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Need for and suitability of industrial wastes as fertilizers and soil amendments

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With increasing scarceness of raw materials, recycling of wastes becomes more and more desirable. Because it is not compulsory for agriculture to utilize industrial wastes, not even those from the agricultural processing industry, recycling in this sector offers prospects only if the waste products are attractive to agriculture. This means that the wastes have to possess qualities as a fertilizer or soil amendment, should be favourably priced, and should not endanger health of the user, yield and quality of crops, and productive potential of the soil.

Need for use of wastes in agriculture. — Most farm enterprises require an annual input of *plant nutrients*. Depending on the crop and the fertility of the soil, this requirement may be as high as a few hundred kg per ha for primary elements like N, P, and K, or a few kg for trace elements like Cu and B. All these nutrients are amply available for sale in Western Europe in the form of mineral fertilizers; for these nutrients, therefore, agriculture is independent of industrial wastes.

In addition to fertilizers, agriculture may have a need for *soil amendments*. These are intended to improve soil reaction and/or biological and physical conditions so as to make the soil environment favourable for biological activity and for unimpeded growth and optimum performance of the plant root. Examples would be lime and materials containing organic matter.

The lime status of the soil, usually characterized by the pH-value, is often too low; in climatic zones in which precipitation exceeds evapotranspiration, it regularly has to be brought back up to the proper level. The annual amounts required to accomplish this vary (for The Netherlands) between 50 and 1000 kg CaO per ha. Liming materials are mined as minerals and are, for the time being,

available in sufficient amounts. Also for these materials, agriculture is independent of industrial wastes.

In many respects, organic matter is an important soil component. The amount present in cultivated soil, usually referred to as the humus content, decreases due to biological decomposition, but is replenished through dead roots and other plant residues. Whether or not organic materials need to be imported to the farm from without depends of course on the difference between the humus content that is desired and that is present, and on the balance between decomposition and supply on the farm.

For a significant rise in humus content, an enormous supply of organic material is needed. For example, to raise the content from 2% to 3% with animal manure within a period of 10 years, it is necessary to apply per ha annually the amount produced by 8 cows. Such high stocking rates are not found anywhere.

On the other hand, it is too easily taken for granted that in modern agriculture decomposition of organic matter exceeds the supply and that therefore the humus content of the soil declines. Perhaps the supply in the form of crop residues is underestimated. For a good cereal crop, it amounts to about 5000 kg organic matter per ha, which gives about 1600 kg 'humus' after one year. Annual decomposition of soil humus in a plow layer containing 2% is estimated to be 1200 kg, which is less than the amount supplied. In some regions, intensive livestock farming results in a heavy production of organic material. In The Netherlands, for instance, this production, converted to the total area of cultivated land, amounts to about 1600 kg organic matter per ha.

Compared with the production of organic wastes by agriculture itself, the amounts originating from other sources are probably insignificant. In The Netherlands, for instance, again converted to the total area of cultivated land, only about 50 kg organic matter is produced in the form of municipal sewage sludge, 10 kg as town refuse compost, and 10 kg as lime sludge from the sugar industry. Thus, the dominant source of organic matter for agriculture is agriculture itself.

In some branches of production, particularly in the culture of ornamental crops, substrates with a high organic-matter content are strongly preferred. So far, natural peat has often been used, but as its supply near the centres of culture is dwindling, the need for sub-

stitutes, including materials from industry (bark, rockwool), increases.

The preceding shows that agriculture, with few exceptions, is independent of waste products from industry for its requirement of fertilizers and soil amendments. This does not mean that such products may not be useful to agriculture. How much can be utilized will be determined by the activity of the producer of the waste material on the one hand, and by the attractiveness of the products to agriculture on the other. In the latter aspect, the presence of valuable constituents and the absence of harmful elements, as well as the price, are the most important considerations. The trade in such materials is subject to legislation; however, the laws are not yet uniform, even in Europe.

Suitability of industrial wastes. — Experience shows that industry regards agriculture as a potential market especially for waste materials that contain *organic matter* or *lime*. The former come from widely different industries that process products from agriculture, horticulture, forestry or stock farms. The wastes containing lime often come from industries that use lime in their production process; not infrequently the raw materials involved are of non-agricultural origin. Before the waste products referred to here can be entered onto the market, they have to possess, like the recognized fertilizers, a demonstrable, positive value for agriculture and must be harmless to man and animal, crop and soil.

