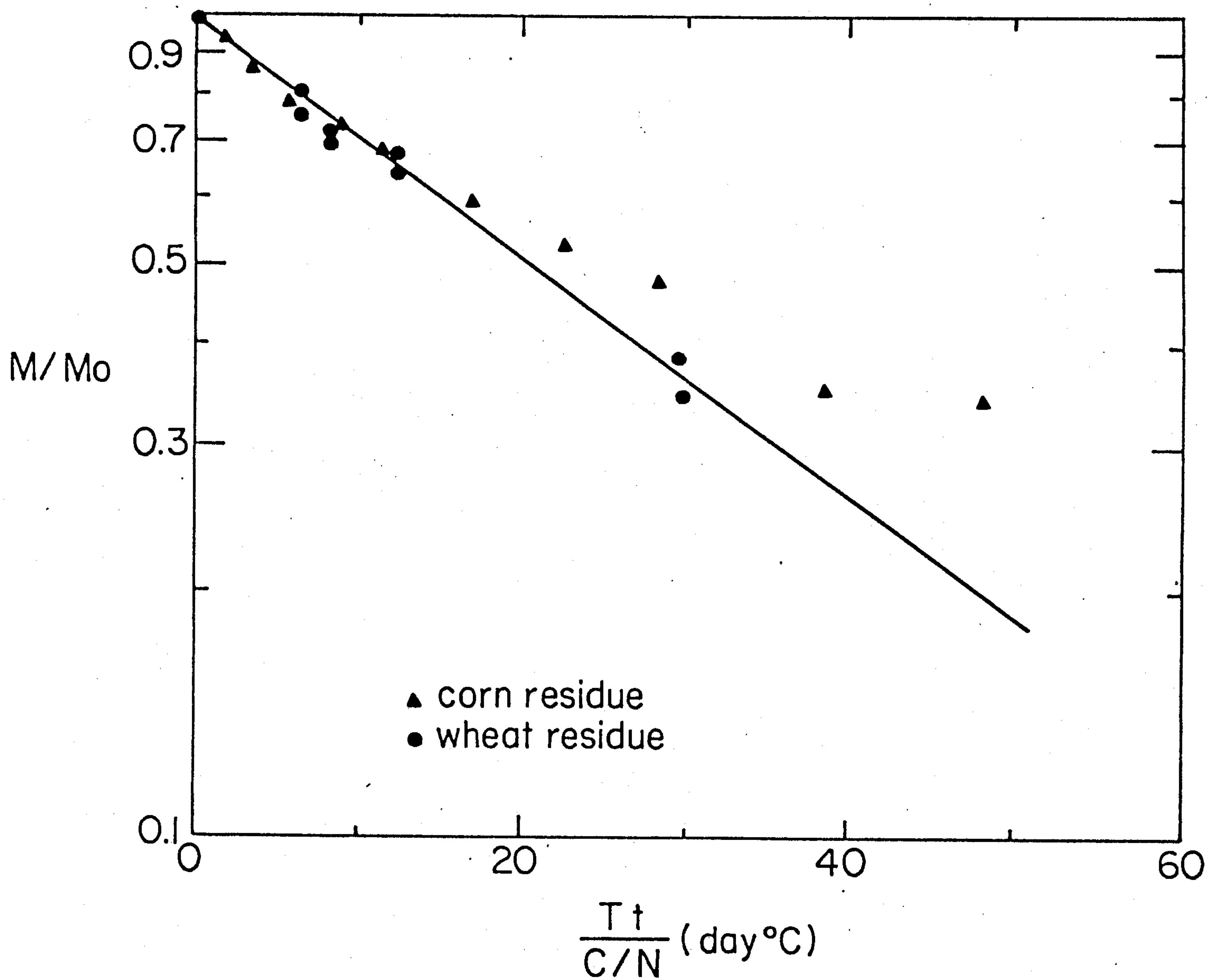

Fig. 3. Prediction of residue decay using an exponential equation of time weighted by air temperature and the initial carbon nitrogen ratio. Data from Parker (1962) and Smith and Douglas (1968).

