Humus for energy and CO_2 storage in agricultural soil
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This presentation aims to prove the importance of regarding humus substance as a CO_2 lunges of the earth, and that it is difficult to almost impossible to recover the loss of humus in Danish farming soil, which has been strongly reduced during the last 50 years of agricultural practice.

Introduction:

When our ancestors began to farm the Danish country by the method of slash and burning agriculture (Scandinavian expression: svedjebrug) there was at the beginning of the Bronze Age a mould rich in humus, probably between 10 and 20 %, and a simple digging stock or the simple plough (named an ard) were the tools they needed for treatment of the soil. The forest was destroyed during a period of about 1000 years and the soils were subsequently deprived of nutrients because organic matter or dung was not added to the fields. By about 1700 only a few percent forest was left, mostly for the benefit of the kings being fond of hunting. When the forest was cut down, sand dunes appeared and invaded some places with the result that farming was abandoned. In general the necessary maintenance of the humus content did not take place where farming was possible, and therefore the crop also declined and the farming conditions became more sensitive to changes in annual precipitation.

Humus and CO_2

Before we discuss the present conditions of the soil, we must describe humus substance, as the content of this is regarded as decisive to which degree we describe the soil as 'mould' (in a temperate climate) and also which influence it has as a lunge for the CO_2 balance on the earth.

The peasants from the Bronze Age hardly defined humus, but they knew for sure the value of fine mould. Today there are several definitions and in Annex 1 a selection is seen which may be condensed to define humus: **a dark organic matter in the soil having no strictly defined composition, but which is unstable, and in order to maintain the content it is necessary regularly to supply fresh organic material.**

The Danish professor and geologist Arne Noe-Nygård wrote in 1957 (Ref. 14): “The soil has a decisive influence on the organic life on and in it, and the geology interacts in this way with both zoology and botany: the soil is today so much a comprehensive area of research that a special science - pedology - takes care of this”. Despite this former statement there are not many scientists who call themselves pedologists, maybe because modern agriculture has been reduced to just being a question of dosing the correct mix of inorganic nutrients in an almost inert growing media - soil without humus - which simply may be compared with Rockwool granulate. My personal interest has moved in the direction of pedology, but I do not nevertheless regard myself as a pedologist.

The approximate chemical composition of typical humus (acid) is shown in the table below (Konova DATE?).

Substances	% dry ash-free basis			
	C	H	O	N
Fulvic acids	44 – 49	3.5 - 5.0	44 - 49	2.0 – 4.0
Humic acids	52 – 62	3.0 - 5.0	30 - 33	3.5 – 5.0
Proteins	50 – 55	6.5 - 7.3	19 – 24	15.0 – 19.0
Lignin	62 – 69	5.0 - 6.5	26 – 33	-

It is judged that the average content of humus in Danish forested soil at the beginning of the Bronze Age covering 40 000 km^2 was 15 % and it may be calculated how much this figure is equivalent to crude oil and how much this amounted to in CO_2. It is assumed that the mould layer was 40 cm.

The humus is defined to have the following chemical composition: 57% C, 4% H_2, 32% O_2 (and 4.5% N_2) (Ref. 12).

As a good approximation the oxygen content of the humus is assumed to be combined in OH-groups and consequently the 57 % C has a calorific value equivalent to carbon. The 15% humus content then approximates to 1.9 $x10^9$ tonnes oil equivalent or 6.8 $x10^9$ tonnes CO_2. The figures do not change substantially by reducing the mould layer to 30 cm. Nitrogen was in this soil mineralised to an amount of approximately 0.1 $x10^9$ tonnes. It must not be forgotten that the phosphor content was about 1% and thus also the resources of this nutrient were large.

During a thousand years up to 1700, a large part of the accumulated content of humus was destroyed (oxidised), because organic matter and dung was not returned to the fields by the peasants. There was at that time still many bogs and meadows covering about 30% of the whole area. When the content of humus was reduced to about 3 % or less in the former forest soils, this represented only 1.3 $x10^9$ tonnes oil equivalent. The nitrogen resources were exhausted and the same happened to the phosphor. It has to be remembered that the formation of humus does not take place when the average annual temperature is above 25 ^oC).