Wastes that contain *organic material* are often considered by the producers to have value as soil amendments, for instance because they may raise the humus content of the soil. Determination of this value by means of experiments may be very time-consuming and expensive. For an evaluation, in general a comparison with known organic soil amendments will have to suffice; this can be done on the basis of information concerning origin, type, method of preparation or manufacture, and composition of the product; if desired, this information may be supplemented with laboratory tests on a limited scale.

In an evaluation, knowledge about the rate of decomposition determines or limits the utility of the product and gives information on the potential contribution to the humus content of the soil. Figure 1 shows the differences in decomposition of widely different

materials. In principle, the effects of easily decomposable wastes on the soil may be expected to be similar to those of green-manure crops and straw, while the effects of difficultly decomposable wastes are more comparable to those of peat.

No rapid laboratory test is available to determine rate of decomposition. An impression may be gained from information concerning origin, type and method of preparation, supplemented with, if desired, results of analysis for lignin and carbohydrates. More solid information, however, can be obtained from an incubation test, in which over a relatively short period of time the decomposition of the organic material is determined experimentally under standardized conditions. Such a test should be aimed at predicting the amount of organic matter that is left in the soil one year after application of the product under normal (farming) conditions. With that information it is then possible to make a link with data in the literature and so to predict the course of decomposition in the long term.

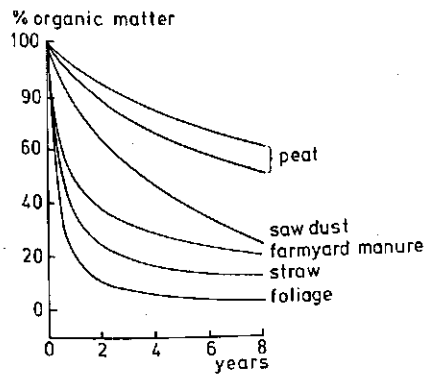

FIGURE 1. — Decomposition rate of different types of organic matter (Kolenbrander, 1974).

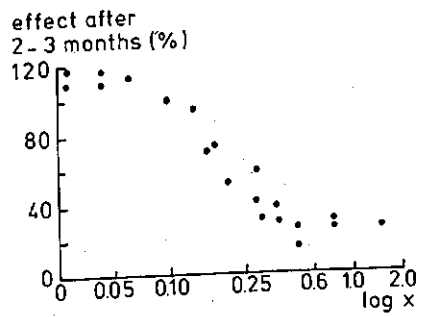

FIGURE 2. — Effect of different size fractions (x) of marl on pH of the soil (effect of fraction 0.1 mm set at 100%). Results of five pot experiments.

The amount of organic matter, left over in the soil under normally prevailing conditions one year after application of the material, is referred to as the humification coefficient (K_1). It gives not only an insight into decomposition in the first year after application, but also makes it possible to estimate the contribution to the humus content in the longer term (KOLENBRANDER, 1974). For example, a K_1-value of 0.50 for farmyard manure (table 1) is associated

TABLE 1. — *Humification coefficient, soil o.m. increase index, and relative quality of organic matter of different origin.*

Origin	Humification coefficient (K_1)	Soil o.m. increase index (S_{10}) %	Quality of the organic matter FYM = 1.00
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 spruce	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

with an S_{10} of 3.0, which means that when a quantity of farmyard manure amounting to (on an o.m.-basis) 1% of the weight of the plow layer is applied annually for a period of 10 years, the humus content will be 3.0% higher than without farmyard manure. The table shows that peat moss is 2.5 times as effective as farmyard manure, but green manure only 0.25 times as effective. By determining the humification coefficient of waste materials to be placed on the market, it would be possible to estimate the values in the other two columns of the table through interpolation. Calculations show that, to increase the humus content by 1%, annual applications of about 4 t of organic matter from peat moss for a period of 10 years are needed, and of o.m. from green manures even 10 times that much.

From this explanation it will be clear that when the manufacturer or producer of a waste material applies for a marketing permit for his product, he should state the intended dosage; this will allow an evaluation of the potential increase in humus content. If less than 1000 kg organic matter per ha per year is involved, effectiveness as a soil amendment can hardly be expected.

To judge the agricultural value of *easily decomposable products*, information on their N-fixing or N-supplying capacity is needed. The C/N ratio of the material is indicative of this. At values above 15 to 18, nitrogen may be fixed in the soil during decomposition, at the expense of the crop. To judge more *decomposition-resistant* materials, which are often used in horticulture (potting soils), determination of the water holding capacity and the cation exchange capacity is useful. For frozen black peat and peat moss, the water holding

capacity required in The Netherlands is 4 times the content of organic matter or 800 g per g dry matter. In addition, resistance to collapse may be important in connection with the required air content.

