CONTRIBUTIONS OF SOIL ORGANIC MATTER TO PRODUCTION POTENTIAL OF SOILS AND SOME PROPOSALS FOR PRACTICAL APPLICATION

Wolfgang FLAIG

Annex II

to the report of W. FLAIG

9 Lectures about: Contributions of soil organic matter to production potential of soils and some proposals for practical application.

delivered at Nuclear Research Laboratory, Indian Agricultural Research Institute, New Delhi, from 12. July to 18. September 1973.

Country	:	India
Project	:	Ind-68-589 - Nuclear Research in Agriculture
Name of Expert	:	Prof. Dr. W. Flaig
Field Report No.	:	Final Report
Period	:	5 July - 30 September 1973
Post Title	:	Soil Chemistry (Soil Organic matter)
Date	:	28th September, 1973

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Wolfgang FLAIG

1973

Preface

The increase of yield/ha is important for the food production of Indian Population. For this purpose firstly high yielding varieties of rice, wheat and other crops were bred. These demand a higher quantity of mineral fertilizers. Fertilization alone does not allow the realization of the full genetical potential of cereals. The inorganic ions of the fertilizers enhance also microbial activity. The microorganisms use the carbon from soil organic matter as source for energy and reproduction. As a consequence of decrease of soil organic matter unfavourable processes in soil, the substrate for production occur, which cause a reduction in plant production. Therefore an increase of yield by fertilization alone is limited.

Another way to overwhelm the biological border for the use of the genetical potential of cereals is to utilize the effect of bioregulators on plant metabolism, such as CCC, "Cycocel" to increase the resistance against lodging of wheat. There are some other substances in soil organic matter, which have bioregulating effects under unfavourable growth conditions. This influence of soil organic matteron yield is well known by the farmers as "humate-effect".

Therefore, it is evident, that special procedures for maintaining a critical status of soil organic matter should be followed. More research about humus is necessary. An intensive cereal production is then economical only, when yields are always maintained at a relatively high level. One should try to minimize the yield depressions by appropriate procedures.

The lecutes are an introduction into the problems. The transfer of results of basic research into practice are mentioned and the experiences about the utilization of new findings are summarized.

I have to thank Mr. M.S. Sachdev (M.Sc.) for his indefatigable help, for the revision of the lectures and for compiling the references.

Wolfgang FLAIG

New Delhi, 29. September 1973

Content

INTRODUCTION TO SOME FIELDS OF SOIL ORGANIC MATTER STUDIES IN RELATION TO SOIL PRODUCTIVITY

Introductory Lecture

W. FLAIG*

1. Introduction
2. Humus content and soil productivity
3. Indirect and direct effects of humic substances on plant production.
4. Environmental conditions and effect of physiologically active substances.
5. Phenolic compounds as one type of physiologically active substances in the soil. Sources for formation
   - 5.1 Lignin
   - 5.2 Microbial synthesized phenols
6. Some important reactions of phenols during humification.
7. Nitrogen in humic acids.
8. Processes during humification.
9. Uptake, transport and transformation of labelled phenol-carboxylic acids.
10. Transfer of scientific results to technical applications
    - 10.1 Slow releasing organic nitrogen fertilizer, N-Lignin.
    - 10.2 Characterisation of humic systems.
11. Why to do research for stabilisation of crop production level.

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1. Introduction

At first I will speak very briefly about the Institute of Soil Biochemistry of the Forschungsan-Stalt für Landwirtschaft, Braunschweig - Völkenrode. The Research Center is a scientific Institution of the Federal Government. Its tasks are:

1) to do basic research with aspects for future application in practice;

2) to make contacts with other scientific institutions in Germany and in other countries;

3) to advise the total German Federal Government for decisions and not only the Federal Ministry of Agriculture.

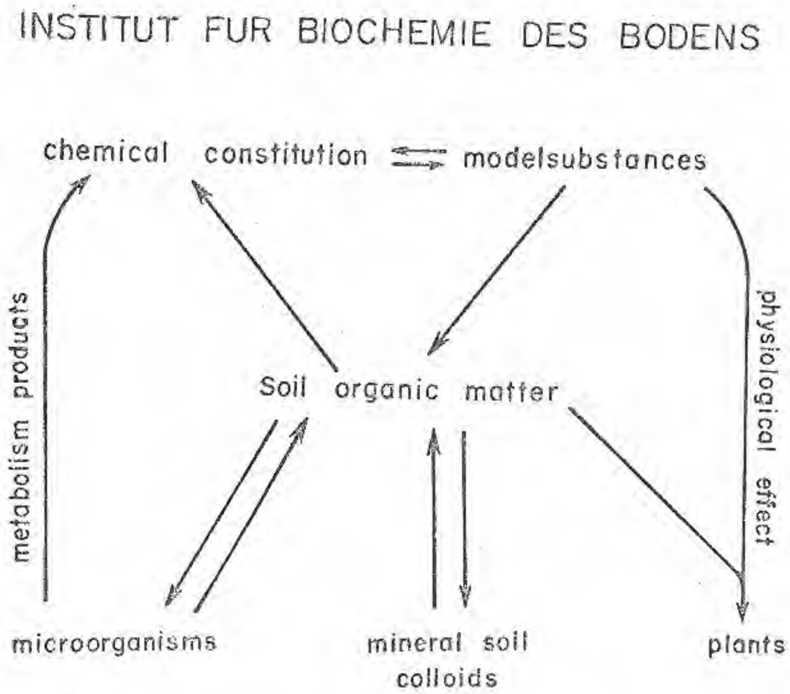


Fig: 1. Scheme of work of Institute of Soil Biochemistry

We are interested in inorganic soil colloids as far as there exist interactions with organic compounds in soil.

Furthermore we study biochemical formation and degradation of substances in humus. One of the main tasks is the elucidation of chemical structure of low and high molecular weight organic substances and the reaction mechanisms which are important for formation and transformation. Often we use model substances. for the chemistry of humic substances. The characterisation of humic systems by evaluation of physical and chemical data with statistical methods belong also to this field of work.

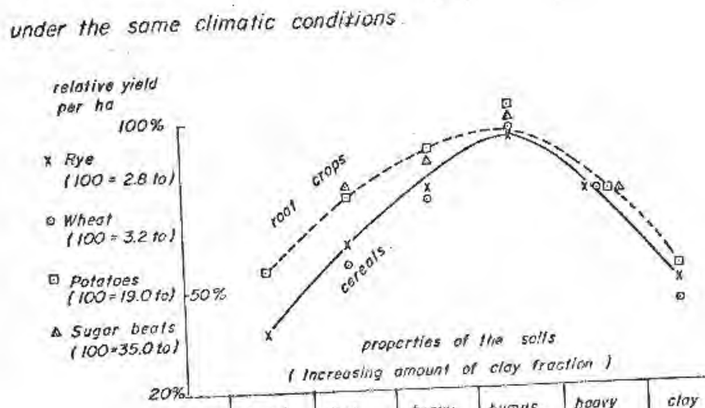
Finally we are very much interested in the physiological effect of constituents of soil organic matter on metabolism, growth and yield of plants. The investigations are concerned from basic research up to the application of the knowledge, for instance a new type of slow releasing organic nitrogen fertiliser, produced by oxidative ammonisation of waste liquors of pulp and paper industry.