When agricultural methods changed at the beginning of the 1800s, when cyclic rotation of crops was introduced together with the distribution of dung etc. on the fields, a method which does not differ much from what we today call 'ecologic agriculture', the content of humus was partially recovered and much indicates that the content of humus increased and stabilized to about 8-9% in the run of the next 100 years (Annex 2).

Quantitative determination of the content of humus in soil

As humus is an organic acid, the content in a given soil may be determined by a method of basic extraction, but it is a fact that nobody applies this method today. The most common method for determining the content of humus, which gives a failure, is to ignite the dried soil and assume that the total weight of loss is equivalent to the content of humus. Wood chips or roots are thus also determined as humus.

The author has, in connection with a large-scale practical work on the composting of sewage slurry, developed a very simple analytical method by which it is possible to determine the content of humus. Using this method the results on 13 samples of soil analyses are presented in Annex 2.

Almost all organic compounds consist of a volatile part and a charcoal part. This is known, for example, from the production of tar. At an appropriate temperature where oxygen is excluded, lignin, sugar and proteins are partially decomposed and distil to a complex mixture of compounds which are condensed to the product named tar. The residual matter, the charcoal, is biologically inaccessible (a property which the archaeologists appreciate very much). The presence of lignin etc. allows the possibility that bacteria, fungus and other simple organisms are able to decompose the organic matter in a short time.

The content of lignin is determined by heating the dry organic matter to an appropriate temperature in an inert atmosphere. The content of charcoal is determined as the loss of weight when the sample subsequently is totally oxidized. The method is understood from the following thorough description and the textbox below.

A sample dried at 105^o C is pyrolysed (gassified) at a temperature of 600 to 650 ^oC (P) in an inert atmosphere and thereafter ignited at 600-650^oC (A) in oxygen. The ratio P/A may be utilized to determine the content of humus but also may be used to determine whether or not the material is suitable to be used for topdressing directly on the soil. For this purpose the composting index should be less than 1.4.

The laboratory method to determine the organic content of soil

% water determined when heating to 105^o

% pyrogas in dry matter (P) 600-650 ^oC in inert atmosphere

% charcoal in dry matter (A) 600-650 ^oC in oxygen

% ash

$comp_i$ % pyrogas/%charcoal (P/A)

$comp_i$ for humus = 0,8-1,2 (in calculations = 1,0)

$comp_i$ for fresh organic material = 3,0-4,0 (in calculations = 3,4)

% humus = ((3,4 – $comp_i$)/(3,4 – 1,0)) x total % organic matter

ex; 23,0 = ((3,4 - 1,4)/3,4 – 1,0) x 27,5 (Annex 2 first line)

If the temperatures given are applied, inaccuracies will not be introduced originating from the calcination of carbonates and only a slight inaccuracy from loss of OH^- from the clay minerals.

In Annex 2 the analysis of 13 soils is presented covering very different types of soil ordered with decreasing total content of organic matter and with the calculated contents of humus shown in a separate column.

Above the double line are examples of soil where either a natural organic annual supply is prevailing (forest or meadows) or where organic matter is added from year to year (ecological agriculture using compost, dung and after sowing). The highest rank has the garden compost, forest on clay soil is lower and still less is forest growing on soil rich in gravel. Meadows have a large content of organic matter but low content of humus. Ecological garden soil has a humus content in the range from 8 to 10%.

Below the double line in Annex 2 are the results from a clayey soil profile from a field not having had crops for the last 7 years and before that grown with wheat for 6 years. In the intermediate layer only fine roots are seen and almost no humus, whereas the upper layer - the turf - not surprisingly has 2.4 % humus. On the other hand, it is surprising that the soil below 50 cm depth has a content of humus higher than the turf. The weighted average of humus for former ploughed layers is less than 1%, which will not increase due to a continued halt in cultivation, that is without letting the forest grow or if no organic matter taken from elsewhere is dressed onto the top layer (se fig. 4 below).

Several types of soil have been analysed and it is evident from the table that this method of analysis of humus gives a good resolution. For example, the soils from the meadows with wild growing orchids have a high composting index, which is easily explained by the fact that they are saturated with water and consequently the admission of oxygen, which is necessary for the formation of humus, is limited and suits the orchids well.

The importance of the humus content for agriculture.

