yet to await the synthesis of certain model 2, 2'-binaphthyl compounds and determination of their absolute configuration by unambiguous methods such as X-ray diffraction method.

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INFLUENCE OF MOISTURE ON SOIL AGGREGATION

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Optimum Soil Moisture for Maximum Plant Growth and Crop Yield

HELLRIEGEL (1883) first demonstrated the relationship between the soil moisture and the final amount of plant growth by growing barley in sand cultures supplied with different amounts of water. The entire crop consisted of straw with the smallest amount of water, and with increasing amounts of water, the yields of both straw and grain passed through a maximum and then decreased; but the maximum yield of grain occurred with a smaller amount of water than did the maximum yield of straw[1,2]. In 1912, Widtsoe obtained similar results with wheat under field conditions and reported that the yield increased with increasing water supply, the straw more than the grain[1]. Traaen (1916) studied the effect of different percentages (3, 5, 10, 15, 17·5, 20 and 25) of moisture in the soil at 13° C and 25° C and found that maximum nitrate was formed with 17·5% moisture at 13° C at the end of 66 days[1].

Since the work of Hellriegel and of Widtsoe, it has been increasingly recognised that the optimum moisture content of soils is a most important factor in soil conditions and plant growth: *e.g.*, "Generally, however, 50 to 60% of the total moisture holding capacity of the soil is optimum for the majority of cultivated crops"[3]; "Considered in relation to both microbial activities and crop growth, the optimum water content of soils is at about two-thirds saturation, leaving one-third of the pore space to be occupied by air"[4]. Additional supplies of water may sometimes be advantageous depending on the nature of crops and other conditions, may sometimes be ineffective and sometimes be harmful[1].

Recently Dakshinamurti and Reddy (1971)[5] conducted field experiments on alluvial soil, irrigating two varieties of wheat at six levels, *viz.*, ½, ¾, 1, 1½, 2 and 3 times field capacity. They obtained the highest yields of grain with both the varieties of wheat on the soil irrigated with water between ¾ and 1 field capacity. They stated that if the irrigation schedules were restricted to ¾ field capacity to one field capacity, most of the mineralisable nitrogen would be available to the roots resulting in maximisation of yields.

Earlier Studies on Soil Moisture

Moisture and Soil Aggregating Effect of Organic Residues.—In the course of their studies on the influence of temperature (10°, 25°, 40° and 55° C) and moisture (25, 50, 75 and 100%) on the soil aggregating effect of organic residues such as alfalfa-grass, hay tops, blood meal, wheat straw, sawdust, cow manure and sucrose for various periods (5, 10, 20, 50 and 100 days), Martin and Craggs (1946)[6] found that greatest over-all aggregation occurred in the soil samples maintained at 25% moisture, that slightly less beneficial action resulted in the series kept at 50 and 75% moisture, and that in the soil kept saturated with water, there was a great reduction in the aggregating effect.

Alderfer (1946)[7] conducted aggregating studies on plots of Hagerstown silt loam surface soil which had been subject to 5 years of each of the following annual treatments: barnyard manure, wheat straw, corn stover, a ryegrass cover crop, and a 4–12–8 fertiliser were incorporated in the surface soil. Soil moisture content was closely related to the amount and size of water stable aggregates when the soil was analysed in its field-moist condition. The effect of soil moisture content was modified, however, by seasonal conditions such as alternate wetting and drying during the summer and by alternate freezing and thawing, which effected a large but temporary increase in aggregation during the late winter. Alderfer's studies[8] suggested the importance of maintaining an adequate supply of moisture in the soil not only as a direct necessity for plant growth but also in view of its possible indirect influence. That plants grow best when the soil contains an adequate supply of moisture may be partly due to an increased amount of soil aggregated into larger sized secondary particles which should provide greater permeability to both air and water.

McCalla *et al.* (1957)[9] studied the influence of various factors, including moisture content (10, 15, 20, 25 and 30%) and temperature (20°, 24° and 28° C) on aggregation of Peorian loess soil by microorganisms (*Streptomyces* sp. and two species of *Fusarium*) and recorded that in all cases an increase of moisture from 10 to 20% resulted in a substantial increase in aggregation, and in general, an increase of moisture content above the 25% level, which was slightly higher than the moisture at 1/3 atmospheres tension (21·3%), did not appreciably influence the degree of aggregation.

Prewetting and Aggregate Analysis.—Evans (1954)[10] examined the effect of prewetting and incubation of soil on aggregate analysis and observed (*a*) that keeping the soil moist for 24 hours at its moisture equivalent* increased the water stability over the soil kept for only 5 minutes; (*b*) that this increase was not caused by microbial action, being apparently associated with the rate of hydration; (*c*) that the increased water stability associated with long duration of premoistening seemed to be in turn associated with the amount of clay in the soil; (*d*) that the mean-weight diameter of aggregates of Luton clay increased 153% when moistened 24 hours as compared to 5 minutes; (*e*) that the increases for less clayey soils were 63 and 32% for Glenecoe silty clay loam and Marshall silt loam, respectively; and (*f*) that factors other than clay might influence the prewetting effect, as in the Carrington soil in which the organic matter content appeared to increase the water stability resulting from 24 hours of prewetting as compared with 5 minutes prewetting.

