INVESTIGATIONS ON THE RÔLE OF ORGANIC MATTER IN PLANT NUTRITION.

Part IX. Oxidation of Organic Matter in the Soil and Plant Assimilation.

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Received May 14, 1935.

IT was shown in the previous communications (Siddappa and Subrahmanyan, 1934; Harihara Iyer, Siddappa and Subrahmanyan, 1935) that minute quantities of certain forms of organic matter, though highly potent in stimulating plant growth and reproduction, are, nevertheless, ineffective when applied to the soil. The active principles, being water soluble, can be supplied either through the medium of water culture or introduced directly into the plant by injection: when applied to the soil they lose their potency and are destroyed by micro-organisms. Evidence was also adduced to show that organic manures act only in bulk, their beneficial effects being greatly enhanced by treatment with chemical oxidisers (Subrahmanyan and Siddappa, 1933; Harihara Iyer, Rajagopalan and Subrahmanyan, 1934). There is greater production of carbon dioxide and larger yield of crop. It is not clear however as to how the various transformations are influenced by the organic matter already present in the soil and the minerals that may be added to it. Further quantitative evidence is also needed to show how the oxidation of organic matter increases plant assimilation; how far the plant is still dependent on the atmospheric carbon dioxide. Some preliminary observations relating to these important subjects have already been published (Subrahmanyan and Siddappa, 1933). Further material will be considered in the present paper.

Experimental.

Carbon contents of some tropical soils.—Before investigating the effect of added organic matter and minerals on different soils, it was considered useful to determine the carbon contents of some representative specimens from India, Burma and Ceylon. It was expected that the analyses would (*a*) give an idea of the range to be normally expected for tropical soils, and (*b*) show how far the known fertility of some of the soils can be correlated with their carbon contents. The determinations were carried out according to Degtjareff (1930). This method is not so reliable as that of Walkley and Black (1934)

TABLE I.

Carbon contents of some tropical soils.

Locality and description of soil	Carbon per cent.	Locality and description of soil	Carbon per cent.
Mandalay (Burma)—Paddy—surface ..	0·57	Travancore—garden soil—alluvium—surface	1·53
Galle (Ceylon)—Garden soil—surface ..	0·55	Travancore—sandy loam—cocoanut—surface	0·05
Dacca (Bengal)—Govt. farm cultivated highland—surface	0·94	South Bihar—alluvium—surface ..	0·32
Dacca (Bengal)—Govt. farm cultivated highland—surface	0·74	Gaya (Bihar)—upland—surface ..	0·44
Tanjore (Madras)—alluvium—surface ..	0·71	Ranchi (Chota Nagpur)—upland—surface	0·46
Tanjore (Madras)—alluvium—sub-soil ..	0·43	North Bihar—Calcareous—sub-soil ..	0·33
Tindivanam (Madras)—alkali soil—wet land—surface	0·72	Dharwar (Bombay)—Govt. farm—surface	0·80
Tindivanam (Madras)—alkali soil—wet land—sub-soil	0·14	Sholapur (Bombay)—karl—surface ..	0·52
Tellichery (Madras)—red, sandy loam—cocoanut—surface	0·30	Ahmedabad (Gujerat)—from Khamba—surface	0·05
Nandyal (Madras)—red clay—surface ..	0·39	Nasik (Bombay)—from Sinnar—surface ..	0·88
Nandyal (Madras)—red clay—sub-soil ..	0·50	Ratnagiri (Bombay)—Govt. farm—surface	1·38
Anakapalle (Madras)—red loam—surface	0·45	Sholapur (Bombay)—light soil—surface	0·39
Anakapalle (Madras)—red loam—sub-soil	0·32	Dharwar (Bombay)—lowland—surface ..	0·44
Devarshola (Madras)—hills—estate soil—surface	2·34	Jacobabad—Govt. wheat farm—surface	0·29
Devarshola (Madras)—hills—estate soil—sub-soil	0·24	Gurdaspur (Punjab)—rain fed area—surface	0·44
Godavari (Madras)—delta area—alluvium—surface	0·88	Sindh—Willingdon cattle farm—Kalar soil—surface	0·43
Maharajgunj, Gorakhpur—upland—surface	0·35	Sindh—reclaimed Kalar (alkali) soil—surface	0·35
Maharajgunj, Gorakhpur—lowland—surface	0·32	Sindh—Swelt hard land—surface ..	0·58
Maharajgunj, Gorakhpur—upland—surface	0·26	Sindh—Willingdon cattle farm—reclaimed alkali—surface	0·39
Indore (C. India)—Inst. of Plant Industry—surface	0·71	Sindh—Mirphukas fruit farm—clay soil—surface	0·44
Hyderabad, Deccan—surface	0·43	Parbhani—main farm—surface ..	0·78