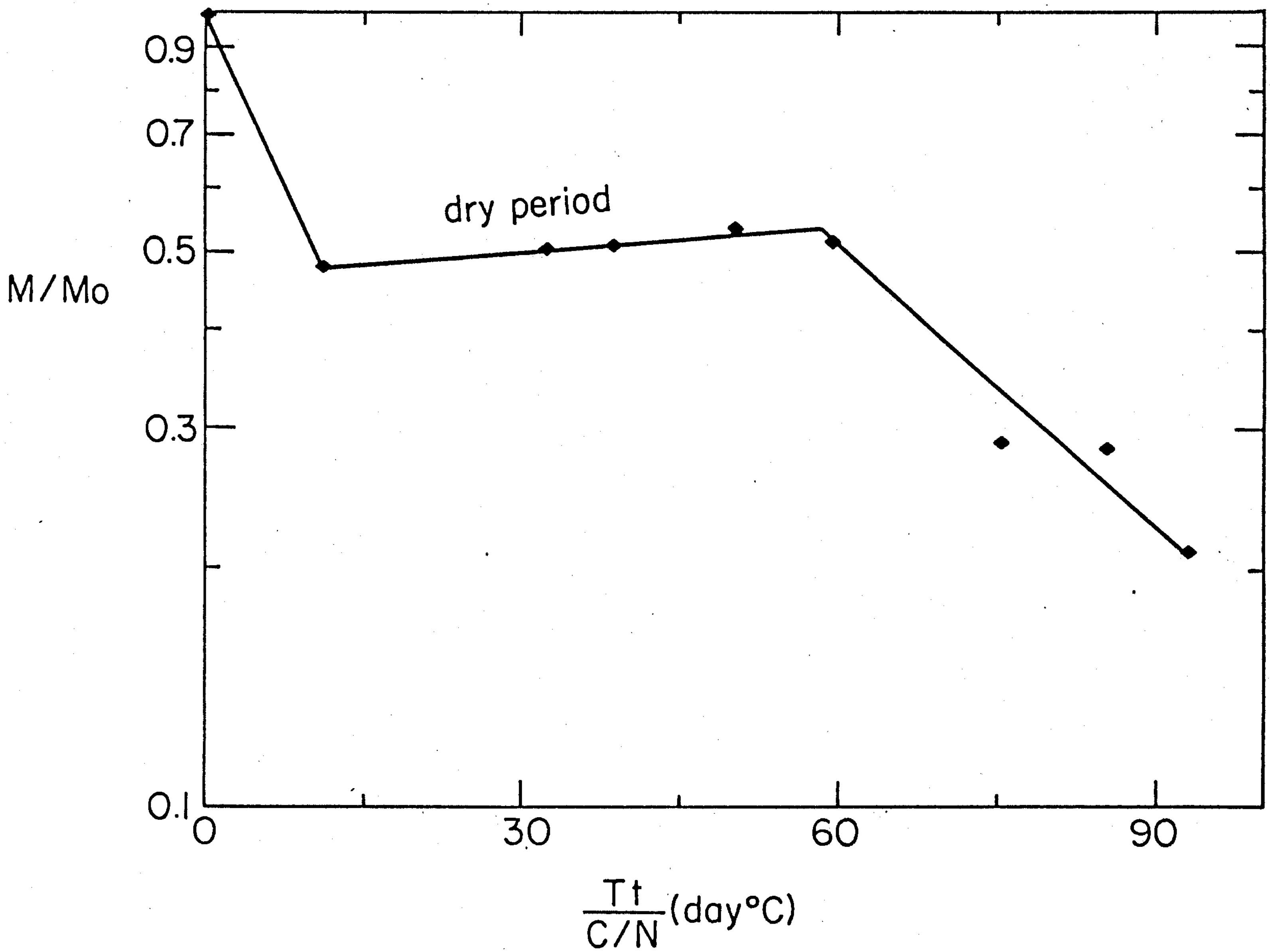

Fig. 4. Prediction of residue decay using an exponential equation of time weighted by air temperature and the initial carbon nitrogen ratio. Data from Alberts and Shrader (1980).