Moisture and Soil Erosion by Wind.—Chepil and Bisal (1943)[11] reported that relatively few soil particles greater than 0·5 mm in diameter were moved by common erosive winds, although a few up to 2 mm diameter might be moved by exceedingly high winds. For most mineral soils, the 0·5 mm diameter of a soil grain corresponds to about 0·84 mm actual diameter. The 0·84 mm is one of the sizes in the sieve series of the United States Bureau of Standards. Chepil (1952)[12], therefore, used this size of square sieve openings to separate the so-called erodible from the non-erodible soil fractions.

Chepil and Woodruff (1963)[13] stated that wetting a loose soil bed followed by drying produced a certain degree of cementation (consolidation) among the various individual particles and aggregates and tended to reduce erodibility by wind; that the degree of cementation was greatest at the surface of the ground, especially if the ground was exposed to impacts of raindrops; that an ideal structure from the standpoint of resistance to erosion by wind and of other desirable features was a soil that had a substantial proportion of water stable aggregates greater than 1 mm diameter; that any treatment that would achieve this condition would aid greatly in establishing lasting resistance to wind erosion; and that more information was needed on the influence of moisture on soil structure under different types of tillage.

Bisal and Hsieh (1966)[14] carried out a study of the influence of soil moisture on the susceptibility of soil to wind erosion: they determined the effects of soil moisture content and soil texture on the initiation of movement when soils were subjected to different wind velocities. With a wind velocity of 12·5 m per second the moisture required to prevent erosion was 7·9, 10·8 and 15·7%, respectively, for the three soils (Hatton fine sandy loam, Haverhill loam and Sceptre clay used in their experiments), which is an equivalent moisture of 1·46, 1·00 and 0·80. The equivalent moisture was indicated as "the ratio of percentage of moisture in a soil divided by the percentage held in the same soil at the 15-atmosphere tension".

There is thus some evidence on (*i*) the influence of soil moisture at a certain level on the soil aggregating effect of organic residues, (*ii*) the effect of premoistening the soil for a longer period on aggregate analysis and on the behaviour of clay and organic matter in this analysis, and (*iii*) the influence of moisture on erodibility of soil by wind. But it is not clear how the soil moisture at a certain level profoundly influences the plant growth and how the variation in the amount of soil water brings about differences in the yields of grain and straw as observed by Hellriegel and Widtsoe.

* The weight percentage of water retained by a previously saturated sample of soil 1 cm in thickness after it has been subjected to centrifugal force of one thousand times gravity for 30 minutes (*Glossary of Soil Science Terms*, published by the Soil Science Society of America, Madison, Wisconsin, May 1970, p. 11).

In this connection we have carried out some experiments and they are briefly described and discussed below.

PRESENT INVESTIGATION

Four main series of experiments were carried out to study (1) the extent of soil aggregation as influenced by different amounts of water, (2) the effects of chloroform and toluene along with different amounts of water on soil aggregation, (3) the effect of autoclaving the soil with different amounts of water on soil aggregation, and (4) the effect of different amounts of organic manure along with water (sewage) on soil aggregation. Chloroform, toluene and autoclaved soil were employed to eliminate biological activity. Sewage (settled, detritus-free domestic sewage) was used because it is a solution and an aqueous suspension mostly of organic matter in a fine state of division, which may more uniformly mix with the soil than other forms of organic matter and may, therefore, minimise the sampling error. The sewage for the experiments here was collected from the sewage works at this Institute.

Bangalore red soil (passed through 2 mm sieve) was used in these experiments and the air-dry soil contained: 2·5% moisture, a total water holding capacity of 60 ml per 100 g; 55·6% sand; 24·4% silt, and 20% clay. The water stable aggregates in the soil samples were determined by the method described earlier[15].

Influence of Moisture on Soil Aggregation.—In a series of 13 conical flasks (100 ml capacity), samples of the air-dry soil (20 g) were taken, and the following different amounts of distilled water were added and the flasks were kept at room temperature (26° C) for 6 hours: 1, 2, 3, 4, 6, 8, 10, 12, 14, 16, 18 and 20 ml water, which represent 5, 10, 15, 20, 30, 40, 50, 60, 70, 80, 90 and 100% moisture level, respectively. There was another flask, a control with the soil only, without any addition of water. At the end of 6 hours, each sample received 100 ml tap water and all the samples were wet sieved.

There was another series of 13 similar flasks with same amounts of soil and water, which also received 100 ml tap water after 6 hours, but they were kept overnight (18 hours) before they were wet sieved. The object of these two series of experiments was to see whether or not there is an optimum level of moisture for the soil to form water stable aggregates.

The observations (Fig. 1) show (*i*) that there were increases in the percentages of water stable aggregates in the soil samples with different amounts of water; (*ii*) that these increases (over the control) varied between 5 (with 2 ml water or 10% moisture and 57 (with 4 ml water or 20% moisture); and (*iii*) that all the samples whether kept for 6 hours and wet sieved immediately or after keeping them in water for a considerably long period (overnight) gave practically the same percentage increases in the water stable aggregates with the different amounts of added water.