Calcareous wastes derive their value primarily from their effect on soil pH. A change in pH is intended to optimize the environment for plant roots and soil organisms. Because calcium is relatively immobile in the soil — at least much more so than, for instance, nitrogen — it should be mixed homogeneously through the soil. The physical condition of the material should be such that it can be evenly distributed over the field; in other words, there should be no lumps. Calcareous wastes shoud be judged on this characteristic, also after wetting and drying.

The effect of liming materials on soil pH depends on their fineness, hardness, and chemical form. To achieve a rapid increase in pH, particles having a cross section of more than 1 mm are barely useful, but particles less than 0.15 mm are very effective (figure 2). Hard materials are less active than soft ones, although this difference becomes small for particles smaller than 0.15 mm. Mg-containing carbonates are somewhat less effective than pure calcium carbonates of the same particle size. The fineness of a material can usually be determined in the laboratory by dry-or wet-sieving; as yet, no suitable method for the determination of hardness is available. An example of a calcareous material that is much appreciated by farmers is lime sludge, a waste product from the sugar industry. It contains lime in a finely divided form, mixed with organic material. The product can be spread readily in liquid as well as in wet and in dried form, provided that the proper equipment is available.

Harmful components that may limit the use of wastes in agriculture may be heavy metals, pesticides, PCB's or other toxic substances, pathogenic organisms or, in specific instances, also seemingly innocent compounds like chlorides. An indication of their noxiousness to crop growth and quality can be obtained grom a pot experiment in which increasing volume fractions of the waste product are substituted for the soil. An example is given in figure 3.

In Western Europe, the current focus of attention is especially on heavy metals. Several of these (Cu, Mn) are indispensable to

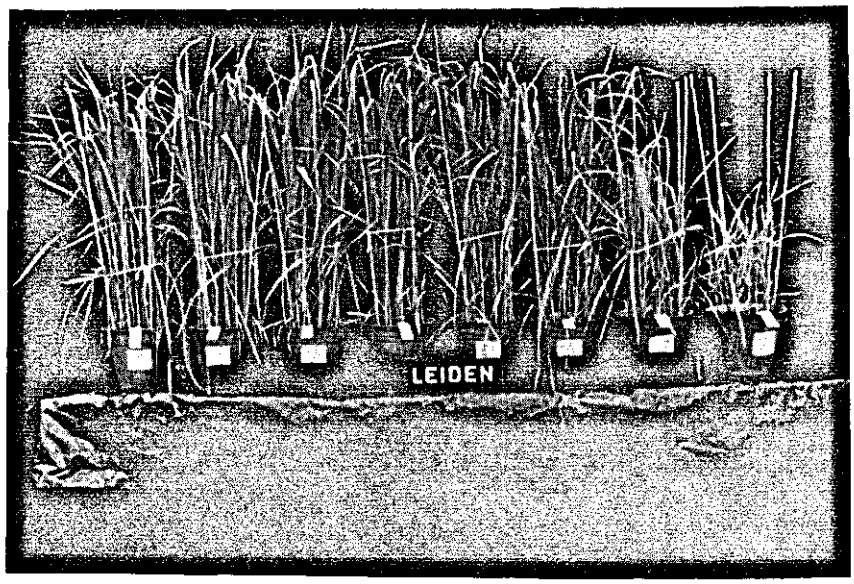

FIGURE 3. — Soil-sludge mixtures with (left to right) 0, 1, 2, 5, 10, 20, 50, and 100 percent sludge from Leiden (De Haan, 1975).

plant growth, others (Cd, Hg) are not functional in that respect. The need for the elements of the first category is usually limited to a few kg per ha; heavier doses are harmful. Also without visual damage to the crop, uptake of these elements by the crop may have dangerous consequences, particularly to the nutrition of man and animals. Figure 4 shows the uptake by the grass in the experiment of figure 3. At the low volume fractions of the waste material that do not yet affect growth, the Ni- and Cd-contents of the grass have already risen enormously.