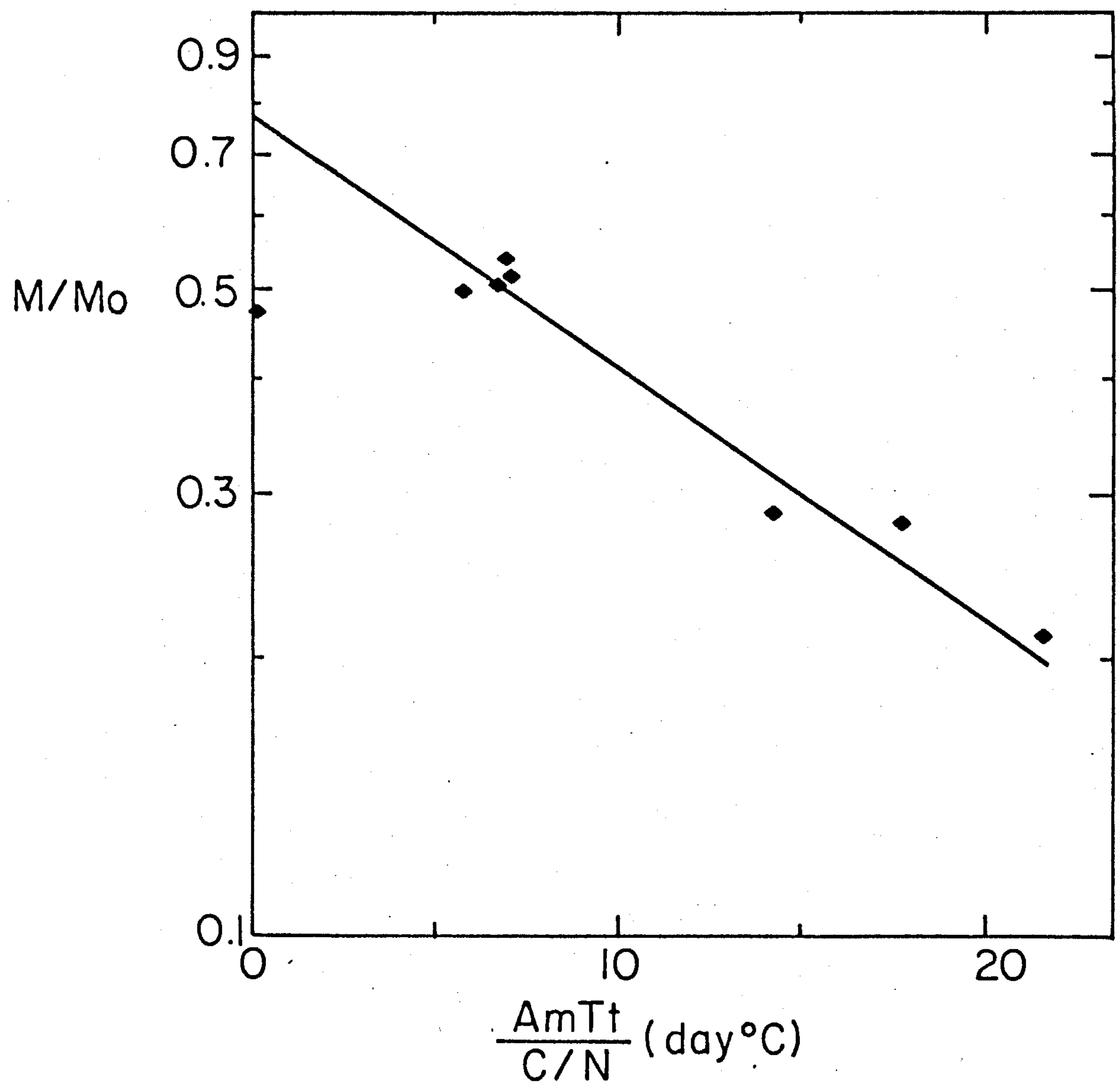

Fig. 5. Prediction of residue decay using an exponential equation of time weighted by air temperature, the initial carbon ratio and a rainfall index. Data from Alberts and Shrader (1980).

