

## AN ASSESSMENT OF THE SOIL-CONDITIONING CAPACITY OF GUMS EXUDED BY SOME TREES IN SIERRA LEONE: I. HYDRAULIC CONDUCTIVITY MEASUREMENTS

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Accepted April 18, 1994

**A b s t r a c t.** Gums exuded by two trees viz., *Anacardium occidentale* and *Parkia bicolor* growing widely in Sierra Leone have each been applied in various concentrations to two local soils with poor structure. Changes in the value of the saturated hydraulic conductivity ( $K$ ) of each soil sample, brought about by the application of the gums, have been used as the index for determining soil conditioning effect; the  $K$  of a carefully selected loamy soil (untreated with conditioner) is used as reference. Poly(vinyl alcohol) (PVA) was also applied in identical concentrations to the same soil samples; this permitted a comparison to be made between the effectiveness of this established synthetic soil conditioner and the plant gums. The results show that the plant gums as well as the PVA exhibited positive soil-conditioning effect by altering the  $K$  of the soils with poor structure to the value obtained for the loamy soil. It was further observed that prior treatment of the soil samples with  $\text{CaCl}_2$  enhanced soil-conditioning capacity. In almost all cases the relative effectiveness of the conditioners was in the order: gum from *P. bicolor* > gum from *A. occidentale* > PVA. The results are explained in terms of factors known to influence soil-polymer interactions.

**Key words:** Soil-conditioning capacity, tree gums, saturated hydraulic conductivity

### INTRODUCTION

A large variety of trees growing in Sierra Leone exude copious amounts of gums which have no other use except as adhesives in very limited cases. The present study is part of a

comprehensive exercise aimed at characterising these gums and establishing their possible usefulness.

Earlier work has revealed that the gum produced by *Anacardium occidentale* is composed of polysaccharides having L-arabinose, D-galactose, D-glucuronic acid and D-galacturonic acid as major monomer units<sup>1</sup> (see also [10]); the gum produced by *Parkia bicolor* (growing in Nigeria) has been reported to contain the D-forms of arabinose, galactose, glucuronic acid, and 4-o-methylglucuronic acid [1]. Given the fact that microbial polysaccharides occurring naturally in the soil are known to play a crucial role in soil structure stabilisation [12,13,17] and also given the high cost of the synthetic polymers currently in use as soil conditioners, it is considered that one possible use to which these tree gums can be put is as soil conditioners or as part of formulations for soil conditioners to be applied on local (tropical) soils.

It is now an established fact that a good and stable soil structure is a crucial factor in sustaining a high level of agricultural productivity as well as in controlling environmental pollution. It is clear that a knowledge of the

<sup>1</sup>F.S.K. Pabai, 1985. Structural studies on the polysaccharide components of gums obtained from *Anacardium occidentale* and *Spondais spp* and their reactions. M.Sc. Thesis, University of Sierra Leone.

mechanism of soil aggregate formation is an essential pre-requisite to an understanding and implementation of the process of soil conditioning (i.e., soil aggregate formation and stabilisation). The genesis of soil aggregate formation is the association of clay particles into quasi-crystals and/or domains and/or tactoids [3,9]. The term 'quasi-crystal' refers to the rather compact stacking of montmorillonite clay particles; the stacking in the (001) direction being crystal-like. The term 'domain' refers to the more loose parallel arrangement of platelets of illite-type clay minerals in such a way as to allow full penetration of  $N_2$  molecules into the interlayer spaces. 'Tactoids', on the other hand, are formed when clay particles associate randomly instead of as packets of perfectly orientated platelets. Soil clay platelets within domains, quasi-crystals and tactoids are held and kept together, largely, by (weak) Van der Waals forces which are easily disrupted by hydration/solvation forces. This therefore gives rise to the need for additional bonding/cementing agents in order to produce larger aggregates and to stabilise the resulting soil structure against disruptive forces (water, wind, mechanical, etc.). Natural as well as synthetic polymeric substances are known to fulfill this role. De Boodt [8] has given a comprehensive and up-to-date review of the use of polymeric substances as physical soil conditioners.