On two of the soil samples shown in Annex 2, named “Field (clayey) without crop for 7 years, Sjælland > 50 cm” and “35 years old ecologic garden soil, Sjælland 1” respectively, a drying experiment has been carried out with 250 g of each. Both soils were sampled in December and subsequently dried at 90^oC. The first mentioned sample dried out after 6 hours and the second after 12 hours. This simple experiment illustrates the well known fact that the less humus in the soil the faster it dries out in a dry season or period. A soil low in humus shows polygonal drying cracks already after 1 week without rain (Fig.1). It is worth knowing that 1 % humus absorbs 2 % of water.

9. Det umiskendelige fodspor fra en kænguru, her den grå kæmpekænguru. Den kraftigt forlængede, højt tilpassede hurtigløberfod har blot én lang, kraftig tå og to små sidetæer, hvoraf den ene ses i fodaftrykket. (M. Trolle)

Fig. 1 Typical polygonal drying cracks in a soil poor in humus. This photograph from Australia with kangaroo foot prints could equally well have been taken in a typical Danish soil low in humus but with a local animal foot print of course.

Dried samples of soils with high and low contents of humus respectively have a very different structure. Comparison of two dried samples mentioned above shows that the field sample low in humus content dries in hard lumps while the garden sample rich in humus keeps a crumbled structure. It is therefore easy to understand why it was so easy for our ancestors to prepare the soil before sowing using the method of slash and burning.

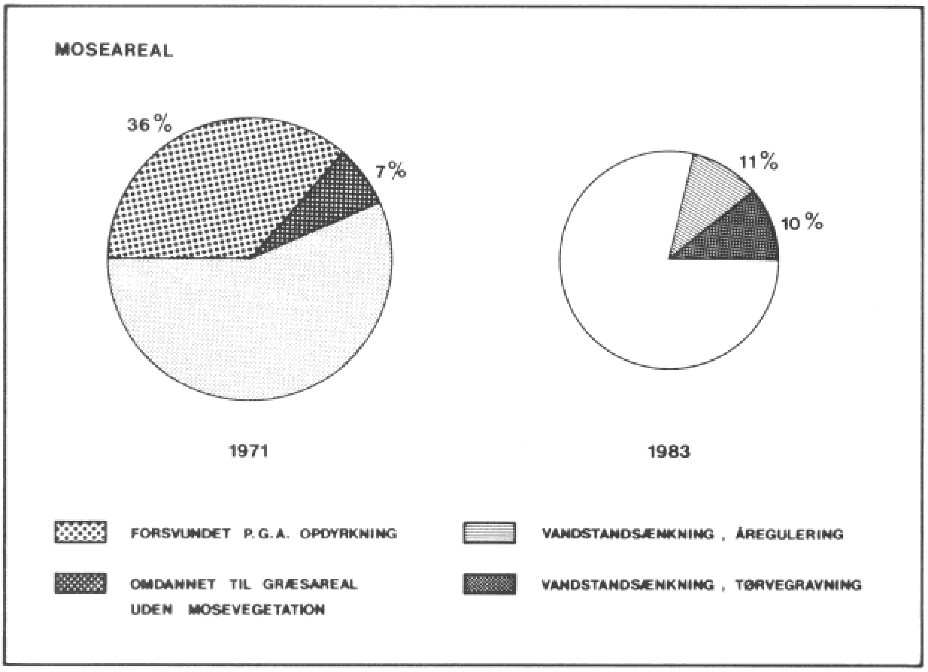
With the increasing content of humus, at the same time the content of mineralised nitrogen increases due to the activity of lower organisms and bacteria. Thus the natural content of nitrogen in the soil may only be taken up if the biologic organisms are fed with organic matter.

A third important property of humus is its ability to bind cations by which the dilution of the nutrients is hampered. The bonded cations are, on he other hand, accessible to the fine root hairs of the growing plants. Before approximately 1940 there was practically no dilution of the nutrients in Danish soils, that is before inorganic or artificial nutrients were introduced. In addition the use of increasing amounts of these increases the degradation of the humus even if fresh organic matter is supplied.

The content of humus in Danish and European agricultural soil since 1945.