Institute works in five sections, (i) Soil structure and physical-mechanical soil properties; (ii) biophysico-chemistry; (iii) organic chemistry; (iv) biochemical transformation of organic matter and (v) biochemistry of plants.

2. Humus content and soil productivity

Nearly nobody doubts, that soil organic matter is an important factor for soil productivity. Its effect cannot be explained by a source for mineral nutrition alone. Many investigations have been made to show this fact. I will only demonstrate one example.

Broader productivity of soils for agricultural plants depends upon the composition of the soils.



relative content:	sand	high loamy sand	heavy sandy loam	humus medium loam	heavy loam	clay soil
Humus	o	+	+	++	+	o
Sand	+++	++	+	+	o	o
Clay	o	+	++	++	++	+++

o=relative small amount ; +, +, +++ = increasing amounts

Fig. 2: Dependency of the yields on different properties of the soils under the same climatic conditions (according to Sagave, 1934).

In this diagram, the components of the soils are divided up in sands (inorganic constituents of a size between 0.05 -2 mm) in a clay fraction (inorganic constituents of a size between 0.05 and 0.01 mm and smaller than 0.01 mm) and finally -- in organic parts -- in humus, to be able to compare the influence of the soil constituents on the soil productivity. The experiments have been made under nearly the same climatic conditions.

The diagram shows in which way the yields of cereals and root crops depend upon the mixture of the mentioned soil constituents.

In the case of humus medium loam (mineral fraction between 0.05 and 0.01 = 58%, fraction smaller than 0.01 mm = 33%), the composition is the most favourable for the production.

To get an idea about the participation of humus in formation of plant mass the yields from the same soils have been compared, from soils which contain in one case a small amount of humus and in the other a larger amount.

Tab. 1: Effect of humus content on yield on the same soils in to/ha and increase in per cent (Sagave, 1934).

	Rye				Potatoes				Soil fractions	
	Climatic Conditions								o,o5 to o,ol mm	< o,ol mm
	favourable		unfavourable		favourable		unfavourable			
	to ha	% increase	to ha	% increase	to/ha	% increase	to ha	% increase		
Sand	1,15		o,9		11,5		1o,o			
		7		6		9		7	1o	9
" , humic	1,35		1,o8		13,5		11,5			
Loamy Sand	1,5		1,14		14,7		12,3			
		8		5		8		5	12	14
" " , humic	1,74		1,42		16,5		13,4			
Mild Loam	2,56		2,46		21,o		17,2			
		8		7		4		9	58	33
" " , humic	2,78		2,62		22,o		18,o			

The increase of the yield is observed under favourable and unfavourable climatic conditions, when the soil has a higher humus content. Till now it has not been investigated the influence of humus or its fractions or which special properties of humus components have an influence on soil productivity. For this reason it is necessary to determine not a single data of some fractions but to characterise the total humic system. Only by these informations it is possible to get a relationship between humus content and soil productivity.

3. Indirect and direct effects of humic substances on plant production

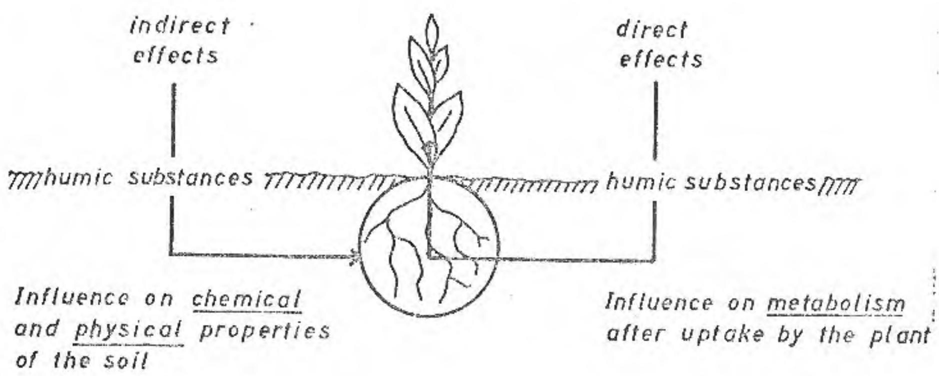


Fig. 3: Scheme of the possibilities of the effect of humic substances on growth and yield of plants.

According to the existing environmental conditions humic substances can have a more or less large effect on growth and yield of plants. The uptake of inorganic nutrients can be influenced by humus in different manners. One differentiates between indirect and direct effects. (Summarised in FLAIG and SÖCHTIG, 1962).

The indirect effect is characterised by the fact, that the organic substances are not taken up by the plant. These processes influenced by soil organic material occur outside of the plant and are concerned mainly with alterations of chemical reactions; to these belongs also the ability of humus to serve as slow releasing nitrogen fertilizers.

Furthermore some physical properties of the soil are changed by the amount and composition of soil organic matter.

We define a direct effect, when the organic substances are taken up by the plant through the roots and enter in the metabolism

In this presentation no more will be said about the indirect effects. There are many publications about the influence of soil structure, exchange capacity, chemical weathering, water management redox processes etc. The most important direct effects are the following:

Tab. 2: The direct effect of organic substances on the uptake of inorganic ions by the plant.

1) Easier uptake and better distribution of heavy metals in form of complexes (Chelates).

2) Influence on ion adsorption

3) Direct use of uptaken organic substances for formation of plant constituents.

4) Catalytic influence on metabolic pathways.

By formation of complexes with heavy metals, the uptake and distribution of heavy metals in the plant is easier.

The effect No. 2 and No. 3 influence on ion-adscrption or direct use of uptaken organic compounds for plant constituents, do not seem to be very important for plant production.

The fourth effect, the influence of organic components of the soil on plant growth, the catalytic effect on metabolism of organisms, may be the most interesting. The more its contribution for the formation of plant mass is much more unknown than in the case of the indirect effect.

From many papers (BLANCHET, CHAMINADE, CHRISTEVA, GUMINSKI, PRAT and co-workers, NIKLEWSKI, TYPACEK, SLADKY, SAALBACH, SÖCHTIG, TICHY and others summarised in FLAIG 1963) it is known that fractions of humic substances can have a favourable effect on growth and yield in nutrient solutions, sand cultures and also in soils as substrates for culture. But in literature, results are also published which do not confirm the favourable effect of humus or its fractions (summarised in SAX, 1963). We tried to elucidate these contradictions (summarised in SÖCHTIG, 1964).

It must be mentioned that the extent of influence of metabolically active substances depends also on the environmental conditions such as temperature, light and humidity, as well as on nutrient supply. Some examples may explain this.

