Land Use Seminar on Soil Degradation / Wageningen / 13-15 October 1980

Survey of Dutch soil organic matter research with regard to humification and degradation rates in arable land

H.VAN DIJK
Institute for Soil Fertility, Haren, Netherlands

INTRODUCTION

After the introduction of mineral fertilisers in the last century, concern has often been expressed that this would lead to a decline of the organic matter level in arable soil resulting in a general soil deterioration. These warning notes sounded every time major changes in the agricultural production system took place, such as:

- farmers doing away with cattle, and therefore with manuring their arable land, and turning their pastures into arable land;
- the large increase in fertiliser use;
- increased mechanisation which, among others, demanded better and deeper drainage of the soil and thus would accelerate organic matter degradation;
- the trend toward a simplified rotation system with an increase in the number of root crops, leaving a smaller amount of crop residues in the soil, and sometimes less or no green manures being grown.

Up until some decades ago this concern was based on a deep-rooted conviction, rather than on cast-iron proof, that soil organic matter or humus in chemical and physical as well as biological respect had an important bearing on soil fertility and productivity. In the last decades enough evidence has been obtained to regard this 'conviction' as generally true, although the questions how and why are still far from being answered satisfactorily. Also more insight has been gained into the quantitative aspects of humus formation and degradation, the Dutch contribution to which will be surveyed here.

MATHEMATICAL DESCRIPTION

Kortleven (1963) tried to find a general mathematical expression for these processes, based on available data of some long-term (mainly field) experiments. He concluded that equation (1) introduced by Henin and Dupuis in 1945 gave a good fit to the data.

$$y_t = \frac{K_1 x}{K_2} (1 - e^{-K_2 t}) + y_o e^{-K_2 t} \tag{1}$$

y_t = humus content at time t; y_o at time zero.

x = yearly input of fresh organic matter (crop residues, animal waste, green manure, etc.). (y_t, y_o and x expressed in the same units).

K_1 = humification coefficient = part of the organic matter input remaining in the soil after one year.

K_2 = degradation rate of all organic material remaining in the soil for more than one year. (Here, K_2 is assumed to be independent of the age of the organic matter; it may be 1½ years old or 1 500 years).

The first term of equation (1) covers the humification and degradation of the yearly input, the second term describes the degradation of the humus initially present.

In the equilibrium situation, i.e. when a constant organic matter input regime has been pursued for an infinite number of years, equation (1) reduces to (2):

$$y_e = \frac{K_1}{K_2} x \tag{2}$$

Applying this equation to the available data on humus contents over a number of years, Kortleven calculated the best

y_e, K_2 and y_o. From y_e, K_2 and x follows the value of K_1. The average percentage of organic matter in mineral soils in the Netherlands is 4%; in the northern part it is about 0.5% higher than in the southern provinces because of climatic differences. For K_2 an average value of 0.02 was calculated, which means that yearly 2% of the 'humus' is mineralised. From these values and x = 0.2% (5 - 6 000 kg organic matter input/ha/year) it followed that on average $K_1/K_2 = 20$, (and thus $K_1 = 0.40$).

Since then the following has often been used as a rule of thumb in the Netherlands:- the amount of humus will ultimately be equal to 20 times the yearly input of organic matter. This rule has also been used to calculate how far the humus level will decrease when the input is lowered and how much the input should be increased to achieve a higher humus level.

It must be emphasised, however, that this is a rather rough generalisation which certainly shows considerable variation in individual cases. There is no firm ground to believe that all soils with a humus content lower or higher than 4% have not reached their equilibrium humus content, y_e. The ratio K_1/K_2 might be different from 20, caused by a different K_1 as well as a different K_2. Later, Kortleven concluded that, in general, a closer fit to the data was obtained by applying equation (3).

$$y_e = \frac{K_1}{K_2} x + y_i \qquad (3)$$

in which y_i = content of inert (i.e. non-degradable) 'humus'. The fact that with ^{14}C-dating average ages of 200 to 2 200 years have been found, indicates that part of the soil organic matter may indeed be very stable.