From 1945 and over less than 50 years a violent change of agricultural methods led to a large reduction of the humus content in Danish soils, not solely in the fields but also by drainage of moors and wet meadows in such an effective way that these last-mentioned types of soil now only constitute 7,5 % of the total area without forest and urban developments. Consequently the total organic constituent stored in the Danish soils is much reduced.

An example of the fast changes (just 12 years) is illustrated in fig. 2.



Forskellen i størrelsen af de to cirkler viser tilbagegangen i mosearealet fra omkring 1971 til 1983. Mosevegetationen er forsvundet på 43% af det oprindelige areal, og heraf tegner opdyrkning (omlægning) sig for 36%. På mindst 21% af moserne er levevilkårene for dyr og planter forringede på grund af vandstandssænkninger (åregulering, tørvegravning).

Fig. 2. Pie diagrams showing relative change in the area of moors from 1971 to1983. (reference no. 8). In the two years specified: Upper left segment: disappeared due to change to agriculture. Lower left segment: changed to meadows and removal of moor vegetation. Upper right segment: disappeared due to regulation of the water level. Lower right segment: turf digging. The moor vegetation has disappeared with 43 % of the original area and 36 % is due to agriculture. On at least 21 % of the moors the living conditions for plants and animals have become worse due to lowering of the water level.

Already before 1945 changes of especially the shallow marine areas and the marginal areas had been seen and this is carefully described in the book by Kjeld Hansen (Reference no. 9 and Fig. 3). This method of land reclamation is not directly connected to the content of this presentation and I only include it in order to mention this work and recommend reading this book, which describes a careless and violent attack on landscape, nature and water resources in the holy names of land reclamation and employment.

On more than 50 % of the agricultural areas after 1945 the methods of cultivation were gradually changed. As generally known, with the use of breeding animals together with cyclic change of seeds, plus the introduction of ever larger ploughs and heavy harvesting machines,, grain crops were the only crop year after year and the use of inorganic (artificial) nutrients increased together with increased pesticide treatments.

In a short span of years the straw was burned in the fields and later harvested for the purpose for power production and only as an exception it was ploughed into the soil, which is not to the benefit of increasing the humus content. The total change of the agricultural methods led to a drastic decrease in the content of humus. The important question is 'how much', as the answer will be used to calculate how much this reduction is equivalent calculated as CO_2 emitted from 1945 until to day?

