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INFLUENCE OF HEAT ON SOIL STRUCTURE

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IT has been known from time immemorial in India that heating a soil, either by lightly burning it or by burning stubble on it, will increase the yield of the following crop.[1] A similar practice in areas having intense dry season is to leave the bare soil exposed to the sun, so it gets baked out. This is again practised in India and in Egypt.[1] However, the scientific basis for this age-old practice is not fully understood.

Early Experiments

In 1888 Franke[2] gave some experimental evidence on the effect of heat on soil: he obtained larger crops of oats and of yellow lupines on heated than on unheated soil; and he showed also that heating increased the solubility of the mineral and of the organic matter in the soil. Five years later Liebscher[2] stated that the sterilisation of soil by steam increased the availability of the phosphates and nitrogen compounds.

Russell and his co-workers,[2-5] who investigated the influence of partial sterilisation of soil on the production of plant food in the early years of this century, reported that when a soil had been heated to 95° C. it produced two, three, or sometimes four times as much crop (*e.g.*, spinach, tomato, turnips, lettuce and tobacco plant) as a portion of the soil which had not been heated.[3] They obtained such results not only with fertile soils but with an exhausted Rothamsted soil. They stated that the heat treatment had in some way brought about a considerable increase in the amount of nitrogen, phosphorus, and potassium obtainable by the plant.[3]

Experiments with "Sick" Soils

Russell and Petherbridge studied the effect of temperature and of antiseptics, such as toluene and carbon disulphide, on "sick" soils from glass-house (sick soils occur in different parts of the world, *e.g.*, beet sickness on the Continent,[4] the flax and corn-sick soils of Dakota,[4] U.S.A.: sewage-sick soils at Kegworth,[6] U.K., Baroda[7] and Bangalore,[8] India) and reported that "exposure to a temperature of 96°–98° C. for two hours has proved the most effective because it not only kills destructive and parasitic organisms, including *Heterodera*, but also effects a certain amount of decomposition, thus lightening the subsequent work of bacteria and bringing about certain secondary results, notably a great development of fibrous root".[4] Russell and Golding,[6,9] who studied sewage-sickness in soil and its amelioration by partial sterilisation, also reported that heating the soil or treating it with antiseptics was effective. Russell and his co-workers believed that the sickness in glass-house soils and sewage-sickness in soil are, in part, due to an abnormal development of a factor always present in ordinary soils and detrimental to bacteria.[6] This harmful factor, which was identified as the protozoa such as *Colpoda cucullus*,[3] *amœbæ*,[9] *Euglena*[9] and *Vorticella putrina*,[9] was put out of action by heat or by antiseptics. The soils thus treated produced more crops.

For over three decades the effect of sewage as a manure as well as irrigation water on soil conditions and plant growth has been under continuous study in this Department. The experimental observations relevant here include[10-13]: (1) Surface heating of "sewage-sick" soil brought about an increase of about 300% in the yield of French beans (*Phaseolus vulgaris*) over the unheated control soil. (2) Other treatments of the "sewage-sick" soil, *e.g.*, heating *en masse*, application of burnt lime at the rate of 10 g. per 30 lb. of the soil and resting it for 3 weeks, and changing the surface layers or bottom layers of the soil, also gave increased yields ranging from 100 to 200%. (3) While these strikingly increased yields were obtained on replacing sewage irrigation with ordinary water following the treatments, continued use of sewage after any of the above treatments gave only an increase of 20 to 25%. (4) Experiments with different soils, with sewage diluted with water in different proportions, application of sewage and water at different stages of plant growth, with sewage effluents purified to varying extent, and related experiments showed clearly that the pore space in the soil and the presence of a certain amount of dissolved oxygen in the diluted sewage or treated sewage (raw sewage contains little or no dissolved oxygen) had a decisive influence on the availability of nitrogen and phosphorus in the soil and its productivity. (5) Further experiments and the field trials emphasized the primary importance of adequate air supply to the soil under sewage for the maintenance of its health and productivity.