Applying equation (2) or (3) gave no different y_e in those cases where y_e was about 4%. However, this does not warrant the conclusion that all Dutch soils with 4% humus actually do not contain an inert part and that the humification and degradation rates K_1 and K_2 are the same for these soils (which would not be very likely anyway, considering the differences in moisture regime, clay content, pH, etc.). Introducing y_i makes the K_1/K_2 ratio variable. For example, Kortleven found for one experimental field a K_1/K_2 ratio of 20 for the highest input rate of fresh organic matter and one of 34 for the lowest input rate. When using Kortleven's best-fitting equation (3) to predict the effect of a diminished or increased input of fresh organic matter in individual cases, the appropriate K_1/K_2 ratio and Y_i must be known.

FACTORS AFFECTING K_1/K_2 RATIO

According to Kortleven, K_2 varies mainly from 0.015 to 0.025, which is considerable. From measurements of the C- and N-mineralisation following incubation of sandy arable soils belonging to different pedogenic groups, it was concluded (Van Dijk, 1968) that the C/N ratio of the soil organic matter gives an indication of its degradability, provided an approximate balance between the input of fresh material and the degradation of humus has been reached. The wider the C/N ratio (mostly accompanied by a higher humus content), the slower the humus degradation. This is confirmed by Figure 1, taken from Kolenbrander (1969), which shows the relation between C/N ratio and K_2, as calculated by Kortleven or derived from other data, for widely different soils.

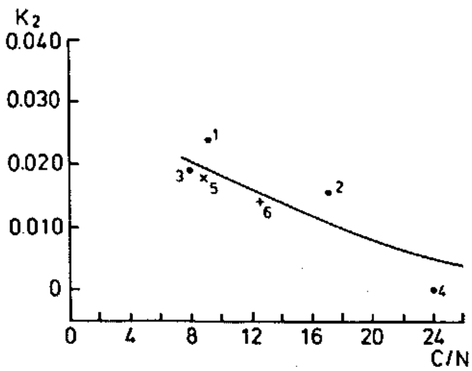

Fig. 1. Relation between degradation rate K_2 and C/N ratio or soil organic matter.

Kortleven calculated K_1 from K_2, y_e, y_i and x (equation 3) which is rather inaccurate. Therefore, he could not differentiate between fresh inputs of crop residues (roots and stubble), green manure and farmyard manure with regard to their contribution to the humus content in soils. Kolenbrander (1969, 1970, 1974) tried to estimate K_1 directly using data from experiments in which the degradation of a single dose of organic material was followed in the course of time. For some materials the results are shown in Figure 2. The degradation course could be described by equation (4).

$$x_t = x_o \, e^{-(n + \frac{p}{t+1})\, t}$$

x_t = amount of original dose x_o remaining at time t;
p and n are parameters which determine how much of the fresh input is left as 'humus' after a certain time, and how many years this requires, respectively.

Thus, instead of one source-independent K_1 for the first year and one K_2 similar for all organic material over one year old (including the humus originally present), a time-dependent degradation rate is assumed, becoming ultimately zero (when x_t is zero). For easily degradable material such as crop residues, straw, animal and green manure there is a rapid decrease of the initially high degradation rate. For difficult degradable material eg. peat, the decrease in the already low degradation rate is slow. For farmyard manure the difference between Kortleven's and Kolenbrander's results is clearly demonstrated in Figure 3.

When using the same organic material, an important observation was that little difference existed in results, whether data were obtained in pot or field experiments or even in composting trials. This led Kolenbrander to the conclusion that the three main factors governing the accumulation of humus are the amount and type of organic input and the duration of the experiment.