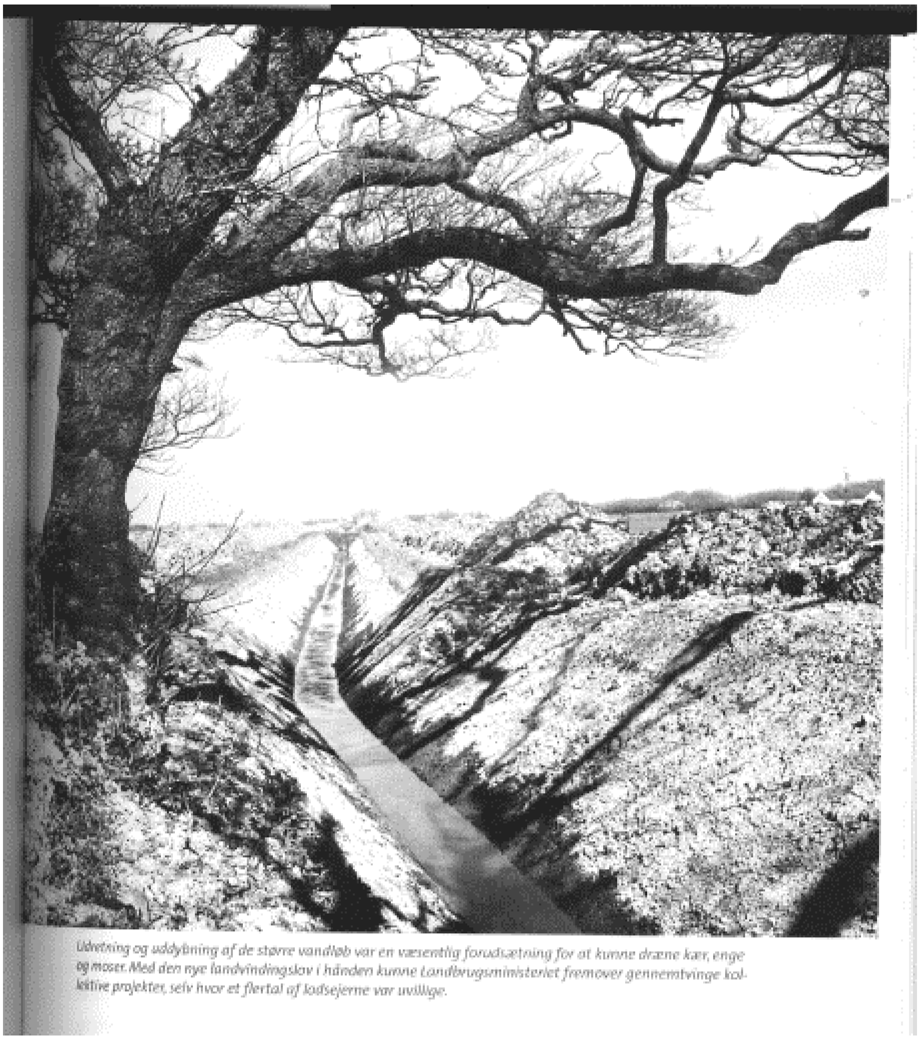


Fig. 3. One example out of many land reclamation projects by means of digging and drainage. From reference no. 9.

In Annex 2, which has been described above, it appears that the content of humus in soil used for ecological farming, i.e. with an annual returning of organic material (compost etc.), an equilibrium establishes with a content of approximately 8% humus or total 10% organics. Also from Annex 2 it is evident that the soil in Denmark today contains about 1% of humus or less. In the calculation of the loss of carbon due to the reduction in the content of humus, a figure of 60% carbon is applied, cf. table on page 1.

From fig.4, the figures used in the calculations of loss of humus (with caution) are shown and there is distinction between soil with clay and sand. (see box). [But the loss of soil properties is connected to the loss of humus. As mentioned before this is due to the ability to absorb water, bind cations, as substances for nitrogen fixing bacteria, the influence on reduced soil treatment, the content of micro fungus, other bacteria, worms etc.]

Fig. 3. Virkning på jordens C indhold af ugødet, ubevokset brak og dyrkning af stråafgrøder med og uden halmnedmuldning på lerjord med højt C indhold (O-ler) og sandjord med lavt C indhold (U-sand).

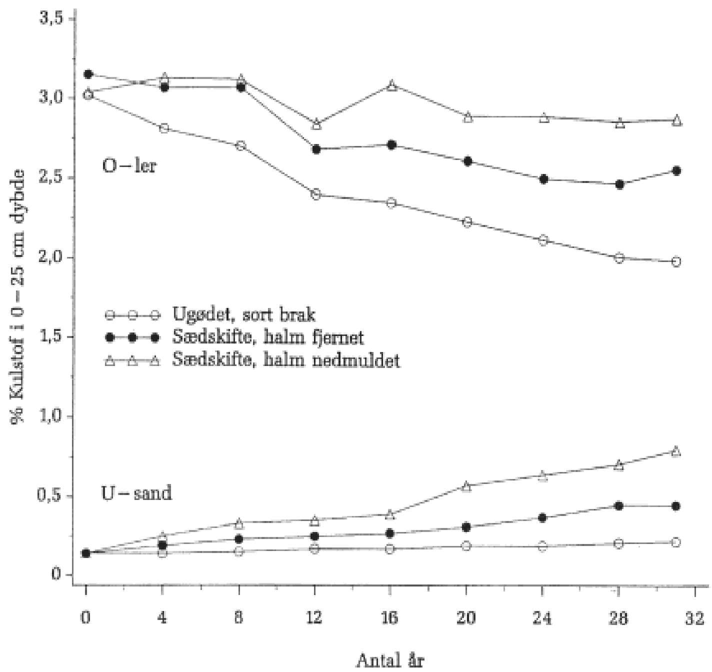


Fig.4. The content of carbon in tested fields from Aulum, Denmark, with different soil treatments over 30 years. A cautious judgement indicates that clayey soil has maximum 4% organic content and sandy soils 1% (See also Ref. 5) Compare with Annex 2.

