HUMUS, ITS FORMATION, ITS RELATION WITH THE MINERAL PART OF THE SOIL, AND ITS SIGNIFICANCE FOR SOIL PRODUCTIVITY

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Abstract

HUMUS, ITS FORMATION, ITS RELATION WITH THE MINERAL PART OF THE SOIL, AND ITS SIGNIFICANCE FOR SOIL PRODUCTIVITY.

In a pot experiment 15 different organic products were added annually during 10 successive years to a diluvial sandy soil and an alluvial clay soil. The amounts of humus formed correlated well with the lignin contents of the products ($r = 0.91$), but not with the nitrogen contents ($r = -0.11$). The new humus formed was less stable than the soil humus present at the beginning of the experiment, and for most products seemed to be somewhat more stable in the clay soil than in the sandy soil; but in an additional experiment with 36 different soils, to which grass meal was added annually, no effect of clay content was found on the amounts of humus formed ($r = -0.11$). Though there may be some effect of soil characteristics on humus formation, characteristics of organic products rather than those of soils are decisive for the amounts of humus formed from the products. Besides changes in organic matter content of the soils, there were changes in nitrogen content, nitrogen loss, pH, water content at different pF-values, bulk density, plasticity and structure, which were sometimes rather extreme in these experiments. In a pot experiment with a different series of unfertilized soils there was a good relationship between humus content and crop yield for soils of the same origin ($r = 0.96$). For soils of different origin the relation was much worse. In long-term field experiments farmyard manure, even at optimum levels of mineral fertilization, substantially increased maximum yields of potatoes and sugar beet, but not of cereals. There is need for more research in this direction.

INTRODUCTION

Among the natural factors determining the productivity of a soil its humus content is the most important. In former times agriculture was not possible without an adequate humus content of the soil. For this purpose farmers on light, sandy soils in the Netherlands built up humus layers of one metre or higher by means of heath or grass sods mixed with animal excrement.

Although humus has been studied by many soil scientists for more than two centuries, there is still much we do not know about its formation and significance for soil productivity. As to the quantitative aspects of humus formation, according to Kortleven [1] there was insufficient reason to assume different humification coefficients (fractions left after one year) for the various sources of organic matter he studied (farmyard manure, town refuse compost, straw, green manure, paper pulp). The nature of the soil, especially its clay content, rather than the nature of the organic matter applied might be decisive for the amount of humus formed from the organic matter.

To verify this, in 1965 an experiment was started with 15 organic products differing in nitrogen content, as data from literature [2-5] suggested a positive influence of nitrogen on humus formation. The products were applied annually over 10 successive years to a diluvial

TABLE I. ORGANIC PRODUCTS USED IN THE HUMIFICATION STUDY WITH THEIR NITROGEN, LIGNIN AND ASH CONTENTS IN PERCENTAGE OF DRY MATTER

	N (%)	Lignin (%)	Ash (%)
Sugar	0.00	0.0	0.0
Cellulose	0.00	1.2	6.5
Rye straw	0.44	11.5	4.2
Oat straw	0.61	11.2	6.6
Rye grain	1.87	3.1	2.3
Oat grain	1.91	4.5	4.8
Grass	2.00	8.0	10.2
Whey powder	2.19	0.0	12.1
Farmyard manure	2.50	29.0	35.0
Lucerne	2.64	4.3	7.6
Cow faeces	2.75	21.7	15.0
Linseed meal	6.00	7.5	6.7
Soya meal	8.11	0.9	6.1
Potato protein	13.60	1.7	2.6
Blood meal	15.00	0.6	5.6

sandy soil and an alluvial clay soil, representing the main soil types in the Netherlands. In 1966 an experiment was begun in which one source of organic matter (grass meal) was applied annually to 36 different soils to study in more detail the effect of soil characteristics (clay and humus content, pH) on humus formation.

Results of these experiments are given here together with results of a pot experiment on the relationship of humus content to crop yield in unfertilized soils and of long-term field experiments on the effect of organic manuring on maximum crop yields under conditions of optimum mineral fertilization.

MATERIALS AND METHODS

The organic products used in the humus formation study are listed in Table I in the order of their nitrogen content (Kjeldahl), together with the lignin content according to the Official Methods of Analysis of the Association of Official Analytical Chemists [6], and the ash content.