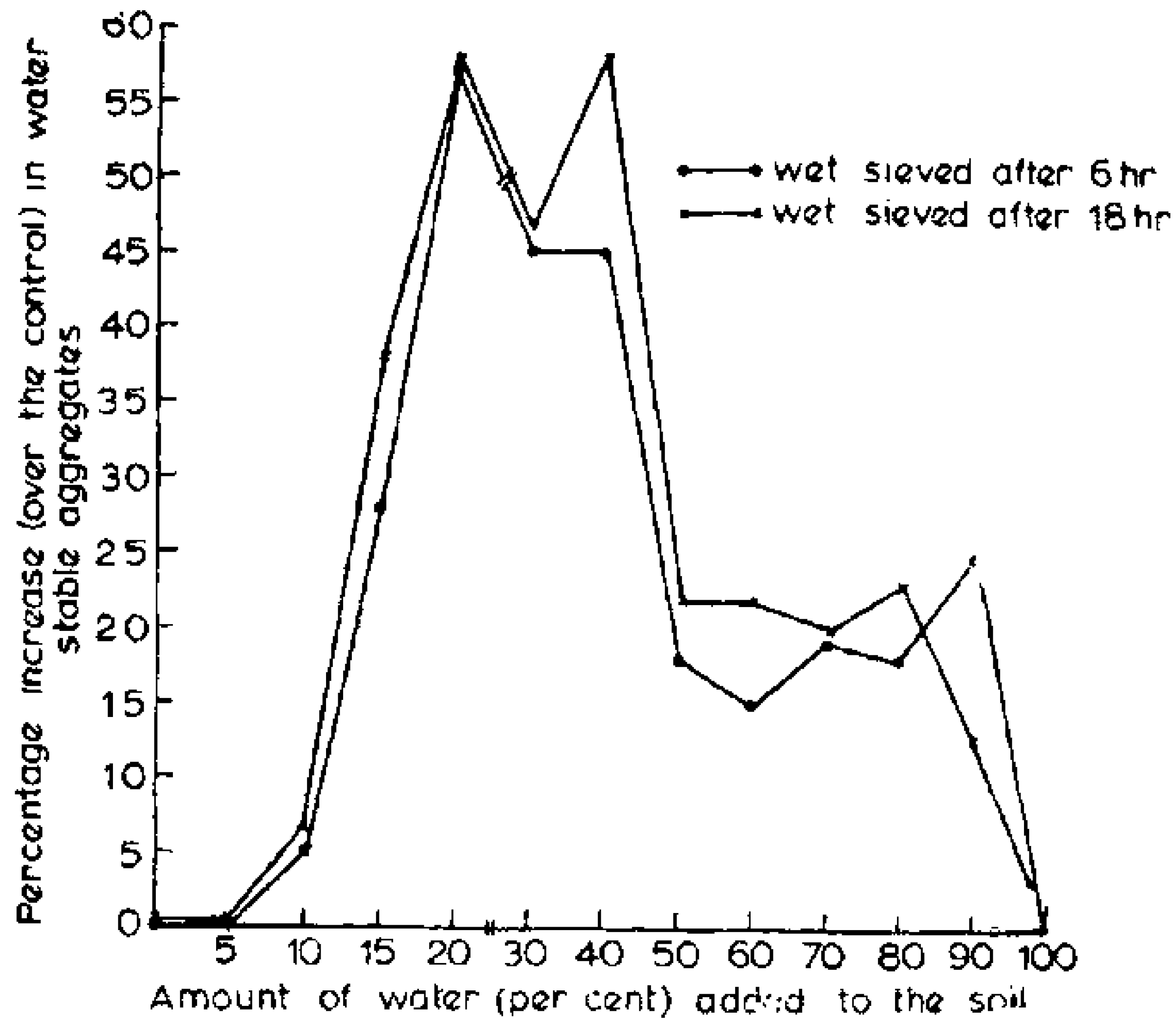

FIG. 1. Influence of moisture on soil aggregation.

It was important to observe that the maximum increase in the percentage of water stable aggregates occurred with 20% moisture in the soil.

In order to examine whether the observed percentage increases in the water stable aggregates in the above experiments was due to any microbial action, three series of experiments were carried out, which were similar to the above series. In the first of these series, 1 ml chloroform was added to each soil sample along with the different amounts of water; in the second series, along with water an equivalent amount of toluene was added in each case; much higher concentrations of toluene (than was necessary for the purpose of sterilisation of soil) were used to see whether the antiseptic would interfere with the action of moisture on soil aggregation; and in the third series, all the flasks were autoclaved.

The nutrient broth tubes inoculated with the soil samples from the flasks treated with 1 ml chloroform or toluene did not show any growth even after 48 hours.

Effect of Chloroform and Toluene on Soil Aggregation.—After the addition of chloroform or toluene as indicated above, the flasks were kept for six hours at the room temperature, then 100 ml tap water was added to each of the flasks and the contents of all the flasks were allowed to stand overnight and wet sieved. The results (Figs. 2 and 3) show that the addition of chloroform or toluene at any of its concentrations did not affect the increases in the percentages of water stable aggregates in the soil samples.