Agriculture is becoming increasingly restrained in using materials that contain hearvy metals. If industry wants to sell its wastes to agriculture, they should preferably be free from heavy metals. In my opinion, entry onto the market should not be permitted if the wastes, when applied in the prescribed amounts, supply more heavy metals than is the case with the materials that currently hold a marketing permit. In this connection, the present-day guidelines for using municipal sewage sludge are instructive. Agriculture attaches value to this material especially because of its content of N, P, and organic matter, but it is apprehensive of the heavy metals. Increas-

ingly the idea finds acceptance that sludges that are more heavily contaminated than those of purely domestic origin should not be used in agriculture. This means that the following contents should not be exceeded: Zn, about 2000; Cu, Cr, and Pb, 500; Ni, 100; Cd and Hg, 10 mg per kg. The question remains, however, how much of such wastes may be applied. An approximate answer to this question is given by the type of pot experiment mentioned before (figure 3). In such trials it was established that up to 10% of the soil volume may be replaced by sludges of domestic origin without reducing yield and without changing the chemical composition of the grass too much (De Haan, 1978). This means that, converted to area units, permanent grassland may be given 100 t dry sludge and arable land about 200 t. However, it would be wise not to apply such amounts all at once. In several West European countries the research institutes recommend that only a fraction of the total amount be given per application, for instance one hundredth, so that it will take many years before the threshold value is reached. The philosophy behind this recommendation is that future experimental results may give cause for more restraint and possibly for prohibition of the product before irreparable damage is done to the soil. From the above-mentioned figures it may be calculated that, using a safety factor of 0.01, via sludge of domestic origin no more should be applied annually to arable land than 4 kg Zn, 1 kg Cu, Cr

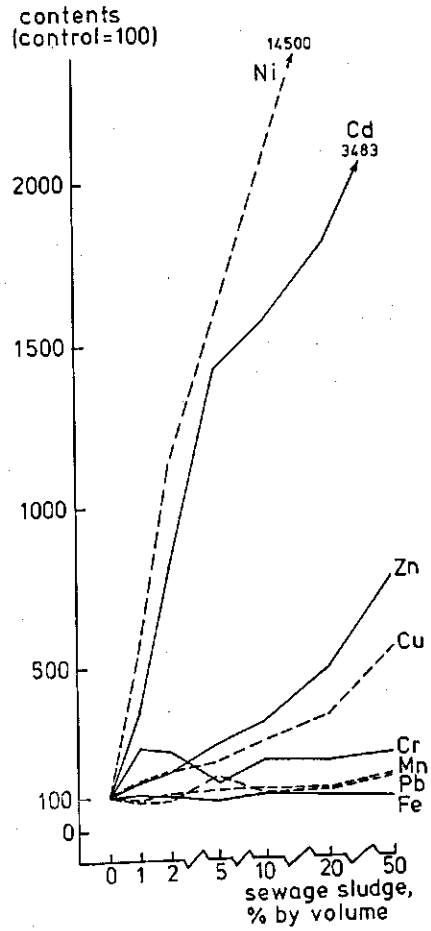

Figure 4. — Contents of microelements in grass of the pot experiment of figure 3.

and Pb, 0.2 kg Ni and 0.02 kg Cd and Hg per ha, and to grassland no more than half these amounts. The standards used by the different European countries vary somewhat, but the order of magnitude of the recommendation is similar. It may be assumed that also for industrial wastes the amounts just mentioned may be used as a standard. It should be mentioned here that the use of sewage sludge in horticulture is clearly advised against, at least in The Netherlands.

If pathogenic organisms are present in waste products, their use in agriculture will generally be objectionable. Also the presence of toxic substances that may enter the human or animal body through inhalation or in any other way during storage or application, or shortly thereafter, may be prohibitive. Obviously the farmer does not count with contamination with pesticides. Less investigative work has been done on the significance of PCB's than on heavy metals. The EPA in the USA seems to have set a limit to PCB-contents in sewage sludge.

In contrast with fertilizers, which are produced for a specific purpose, industrial wastes often contain whole series of elements, both useful and noxious to plants. Chances are that the proportions in which these elements occur in the material are unsuitable for agricultural crops in general (e. g. in heavily contaminated municipal sewage sludges) or for specific crops. For instance, the presence of much Cl relative to K may be objectionable when the material is to be used for potatoes; also, a high Cl-level may make the use of organic materials as substrates in pot cultures of horticultural crops unattractive. It is therefore advisable for industry to seek assistance from authorities with the necessary expertise when directions for use are drawn up for the relevant products.