or the still more accurate, direct procedure of Subrahmanyan, Narayanayya and Bhagvat (1934), but unfortunately those methods were not known at the time (1933) when the present work was carried out. The results cited in the above table (Table I) were obtained under similar conditions and could well be compared with each other. The samples were all air-dried and ground to pass the 100-mesh sieve before treatment with the oxidising mixture.

It may be seen from the table that although in a few stray cases the carbon content exceeded 1 per cent., it was generally very much less in quantity. The only specimen which contained more than 2 per cent. was an estate soil which had presumably received a heavy application of organic manure. This inference is supported by the very low carbon content of the sub-soil from the same area. Moreover, that sample was derived from a hill station the climatic conditions of which would correspond to those of temperate regions. The majority of the soils contained less than 0·5 per cent. The samples from the rich, deltaic areas contained generally between 0·5 and 0·8 per cents. Some of the sandy soils contained practically no organic matter.

When compared with the soils of temperate regions which often contain over 2 per cent. of carbon, the tropical specimens —including those which are generally recognised to be highly fertile—contain a distinctly lower level of organic matter. This is, presumably, largely due to the difference in climatic conditions. The long spells of hot, and often humid, weather which prevails in most parts of the tropics may be normally expected to facilitate rapid destruction of organic matter. Moreover, many of the Indian soils have been under cultivation for at least two thousand years. This may also have contributed to the depletion of those soils.

Contribution of soil organic matter to crop yield.—With a view to obtaining a quantitative estimate of the extent to which different forms of organic matter contribute to the fertility of a soil, the following experiments were carried out:—An area of land, with an apparently uniform type of soil, was divided into a number of sections which were treated with different fertilisers. Samples from these areas were filled into pots and used for growing barley (Var., Plumage Archer). They were also analysed for their carbon contents. Ten pots were allotted for each treatment. The details relating to the making of the pots, sowing, thinning and periodic observations were the same as those described in the previous communications.

In another set of experiments, sand, previously washed with water, was treated with farmyard manure both with and without minerals and the yields compared with those of the previous series. Farmyard manure was added at 7·5 g. per pot (30 lbs.). The minerals included potassium nitrate (0·98 g), potassium sulphate (1·52 g.), and superphosphate (3·05 g.) per pot.

The results have been presented in Table II.

TABLE II.

Treatment	Carbon per cent.	Average yield per plant		Grain/Straw × 100
		Grain (dry wt. in g.)	Straw (dry wt. in g.)	
Soil alone (control)	0·48	0·08	0·74	10·6
„ + complete minerals ..	„	0·64	2·42	26·6
„ + farmyard manure ..	0·50	1·51	2·72	55·4
„ + leaf mould	0·58	3·06	4·80	63·6
„ + activated sludge ..	0·62	1·11	2·73	40·7
„ + f.y. manure + minerals ..	0·50	1·73	3·55	48·8
„ + leaf mould + „ ..	0·58	2·04	3·58	57·1
„ + activated sludge+minerals	0·62	1·42	2·91	48·7
Sand alone (control)	0·02	0·04	1·08	3·53
„ + minerals	„	0·75	2·13	35·1
„ + farmyard manure ..	..	1·30	1·90	68·3
„ + „ + minerals ..	..	0·84	2·92	28·8

