HUMUS AND ROOT ACTIVITY.

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Introduction

The root system of the common higher plant has the main task in supplying it with water and mineral nutrients, while it may also be concerned in the uptake of other dissolved substances.

Since von Liebig 1) discarded the older humus theory the large array of results obtained in solution cultures (e.g. Sachs 2), Hoagland 3), Gericke 4), Hewitt 5), Homès 6)) and even more strictly those obtained in sterile root media (Gerretsen 7), Nilsson 8)) have established that only water, carbon dioxide and a number of mineral elements are essential to growth of the plant. The soil, however, in general contains a varying amount of organic matter from fresh plant and animal remains to the more or less stabile endproducts of decomposition, the humus. It thus contains an enormous array of the most varied organic substances, some consisting of small, easily soluble molecules, others of large polymer molecules and often insoluble in water. As research on permeability of cells and tissues 9) has shown that some of the medium sized organic molecules can penetrate into the plant and results obtained with antibiotics have demonstated that substances up to a molecular weight of about 600 can enter the plant (Winter 10)), it is evident that we must reckon with the uptake of many smaller soil-contained organic substances.

The question now arises: are these substances to be considered as noxious. inoccuous or favorable for growth of the plant. Partly they might be of importance as accessory nutrient and partly the possibility of a stimulating activity on root growth and metabolic activity exists. It is the latter aspect of the influence of humus to which attention will be mainly drawn. In order to be more concise the term humus will be used to designate the more or less stabile, brown coloured end-products of decomposition. All other non mineral substances in the soil, without regard to their stage of decomposition will be designated organic matter.

Effects on root growth and branching

In order to be able to extract a sufficient or a large amount of mineral nutrient from the soil per unit of time the root system must have a large surface of cells with absorptive capacity in intimate contact with the substrate. The absorptive capacity is mainly restricted to the young parts of the roots, usually having root hairs. As the amount of soil with the young roots are in intimate contact in general will be less than 1% of the whole soil volume occupied by the roots, local depletion is likely to occur. So the young roots have to be kept growing to be able to tap new nutrient sources, especially with regard to the less mobile ions.

One of the main factors governing root growth in the soil is moisture content. As humus and also organic matter can inbibe large quantities of water, its occurrence will result in a larger stock of moisture in the soil, although a considerable part of this water may not be plant available. Humus and organic matter also favorably influence soil structure. This also results in a raise in content of available water. The consequences of draught will thus be minimized as the root will keep growing for a longer time. Also in dry soil the root may be induced to suberization of the epidermal tissue 11), a fact by which, after remoistening of the soil, renewed uptake will not set in before growth has again started.

As occurrence of oxygen is also a necessary prerequisite for growth the favorable influence of humus on soil structure (Deuel 12), Kononowa 13), Quastel 14)) will in this manner surely enhance root growth.

The soil in the field is by no means homogeneous in regard to its contents of nutrients. Fertility differences usually occur between soil layers at different depths and even in the same layers local differences in nutrient concentration may exist, e.g. granular fertilizers, placed fertilizers. So it would be important for the plant if its roots were able to take full advantage of these differences by a thorough exploitation of these layers or spots. This can only be achieved by growth and branching regulation in reaction to stimulus from the substrate.

Can we imagine that humus plays a role in inducing growth regulation of roots in connection with fertility level? The answer must be in the affirmative as general experience in nearly all soils shows that most roots are usally to be found in the soil horizons with a high humus content (Goedewaagen 15)). Recent investigations concerning factors inducing root branching have shown that contact with peat enhanced formation of secondary roots in comparison to sand and resinous ion exchangers. The explanation put forth is that the high concentration of adsorbed ions in the surface of the humic substance 16) acts as stimulus (Wiersum 17)). It was also demonstrated that of the separate ions nitrate was the most active in inducing dense branching. As humus and organic matter can be a main source of nitrate as a result of their decomposition, this would be a second way in which these substances would influence root distribution in the soil.

As dense branching and extension growth of a main axis are inversely related, a searching root striking a fertile spot will automatically react in a manner so as to take full profit of this circumstance.

Attention was already drawn to the fact of the innumerable organic substances occurring in the soil, many of those with smaller molecules should be able to penetrate into the root. Thus the question arises if humus and organic matter contain substances influencing extension growth and branching of roots.

In recent times increasing interest has arisen in problems concerning the possibility of a favorable influence of humus on plant growth and crop yields. Some of these investigations have been concerned with root growth. Effect on roots in stimulation of root-hair formation has been mentioned by von Zeschwitz 18) in using water extracts of peat. A favorable influence on root growth of soluble humus and Na-humate is mentioned by Chizhevskii and Dikusar. However, the same results could not be obtained under sterile conditions 19). Humic substances derived from shale and discarded material of the oil industry in a concentration of 0.0004% and a humic acid extracted from bituminous rock at a concentration of 0.004% increased the length of wheat roots by 100-200% according to Guseinov, Edigarova and Kasimova 20). According to Soukup and Matous 21) humic acids from several leaf moulds stimulated seedling root growth stronger than humic acids from peat. Not only growth in length was influenced but also branching habit. Recent own experience has taught us that increased root growth in the Lepidium root test may be achieved by applying humus extracts. The results vary according to the type of extract used - fulvic or humic acids - and degree of purification. Root inhibition may also be observed. Slight indications were obtained by adding humus extracts to the medium in sterile root-tissue culture, that although growth of the main axis may be retarded, branching may be more profusive and increase in dry matter slightly enhanced.