Soil Structure and Aeration

Hall *et al.*[14] demonstrated the remarkable influence of continuous æration of nutrient solutions on the development of the root system and its close bearing on the superiority of the cultures in coarse sand and kaolin over the ordinary water cultures in which the æration was not continuous. Howard and Howard,[15] and Howard[16] who made a study of soil "ventilation" or æration and productivity of soils at Pusa, Lyallpur, Quetta, and in Central India reported that: "In many cases, results have been noticed which are most easily explained by the want of an adequate supply of air in the soil".[15] They also reported that: "Water, when it excludes air from the roots, acts as if it were a poison to crops".[15]

Aeration in soil is closely related to its structure which is essentially the arrangement of soil particles. The percentage of water-stable aggregates of different sizes generally gives a measure of the extent of air supply in the soil. While it is known that soil aggregation is mainly brought about through the agency of clay particles, the exact way in which clay binds soil particles together is still not known.[1]

Rao and Ramacharlu[17] studied water-stability in heated soil (using Gangetic alluvial soil of Delhi) and reported that the function of temperature is mainly to stabilize the aggregates already present in the normal soil, in addition to promoting a slightly fresh aggregation; that this stabilization of soil aggregates with respect to water steadily increased with increasing temperature of heating up to 360° C. at which point the aggregates became quite water-stable; and that the stability remained unchanged above this temperature. The studies of Gupta and Dutta[18] on water-stability of aggregates in heated black cotton soil of Nagpur indicated that "an extremely low temperature (360° C.) for attaining a very high water-stability of the soil coincides with the temperature for collapse of the clay structure"; and that "further heating of the soil results in a little increased water stability, though the end result of heating soil to high temperatures (1000° C.) is aggregation of the primary particles but disintegration of the larger aggregates." Salonius *et al.*,[19] in a comparative study of autoclaved and gamma-irradiated soil as media for microbial colonization experiments, found that the aggregate stability of Lincoln Clay was decreased (by 6·18%) by irradiation and increased (by 11·62%) by autoclaving (121° C. for 1 hr.). Their measurement of the soil aggregates was limited to the size $>$ 0·025 mm. Tiulin[20] has suggested that only those aggregates that are larger than 0·25 mm. are responsible for stable soil structure.

Recently, in the course of a study of the effect of different forms of organic matter and inorganic fertilisers on the formation of soil aggregates, we have made some interesting observations on the influence of heat on soil structure. These observations are briefly described here.

Influence of Heat on Soil Aggregates of Different Sizes

Influence of heat on the aggregates in soils containing different forms of organic matter.—Samples of Bangalore red loam soil (200 g.) were mixed separately with defatted groundnut cake (2·23 g.), cow dung (12·00 g.), straw powder (27·60 g.), leaf powder (27·60 g.), and a mixture of ammonium sulphate (0·933 g.) and superphosphate (0·267 g.). All these materials were added on an equal nitrogen basis. 800 ml. distilled water was added to each of them in a series of glass jars (2-litre capacity) kept on the laboratory bench. A control was maintained with the soil (200 g.) and distilled water (800 ml.) in one glass jar. It was considered that this soil-water proportion might facilitate the changes in the different systems. On the sixth day, the supernatant liquids were decanted and the sediment in each case was divided into two portions. One portion was dried on a water-bath for 12 hours and later in an oven (103° C.) for 3 days and the other portion was kept in the jar itself.

Both the heated and the unheated samples were kept under 1 : 5 water for 24 hours and were then sieved by the method of Tiulin,[2] which was modified as follows: In a bucket of water, a series of sieves (2 mm., 1 mm., 0·5 mm. and 0·25 mm. in the order from the top) were kept in a vertical row and the soil sample was placed on the top sieve. The sieves were moved up and down in water ten times, each time allowing the water to leave from the sides of the sieves. The sieves were then taken out and the material remaining on each sieve was washed into an evaporating dish. The excess water was decanted and filtered through filter-paper. The filter-paper, together with the soil, was dried in an oven (103° C.) and weighed. The percentages of water-stable aggregates were calculated and are given in Table I. The total percentages of soil aggregated are given in Fig. 1. The differences in the total percentages of soil aggregated in the heated and unheated series were statistically analysed (Table II).