Calculation of the loss of humus (organic matter) in Denmark from 1945 to 1995

On 32 % agricultural area with clayey soil the reduction has been from 10 to 5 % (organic)
On 22 % agricultural area with sandy soil the reduction has been from 5 to 1 % (organic)
On 3.5% meadow due to drainage the reduction has been from 15 to 8 % (organic)
Weighted average loss of the humus content for the whole country is from 8.3 to 3.6% for 57% of the total area of Denmark being 43.000 km^2.
The population was assumed to be 5.5 million as an average for the period.
The loss of humus (organic) calculated as oil equivalent:1.4 tonnes/person/year in 50 years
The total energy consumption for each Dane in 2005 was 2.7tonnes/year oil equivalent.

The same calculation could be carried out for the rest of Europe with a temperate climate, but taking into consideration that the content of humus decreases slightly towards southerly latitudes.

It thus appears that enormous amounts of carbon has been emitted to the atmosphere in the last 50 years alone from the loss of humus in the soils, and that it is in the same order of magnitude as the amount of fossil energy consumed in the same period.

Therefore it is very much correct to describe the agricultural soil and the content of humus herein as a CO_2 lunge, although it is not in the same order of size as represented by an old forest. Because the agricultural area is 10 times larger than the forested area in the temperate zones, it is in the former that the potential influence on the change of the content of CO_2 may be found.

Due to the reduction in the content of humus in Denmark in the same period, the need for taking care of the environment in fresh as well as saline water has increased, because of leaching of nutrients no longer bound in humus, and despite the introduction of filtering of rural foul water.

1. Økologiske jorde indeholder 5-10 gange flere regnorme end konventionelt dyrkede jorde. Her et eksemplar af rosa orm (Apporectodea Rosea) (Gert Hansen /Biofoto.)

May these considerations by utilized in the future?

Theoretically it is stimulating to imagine that if we are able to increase the content of humus in the soil by adding some organic matter and by changing the methods of agricultural soil treatment, over the next 50 years we might be able to store in the order of 50% of our present CO_2 emission in the upper 50 cm of soil. This would influence a lot of other conditions. The need for inorganic nutrient will decrease, especially the high energy consumption for production of nitrogen, because the content of worms (fig. 5) together with other soil organisms and fungus furnishes the mineralising of the atmospheric nitrogen. The soil treatment would need fewer machines and consequently the energy consumption would decrease, the soil compression would cease and the water percolation would be better. The need for irrigation would diminish because the humus absorbs two times its weight. The leaching of nutrient to the environment would diminish to the benefit of lakes, rivers and sea. The plants would develop better resistance against disease and insects and therefore the need for pesticides would decrease to the benefit of pure groundwater

Fig. 5. The well known rain worm (Reference 13), of which the number of individuals per square meter depends on the methods of agriculture. If enough organic matter is fed into a soil low in humus the number will increases as also will the humus content. The rain worms are sensitive to dunging, pesticides and the method of soil treatment (Reference 12). On a recent field grown with seed every year there are fewer than 1/10 rain worms, compared with a forest growing on a clayey soil.

Indeed it sounds promising that it is possible to store the CO_2 in the soil but one should not be fooled, as it is as difficult in the extensive method of agriculture on large fields as it is easy in the small hobby gardens. We are forced to realize that we have lost (consumed) the stock of humus in the same way as we are spending our capital of non-renewable fossil resources.

If Denmark was forested, the upper layer would probably be renewed with respect to the humus contents in at least 700 years without being farmed or harvested, but this will not happen as we are forced to use the present methods of agriculture to keep up with food production for man (and pig). The organic waste we do not eat we either burn or we think of being utilised for production of biogas, which will save only some trifling drops in the comprehensive global oil consumption and with a probably negative contribution to the limitation of the CO_2 emission.

In any case there is little probability that it is possible to return enough organic matter to the agricultural areas to the benefit of restoring a satisfactory humus content (also to the benefit of reducing the CO_2 emission). We must simply realize that there is a negative energy output from our present way of cultivating our farmland and when the fossil energy resources are one day consumed, we will hardly be able to keep up the food production due to the reduced natural fertility of the soils.

Much knowledge exists about the importance and influence of humus on the plant growth, but only little attention has been paid on its influence on CO_2 emission. From this point of view we can hardly blame countries burning their forests as we in the western hemisphere have not been able to keep our important humus content at a reasonable level.