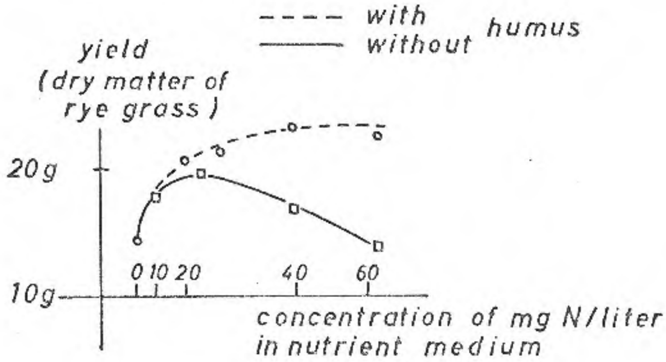


Fig. 4: Influence of humic substances on yield formation in the case of overdoses of inorganic nitrogenous salts (according to CHAMINADE 1965).

So, for instance, CHAMINADE (1965) found that overdoses of inorganic nitrogenous salts remain effective for yield production in the presence of humus, whilst without humus a decrease of yield occurred. The investigations were made in pots with sand cultures and rye grass.

Furthermore he reports about experiments in francophone Africa, where addition of different type of organic material on ferrallitic soils had an favourable effect on crop yield by better utilisation of nitrogen during several years.

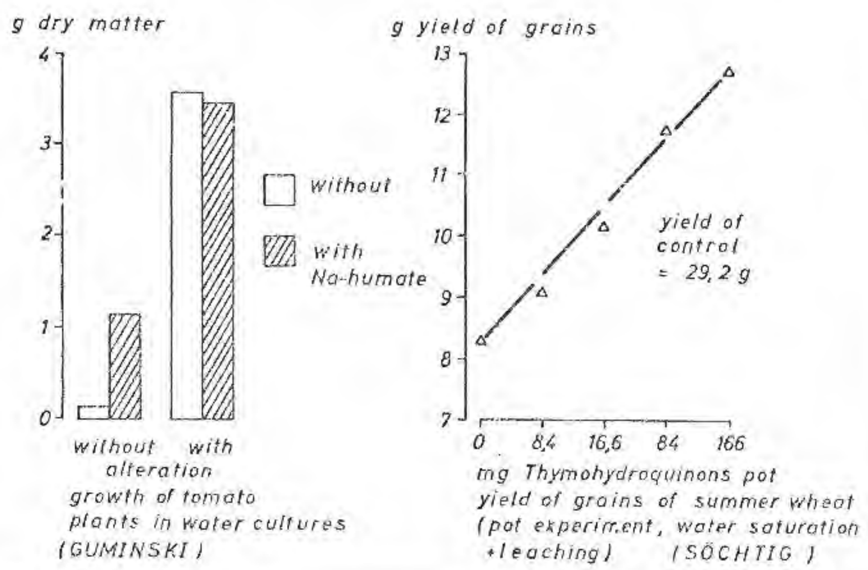


Fig. 5: Scheme of investigation of oxygen deficiency in nutrient cultures (GUMINSKI) and on the leaching of the water in the presence of thymohydroquinone (SÖCHTIG).

GUMINSKI and GUMINSKA (1953) investigated the influence of fractions from humus on the production of plant mass of tomatoes at low oxygen tension in water cultures. The yield of unaerated nutrient solution was higher by the addition of humic substances than without them. But the yield was the same in aerated culture with and without the addition of humic substances.

In pot experiments SÖCHTIG (1964) investigated the influence of a model substance of oxidised lignin degradation product; the substance was thymohydroquinone. The soil was always water saturated and the water flow was about 100 ml. The leaching of nutrients was not influenced by the addition of thymohydroquinone.

In spite of these unfavourable conditions such as leaching of nutrients, water saturation of soil, small oxygen tension, the hydroquinones increased the yield (up to 13 g.) remarkably, but not up to the amount of control (29.2 grams) without leaching of nutrients and water saturation of the soil. Further observations of the favourable effects have been made in the case of deficiency of light and water; in the latter case the resistance against drought is increased.

4. Environmental conditions and effect of physiologically active substances.

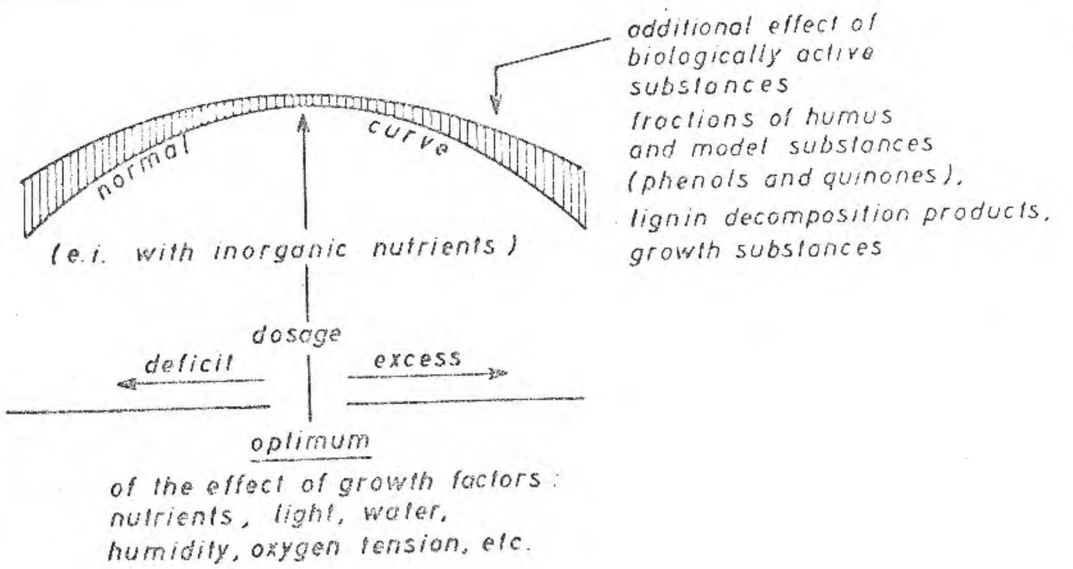


Fig. 6: Influence of physiologically active substances on yield formation in dependence of environmental factors.

The experiments mentioned demonstrate that the effect of a metabolic active substance on plants depends on the environmental conditions. We explained the favourable effect of humus on plant growth and yield in the following way (summarised in SÖCHTIG, 1964). When growth factors, such as temperature, humidity, light, oxygen tension of the culture medium, water saturation of the soil, as well as the supply of nutrients are in the "optimum", the yield on the plant mass is the highest.

The effect of physiologically active substance improved the formation of yield if one or several growth factors are in deficit or in excess. With this explanation of the effect of substances from humus, of lignin degradation products or other physiologically active substances, all the contradictory results from literature can be explained. Economically, the results mentioned mean a partial diminution of the risk of yield formation by components of soil organic matter, such as climate factors, heavy rainfall, dry seasons, etc. and therefore soil organic matter can be a factor for stabilisation of soil productivity under unfavourable environmental conditions.