The obvious difficulty in the interpretation of these results is the poor specification of the applied substances and their impurity, especially the usual high mineral content.

In Braunschweig/Völkenrode Flaig and coworkers, however, have been testing synthetically produced pure substances, which are considered to be analogous to intermediates in humus metabolism.
Quite a number of ortho-chinones have been shown to enhance root growth in a cress root test. Positive results were also obtained with oxy-anthrachinones, although a few negative results were noted. Thymo-hydrochinone was tested in sterile root-tissue cultures and enhanced root growth. 22), 23), 24), 25).

A stimulation of root growth should have consequences regarding nutrient uptake and growth by the plant. That this can indeed be the case is shown in results obtained in hydroponics. Penningsfeld 26) mentions the advantageous effects of adding to the inert substrate, which indeed promotes root growth. Similar experience has also been obtained elsewhere 27).

We are still far from a complete understanding of the variable, though most often advantageous, results of these investigations. Flaig and coworkers 28) are actively engaged in investigating the metabolic changes induced by administration of model substances.

Part of the observed favorable effects may be related to the chelate forming ability humus compounds possess. By means of this ability several minerals, especially the micro-elements and notably Fe, may enter the plant much more easily 29). Iron is indispensable for root growth 30). Burström and Tullin 31) also discuss the role of chelates in root growth. Occurrence of chelating agents in manure and other organic material is demonstrated by Miller and Ohlrogge 32).

A large mass of facts is accumulating on the influence of various organic substances on root growth. It is evident from critical experiments that many substances may influence root growth either as accessory nutrient or as a stimulating agent. Favorable affects are generally limited to specific concentration ranges and excess is often toxic. Other substances are definitely deleterious. It has also become increasingly clear that the organic matter in the soil, being mainly derived from plant remains, consists of an innumerous number of substances. Most of these, however, only occur in minute amounts as they are continuously consumed and metabolized by the soil micro-organisms.

To summarize a number of facts a tabulation will be given of substances, which in purely physiological research have been shown to influence root growth. A comparison can then be made with substances, whose occurrence in soil has been demonstrated.

Table 1. A comparison of substances influencing root growth and their occurrence in the soil.

physiologically active		found in soil and humus		chelating ability	
saccharose	j[+]	sugars	h		
		acetic acid	h,o		
		citric acid	h	+	1
		formic acid	o		
		lactic acid	h,o	+	1
malate	q	malic acid	h	+	1
		oxalic acid	g		
		succinic acid	o		
tartrate	m	tartaric acid	l	+	o
aspartic acid	a	aspartic acid	a,n		
glutamic acid	j	glutamic acid	a,n		
alanine	j	alanine	a,n		
		arginine	a,n		
		asparagine	n	some amino acids	
		cysteine	n		1
glycine	j	glycine	a		
		histidine	n		
		leucine	n		
		lysine	n		
tryptophan	e	tryptophan	a		
		valine	n		
adenine	d	adenine	r		
2,6-diaminopurine	d				
guanine	d	guanine	r		
hypoxanthine	d				
B_1 thiamine	j				
B_2 nicotinic acid	e	(some vitamins)	h		
B6 pyridoxine	j	(possibility of			
C ascorbic acid	j	formation by			
folic acid	f	microbes)	b		
indole acetic acid	e	(formation by			
		bacteria and		+	k
		fungi)	c,p		
actidone	p	actidone	p		
azaserine	p	azaserine	p		
polymyxin	p	polymyxin	p		

+ see references

The conclusion can be drawn that in a soil rich in organic matter or soil to which manure or compost has been added the root system may be specifically influenced. Some substances may effect the roots as accessory nutrient, others may influence uptake of minor elements via chelating ability and some, notably a number excreted by bacteria and fungi, could act as regulating hormones.

Of course most substances being discussed here can work noxious as well, depending on the concentration in which they occur. But practical experience, such as that presented by Kortleven 33), seems to demonstrate that enrichment of the soil with organic matter has specific advantageous effects. A part of this effect can be related to influences as just described, although it is by no means quantitatively assessed.

Effects on rate of uptake

The feeding power of the root system is for a part governed by its extension and ramification. With a well developed root system a thorough exploitation of the soil can be achieved if the conditions in the medium are favorable. But uptake by the root is not only governed by its surface but also by the rate of intake. The rate of uptake will partly be governed by the rate of supply from the soil, a factor on which humus and organic substances definitely have a favorable influence. But this effect will hardly be considered here. But if the supply is not limiting rate of nutrient uptake is regulated by the intensity of metabolism, as accumulation can only be achieved under expenditure of energy. Ease of transport inside the plant may also be of importance.