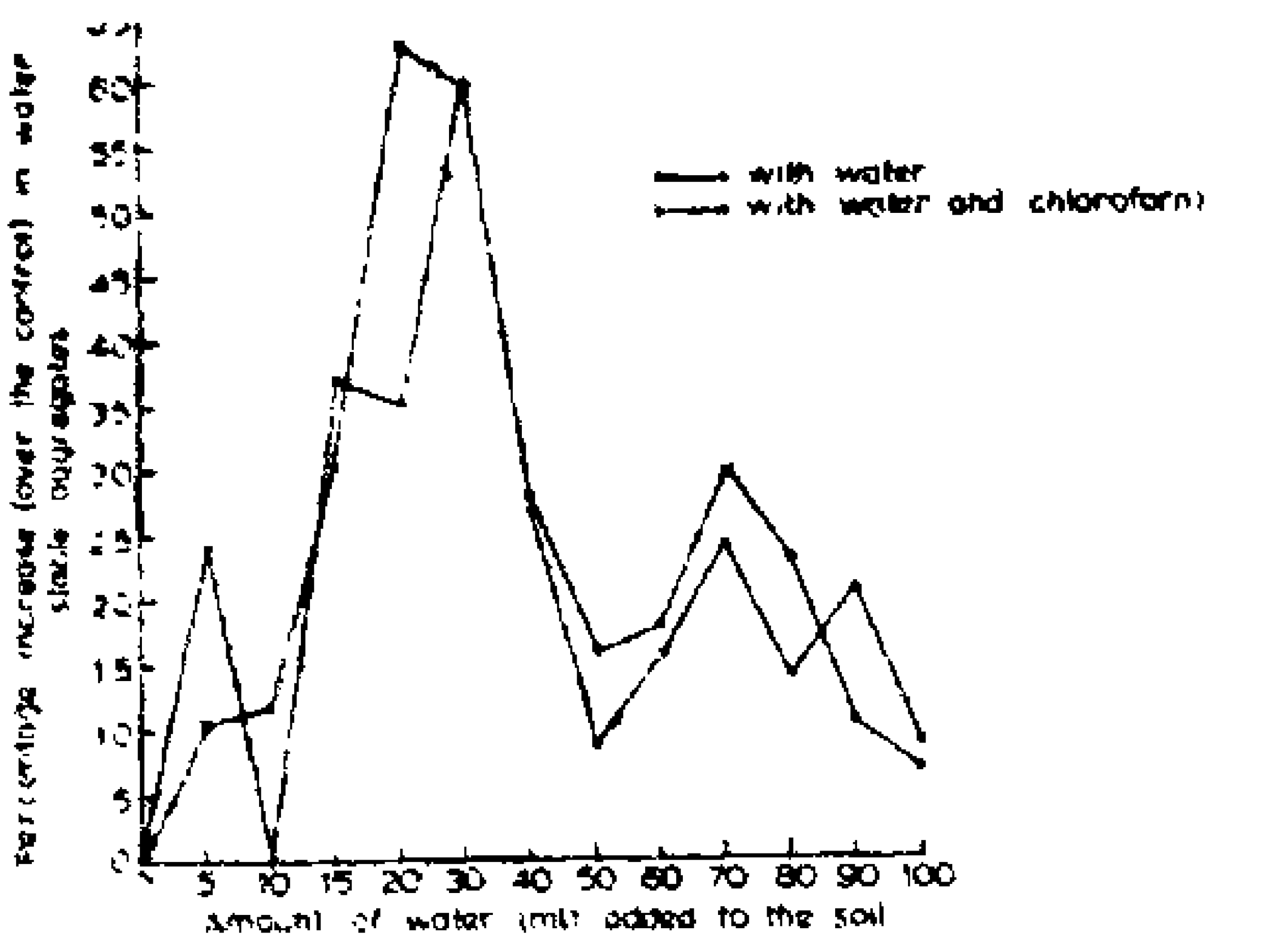

Fig. 2. Influence of moisture in the presence of chloroform on soil aggregation.