5. Phenolic compounds as one type of physiologically active substances in the soil. Sources for formation:

5.1 Lignin

Mainly we investigate first some phenolic compounds for their activity for plant production because the sources for phenols are relatively high in the organic fraction in the soil. One of the source is lignin.

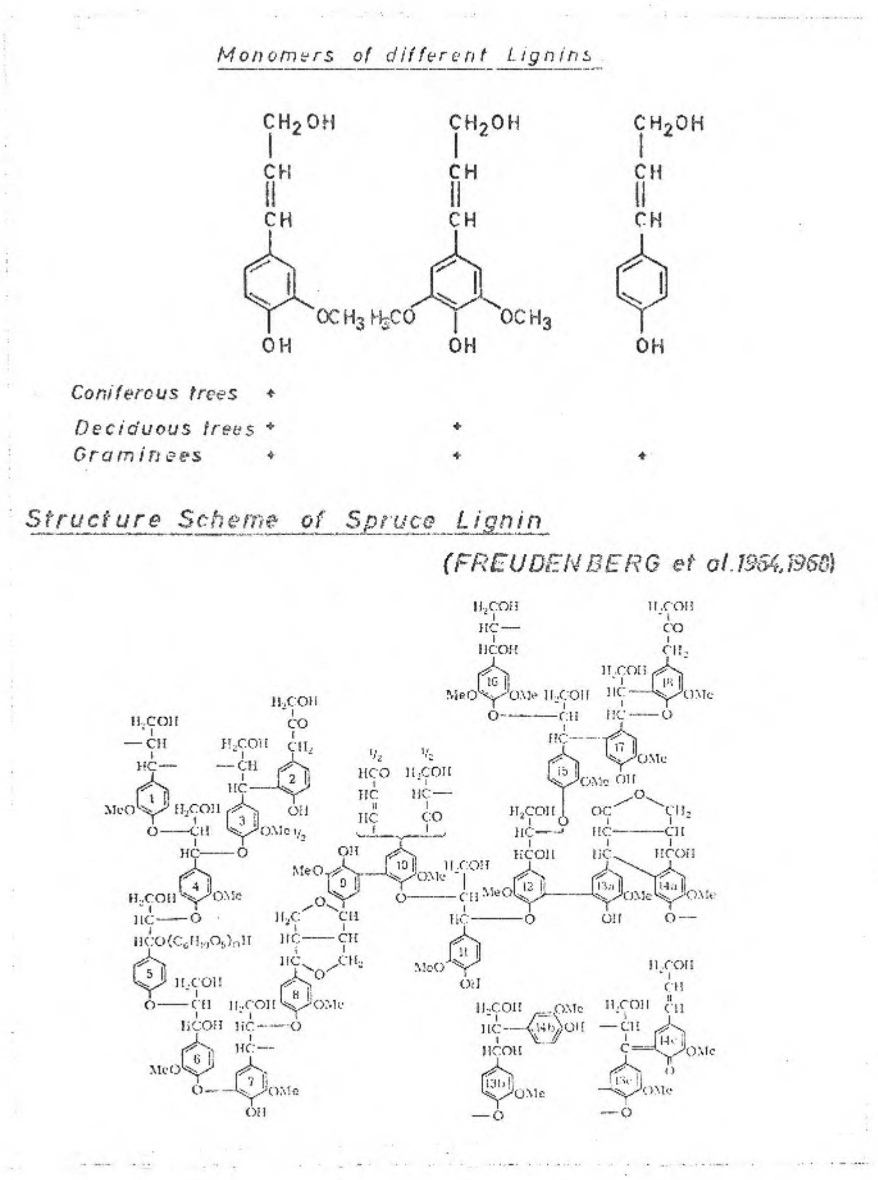


Fig. 7: Structure scheme of lignin.

For remembarance the structure scheme of lignin according to Freudenberg (1968) will be briefly reported. Coniferous lignin is formed by the condensation of coniferyl alcohol. The lignin of deciduous trees is a polymerisation product of two monomers, graminaceous lignin consists of the three monomers: coniferyl-, sinapyl- and p-coumaryl alcohol.

We labelled different carbon atoms of the monomers, synthesized the different types of lignin and studied the microbial decomposition. In this way we have been able to elucidate single steps of lignin degradation during humification (summarised in: MARTIN and HAIDER, 1971).

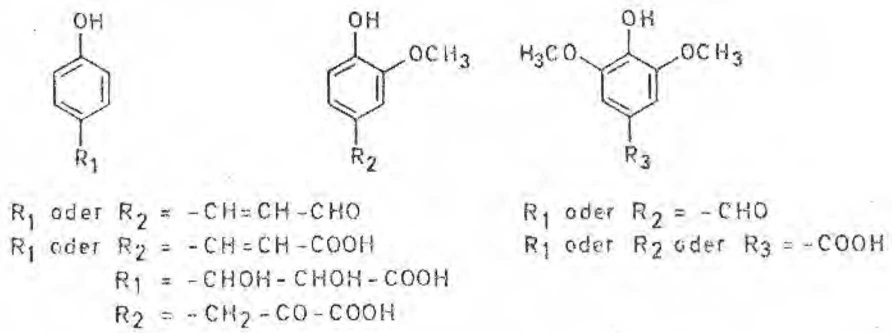


Fig. 8: Lignin degradation products.

The most important lignin degradation products are phenol carboxylic or phenolcinnamic acids

Some of them are mentioned in the scheme. The importance of these in humus biochemistry will be discussed in another lecture.

5.2 Microbial synthesized phenols.

Another type of phenolic compounds are synthesized by microorganisms.