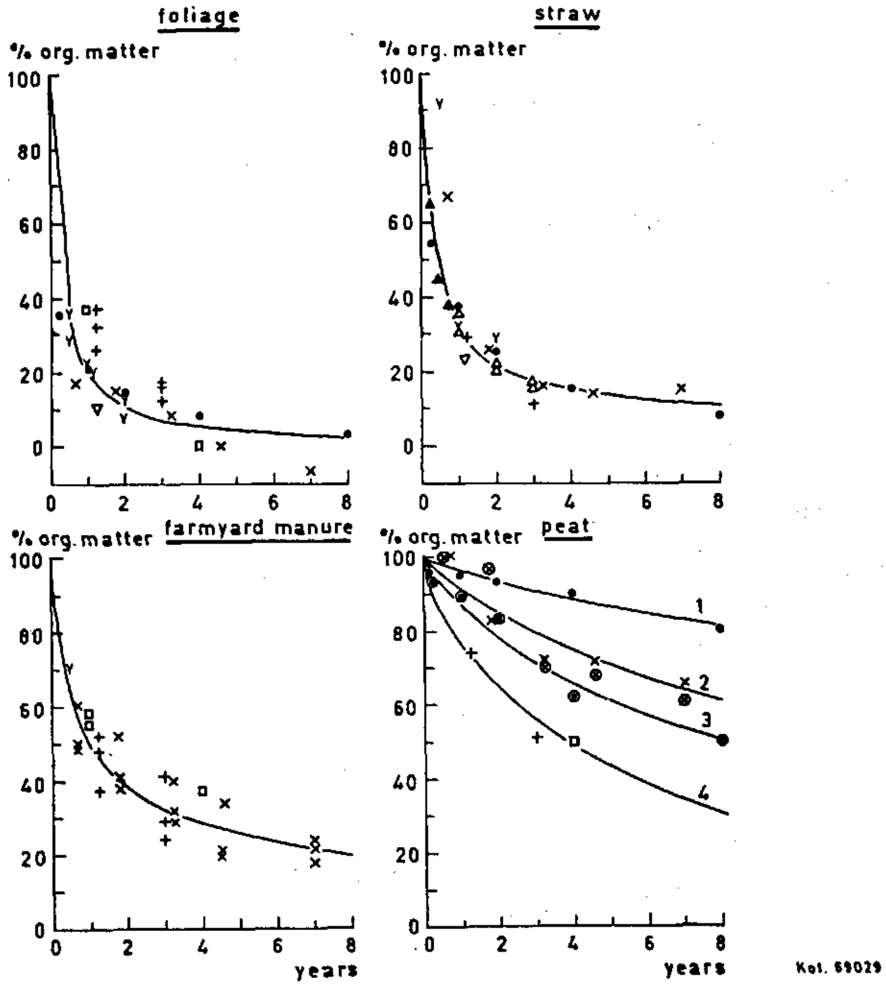

Fig. 2. Course of degradation of various materials, compiled from data of different investigators (denoted by different symbols).

On the basis of his findings, Kolenbrander calculated the contribution of an annual dose of different organic materials to the humus content and compared this with the data of field and pot experiments. He expressed the results in a 'soil organic matter (S.O.M.) increase index' S_{10} which gives the increase in soil organic matter in % after 10 annual applications of fresh material at a rate equalling 1% of the weight of the tilled layer. The relation between the K_1 (the part of the input

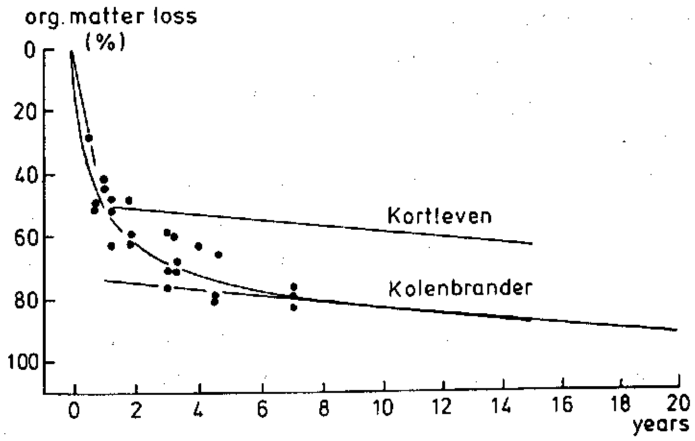

Fig. 3. Course of degradation of farmyard manure according to Kortleven and Kolenbrander.

remaining after one year) of the separate materials and the increase index S_{10} was found to be $S_{10} = 10 \cdot K_1^{1.70}$. In Table 1 the humification coefficients K_1 and the increase index S_{10} for a number of materials are given, together with their 'quality mark' (FYMeq), which is the ratio between their S_{10} and the S_{10} for farmyard manure.