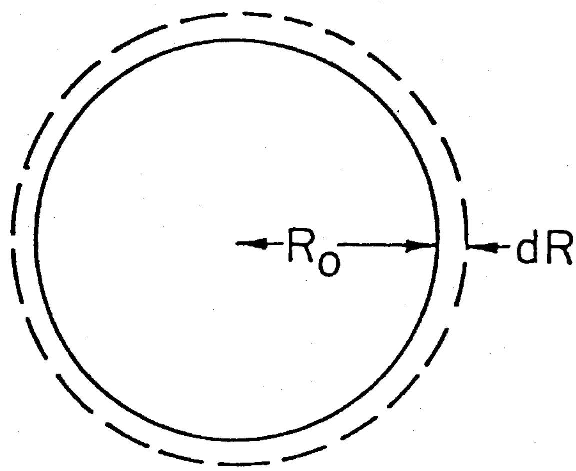

Fig. 6. Change of radius with residue decay.

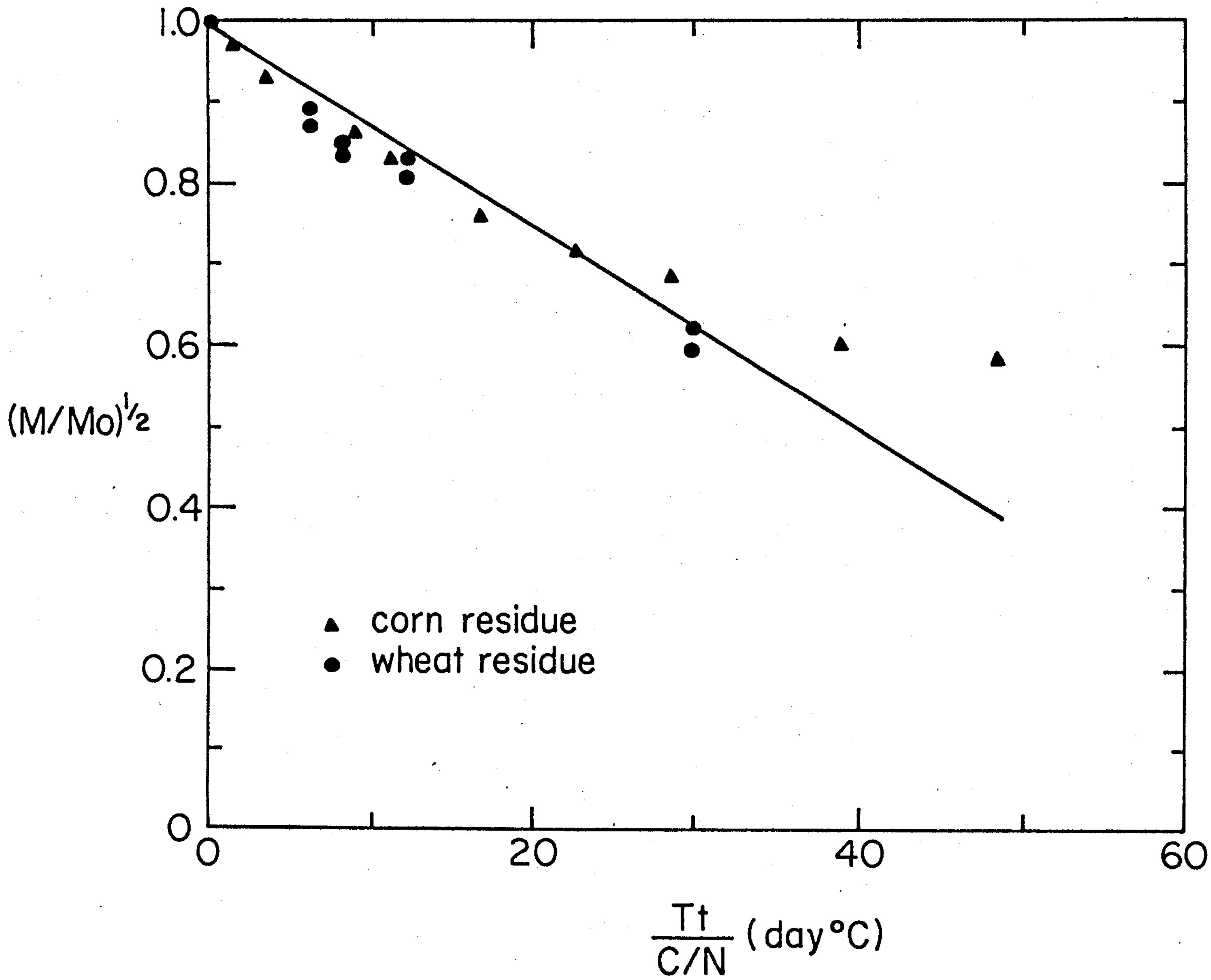

Fig. 7. Prediction of residue decay using equation 12. Data from Parker (1962) and Smith and Douglas (1968).