The products were ground where necessary, and applied annually over 10 successive years in quantities (on a dry matter basis) of 100 g to 5.3 kg of a sandy soil with 3.89% humus, 0.156% N and pH-KCl 4.74, and to 4.7 kg of a clay soil with 3.00% humus, 0.224% N, 22% clay (< 2 μm) and pH-KCl 6.63. The soils were left fallow and kept at about 50-70% of the water-holding capacity in undrained pots under ambient temperature conditions. At the end of each year humus (= total organic matter) and nitrogen were determined, humus according to Mebius [7], except for peaty soils in which it was estimated by loss-on-ignition, and nitrogen according to Deijs [8]. At the end of the 10-year period also pH-KCl, water contents at pF 2.0, 3.4 and 4.2, bulk density and plasticity (clay soil) were determined. Each treated soil was replicated twice, except the untreated soils in the experiment with 15 organic products, which were replicated six times.

For the pot experiment in which the effect of humus on crop yield was studied, the following soils were used: 60 alluvial soils from one polder (Johannes Kerkhovenpolder), 94 alluvial soils and 76 diluvial soils from different regions. In these soils also humus contents in soil fractions of different settling velocity in water and of different specific gravity (using $CHBr_3/CCl_4$-mixtures) were determined.

In field experiments the effect of organic manures was studied on various soils with different crops using optimum mineral fertilizer rates, except for nitrogen, which is given in rates from zero to above optimum. Thus yield curves are obtained showing whether or not maximum yields can be increased by additional organic manuring. It is this increase in maximum yield which makes the use of organic manures attractive under conditions in which mineral fertilizers are abundant and cheap.

RESULTS

Humus formation from various organic products

The amounts of humus formed in the successive years from annual additions of the products sugar, farmyard manure and potato protein are shown as an example in Fig. 1.

In Table II the amounts of humus formed from all products after one and ten years are given. In the table, the amounts of humus have been expressed in gram per 100 and per 1000 g organic matter applied in one and ten years respectively. The ash contents of the products have been taken into account here.

It is clear that the amounts of humus formed after 10 years are less than 10 times the amounts of humus formed after one year, because the humus formed is subject to decomposition. Decomposition rates of the humus formed from the various products are also given in Table II.

Remark. If the amount of humus formed from one annual application of a certain amount of organic matter is a, then it is from two annual applications of the same amount $a + ar$ if r is the part (%) left in the second year from the humus formed in the first year. If r is assumed to be constant in the course of time (ten-year period), then the amount of humus formed from three annual applications of the same amount of organic matter is $a + ar + ar^2$, etc. So humus accumulates according to the equation for the geometric progression $y = a \times (1 - r^n)/(1 - r)$. Original data for the amounts of humus formed have been adjusted by means of this equation, and these adjusted data are given in Table II. The decomposition rates were calculated in the same way.

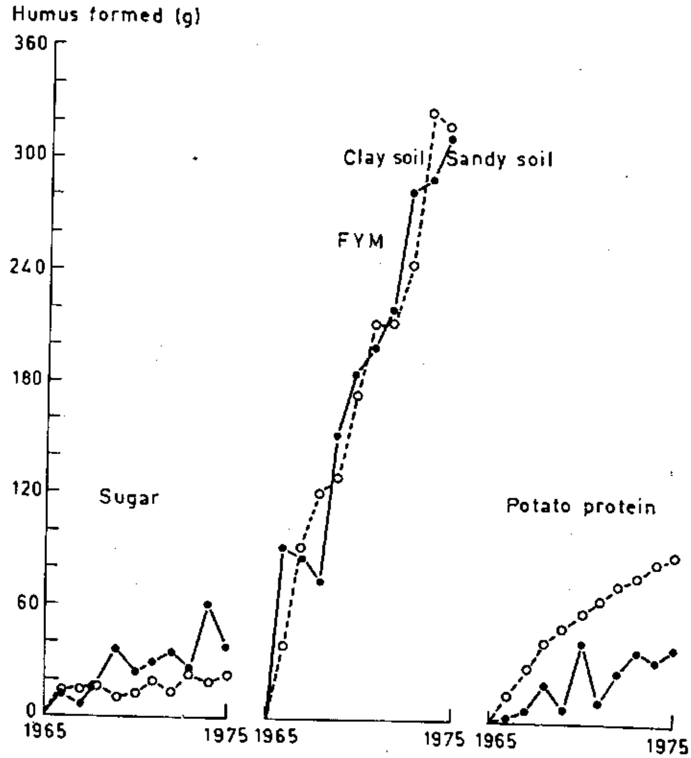

FIG.1. Amounts of humus formed following annual applications of 100 g organic product (dry matter) as sugar, farmyard manure (FYM) or potato protein.