It may be possible to carry out some more accurate calculations as a more detailed knowledge about the humus distribution in former times and in present soils are determined, but I have the strong opinion that the order of magnitude presented above is a very good approximation and therefore the overall conclusions will not change.

As a consequence I am not able to point to a solution better than that each of us must strive in every respect to reduce the consumption of fossil energy and to develop alternative ecological farming and energy producing methods, hopefully supported by government legislation.

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Annex 1. Selected references on the definition of humus

Strahler& Strahler 7) Introduction to Environmental Science

.....humus, which is finely divided, partially decomposed matter.

... humification is essential the slow oxidation of the vegetative matter. Organic acids formed during humification, aid in decomposing the minerals of the parent soil material.

Turning now to the micro flora, we find that bacteria consume humus, oxidizing the organic compounds and releasing carbon dioxide. In cold climates, bacterial growth is slow, with the result that humus accumulates on and in the soil.

Glossary of Geology (10):

Humus. The generally dark, more or less stable part of the organic matter of the soil, so well decomposed that the original sources cannot be identified. The term is sometimes used incorrectly for the total organic matter of the soil, including relatively un decomposed material. synonym: soil ulmin.

Hans Pauly: Geokemi (11)
The organic compounds of soil - the humus – are parted in groups. The designation humin is used for newly formed organic compounds. The humin substances are parted due to their solubility in f.i. Na(OH): 1) fulvo acids, 2) humin acids, 3)humans.
The two first mentioned are most important. In extracts of humin substance a number of organic compounds have been proven: E.H. Hansen has in the B- horizon from a podsol from Jutland found the existence of isolated aromatic rings possible connected with aliphatic chains.

Lademans Encyclopaedia 1986
Humus: Dark coloured organic substances with a complicated composition derived from partial rotted plant issues. The reaction is acidic due to the content of humin acids, and are responsible for the dark colour of mould and moor. It is of importance for the soils ability to withhold water and keep a desired crumbled structure, which again furnishes the growth of the plant roots and their ability to take up nutrients; humus is in it self not a nutriment. If the soil reacts basic and the atmospheric oxygen is admitted the humus is gradually decomposed to inorganic compounds, among others nitrates necessary for the plant growth. If the humus does not decompose it is accumulated and moor forms, by which the soil becomes acid or partially carbonises to turf of brown coal.

Asger Klougart: Jordens Frugtbarhed 1953.
It is valuable to know the content of organic matter in the soil, partially in order to know the property of base saturation and partially in order to know its heavily bound humus nitrogen and finally in order to know the physical properties.

Annex 2 . Analysis of soils samples and the calculated content of humus

Sample description	% Pyrogas (P) of dry matter	% Charcoal (A) of dry matter	$Komp_i$ (P/A)	% Organic total	% Humus calculated	% Moisture as sampled
Garden compost 1 year old	16,0	11,5	1,4	27,5	23,0	53,3
Wet meadow with orchids, Øland Sweden	14,7	5,8	2,5	20,5	7,7	40,1
Forest on clayey soil, Sjælland	9,0	7,0	1,3	16,0	14,1	23,6
Wet meadow with orchids, Sjælland	8,8	4,4	2,0	13,2	7,7	33,0
Ecologic garden soil older than 10 years, Öland Sweden	7,5	4,7	1,6	12,2	9,1	15,3
Ecologic garden soil older than 10 years, Älmhult Sweden	6,8	3,6	1,9	10,4	6,6	22,0
35 years old ecologic garden soil, Sjælland 1	4,6	5,0	0,9	9,6	9,6	15,1
Forest on sandy soil, Sjælland	5,0	4,2	1,2	9,2	8,5	14,7
35 years old ecologic garden soil, Sjælland 2	4,8	4,0	1,2	8,8	8,1	16,0
Field (clayey) without crop for 7 years, Sjælland 0-10 cm	4,8	2,0	2,4	6,8	2,8	19,5
Field (clayey) without crop for 7 years, Sjælland 20 cm	4,0	1,2	3,3	5,2	0,2	15,5
Field (clayey) without crop for 7 years, Sjælland 30 cm	4,0	1,2	3,3	5,2	0,2	16,9
Field (clayey) without crop for 7 years, Sjælland > 50 cm	4,9	2,1	2,3	7,0	3,2	15,3