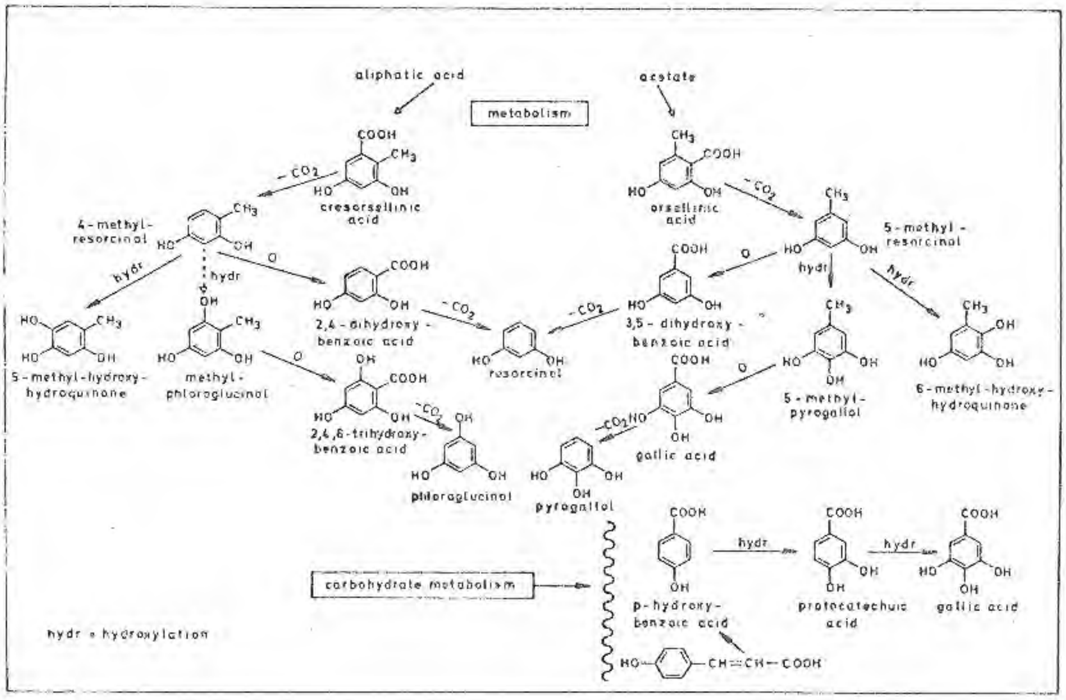


Fig. 9: Formation and transformation of phenols by micro-organisms (*Epicoccum nigrum*) (HAIDER and MARTIN 1967).

Recently the participation of phenols of resorcinol type in the formation of humic substances has been demonstrated (HAIDER and MARTIN, 1967, 1968, 1970; MARTIN and HAIDER, 1971(Summary); MARTIN, RICHARDS and HAIDER, 1967). The following reactions occur for instance in the culture of micro-organisms such as Epicoccum nigrum.

This fungi as well as other fungi form dark coloured substances with properties, which are comparable with those of the humic acids. Different resorcinol derivatives could be identified after reductive cleavage of the microbial synthesized humic acids. Some more phenolic intermediates could be isolated from the culture media.

All the phenolic compounds which can be derived from cresorsellinic or orsellinic acid in the case of Epicoccum nigrum could be identified. It must be specially mentioned that only then when dihydroxy-phenols with CH groups in o- or p- position are present the dark coloured humic acid like substances are formed. To a smaller amount also phenol carboxylic- and phenolcinnamic acids could be identified.

6. Some important reactions of phenols during humification.

The most important reactions of the mentioned phenols are described in the following scheme.

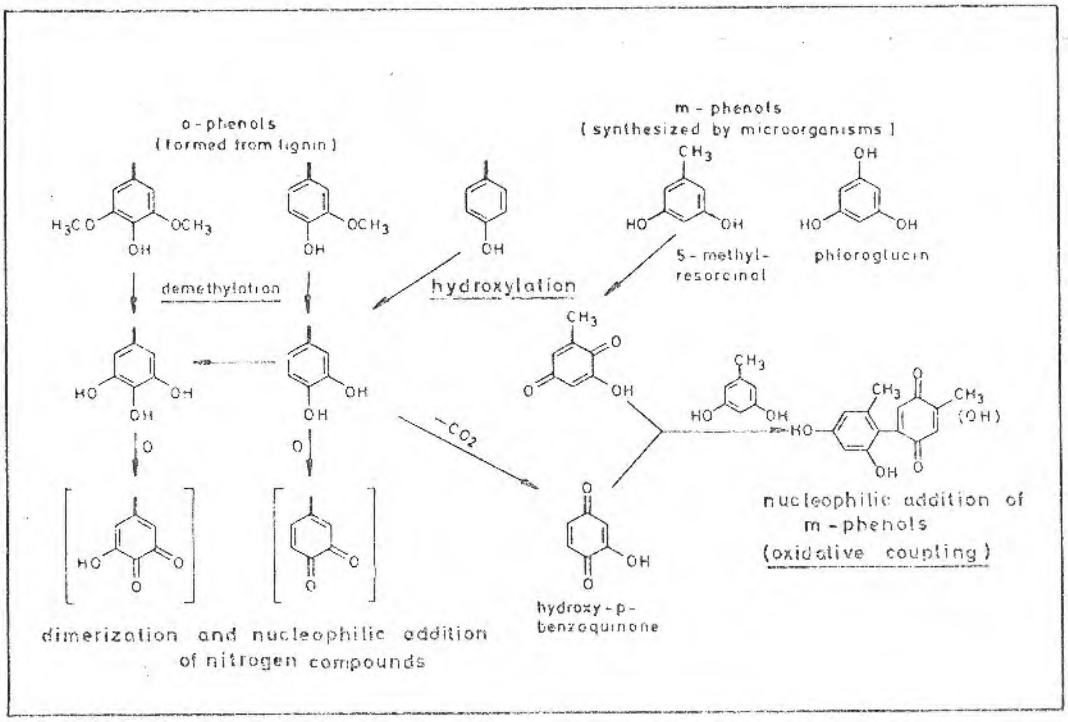


Fig. 10: Scheme of transformation of phenols during humification.

In the case of lignin and its degradation products the following reactions have been studied:

1. Dimethylation, cleavage of phenolmethylether
2. Hydroxylation, formation of o-diphenols
3. Intermediary formation of o-benzoquinones
4. Oxidative decarboxylation, formation of p-diphenols or respectively p-benzoquinones.

In the case of microbial synthesis, also m-diphenols are formed, such as 5-methylresorcinol and phloroglucin as two representatives of several. m-Diphenols can only be oxidised to quinones after hydroxylation. In the two ways formed p-benzoquinones, add nucleophilic m-diphenols to the corresponding diphenyl compounds. These are the principles of chemistry which are needed to understand the following considerations.

7. Nitrogen in humic acids

Normally humic acid fractions contain nitrogen. Fixation mechanism will be reported in another lecture.

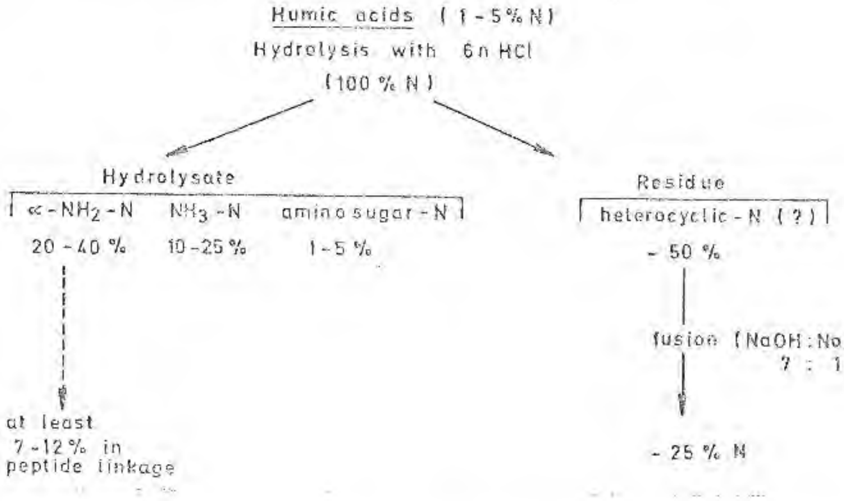


Fig. 11: Distribution of nitrogen in humic acids.