From Table II it is clear that from different sources of organic matter different amounts of humus are formed. There is no relation with the nitrogen content of the products, but with the lignin content there is, except for blood meal, which behaved abnormally in this respect. Examination of the product and of the soil with a binocular microscope showed that it partially consisted of little hard grains, probably as a result of drying at too high a temperature, which remained intact in the soil, at least in the first years. Later there were signs of a breakdown of these hard grains. The correlation coefficients (r-values) for the relationship between nitrogen and lignin contents of the products (except blood meal), and the amounts of humus formed after one and ten years, are given in Table III.

The amounts of humus formed were greater than the lignin contents of the products. Therefore other components of the organic matter contribute to the humus formation. From products such as sugar, cellulose and proteins very low amounts of humus (5%) are formed, probably the residues of micro-organisms that decompose organic matter.

TABLE II. AMOUNTS OF HUMUS (g) FORMED FROM 1 AND 10 ANNUAL APPLICATIONS OF 100 g ORGANIC MATTER OF DIFFERENT PRODUCTS AND DECOMPOSITION RATES (%/year) OF THIS HUMUS

	1 year		10 years		Decomposition rate	
	Sand	Clay	Sand	Clay	Sand	Clay
Sugar	7	4	44	19	10	19
Cellulose	11	7	58	33	15	21
Rye straw	31	31	118	169	25	15
Oat straw	25	27	150	177	11	10
Rye grain	18	15	93	118	16	6
Oat grain	21	18	128	146	12	5
Grass	37	24	202	219	14	2
Whey powder	11	9	67	58	14	12
Farmyard manure	60	57	485	495	5	3
Lucerne	22	17	177	152	5	3
Cow faeces	47	40	278	284	13	8
Linseed meal	27	21	123	195	19	3
Soya meal	7	11	56	94	8	2
Potato protein	5	14	40	89	4	13
Blood meal	71	33	249	232	29	8

TABLE III. r-VALUES FOR THE RELATIONSHIP BETWEEN THE AMOUNTS OF HUMUS FORMED AFTER 1 AND 10 YEARS FROM ANNUAL APPLICATIONS OF DIFFERENT ORGANIC PRODUCTS AND THE NITROGEN AND LIGNIN CONTENTS OF THESE PRODUCTS

	1 year		10 years	
	Sandy soil	Clay soil	Sandy soil	Clay soil
% nitrogen	-0.11	-0.12	-0.24	-0.05
% lignin	-0.88 ***	-0.93 ***	-0.92 ***	-0.92 ***

*** = P > 99.9%

After one year more humus is formed from most products in the sandy soil than in the clay soil, but after 10 years the reverse is true. The new humus from most products therefore seems to be more stable in the clay soil. This is also apparent from the decomposition rates. The mean decomposition rates for the new humus formed are 13 and 9% for the sandy and the clay soil respectively. For the untreated soils, the decomposition rates for the old (native) humus are 1.7 and 2.2% for the sandy and the clay soil respectively, the new humus therefore being less stable than the old. The decomposition of the new humus will be studied more thoroughly in the 5- or 10-year period following the 10-year application period of organic matter.

Changes in other soil characteristics following application of organic products

As no crops were grown and no leaching took place, there was, of course, an increase in nitrogen content of the soils which was in general in agreement with the nitrogen content of the products. However, a rather large part of the nitrogen was lost, especially from the protein-rich products. For instance, from potato protein more than 80% of the nitrogen (100 g/pot in the 10-year period) was lost. Preliminary results showed that the water-soluble nitrogen in the soil was almost all in the nitrate form and there were remarkable decreases in pH. Potato protein decreased pH-KCl in the sandy soil to 3.85, and in the clay soil to 4.34. As at these low pH-values nitrogen loss as ammonia seems to be improbable, nitrogen may have been lost in this case as a result of denitrification.

Water contents at different pF-values were increased by all products in the sandy soil, and in the clay soil at pF 4.2 and 3.4, but not or to a lesser degree at pF 2.0. The content of available water (pF 2.0 - pF 4.2) was therefore not increased in the clay soil.

Volume was much more increased and bulk density therefore much more decreased by the organic products in the sandy soil than in the clay soil.

In the clay soil, structure effects were more pronounced. Even products like sugar and cellulose had a highly improved structure in the clay soil. With protein-rich products the structure units became rather large clumps, which were hard after drying. In an experiment not described here, in which annual application of organic products was terminated after five years, three years later almost all structure effects had disappeared except in the case of the protein-rich products. With these products the clumps gradually disintegrated into crumbs with a favourable structure. Photographs of these effects were made.