TABLE 1

HUMIFICATION COEFFICIENT, S.O.M. INCREASE INDEX, AND QUALITY MARK (FYM-EQUIVALENT) OF SOME ORGANIC MATERIALS (AFTER KOLENBRANDER, 1974).

Origin	Humification coefficient (K_1)	S.O.M. increase index (S_{10}), %	FYM equivalent
Plant foliage	0.20	0.7	0.25
Green manures*	0.25	1.0	0.35
Straw (cereals)	0.30	1.3	0.45
Roots of crops	0.35	1.7	0.55
Farmyard manure	0.50	3.0	1.00
Litter of deciduous trees	0.60	4.2	1.40
Litter of coniferous trees	0.65	4.8	1.60
Sawdust	0.75	6.1	2.00
Peat moss	0.85	7.6	2.50

* 2 parts foliage and 1 part roots.

The use of these different values for K_1 was quickly adopted in calculating the organic input necessary for maintaining or increasing the humus content in Dutch soils. Rather inconsistently, however, the use of a constant degradation rate K_2 of 2% was often continued. For example, it is still assumed that in a soil with 4% humus and a tilled layer of 3.10^6 kg/ha, 2 400 kg humus is mineralised annually and that for compensation a supply of 4 800 organic matter in the form of farmyard manure (K_1 = 0.50) or 9 600 kg in the form of green manure (K_1 = 0.25) would be needed when no crop residues form part of the fresh input.

Following Kolenbrander's line of thought, however, this would mean the replacement of 2 400 kg humus, of which at least part was stabilised old humus, by 2 400 kg one-year-old humus which is more easily degradable. Judging from the S_{10} values a considerably larger amount of farmyard manure would be necessary. Kolenbrander, moreover, using the same data as Kortleven, showed that his approach gave curves that certainly fitted to the data equally well. Thus, the contribution of fresh organic matter to the accumulation of humus as stated by Kortleven may be severely overestimated.

LONG TERM EXPERIMENTS

Support for the view that 'young' and 'old' humus differ considerably with regard to their degradation rate was derived from results obtained on the 'Three organic matter farms' in the North-Eastpolder. During 25 years a farming system with mineral fertilisers only was compared with one that included green manures and one with a ley-farming system including farmyard manure.

Table 2 shows that after 25 years the difference in nitrogen mineralisation (determined in a 6-week laboratory incubation experiment) is much larger than that in the organic matter or total nitrogen contents. The same is true for the enzyme activities which to a certain extent reflect the microbial activity.

TABLE 2

SOME DATA ON THE SOIL OF THE 'THREE ORGANIC MATTER FARMS' AFTER 25 YEARS (AFTER VAN DIJK).

	Mineral fertiliser only	Min. fert. + green manure	Min. fert. + ley farming (livestock)
% soil org. matter	2.09	2.26	2.57
% total N	0.107	0.120	0.135
N-content of S.O.M. (%)	5.1	5.3	5.2
N-mineralised in 6 w. incub. (mg/kg soil)	14	17	25
Dehydrogenase act. (µl H_2)	11	15	22
Phosphatase act. (V_{max} in µmol/g/h)	60	90	110

B.H. Janssen (Agric. Univ. Wageningen; unpublished results) calculated the amount of 'young humus' formed during these 25 years, assuming a time-dependent (i.e. decreasing) degradation rate for every fresh input. By subtracting this amount from the total amount of humus, he obtained the amount that is more than 25 years old. For the 'young humus' he calculated an average degradation rate of 13.5 - 15%, for the 'old humus' an average rate over 25 years of 1.83%, decreasing over the last six years to 0.7%. With these data he calculated nitrogen mineralisation after 25 years. The results are shown in Table 3. The differences in estimated nitrogen mineralisation correlate with those measured in the incubation experiment and with the differences in enzyme activities (Table 2).