The nitrogen content of humic acids is between 1 and 5%. By hydrolysis with mostly 6 N HCl (BREMNER 1955) can be split off

20-40% as a-NH_2-N

10-25% as NH_3-N

1-5% as amino sugar-N

At least 7-12% of the a-NH_2-N is in peptide linkage. In the residue of hydrolysis about 50% N remain, which are supposed to be bound to a large extent in heterocyclic form. In a fusion with a mixture of sodium hydroxide and sodium acetate up to 2.5% N can split off again Only the hydrolysable nitrogen is a source of available nitrogen for the nutrition of organisms.

In this connection it may be mentioned that humus can also serv as a slow releasing nitrogen fertilizer. Under our conditions experiments with N_{15} labelled mineral nitrogen fertilizer it could be shown that approximately 50-60% of the uptaken nitrogen comes from the mineral nitrogen fertilizer and 40-50% from the nitrogen of soil organic matter.

8. Processes during humification.

The processes during humification of dead plant material are briefly summarised.

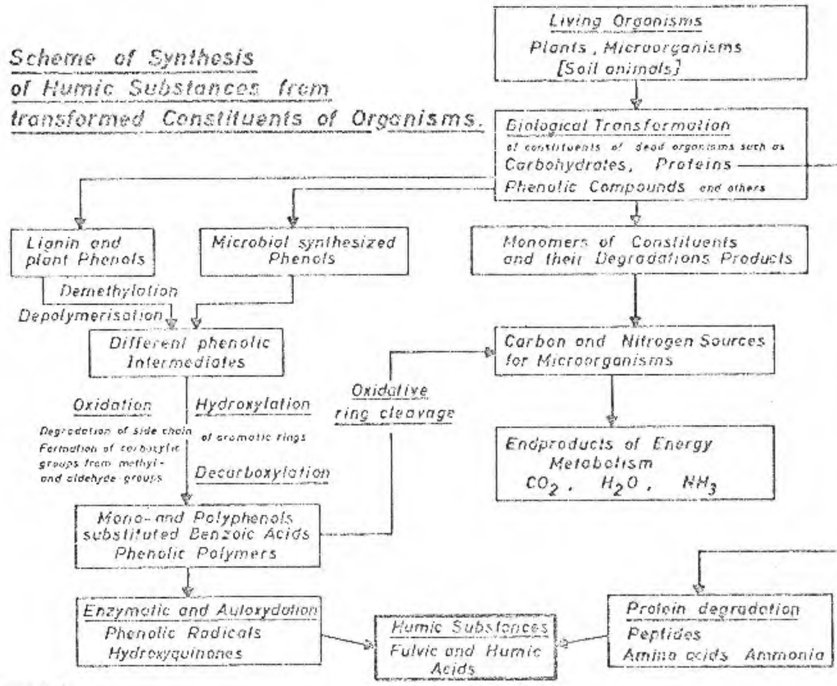


Fig. 12: Scheme of synthesis of humic substances from transformed constituents of organisms.

The most important organisms for humification processes are plants and micro-organisms. The most important constituents of the organisms are carbohydrates, protein, phenolic compounds which are transformed to the monomers and their degradation products used as carbon and nitrogen sources for micro-organisms or formation of humic substances. The end products of the energymetabolism are CO_2, H_2O and NH_3. Phenolic compounds can be derived from lignin and other plant phenols or are synthesised by microorganisms. Lignin is demethylated and depolymerised. Different phenolic intermediates are formed. The main reactions are:

oxidation

hydroxylation

decarboxylation

In this way mono- and polyphenols, substituted benzoic acids and phenolic polymers are formed. By oxidative ring cleavage aliphatic compounds are formed, which can be used by the microorganisms as carbon source and disappear in this way from the mixture of compounds which form humic substances.

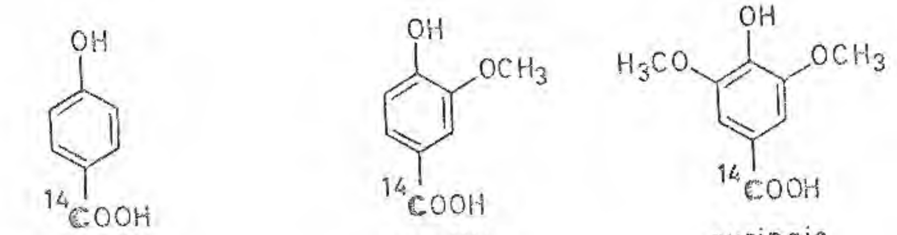
By enzymatic and autoxidation phenolic radicals and hydroxyquinones are formed.

By condensation reactions between the mentioned phenolic compounds and protein degradation products such as peptides, amino acids and ammonia humic substances are formed, which are mainly divided up into fulvic, humic acids and humins by different separation operations. In the other lectures, we will discuss, which of all the mentioned factors may have an effect on soil productivity.

Previously I mentioned that phenols are important building blocks for the synthesis of humic fractions. By oxidative or reductive cleavage different types of phenolic compounds could be isolated. Some of these phenolic compounds can also be extracted from the soil. The concentration of vanilic or syringic acid in soil is about 10^{-4} up to 10^{-5} mole per kg. soil (WHITE HEAD, 1964 and others). About these concentrations an effect on plant metabolism is observed in water cultures.

9. Uptake, transport and transformation of labelled phenol-carboxylic acids.

To get causal connections between the effect of physiologically active compounds from humus and plant productivity it must be first proved that organic substances, for instance, phenols are taken up and have an influence on metabolism. But this result is not sufficient for an explanation of bioactivity. It must also be elucidated in which way these substances are transported or transformed in the plant itself.



p-hydroxy-benzoic vanillic syringic acid

Fig. 13: ^{14}C-carboxyl-labelled phenolcarboxylic acids as lignin degradation products.

In this connection some of the results of our investigations with ^{14}C-carboxyl-labelled phenolcarboxylic acids such as p-hydroxybenzoic-, vanillic- and syringic acid will be briefly mentioned. Informations about other labelled phenolics will follow later. Spacial investigations have to be done in a closed system and under absolutely sterile conditions for this purpose (HARMS et al. 1969, a, b, 197 Seedlings of wheat have been cultivated for seven days in the nutrient solution and then phenolcarboxylic acids were added so that the concentration was about 10^{-3} molar. After three or six days the seedlings were harvested.