With increasing scarceness of raw materials, recycling of wastes becomes more and more resirable. Nevertheless, the disposal of industrial wastes to agriculture will require effort and care from industry, because agriculture does not depend on these products. Plant nutrients are abundantly available from other sources and even for the so-called soil amendments as lime and organic materials, agriculture does not turn to industry as its primary supplier. An exception is perhaps horticulture, which increasingly utilizes substitutes for peat, the traditional culture medium. If industry wants to market its waste products in agriculture, then they will have to be

attractive on the basis of presence of valuable constituents and absence of harmful ones, and be favourable priced.

Experience has taught that especially materials that contain organic matter and lime are offered to agriculture. Primarily needed to evaluate the first group is information about their rate of decomposition, which determines or limits their purpose and gives an indication of their potential contribution to the humus content of the soil. However, a rapid laboratory method to determine this property is as yet lacking. In the case of easily decomposable products, information about their C/N-ratio is important, while data on water holding capacity, resistance to collapse, and cation exchange capacity are wanted in the case of more resistant materials. Calcareous materials should have a physical condition that allows them to be spread evenly over the land, and they should possess a high degree of fineness.

Harmful components that may occur in wastes are heavy metals, pesticides, PCB's and other toxic substances, pathogenic organisms and, in specific instances, even seemingly innocent compounds like chlorides. Hearvy metals are emphasized in this paper. On the basis of current knowledge and use of municipal sewage sludge an indication is given of the maximum permissible amounts of these metals in waste materials.

Industry is recommended to seek assistance from soil fertility experts in drawing up directions for use of waste products.

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SUMMARY. — If industry wants tc market its waste products in agriculture, then these products have to be attractive on the basis of presence of valuable constituents and absence of harmful ones, and be favourably priced. In the paper special attention is given to the evaluation of organic-matter and lime-containing materials. As harmful components, heavy metals are emphasized. Industry is recommended to seek assistance from soil fertility experts in drawing up directions for use of waste products.

RÉSUMÉ. — L'industrie qui voudrait se débarasser de ses déchets par l'entremise de l'agriculture, doit examiner s'ils sont attractifs de par leur valeur fertilisante ou améliorante pour le sol et inoffensifs pour la production alimentaire ou fourragère et pour la santé du betail. Le prix de ces déchets doit être en concurrence avec les autres moyens de production. L'exposé traite de la valorisation de produits contenant de la matière organique ou de la chaux et, du coté éléments nocifs, souligne le danger des éléments lourds et la limitation dans l'emploi de déchets qui en resulte. L'industrie est conseillée d'emprunter l'aide d'experts de fertilisation pour l'élaboration des recommendations d'utilisation des déchets qu'ils tiennent à offrir à l'agriculture.

ZUSAMMENFASSUNG. — Falls die Industrie ihre Abfälle in die Landwirtschaft absetzen will, dann sollten diese Abfälle Düngungs- oder Bodenverbesserungswert besitzen, nicht schädlich und überdem konkurrenzfähig sein. In dieser Arbeit wird insbesondere der Bewertung von organischer Substanz und Kalk enthaltenden Materialen Aufmerksamkeit gegeben. In bezug auf die schädlichen Komponenten sind die Schwermetalle hervorgehoben. Der Industrie wird empfohlen zur Abfassung der Gebrauchsanweisungen die Hilfe von Bodenfruchtbarkeitsexperten anzurufen.

RESUMEN. — Si la industria quiere lanzar sus productos residuales al mercado agricola, éstos deben ser atractivos a condición de que contengan elementos valiosos y sin elementos ofensivos y a un precio módico. En este informe se dará especial atención a la evaluación de los aspectos orgánicos y de las materiales que contengan cal, poniendo énfasis en los metales pesados como componentes ofensivos. Se recomienda a la industria que pida asistencia a los peritos en la fertilidad de suelo para formular las instrucciones de uso de los productos residuales.

RIASSUNTO. — L'industria, che dovrebbe sbarazzarsi dei suoi rifiuti per introdurli nell'ambiente agricolo, deve esaminare se sono convenienti per il loro valore fertilizzante o per le proprietà miglioratrici e se sono inoffensivi per la produzione alimentare e foraggera e per la salute del bestiame. Il prezzo di questi prodotti deve essere in concorrenza con quello degli altri mezzi di produzione. Il presente articolo tratta la valorizzazione dei prodotti contenenti sostanza organica o calce e insieme elementi nocivi, sottolineando i danni e le limitazioni che ne derivano. L'industria è consigliata di ricorrere all'aiuto di esperti nella fertilità del suolo, in vista dell'utilizzazione di questi rifiuti in agricoltura.

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