It may be noted that the carbon content of the soil was not appreciably improved by treatment with farmyard manure whereas leaf mould or sewage caused more marked increase. As may be naturally expected, the sand contained practically no organic matter. Periodic observations on the plants showed that those raised on soil which had originally received leaf mould or sewage showed the best vegetative growth. The response to soil treated with farmyard manure or minerals was not very pronounced in the early stages though the plants were distinctly superior to the control. The yields did not, however, entirely support the earlier observations. The leaf mould by itself yielded the best results, though, when combined with minerals, the production of both grain and straw was suppressed. Farmyard manure came out better with time, and responded favourably to addition of minerals. Sewage sludge yielded results of the same order as farmyard manure though it contained more organic matter. Its action was not greatly improved by treatment with minerals. The plants raised on untreated sand yielded practically no grain. On treatment with farmyard manure they yielded much more of both grain and straw. Minerals increased the yield of straw but the grains were not favoured to the same extent. On combining minerals with farmyard manure, the yield was slightly improved, but the effect was still of the same order as that with minerals alone. The ratio of grain to straw was highly variable, but it may be stated, in general, that organic manures increased it to a greater extent than the combined mineral fertilisers.

The foregoing observations show clearly that the original organic matter of the soil did not appreciably contribute to plant growth. Although the added manures improved the yields, the response was not generally proportional to the increase in carbon content. The different manures varied in their availabilities to plant nutrition and in their reaction towards minerals.

Increased availability of plant nutrients on treatment with chemical oxidisers.—It is well known that cultivation operations improve the physical condition of the soil and increase the availability of plant nutrients. There is a limit however to the benefit which can thus be obtained. Any further expenditure on cultivation will not improve the yield—at any rate to an extent commensurate with the extra time and labour spent on it.

The chemical changes that proceed in a well-cultivated soil are essentially of the nature of oxidation. It appeared probable, therefore, that if those changes can be accelerated by certain chemical treatments (which would not, at the same time, have any adverse effect on plant growth), better plant growth and greater increase in yield may be expected. The following experiments were accordingly carried out.

A number of small pots were made up in the usual way with sand and soil (3 lbs.). They were then divided into groups of twelve each which were treated as follows.—(*a*) Calcium carbonate at 3 g. per pot (corresponding to 2 tons per acre); (*b*) ferric oxide (3 g.); (*c*) laterite (3 g.); (*d*) potassium permanganate (0·075 g.) corresponding to 1 cwt. per acre; (*e*) copper sulphate (0·034 g.) corresponding to 50 lbs. per acre; (*f*) hydrogen peroxide (1 c.c. of 3 per cent.) corresponding to 50 lbs. per acre; (*g*) pot shreds (a handful of broken bits mixed with the soil); and (*h*) control (untreated). The treated samples were further divided into two sets, one of which was sown immediately and the other, after three weeks. The treatments were so timed that all the pots were ready at the same time for sowing. Barley of malting quality (No. 251, Cawnpore) was sown at the rate of 50 per pot. The seedlings which came up were nursed in wire-gauze cages. At the end of three weeks, the seedlings were removed, the necessary measurements taken and dry weights determined. The results have been presented in Table III.

There was a high percentage (about 90) of germination in all the cases. The seeds sown immediately came out generally better and the resulting

TABLE III.