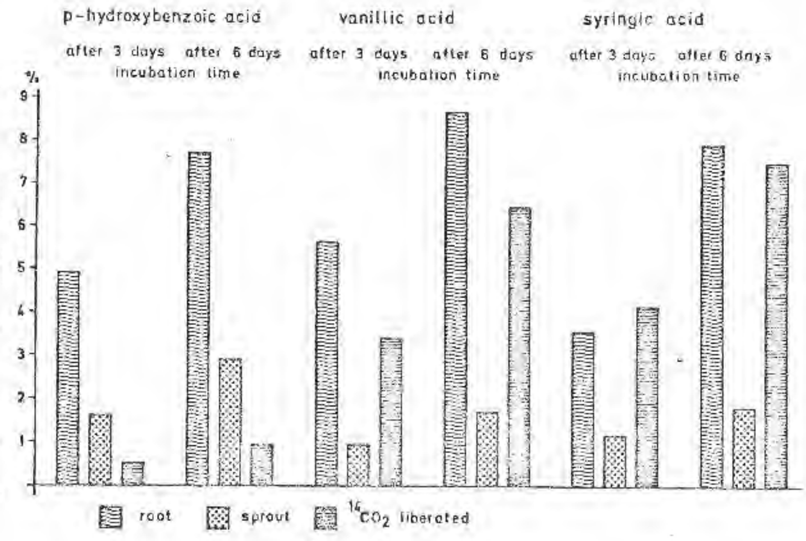


Fig. 14: Uptake of labelled phenolcarboxylic acids in % of added quantity (HARMS 1967).

The diagram summarises the results:

1. With incubation time the activity in roots, sprouts and released carbondioxide which is caused by oxidative decarboxylation of the phenol carboxylic acids increases. Methoxyhydroquinone respectively methoxy-p-benzoquinone from vanillic acid or 2,6-dimethoxy-hydroquinone and also the corresponding quinone from syringic acid were identified.
2. The highest amount of activity is in the roots. Presumably a part of the activity is only sorbed on the surface on the root, because it cannot be displaced by dilute sodium hydroxide solution.
3. Sorption and decarboxylation depend on the substitution of the phenolic acids with methoxyl groups.

The determination of the activity in the plant organs does not answer the fixation of the activity in different compounds.

Therefore the plants were extracted with different solvents successively.

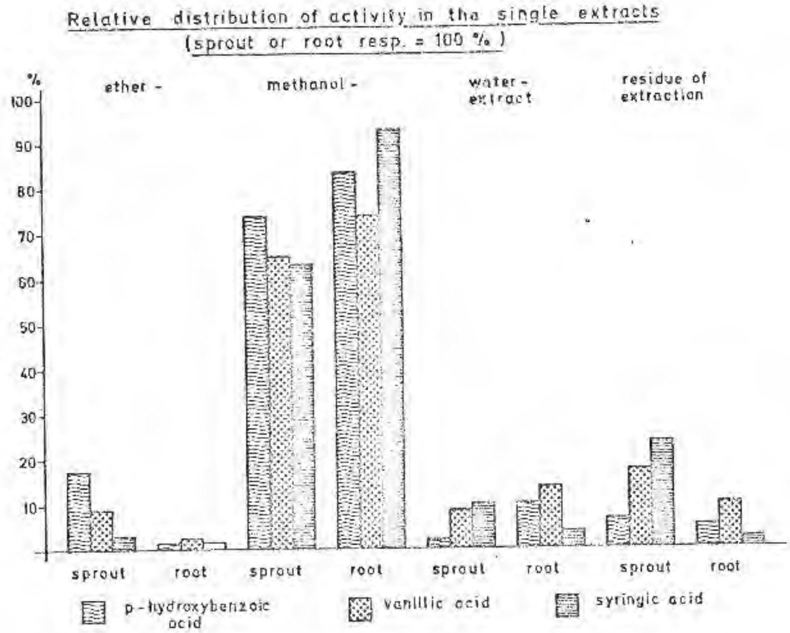


Fig. 15: Relative distribution of the activity in the different extracts (sprout or root resp. = 100%) (HARMS 1967).

The low activity in the ether extract shows that only small amounts of free carboxylic acids are in the plant organs.

The high amount of activity in the methanol extracts belongs mainly to the presence of glycosides of the phenol carboxylic acids or their glucose esters. The importance of these depots of glycosides must still be elucidated. The relatively low activity in the water extract and in the residues of extraction is caused by fixation of 14C-carbon dioxide and formation of different metabolites of carbohydrate and protein cycle. This means also that the released 14C-carbondioxide is fixed in plant metabolism to a low extent.

10. Transfer of scientific results to technical applications

These are some of the results of basic investigations. They contain several requisite data for our applied research. Two examples will be mentioned:

1) Production of a slow releasing organic nitrogen fertiliser from lignin waste products;
2) Characterisation of humic systems with the aim of better evaluation of soil organic matter for soil productivity, because the other factors such as soil structure, water management, fertilizer etc. are much better known.

The reported scientific results led us to try to use the knowledge for technical applications.

10.1 Slow releasing organic nitrogen fertilizer, N-Lignin.

Lignin sulfonates from cellulose industry have been oxydatively ammonified (FLAIG, 1972; FLAIG and SÖCHTIG, 1967). The resulting product was a slowacting nitrogen fertilizer with physiologically active components from the degradation of the lignin derivatives. We call this product "N-lignin".

Tab. 3: Composition of N-lignin

Total N = 18 - 20 %

from this (Total N content = 100 %)

30 % - 40 % NH_4^+ - N

ca. 10 % "amide-N"

50 % bound in other organic form.

"Amide-N" is nitrogen which can be hydrolized with 30% sodium hydroxide solution after the distillation of the ammonium ions with magnesium oxide. The largest part of organic bound nitrogen becomes available for the plant during the first vegetation period by the activity of microorganisms. The total for plant growth required amou of nitrogen can be given in one dose. No plasmolysis occurs because the concentration of ions is not increased too much in soil by the addition of N-lignin, or even in mixtures with inorganic nitrogen fertilizers.

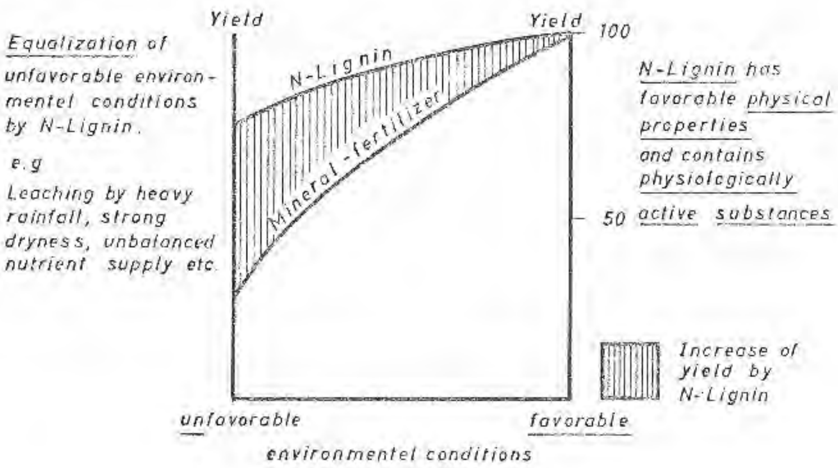


Fig. 16: Favourable properties of N-lignin.