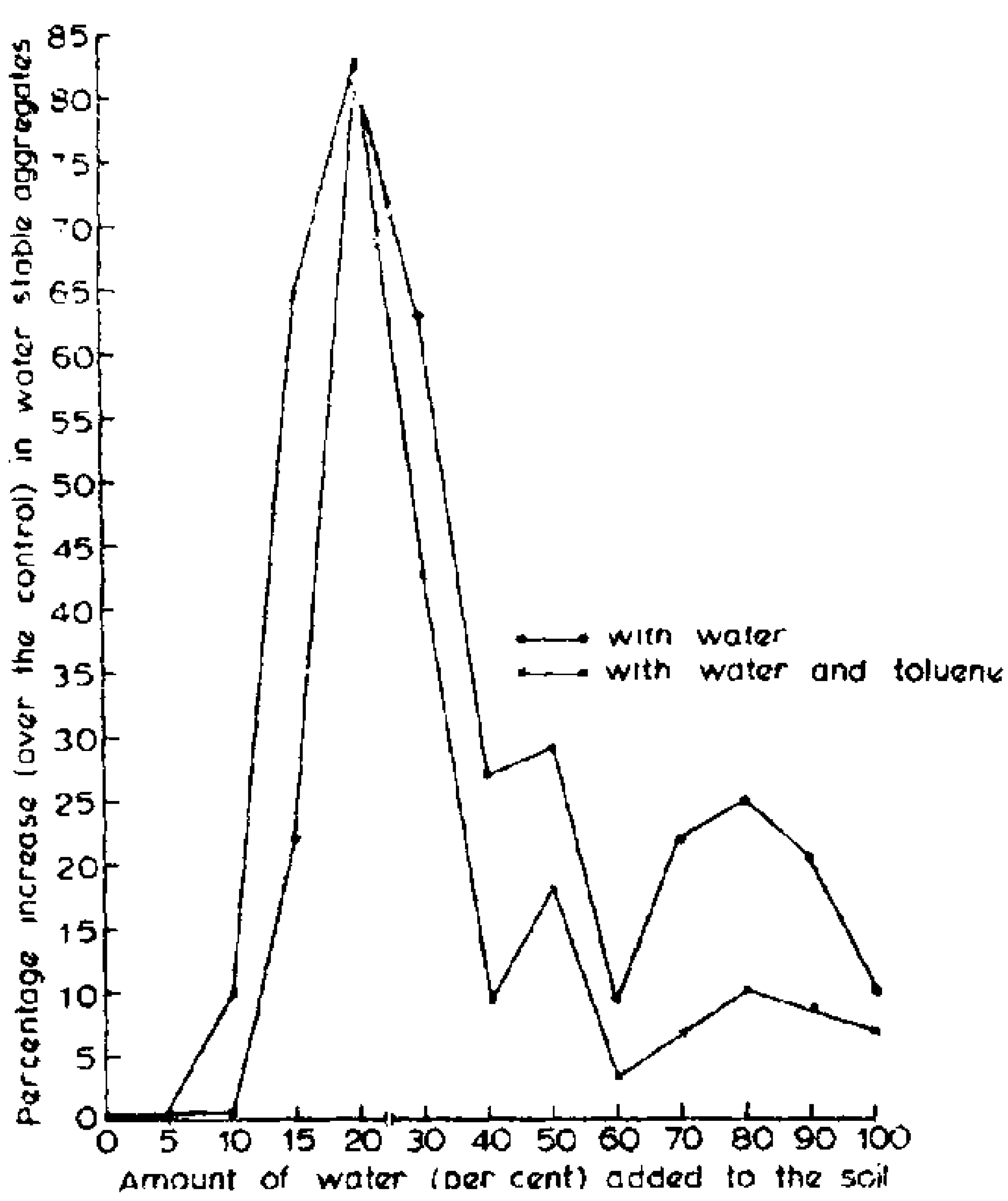

Fig. 3. Influence of moisture in the presence of toluene on soil aggregation.

Effect of Autoclaving Soil Samples with Different Moisture Contents on Soil Aggregation.—There were three sets of flasks, each set having 13 flasks with the same amounts of soil and water as in the previous experiments. Two of these sets of flasks were autoclaved, one set at 15 lb pressure for 15 minutes and the other set at 15 lb pressure for 30 minutes. The third set was not autoclaved, and it served as the control.

After autoclaving the samples, they were cooled. 100 ml tap water was added to each of the flasks and they were kept overnight at the room temperature. Then they were wet sieved.

There were practically no differences in the increases in the percentages of water stable aggregates in the soil samples autoclaved for 15 minutes and for 30 minutes The results of the samples autoclaved for 15 minutes are not therefore given here. As compared with the control soil samples (not autoclaved) the autoclaved samples showed a general increase in the percentage of water stable aggregates at the different levels of moisture and an appreciable increase (about 118%) in the soil with 20% moisture (Fig. 4).