These results indicate (1) that in all cases, including the control soil, heating caused an increase in the total percentages of soil aggregated; (2) that heating in every case considerably increased 0·25 mm. size aggregates; (3) that in the control soil and in the soils treated with groundnut cake and cow dung the percentages of 1 mm. and 0·5 mm. size aggregates increased as a result of heating, the increase in 0·5 mm. aggregate with cow dung and the increase in 1 mm. aggregate with groundnut cake were marked; and (4) that only in soils treated with leaf and straw powder there was an increase in 2 mm. aggregates.

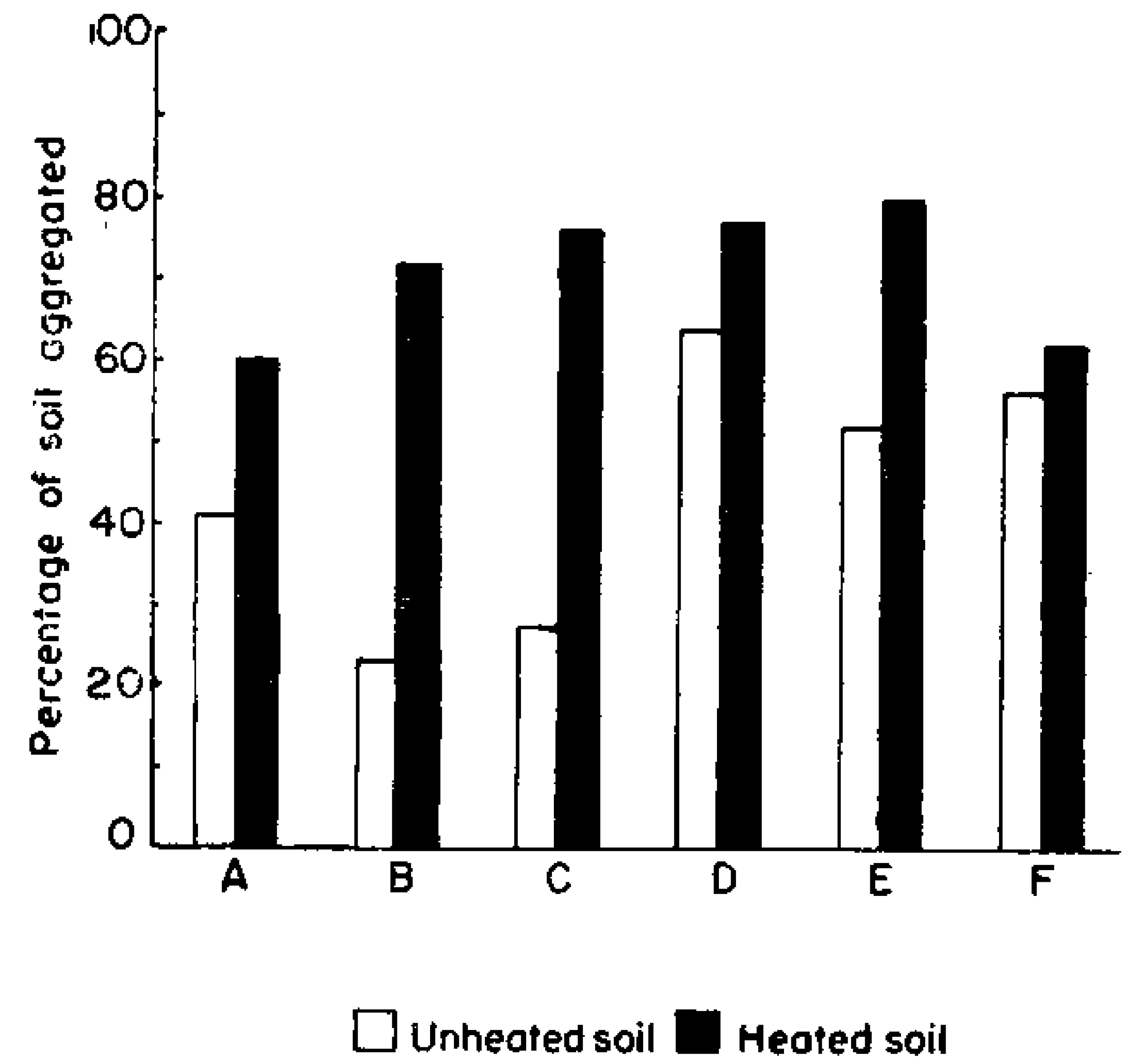

FIG 1. Influence of heat on the total percentage of aggregation of soils treated with organic materials and inorganic fertilisers. A. Control; B. Groundnut cake; C. Cow dung; D Leaf powder; E. Straw powder; F. Ammonium sulphate + superphosphate.

TABLE I

Influence of heat on the percentage distribution of water-stable soil aggregates formed under different treatments

Treatment	2 mm.		1 mm.		0·5 mm.		0·25 mm.	
	Unheated	Heated	Unheated	Heated	Unheated	Heated	Unheated	Heated
Control ..	Nil	Nil	7·0	8·5	10·0	15·0	24·0	36·0
Groundnut cake ..	Nil	Nil	1·0	11·0	10·0	16·0	12·0	45·0
Cow dung ..	2·5	Nil	2·5	7·0	7·5	33·0	14·5	36·0
Leaf powder ..	4·0	21·0	32·0	10·0	24·0	18·0	4·0	28·0
Straw powder ..	12·0	24·0	16·0	12·0	12·0	28·0	12·0	16·0
Ammonium sulphate + superphosphate	Nil	Nil	8·0	11·0	24·0	14·5	24·0	36·0

Influence of heat on the aggregates in soils treated with aqueous extracts of organic matter and solutions of inorganic fertilisers.—In another series of experiments, these different forms of organic matter and inorganic fertilisers (same amounts as in earlier series)

TABLE II

Analysis of variance of the total percentages of the soil aggregated

Source	d.f.	Sum of squares (SS)	Mean sum of squares (MSS)	F