With N-lignin also the effect of the diminution of the risk of the yield formation was observed. In pot experiments under artificial unfavourable conditions the yield is sometimes increased up to double The last two years we had a dry season and therefore unfavourable climatic conditions. We observed in a field experiment with barley an increase of the yield of about more than 20%. But this is exceptionally high.

The nitrogen of N-lignin cannot be leached so much as the nitrogen of inorganic fertilizers, because about 50% of N-lignin are high molecular weight substances which contain 40% - 45% of the total nitrogen content. Furthermore, some constituents are in N-lignin, which inhibit nitrification in soil. By fertilization with N-lignin different legumes, such as spinach, can be produced with a low nitrate content for baby food (SÜCHTIG 1970).

In many cases an increase of phosphate content of plants was observed. Some other properties will be mentioned in two special lectures.

At the moment a pilot plant is working with a capacity of 500 tonnes per year.

10.2 Characterisation of humic systems

When we speak about soil production in relation to content of humic substances, then the different fractions in humus must be characterised with standardised methods, that the results of the different investigators can be compared. The humus research worker know, that the usual method for characterisation of soil in organic matter are not always sufficient. Often it is worked as the humic fractions would be chemical individuals. But in humus there are many more or less similar substances according to the conditions of formation, as to the type of initial materials and as to the environmental conditions such as climatic factors and as to inorganic soil components. In humus therefore a system of substances exists which have similar physical and chemical properties.

The similarity of humic systems or of their components therefore can only be characterised by statistical calculations of the chemical and physical, analytical data.

The next slide shows a scheme of analysis of humic substances.

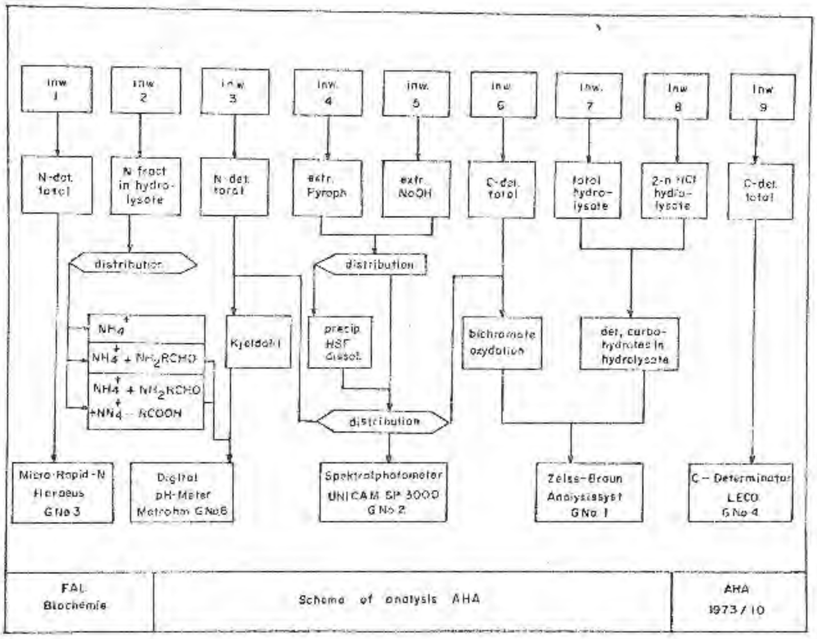


Fig. 17: Scheme of analysis of humic acid system.

Summarising it can be said, that

total carbon and total nitrogen in soil is determined,

Furthermore the different functions of nitrogen in its hydrolysate,

The light absorption of humic fractions in the extract with phrophosphate, sodium hydroxide and with sodium hydroxide alone

milder and stronger hydrolysable compounds especially carbohydrates in the soil

and several other data, about 25, are determined.
Most of the measurements are done in automatic instruments, the value are calculated with the help of computers or the programme by feeding the punch card with the computer. This work will be further explained in detail in a later lecture.

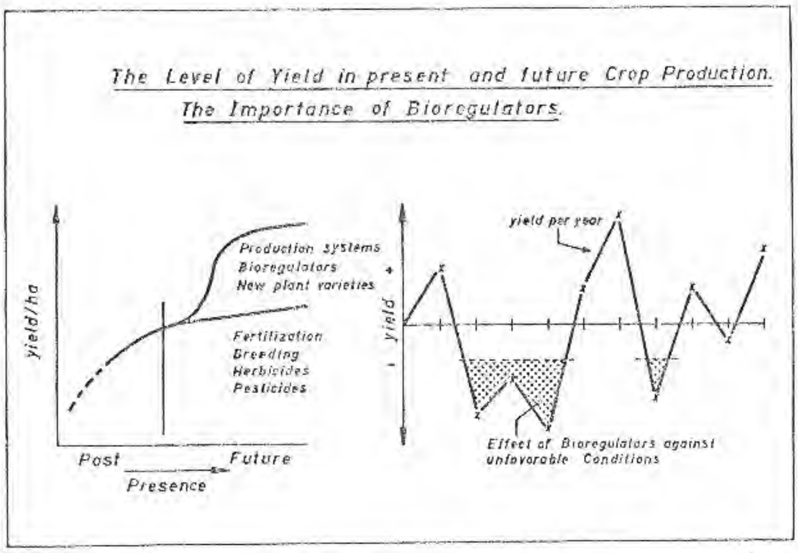


Fig. 18: The level of yield in present and future crop production - the importance of bioregulators

From the present upto the future remarkable increase of the production of agricultural plants per ha occurred by an additional nutrition of plants with mineral fertilizers, by the success of plant breeding, the use of herbicides and pesticides and by soil management. For future increase of the production per ha some other production systems may be borne in mind, such as hydroponic, but this type of production is very costly. Furthermore new varieties of plants could be used, which have not yet served for nutrition of mankind and animals.

A future increase of plant production would also be possible by the use of bioregulators. Some of the bioregulators such as CCC or "Cycocel" (Trichloro-cholin-chloride) to diminish the length of the wheat stem for higher resistence against lodging is still used in practice. Furthermore slow releasing N-fertilizer are used in special cases. As it was demonstrated that some parts of the humus has also bioregulating properties. Certainly some further possibilities may exist which are unknown to us till now.

Although there exist some other possibilities to produce food, soil will be in the next future always the most important substrate for plant production. Therefore all properties of this substrate must be preserved which are useful for plant production. The importance of soil organic matter for physical properties of soil are universally acknowledged. The effect of components of humus on the plant metabolism must be more elucidated.

At first it was important to increase the yield by the use of mineral fertilizer. A task for the future will be to lower the depressions of the yield which are caused by unfavourable conditions. The stabilization of the level of the yield is an important economic factor.

In this report only a part of the future importance of economic use of bioregulators in plant production has been mentioned. The report has, however, clearly shown that causal connections, which are necessary for application of basic research in practice, can only be found, if the required basic knowledges are worked out in cooperation of the different disciplines of pure and applied natural sciences.

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