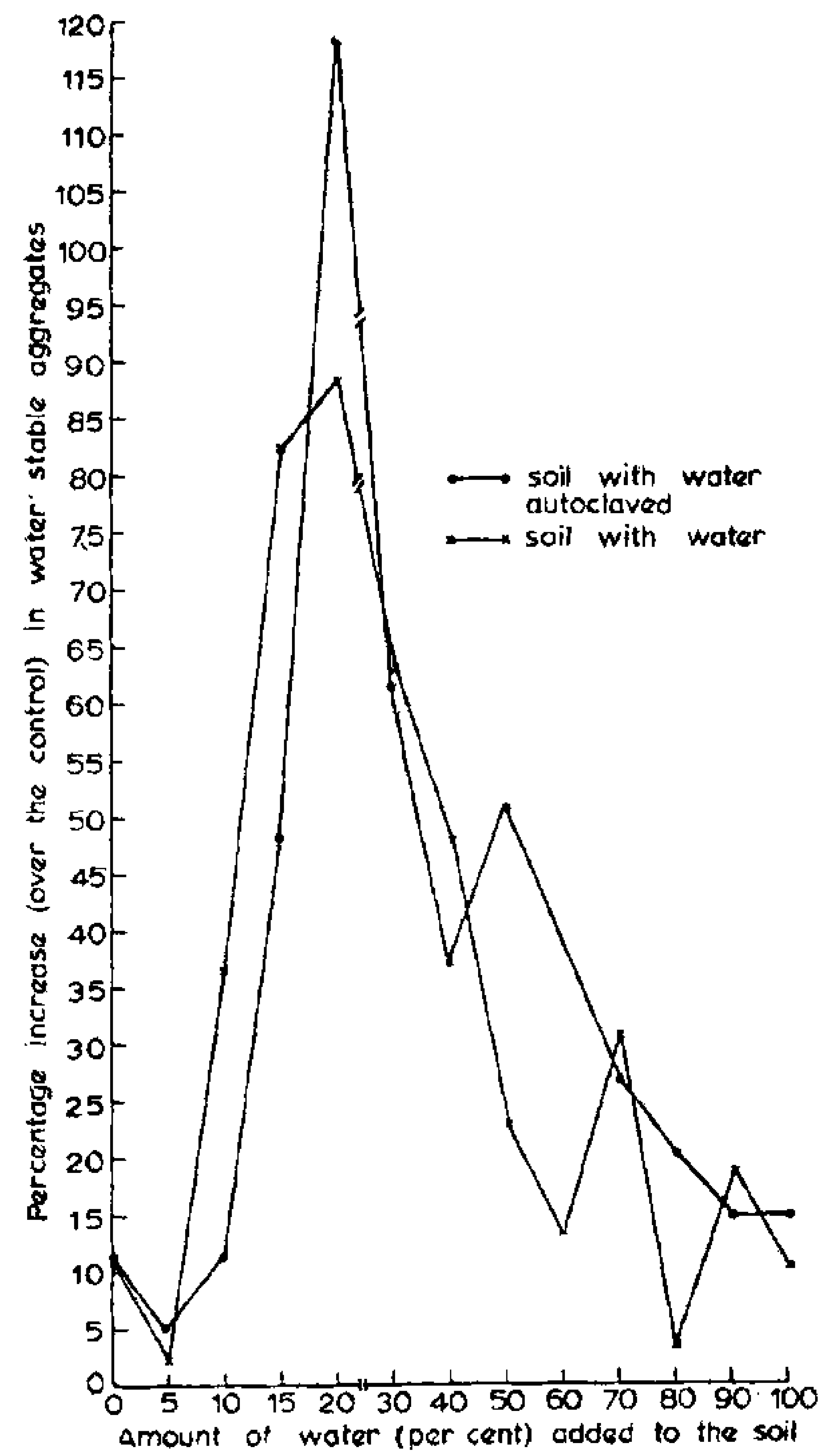

Fig. 4. Effect of autoclaving soil with different amounts of water on soil aggregation.

It may be relevant here to refer to the observations of Van Bavel (1950)[16] who studied the aggregate stability of the soil as affected by sterilisation with ethylene oxide at 5, 10, 15 in. of mercury partial pressure and heat in a steam autoclave at a pressure of 15 p.s.i. for 20 minutes. He reported (*i*) that aggregation was increased by heat and by "the two highest rates of ethylene oxide", when the soil was sterilised in the air-dry state and analysed without any further treatment but that on wetting and drying no significant effects on aggregation could be found ; and (*ii*) that aggregation was also increased by heat and by "the two lowest rates of ethylene oxide", when the soil was wetted and kept at moisture equivalent under sterile conditions in an incubator for two weeks. He further reported that no differences in aggregation were found when the wet soils were incubated after inoculation with a mixed population and that the conclusions drawn from the experiments, where heat sterilised soils were employed, could be erroneous if the effect of sterilisation itself was not accounted for.

In this connection a reference may also be made to the work of Martin and Aldrich (1952)[17] who investigated the effect of fumigation with D-D, chloropicrin, carbon disulphide, propylene oxide, ethylene dibromide, and steam sterilisation on soil aggregation. They found that in high dosages, D-D, chloropicrin, and ethylene dibromide slightly increased the aggregation of Yolo loam at the 0-day incubation period only. Steam sterilisation increased the aggregation of Yolo loam, an unnamed mountain soil, and Hanford sandy loam and in the latter two soils, the effect was not significant after the 0-day incubation period. They stated that the increased aggregation was associated with decreased "wettability of the soil".

McCalla *et al.* (1958)[18] studied soil aggregation by microorganisms following soil fumigation and noticed that only in the autoclaved soil was a mixed soil flora inoculum consistently superior to the blank inoculum in promoting aggregation of the Peorion loess.

Influence of Organic Matter with Water (Sewage) on Soil Aggregation.—The details of the experiments were the same as in the previous experiments except in the use of sewage instead of water. As in all the above experiments, a parallel series with water was also run. After keeping the soil samples with different amounts of sewage or water for 6 hours, 100 ml tap water was added to each flask and the samples remained in contact with water overnight and were then sieved.

The results (Fig. 5) show that the addition of the different amounts of sewage to the soil increased the water stable aggregates and that this increase was maximum (122%) with 20% sewage. The increases in the percentage of water stable aggregates with sewage were, however, higher than those with water and they were comparable to those obtained in the autoclaved soil with water.