Heat ..	1	2213·333	2213·333	13·010*
Manures ..	5	861·917	172·383	1·013
Errors ..	5	850·417	170·083	

* Significant at 5 per cent. level. (Heating improved the total percentages of water-stable aggregates in the soil).

were added to 800 ml. distilled water and were agitated on a mechanical rotary shaker (200 r.p.m.) for 36 hours. The solutions were filtered through cotton wool. The filtrates were added separately to each sample of 200 g. Bangalore red loam soil kept in glass jars. There was a control with 200 g. soil and 800 ml. distilled water. They were all kept for five days on the laboratory bench and on the sixth day the supernatant liquids were removed. The soil was divided in each case into two portions. One portion was dried on a water-bath for 12 hours and later in an oven (103° C.) for 3 days. Both the heated and the unheated samples of soil were then kept in water (1 : 5) for 24 hours and were later wet sieved as described above. The results of wet sieving and their statistical analysis are given in Tables III and IV. The results in Tables III and IV show (1) that 0·5 mm. and 1 mm. size aggregates increased in all cases: (2) that 0·25 mm. size aggregates also increased

TABLE III

Influence of heat on the percentage distribution of water-stable aggregates formed in soils treated with solutions of different fertilising materials

Treatment	1 mm. Unheated	1 mm. Heated	0·5 mm. Unheated	0·5 mm. Heated	0·25 mm. Unheated	0·25 mm. Heated
Control ..	4·0	5·2	10·0	30·0	20·0	35·2
Groundnut cake*	4·0	9·6	7·0	60·8	24·0	12·0
Cow dung ..	2·0	14·5	4·0	39·0	18·0	22·6
Leaf powder	2·0	16·0	8·0	71·8	19·0	7·0
Straw powder	Nil	12·0	3·0	60·0	21·0	14·0
Ammonium sulphate + superphosphate	Nil	13·2	3·0	51·0	6·0	24·9

* 2 mm. diameter aggregates were formed only with groundnut cake in the heated soil sample (2·4 per cent).