Effect of soil characteristics on humus formation from grass meal

In the experiment with grass meal application to 36 different soils, so far the results of the first nine years only are known. r-values for the relationship between pH, humus and clay contents of the untreated soils and the amounts of humus formed from seven, eight and nine annual applications of grass meal respectively are given in Table IV.

TABLE IV. r-VALUES FOR THE RELATIONSHIP BETWEEN pH, HUMUS AND CLAY CONTENT OF UNTREATED SOILS, AND THE AMOUNTS OF HUMUS FORMED FROM 7, 8 AND 9 ANNUAL APPLICATIONS OF GRASS MEAL

	Annual applications		
	7	8	9
pH-KCl	-0.57***	-0.40*	-0.52**
Humus content	0.89***	0.78***	0.84***
Clay content	-0.10	-0.00	-0.11

*, **, *** = P > 95, 99 and 99.9% respectively.

From this table it appears that there is some relation between pH and the amount of humus formed. This may be due to the fact that the pH of most peaty soils is low, and the largest amounts of humus are formed especially in these soils. This again is at least partly due to the fact that humus in these soils was determined by the loss-on-ignition method which gives somewhat higher contents than wet oxidation. Therefore the relation between humus content of untreated soils and the amounts of humus formed is not as good as it seems here.

It is clear from the table that there is no effect of clay content on humus formation. In the Netherlands there is for alluvial soils a rather close relation between clay and humus content (in virgin marine soils humus content is about $10^{-1} \times$clay content), but this relation may be due to the fact that the settling velocity of clay and humus particles in water is about the same. Fractions of clay soils with a settling velocity in water equal to that of clay particles may have humus contents up to 10%. Corresponding fractions of sandy soils may even have humus contents of 50% or more. If these soils are transported by water new soils may therefore be formed with differences in humus content due to soil formation and not to humus formation.

Relationship between humus and crop yield

As differences in humus content are accompanied by differences in other soil characteristics, the relationship between humus and crop yield may be a rather complex one. Obviously there are effects of humus on soil (structure, water-holding capacity) which are not expressed in crop yields in a pot experiment.

In our experiment three crops were grown in succession. The best relationship between humus content and crop yield (dry matter) was found for the first crop. Table V gives r-values for yields of crop 1 + 2 + 3 and humus, together with total nitrogen contents of the soils.

TABLE V. r-VALUES FOR THE RELATIONSHIP OF CUMULATED CROP YIELDS AND HUMUS AND TOTAL NITROGEN CONTENTS OF SOILS

	Humus	Total nitrogen
60 alluvial soils (one polder)	0.96	0.96
94 alluvial soils (different regions)	0.53	0.56
76 diluvial soils (different regions)	0.58	0.69

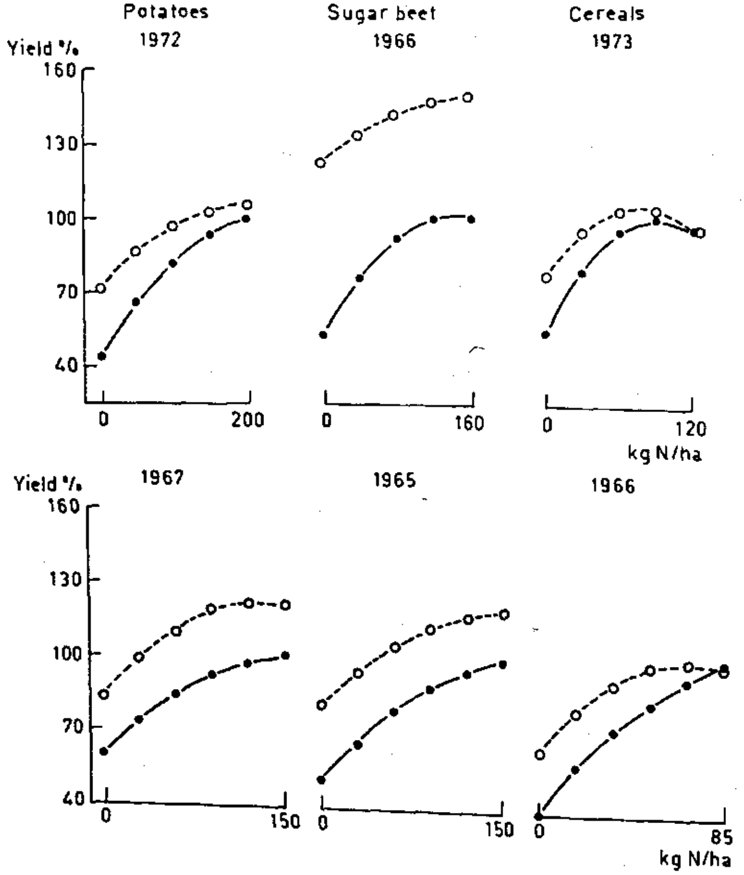

FIG.2. Yields without (●———●) and with (O- - - -O) farmyard manure in percentage of maximum yield without farmyard manure (= 100).