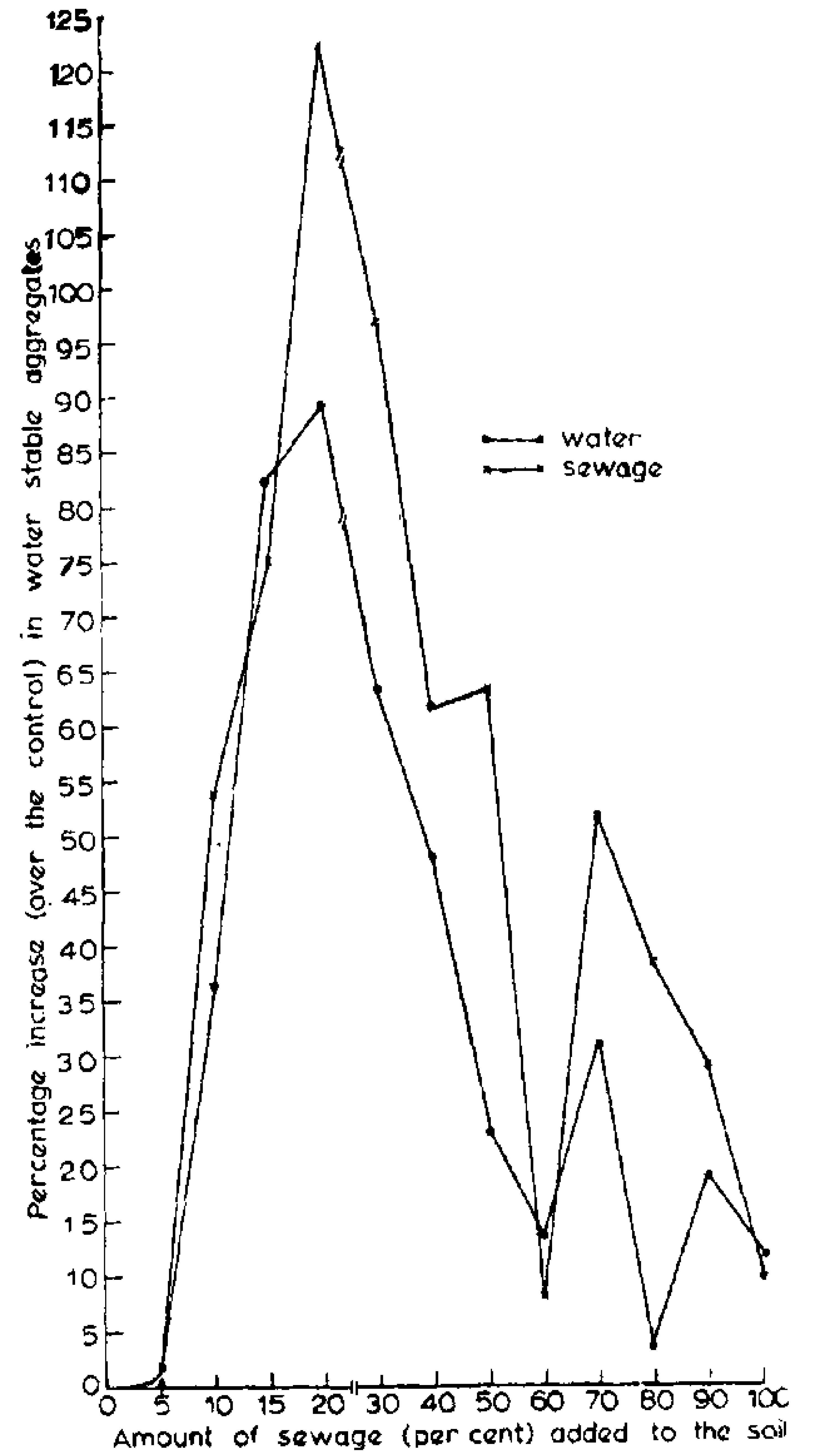

FIG. 5. Influence of aqueous suspension of organic matter (sewage) on soil aggregation.

MOISTURE AS A FACTOR IN SOIL AGGREGATION

There has been considerable evidence[1,2,5] to show that for a given soil and possibly for a given crop there is an optimum level of moisture which contributes to the productivity of the soil. This moisture level, like the optimum temperature, has been considered as an environmental factor in the aggregating effect of organic residues[6-9]. It was also observed that in aggregate analysis prewetting the soil for a certain period increased the water stable aggregates[10]. Further, the water stable aggregates would control the erosion of soil by wind[13,14]. There is thus a suggestion in the evidence of the earlier investigators that a certain moisture content of soil facilitates the formation of water stable aggregates which are known to promote aeration and other favourable conditions for plant growth.

The experimental evidence described in this paper clearly shows that at one-third water holding capacity of Bangalore red soil there is a significant increase in the percentage of water stable aggregates. The immediate cause for this increase in soil aggregation was not microbial activity but it might be the behaviour of clay, which has to be further investigated.

Even when the soil samples with different moisture contents were autoclaved, the one-third moisture holding capacity of the soil showed up its significance in increasing the percentage of water stable aggregates in the soil, although the percentage increase was considerably more than that in the soil with corresponding moisture kept at room temperature. The increase in the water stable aggregates in the autoclaved soil was, however, comparable to the increase in the soil wetted with an equivalent amount of aqueous suspension of organic matter as in sewage.