Of the many synthetic polymers that have been employed as soil conditioners, poly(vinyl alcohol) (PVA), is perhaps the one that has been studied most, and consequently the one whose soil-conditioning behaviour is most understood (see for instance [6,11,16]). PVA is believed [11] to interact with soil colloids largely via the formation of short-range two-dimensional surface-adsorbed networks which cover the pore walls and thereby strengthen the interparticle associations. In the case of soil oxides (goethite and gibbsite), Kavanagh *et al.* [15] aver that at high PVA concentrations only a few segments of the polymer strands are attached to the surface and that the bulk of adsorbed PVA molecules from the sur-

face as 'loops and tails' to distances greater than 10 nm - thereby giving rise to strong possibilities for considerable interparticle bonding.

Polysaccharides are among the more important natural soil-conditioning agents. These polymers are believed [6,7] to bring about interparticle bonding by means of (electrostatic) interactions between charged entities (including charge-neutralising cations) on the surface of the soil colloids and functional groups on the polymer strands; the polymer strands being held on to the surface via extensive 'loops-and-tails-type' configurations.

An important consequence of the model of soil aggregate formation described above is that when domains, tactoids, sand particles, etc. associate to form macroaggregates, and eventually soil crumbs, peds, etc., numerous pore channels ramify the resulting structure leading to the formation of a spatial network of soil particles commonly referred to as 'soil fabric'. Movement of water in the soil takes place within these pore channels. The flow of water in the soil under saturated conditions is determined by two factors viz., the hydraulic force driving the water through the soil; this force represents the sum of the gravitational and hydrostatic potential gradients, and (for vertical flow in non-saline soils), is measured by the height of the water above the water table (in the field) or above and below the soil column (in the laboratory). The flow of water is also determined by the ease with which the soil pores permit water movement - this ease is characterised by the hydraulic conductivity of the soil and is dependent on the size and configuration of the soil pores. The pore size is in turn determined by the size, shape, and arrangement of the individual soil particles (i.e., soil texture); for uniformly shaped soil particles arranged uniformly, the smaller the soil particles the smaller the soil pores, and vice versa. Thus under given conditions hydraulic conductivity can reliably reflect the state and stability of soil texture and can be used as a key index in assessing changes in the state and stability of soil structure. It should be clear

from the foregoing that when the hydrostatic force driving the water through the saturated soil is held constant, the water flux (i.e., the volume of water flowing through the soil per unit time) is directly proportional to (and is therefore a measure of) the hydraulic conductivity of that soil - this is a statement of Darcy's law.

## EXPERIMENTAL

### Description of soil samples

The samples were carefully selected in order to reflect differences in structural characteristics; the samples were all collected from the top 15 cm of the respective profiles.

**Sample A:** This meticulously selected loamy soil (with good crumb structure - the type that is easily recognised as a good agricultural soil) was collected from a piece of land belonging to Prowince J of the Soil Map Sierra Leone [20]; this piece of land had not been cultivated for at least 10 years. This sample was mechanically analysed by the wet-sieving and pipette methods [5] and found to be composed of 30 % silt, 42 % sand, and 28 % clay.

**Sample B:** This rather structureless, reddish-brown lateritic soil, was collected from an eroded excavated wasteland belonging to Prowince A of the Soil Map of Sierra Leone.

**Sample C:** This light, highly leached sandy soil was collected from a deposited run-off originating from a slash-and-burn wasteland belonging to Prowince J.

### Characterisation of soil and gum samples

The soil samples were further characterised in terms of their pH, CEC, and organic matter (OM) and free iron oxide contents. The CEC was determined by the  $^{22}\text{Na}$  isotope dilution technique in a Britton-Robinson buffer solution at pH 6.4<sup>2</sup>; the OM content was deter-

mined by the Walkley-Black Method [2]; the free iron oxide content was determined by the sodium-dithionite method [21]; the pH was determined in distilled water and in 1M KCl using a 1:2.5 ratio of soil:liquid. A summary of the results is given in Table 1.