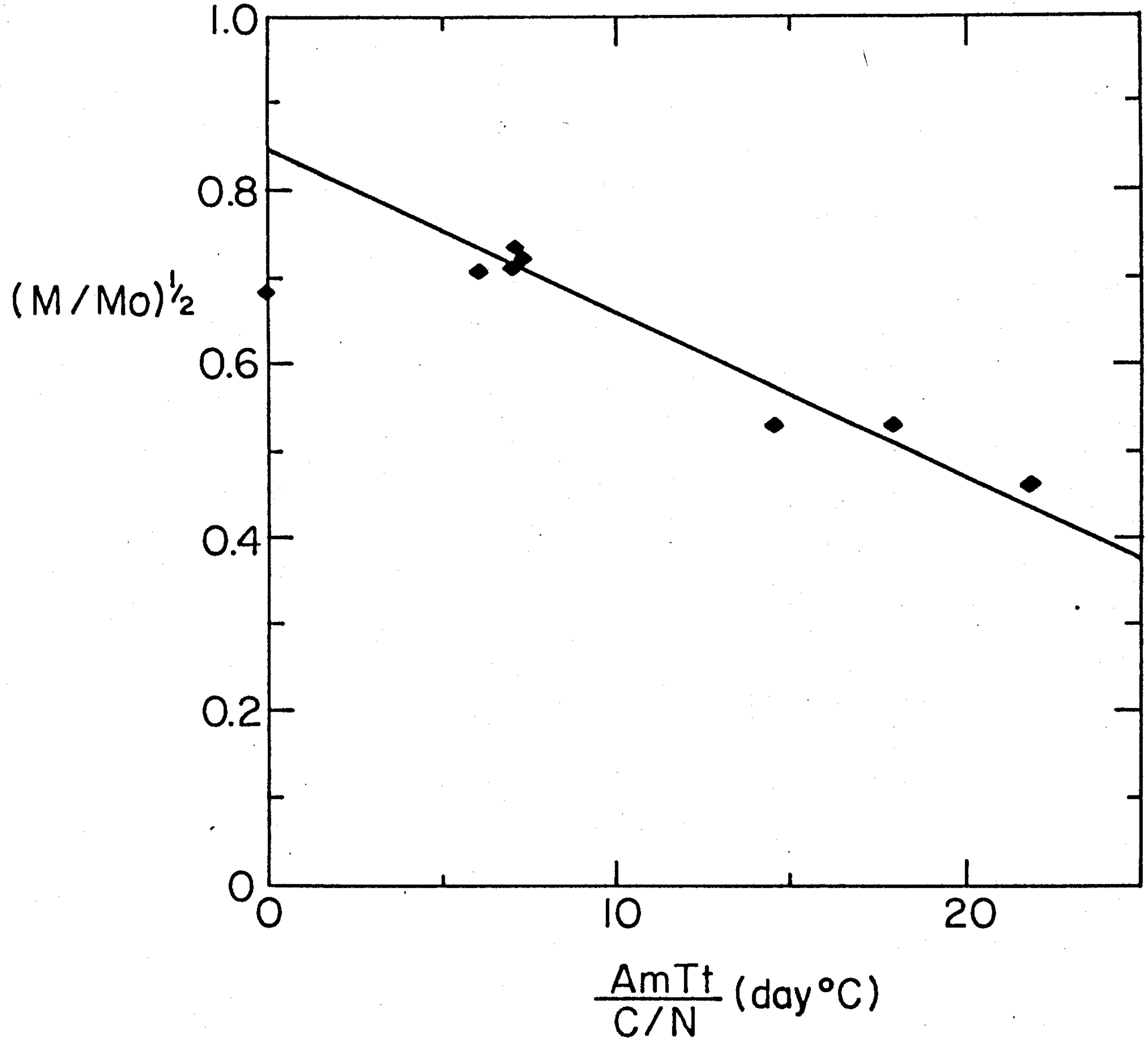

Fig. 8. Prediction of residue decay using equation 12. Data from Alberts and Shrader (1980).