TABLE IV

Analysis of variance of the total percentages of the soil aggregated

Source	d.f.	Sum of squares (SS)	Mean sum of squares (MSS)	F
Heat ..	1	9987·870	9987·870	805·34*
Manures ..	5	782·177	156·435	12·61*
Error ..	5	60·010	12·402	

* Significant at 1 per cent level (Heating improved the total percentages of water-stable aggregates in the soil).

in the control soil and in the soils treated with aqueous extract of cow dung and solution of ammonium sulphate and superphosphate; and (3) that 2 mm. size aggregates were found only in the soil treated with groundnut cake. Figure 2 shows that the total percentages of water-stable aggregates were strikingly more in the heated soils under different treatments than in the corresponding unheated soils.

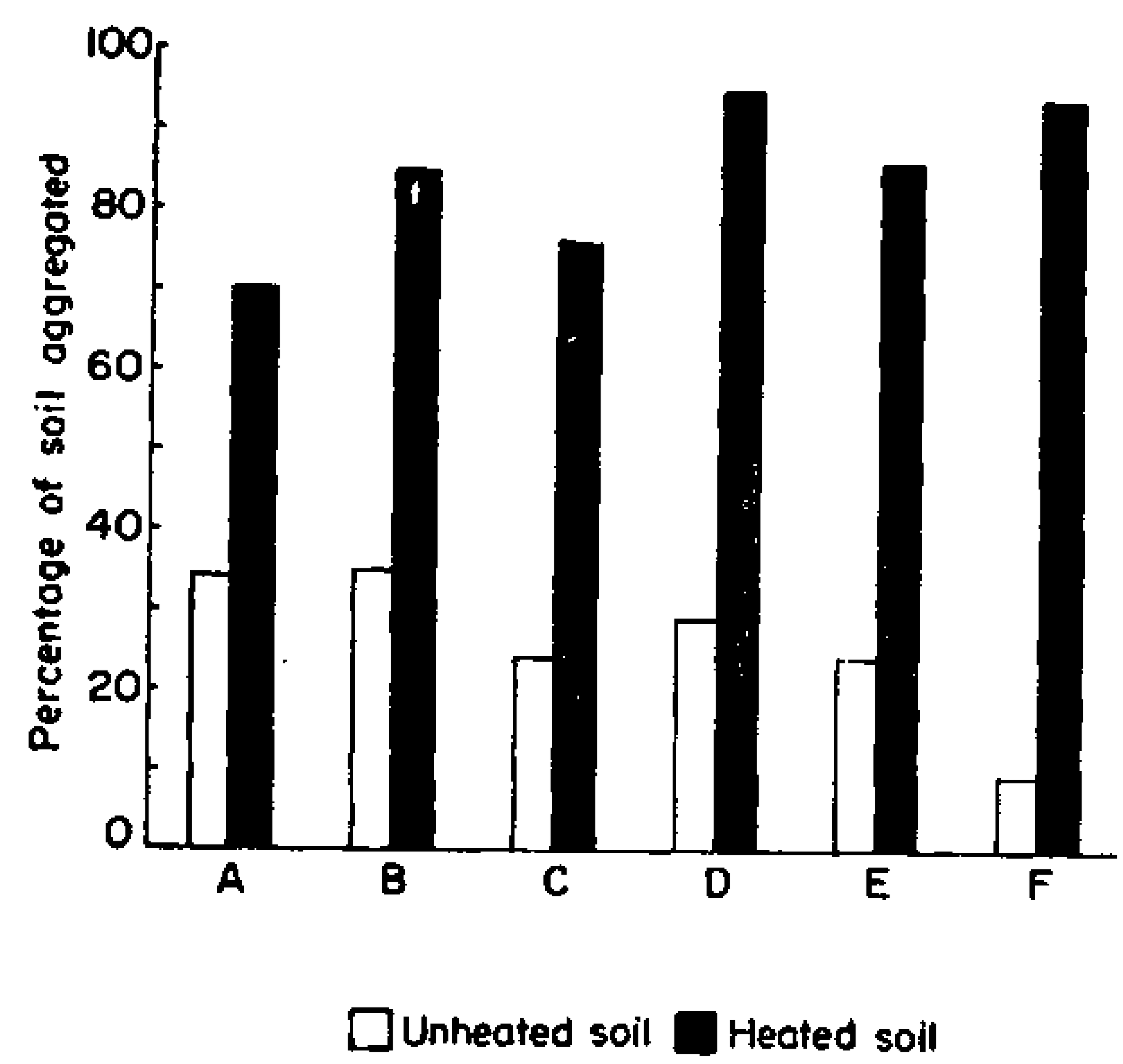

FIG 2. Influence of heat on the total percentage of aggregation of soils treated with aqueous extracts or solutions of fertilising materials. A. Control; B. Groundnut cake; C. Cow dung; D. Leaf powder; E. Straw powder; F. Ammonium sulphate + superphosphate.

SUMMARY

The experimental results described here show that heating the soil, with or without organic matter or inorganic fertilisers, increased to varying extent the total percentage of water-stable aggregates; and the extent of increase depended upon the type of fertilising material and the manner or mode of its application.

The more interesting observation was on the influence of heat on the aggregate-size distribution: aggregates of greater diameter were generally formed, particularly in the soil samples treated with aqueous extracts or solutions of fertilising materials.

Temperature thus seems to be a physical factor of considerable importance in the formation of suitable aggregates in soil, which facilitate aeration and productivity of the soil. The presence of decomposing organic matter also contributes considerably to soil aggregation. Liming the soil has been known to aid its productivity, presumably by flocculation or aggregation. Among the physical, chemical and biological factors influencing soil structure, temperature is apparently of some special significance to tropical agriculture.