Treatment	Sown immediately Averages				Sown after three weeks Averages			
	No. of seedlings	Shoot length in cm.	Root length in cm.	Dry wt. (in mg.) per seedling	No. of seedlings	Shoot length in cm.	Root length in cm.	Dry wt. (in mg.) per seedling
Calcium carbonate ..	269	29·0	22·7	34·1	260	24·5	22·2	29·3
Ferric oxide	257	19·2	23·8	51·2	271	26·0	22·0	31·9
Pot. permanganate ..	255	22·8	19·5	53·6	271	31·0	21·3	35·4
Copper sulphate ..	262	18·2	23·0	52·5	279	31·2	24·7	35·6
Hydrogen peroxide ..	256	17·7	21·2	49·8	282	34·0	27·8	38·4
Pot shreds	..	..	..	..	269	29·3	21·8	34·9
Laterite	..	..	..	..	255	23·3	19·7	30·6
Untreated (control) ..	270	27·8	22·8	38·2	265	23·2	18·2	30·1

seedlings appeared healthier and better formed than those from seeds which were sown after three weeks. The lengths of shoots and roots were however rather misleading. The seedlings from seeds which were sown immediately were rather short as compared with the others but had more of girth, which more than made up for the difference. The final dry weights showed that in both the batches, treatment with the oxidisers proved beneficial. The effect was very much more pronounced when the seeds were sown immediately than after the lapse of three weeks. The control (untreated) soil itself showed some difference on being moistened and allowed to stand for three weeks. It would appear, therefore, that a large part of the nutrients which were released, were either lost or otherwise rendered unavailable after standing for some time.

Among the individual treatments, ferric oxide, potassium permanganate and copper sulphate were of nearly equal merit, while hydrogen peroxide came slightly lower. Calcium carbonate depressed the yield. Pot shreds and laterite were tried in one series but did not appear to be superior to the chemicals.

The foregoing observations would suggest that treatment with chemical oxidisers can cause larger release of plant nutrients than would be available under normal soil conditions. The practical significance of this finding has already been shown (Harihara Iyer, Rajagopalan and Subrahmanyan, *loc. cit.*) in the case of pot-cultured plants and field crops. The time and the manner of application in the case of a few oxidisers have been standardised.

The attendant chemical and biological changes have also been studied. Further observations leading to the mechanism of action of oxidisers and their bearing on crop yield will be considered in the next communication.

Contribution of soil organic matter to plant assimilation.—A number of previous workers have suggested that the decomposition of organic matter in the soil results in the production of carbon dioxide which is assimilated by the growing plant. Positive evidence in this direction was obtained by Lundegårdh (1924, 1927, 1928), who showed by a series of elaborate experiments that (*a*) the concentration of carbon dioxide over a manured soil is higher than that over an unmanured one, and (*b*) the plant benefits to a greater extent from the air above a manured soil than from that above an unmanured one. These observations, as also those of others, would suggest that better plant growth can be obtained by artificially enriching the atmosphere around the growing plant with carbon dioxide. Extensive experiments conducted with this object have not, however, led to consistently favourable results. Some workers reported having obtained marked increase in yield while others noticed the reverse effect (Keuhl, 1925; Reinau, 1926; Rippel, 1926; Gerlach, 1926; Bolas and Henderson, 1928; Hasse and Kirchmeyer, 1928; Small and White, 1930; White, 1930 and others). The depression observed in some of the cases may have been due to inadequate root aeration, but such observations do, nevertheless, cast a doubt on the original theory of increased assimilation. Furthermore, it is known that when there is vigorous plant growth, there will be greater respiration both by the plant (*e.g.*, Neller, 1922) and by the soil, so that what is really an effect may be mistaken for the cause. In addition to this, direct proof to show that the plant can grow independent of the atmospheric carbon dioxide is still lacking. In view of the above and the need for further knowledge regarding the extent to which the plant depends on soil organic matter for its assimilation, the following experiments were carried out.