Soil organic matter is a source of nitrogen for the plant and also of great importance to soil structure. Both are considered to be directly related to microbial activity and, thus, to the degradability of the soil organic matter. It is, therefore, of paramount importance to investigate more closely the adequacy of the 'models' developed by Kolenbrander and Janssen in describing the practical situation. If true in principle - and in my opinion there is not much room for doubt

TABLE 3

CALCULATED ANNUAL MINERALISATION OF NITROGEN ON THE 'THREE ORGANIC MATTER FARMS' AFTER 25 YEARS OF DIFFERENT ORGANIC MATTER INPUTS (AFTER JANSSEN, 1977).

	Mineral fertiliser only	Min. fert. + green manure	Min. fert. + ley farming (livestock)
% 'Young humus' built up in 25 years	0.2	0.4	0.6
Average rate of degradation (%/yr)	14.5	15.0	13.5
C/N ratio	12	12	12
Bulk density of soil (g/cm^3)	1.50	1.45	1.35
N-mineralised (kg/ha/yr)			
A. 'young humus' (< 25 yrs)	42	84	105
B. 'old humus' (2%; degrad. rate 0.7%/yr (C/N = 12)	20	20	20
(A + B) total	62	104	125

- then the higher the relative contribution of 'young humus', e.g. in the flow of nitrogen, the greater and also the faster is the loss of soil fertility when the supply of fresh organic matter is neglected. A peaty sand with 10% organic matter, reducing to 9%, may have lost only 10% of its total organic matter but perhaps 25% of its 'active' organic matter.

CONCLUSION

It is recommended that, based on present knowledge, a comprehensive model for the build-up and degradation of soil organic matter be developed. This model should include both the nitrogen and carbon cycles. Further work is all the more worthwhile because most long-term experiments have been continued and, thus, data for another ten years are now available. Data from other long-term experiments, for example, pertaining to organic-matter degradation as a result of deeper drainage and build-up from the inclusion of grasslands, widen the perspective of attaining a better understanding of the dynamics of the processes involved.

REFERENCES

Dijk, H. van, 1968. Das C/N-Verhältnis im A_1 (p) -Horizont von kultivierten Sanböden im Zusammenhang mit Kohlenstoff - und Stickstoffmineralisierung. Stikstof (Dutch Nitrogenous Fertilizer Review) 12: 89-96.

Kolenbrander, G.J., 1969. De bepaling van de waarde van verschillende soorten organische stof ten aanzien van hun effect op het humusgehalte bij bouwland. Inst. Bodemvruchtbaarheid, Rapp. C 6988.

Kolenbrander, G.J., 1970. De verandering van het humusgehalte bij bouwland onder invloed van de organische bemesting, Inst. Bodemvruchtbaarheid, Rapp. C 7696.

Kolenbrander, G.J., 1974. Efficiency of organic manure in increasing soil organic matter content. Trans. 10th Int. Congr. Soil Sci. 2: 129-136.

Kortleven, J., 1963. Kwantitatieve aspecten van humusopbouw en humusafbraak. Diss. Agr. Univ. Wageningen; Versl. Landbouwk. Onderzoek 69, p. 109.

DISCUSSION

1. Degradability of organic matter depends on the carbon/nitrogen ratio, in that the smaller this ratio the quicker the degradation.

   However, soil humus is more stable the narrower its C/N ratio.

   Relationships between C/N ratio and degradability only hold for material at the beginning and not for material during the degradation.

2. New models are recommended. The question is should these models be focussed on understanding or on prediction? Within predictive models black boxes are allowed whereas in understanding models each parameter should have a biological, physical or physical-chemical meaning.

The new models should be predictive. Nevertheless a degree of understanding is necessary.

3. Effects of water management are not considered while Schothorst has shown in his work on peat soil that with improving drainage conditions mineralisation increased by as much as a factor of four.

The long term experiments are generally irrespective of water table. There are no data on water tables.