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PREPARATION AND PROPERTIES OF BISCYCLOPENTADIENYL TUNGSTEN OXYDICHLORIDE AND BISINDENYL TUNGSTEN OXYDICHLORIDE

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TUNGSTEN cyclopentadienyl chlorides,[1] carbonyls[2] and hydrides[3] have already been reported. No work has however been done on the preparation of indenyl derivatives of tungsten, although indenyl derivatives of iron and cobalt,[4] tin,[5] lead,[6] gallium and mercury[7] have been reported by various workers. The present communication deals with a study of preparation and properties of biscyclopentadienyl tungsten oxydichloride (I) and bisindenyl tungsten oxydichloride (II). These compounds have been prepared by direct reaction of tungsten oxytetrachloride with cyclopentadiene as well as with indene in liquid phase using tetrahydrofuran. Compounds (I) and (II) so formed were isolated by removing the solvent under reduced pressure and subsequent recrystallization from THF or diethyl ether. The percentage yield was nearly 80%. Tetrahydrofuran has proved to be a satisfactory medium for carrying out the reactions of tungsten oxytetrachloride with cyclopentadiene and indene.

EXPERIMENTAL

Tungsten oxytetrachloride was prepared by refluxing tungsten trioxide with thionyl chloride and the excess of thionyl chloride was removed by evaporation under reduced pressure. The bright reddish mass so formed was sublimed at 130–35° and yielded scarlet red needles.

Preparation of Biscyclopentadienyl Tungsten Oxydichloride.—To 3·5 gm. of tungsten oxytetrachloride (0·1 mole) in 100 ml. of tetrahydrofuran was added 2·7 ml. of cyclopentadiene (0·2 mole) and the mixture was refluxed for 6–7 hours at 75°–80° C. The resultant deep brown solution was freed from solvent by evaporation under reduced pressure and on repeated crystallization from tetrahydrofuran gave light pink crystals (Found: C, 29·9; H, 2·5; W, 45·9; Cl, 17·6%; Calc. for $(C_5H_5)_2WOCl_2$: C, 29·92; H, 2·49;