It is evident from this table that for cogenetic soils there may be a close relationship between humus and crop yield. For soils of different origin the relationship is much worse. After complete fertilization of the soils (fourth crop) hardly any relationship between humus and crop yield remained.

The relationship of crop yield with total nitrogen content was about the same as with humus content. The main effect of humus in this experiment may therefore have been a nitrogen effect. Humus in soil fractions with a settling velocity in water < 2 cm/min or specific gravity < 2.0 (the so-called free humus) gave no better relationship with crop yields than total humus. The same was true for water-soluble nitrogen and total nitrogen content of the soil [9].

Increases in maximum yield with farmyard manure in combination with optimum mineral fertilization

Figure 2 gives results for different crops on a reclaimed peat soil (IB 0061) and a reclaimed clay soil in the former Zuiderzee (IB 0010). The experimental fields were laid out in 1944 and 1945 respectively. Farmyard manure was given every two years to potatoes or sugar beet. In the intervening years cereals were grown. The results in Fig. 2 are for a farmyard manure rate of 40 and 20 tons per ha every two years for the peat and the clay soil respectively. Short-term effects of farmyard manure are mainly due to its NPK-contents. In these experiments P and K are compensated, assuming 100% activity of these elements in comparison with common mineral fertilizers, so that the effect of farmyard manure is reduced to a nitrogen effect, which expresses itself most clearly at low mineral nitrogen fertilizer rates, plus a possible rest-effect, which expresses itself most clearly at the optimum mineral nitrogen fertilizer rate. Rest-effects may express themselves only after repeated applications of organic manures. The results shown in Fig. 2 can be considered representative for the last ten years.

It is evident from Fig. 2 that on both soils maximum yields for potatoes and sugar beet could be substantially increased by farmyard manure, but not for cereals. The reason for this cannot yet be clarified. There are other experimental fields where increases in maximum yield are lower or absent, and therefore there is need for more research as to the question on which soils maximum yields can be increased economically by organic manures.

REFERENCES

[1] KORTLEVEN, J., Kwantitatieve aspecten van humusopbouw en humusafbraak, Versl. Landbouwkd. Onderz. 69.1 (1963).
[2] ALLISON, F.E., Does nitrogen applied to crop residues produce more humus?, Soil Sci. Soc. Am., Proc. 19 (1955) 210.
[3] LUEKEN, H., HUTCHEON, W.L., PAUL, E.A., The influence of nitrogen on the decomposition of crop residues in the soil, Can. J. Soil Sci. 42 (1962) 276.

[4] PINCK, L.A., ALLISON, F.E., SHERMAN, M.S., Maintenance of soil organic matter: II. Losses of carbon and nitrogen from young and mature plant material during decomposition in soil, Soil Sci. 69 (1950) 391.

[5] SCHMIDT, U., SCHMIDT, G., Zur Frage der Mineralisation von Ernterückständen in Abhängigkeit vom Stickstoffgehalt, Z. Pflanzenernaehr. Bodenkd. 101 (1963) 99.

[6] ASSOCIATION OF OFFICIAL AGRICULTURAL CHEMISTS, Official Methods of Analysis of the Association of Official Agricultural Chemists, 12th Edn, Washington, D.C. (1975).

[7] MEBIUS, L.J., A rapid method for the determination of organic carbon in soil, Anal. Chim. Acta 22 (1960) 120.

[8] DEIJS, W.B., "De bepaling van totaal-stikstof in gewasmonsters, inclusief nitraat-stikstof", Jaarb. Inst. Biol. Scheikd. Onderz. Landbouwgewassen, Wageningen (1961) 89.

[9] DIJK, H. VAN, Der Aussagewert der verschiedenen Analysemethoden für "potentiell pflanzenverfügbaren Stickstoff" in Ackerböden, Landwirtsch. Forsch., Sonderh. 27/II (1972) 138.