The foregoing observations on the influence of moisture on soil aggregation, the earlier work on the aggregating effect of heating agricultural soils[12-19] and the evidence accumulating in this laboratory on the role of certain protozoa in the flocculation or aggregation of clay and soil[20-22] indicate that formation of water stable aggregates in soil is of far greater significance in soil economy than has hitherto been considered.

Water stable aggregates with more moisture may be expected to resist wind erosion and thus help in soil conservation. They, of course, directly increase the air supply in the soil and the increased aeration facilitates oxidative changes like nitrification[1]. The aggregates also seem to control the availability of phosphorus[23]. It may be of special interest here to recall an observation on the question of phosphorus availability as evidenced by the growth of rice plants (raised by a system of "hanging gardens") in the activated sludge tank, in which "flocs" or a species of extremely water stable aggregates are continuously formed from crude, colloidal sewage and a large part of the phosphorus from the sewage is removed into the sludge flocs[24-27]. The striking difference that was observed between vegetative growth and grain formation in the rice plants under these conditions[24-25] was suggestive of the differences in the yields of grain and straw in the experiments of Hellriegel[1,2] and Widtsoe[1].

"Soil structure is the key to soil fertility!", as Baver[28] put it, and soil structure depends largely on water stable aggregates. But, as Allison[29] pointed out, "Our understanding of soil aggregate formation and stabilization is probably as unsatisfactory at the present time as that of any other phase of soil science" and he made this statement, as he added, "regardless of the existence of an extensive literature on the subject". It is in this context that the experimental results presented in this paper and in the related papers on sewage and soil from this laboratory are of interest and value.

SUMMARY

It was observed that at a certain level of moisture in the soil in relation to its water holding capacity the percentage of water stable aggregates increased. There was a maximum increase in the percentage of water stable aggregates at one-third water holding capacity, as shown by the results of analysis of over 500 samples of Bangalore red soil.

This action of moisture in increasing the water stable aggregates was evident in six hours, even in the presence of chloroform or toluene. It was facilitated by autoclaving the soil and also in the presence of organic matter (sewage). These observations seem to enable a better understanding of soil aggregation and its influence on plant growth.

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STOMATAL RESPONSES OF SOME ARID ZONE PLANT SPECIES

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ABSTRACT

Stomatal responses in intact and isolated epidermis of some arid zone plant species like *E. neriifolia, C. colocynthis* and *P. cineraria* in relation to epidermal turgor, cation exchange, growth regulators and antitranspirants have been studied. It is concluded that the case of each species and its prevalent environmental conditions must be examined specifically. Recent hypotheses of the stomatal regulation are discussed in relation to our new observations.

INTRODUCTION

WATER deficits in the field are expected to develop when transpiration exceeds water uptake by plants, and the induced deficits will, in turn, cause a compensatory closing of the stomata. The velocity of stomatal response is presumed to be dictated by the external conditions, although this is not always true. The relationship between the relative water content and water potential of leaves is more commonly termed the resistance of leaf tissue to desiccation and is taken to indicate one aspect of drought resistance of the particular species[1-3]. The species with smaller change in relative water content for each interval of water potential is considered to be more drought resistant[4].

Stomata serve two conflicting needs: first, to conserve water, and second, exchange of CO_2 and O_2 for metabolic processes to go on smoothly. In general it is accepted that in light CO_2 concentrations are reduced, which result in a rise of pH in the guard cells; the higher pH allegedly stimulates the conversion of starch to sugar so that an increase in the osmotic value of the guard cell occurs; water is accordingly taken up and the stomata open. This process is reversed in the dark. This may be right or wrong, but it is certain that for opening of the stomata there must be an uptake of water resulting in an increase in the turgidity of the guard cells. Most commonly, stomatal opening and increased osmotic value in the guard cell occurs in light. This may result due to organic solutes produced in the guard cells or from the "pumping" of ions into the guard cells.

The present work is intended to provide some specific information on the relative contribution of the guard cells and the epidermal cells by which stomatal opening is caused. Behaviour of stomatal regulation is also observed in plants growing in natural environment. The effects of different sugars, cations, growth regulators, antitranspirants and water on the stomatal regulation in isolated epidermal peelings of a few arid zone plants are presented here.

MATERIALS AND METHODS

Plant species included in the present study were: *Euphorbia neriifolia* L., *Citrullus colocynthis* (L.) Schrad. and *Prosopis cineraria* L. Epidermal peelings from the leaves of these species were immersed in different concentrations of test solutions: sugars (glucose, sucrose, mannitol), potassium chloride (KCl), calcium chloride ($CaCl_2$), growth regulators (B_9, CCC, GA, kinetin, ethrel), antitranspirants (phenylmercuric acetate—PMA), etc. The peelings were either incubated in continuous light (about 1,000 lux) or in total darkness. For control, the peelings were kept accordingly in distilled water. The incubation period for different tests varied from 3 to 24 hours.

The histochemical detection of potassium was performed by employing cobalt-sodium nitrite as described[5-7]. The presence of starch in guard cells was estimated by usual iodine test or by Heath's reagent. The width of the stomatal pore was measured by precalibrated microscope. Plasmolysis, if doubted, was observed with the help of neutral red.