Soil (3 parts) from a neighbouring virgin tract was mixed with washed sand (2 parts) and the mixture treated with well-rotted farmyard manure so as to correspond on the usual basis to 10 tons per acre. The product was then filled into a number of glass jars at 400 g. each. The jars were then divided into three batches which were treated as follows:—(1) placed inside a big glass dome and a gentle current of air drawn over the system; (2) similar to (1) except that the air was freed from carbon dioxide before being sent in; and (3) the jars were placed in a wire-gauze cage exposed to atmospheric conditions. In all the pots moisture was first made up to 50 per cent. saturation. With a view to maintaining this constant, the air was drawn through distilled water or baryta, as the case may be, for the two sets within domes. To the jars kept in open air, the necessary quantity of water was added from time to time. After the experiment was commenced, the jars were left undisturbed for fifteen days. The general observations, as also measurement of heights, were made from outside.

The materials used for filling the pots were analysed for their moisture and organic matter contents (Table IV).

TABLE IV.

Item	Percentages			
	Soil	Sand	Manure	Mixture filled into the jars
Moisture	2·2	0·1	3·4	1·3
Loss on ignition	7·4	0·2	27·9	4·9
Organic carbon	0·52	0·02	10·90	0·51

After completing the experiment, samples of the soil mixture left in all the jars were analysed. It was found that the moisture content remained more or less the same (±4·4 per cent.) as that originally adjusted. Organic carbon was slightly less and was of the order of 0·49 per cent.

The seedlings came out well in all the cases. The periodic measurements showed that those receiving ordinary air under the dome were slightly taller than the others. This was not reflected however in the dry weights which were about the same in all the cases (Table V).

TABLE V.

Treatment	Number of seedlings	Averages in cm.		Total fresh wt. in g.	Total dry wt. in g.	Average dry wt. (in mg.) per seedling
		Shoot height	Root length			
Under glass dome—ordinary air	28	25·7	9·0	8·94	0·916	32·7
Under glass dome—CO_2-free air	27	22·0	6·3	8·41	0·888	33·2
Inside wire-gauze cage—atmospheric conditions	36	21·0	6·0	10·76	1·197	33·3

It may be noted that plant assimilation proceeded equally well with or without the supply of atmospheric carbon dioxide. It would appear, therefore, that the plant derived the bulk of its carbon dioxide requirements through the decomposition of organic matter in the soil and was, at any rate during the short period of study, independent of the gas present in the atmosphere.

Although the foregoing observations are highly suggestive, it is yet possible that a useful part of the dry matter of the seedlings may have been derived from the original seeds. The work is therefore being repeated, extending the observations to grown-up plants which have been raised inside specially constructed glass cages, the air and the moisture supply of which can be controlled. The results of that enquiry will form the subject of a later communication.

Summary.

1. The organic carbon contents of a number of tropical soils (from India, Burma and Ceylon) were determined. It was found that most of them —including some which are reputed to be fertile—are poor in that constituent as compared with the soils of temperate regions.

2. When a manure is applied to a soil (under tropical conditions), the increased benefit to the crop is more due to the decomposition of the added material than to greater availability of the original organic matter of the soil. The carbon content is not a correct measure of the possible availability of a manure. Addition of minerals may increase or depress the beneficial effects that may be derived through application of organic manures.

3. Treatment with minute quantities of chemical oxidisers such as permanganate, hydrogen peroxide or ferric oxide helps to increase the availability of the organic matter of the soil. In the case of barley, the effect is best seen if the seeds are sown shortly after the treatment. In the course of three weeks, the dry weights of seedlings are increased by over 50 per cent.

4. It has been shown that plants receiving a useful supply of farmyard manure (10 tons) can grow, at any rate in the early stages, independent of atmospheric carbon dioxide. The dry weights of seedlings receiving CO_2-free air were of the same order as those receiving ordinary air.

5. The significance of the foregoing and other observations has been discussed.

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746-35.—Printed at The Bangalore Press, Mysore Road, Bangalore City, by T. Subramania Aiyar, Superintendent, and Published by The Indian Academy of Sciences, Indian Institute of Science, Bangalore.

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