In much of the literature the results mentioned are only those concerning the overall end-effect on plant growth or yield and this is especially the case in the older investigations, e.g. Cameron 34) and also Bottomley 35). Still we may usually conclude that enhanced root activity was implied.

In recent times several investigators have been concerned with influence on metabolism, especially respiration. Christewa 36) gives a summary of results and explanations in 1953. Both humic acid and bituminous products are considered to enhance oxidation processes. For an excellent review of all Russian work on humus reference must be made to the recent book (1958) by Kononowa 37). As Guminski et al. 38) find a reduced oxygen consumption of excised roots when humate has been added, they conclude that the humate partly replaces oxygen used in root respiration.

Intensive research has been conducted in Völkenrode. Saalbach 39) concludes that the model substances tested enhance tyrosinase activity of the root, and also that enzymes such as aldolase, amylase, saccharase and phosphatase are stimulated. Effects on mineral uptake are also reported. Different kinds of humic acids all induce a higher N-content, while K-content may be smaller. The effect on phosphate is variable, although generally favorable. Results obtained by Blanchet 40), however, clearly demonstrate increased uptake for N, P, S and K. Humus is postulated to enhance K-absorption on root colloids in the first phase of uptake. But in a later stage of the uptake accummulation is stimulated as well. Part of the effect is also ascribed to enhanced permeability. The influence of humus extracts in increasing permeability had already previously been described by Chaminade and Blanchet 41).

Further advances in research of the influence on metabolism by substances considered as intermediates in the formation of humus have been summarized by Flaig 42). That the substances occurring in humus extracts do indeed penetrate into the root is stressed by Aleshin and Tyuneeva 43).

Both in the Russian and German investigations the main effect of the active substances is related to the chinoid groups (Flaig 42), Guminski 44)).

One of the difficulties encountered in the explanation of the observed effects is that many of the active humic substances have chelating ability. Saalbach 45) already mentions the resemblance of some effect to those obtained under a more favorable Fe-supply and research by de Kock 46) points to the same possibilities.

In general the advantageous results of applying humates to roots have had the most attention, but a scanning of the literature soon shows that in many cases decreased activity has been mentioned as well. Most substances tested have a very low optimal concentration in stimulating activity and may become noxious at high concentrations. Many secondary factors are also of influence and preliminary experience already learnt us that the results expected are not always achieved.

The root as centre of metabolic and of synthetic activity has in later times received more recognition (Mothes 47), Kursanov 48)). Also we have become much more aware of the fact that numerous organic substances can enter the root (see the previous data concerning root growth). The organic matter in the soil and excretion products of the soil microbes can thus also be expected to influence root activity to a greater or smaller extent. Some effects may be favorable, others definitely noxious (Patrick and Koch 49)).

To conclude our remarks attention may be drawn to another possibility. Addition to the soil of large amounts of decomposable organic matter will surely in increased microbial and faunistic activity in the soil. It may be conceived that as a result toxic excretion products, produced by the plants thenselves 50), will then also be easily decomposed. This indirect activity might also act favorably in some cases.

Summary

An attempt has been made to give a concise review concerning our knowledge with regards to some ways in which humus and organic matter may influence root performance in nutrient uptake.

As soil exploitation depends on total active root surface and soil volume occupied, attention has first been directed to root growth and branching. Both true humus compounds and many organic substances found in the soil have been found able to exercise stimulating influence. In general a causal explanation of the manner in which the effect is brought about is still impossible. Increased penetration of micro-elements as a result of chelation, hormone activity, direct influence on metabolism and use as an accessory supply of nutrient may all be means to effect the result. Further research will have to provide a better insight, which can only be achieved in working with purified substances and under strictly defined conditions.

Although many favorable effects have been demonstrated it must be clear, that these are usually obtained in a certain range of concentrations and under certain conditions. Adverse effects are no exception. The soil also may contain many noxious substances as well in its organic matter.

The performance of the root system also depends on the rate of uptake of ions. Substances of organic nature occurring in the soil may enhance ease of penetration of some mineral ions, e.g. chelation of Fe. Many other substances can induce enhanced metabolic activity, which results in an increase in energy able to effect accumulation.

Although the normal higher plants can thrive when being fed with mineral nutrients only and organic substances are in no way essential, yet in farming and horticulture much importance is attached to them. Besides the supply of mineral nutrients they carry and which is freed during the mineralization process, humus and organic matter have been shown to possess specific stimulating capacity. These facts may partly explain some of the favorable influences attributed to a high humus content, although influences related to improvement of physical soil factors are very important.

However it all may be, in general a farmer will be wise to complement mineral fertilization with measures inducive to retaining or improving the humus content of his soil. Application of good composts, if not too expensive, may be one of the methods to achieve the desired result.

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