**Table 1.** Relevant physico-chemical properties of the soil samples

Sample	pH (1M KCl)	CEC (meq/100 g)	OM content (%)	Iron oxide content (%)
A	4.4	16.5	5.1	9.4
B	5.6	3.1	2.8	2.0
C	7.6	2.7	0.8	0.3

Samples of the plant gums were collected from *A. occidentale* and *P. bicolor*. These gums were purified by separately dissolving about 50 g of each sample in 200 cm<sup>3</sup> of distilled water. The solutions were then filtered and just enough ethanol (95 %) to effect precipitation was gradually added to the filtrate. The yield in the case of *A. occidentale* was 68 % and that in the case of *P. bicolor* was 38 %. The ash content and the relative viscosity (in distilled water) had previously been determined<sup>3</sup> (Table 2). The molecular weight of the PVA sample was given<sup>4</sup> as  $1.4 \cdot 10^4$ .

**Table 2.** Some properties of the conditioners

Sample	Ash content (%)	Relative viscosity
<i>A. occidentale</i>	0.54	1.1
<i>P. bicolor</i>	0.93	19.8
PVA	0.05	0.7

### Application of conditioners to soil samples

Each soil sample was treated with various concentrations viz., 0 (i.e., distilled water), 0.1, 0.3, 0.5, 0.7, and 1.0 % (w/v) of the conditioners

<sup>2</sup>T.B.R.Yomah, 1981. The composition and properties of selected samples from a tropical soil profile. Ph.D. Thesis, University of Birmingham, U.K.

<sup>3</sup>C.A.Hingston, 1985. A preliminary investigation into the use of gums and resins from local trees as soil conditioners. B.Sc. (Hons.) Thesis, University of Sierra Leone.

<sup>4</sup>sample and value supplied by M.H.B.Hayes of University of Birmingham, U.K.

in distilled water using a device constructed locally. The  $\leq 2$  mm fraction of each soil sample was first carefully and uniformly packed in a cylindrical glass column, having a diameter of 3.2 cm and a total length of 19.5 cm; a screen support (to hold the soil column in place and to prevent the soil particles from falling through) had been fitted at one end which was then drawn into a funnel-shape and became the bottom end. This end was connected to a glass reservoir containing the solution of the conditioner (or  $\text{CaCl}_2$  solution or distilled water) by means of flexible pvc tubing. The height of the reservoir was then adjusted in order to get its liquid content to flow upwards into the soil sample via the perforated screen-support base of the glass column. The flow of the liquid was carefully (mechanically) controlled in order to just saturate the soil sample to 'field capacity' and to achieve a reproducible and slow rate of wetting. The samples were each kept saturated in this manner for 6 h, after which the solution of the conditioner (or distilled water) was allowed to drain out of the soil. The soil samples were then air-dried *in situ* (i.e., undisturbed and while still in the glass column) for 4 days. Another treatment involved saturating the soil samples (as described above) with 1 %  $\text{CaCl}_2$  solution and then followed by another bout of saturation with a particular concentration of the conditioner solution.

#### Measurement of hydraulic conductivity

The experimental procedure for the determination of the saturated hydraulic conductivity,  $K$ , of a soil is based on Darcy's equation, viz.,

$$k = Q \frac{L}{\Delta H}$$

where  $Q$  (the water flux density) is the volume of water flowing through a unit cross-sectional area of the soil per unit time;  $\Delta H$  is the hydraulic head, and  $L$  is the length of the soil column - ( $\Delta H/L$ ), the hydraulic gradient, is the driving force of the water.

The glass column containing the air-dried

sample (described above) subsequently served as the main component of the apparatus used for the determination of the hydraulic conductivity. The method of 'downward flow' in a vertical saturated column - illustrated by Hillel [14] was used. In this case the volume of water collected during 30 min of steady flow was accurately determined and the result used to determine the water flux,  $Q$ . The hydraulic head,  $\Delta H$ , was taken to be equal to the sum of the constant head of water and the length of the soil column. A running tap and a spout at the top of the glass column maintained a constant head of water of 5 cm (above the soil column) for all measurements of  $K$ . Measurements for each conditioner treatment were made in triplicate.

#### RESULTS

The measured saturated hydraulic conductivity of the loamy soil (sample A) - untreated with conditioner, and used here as standard - is  $15.5 \cdot 10^{-6} \text{ m s}^{-1}$ ; this value, which compares well with those reported for silt loams [24] will be referred to here as the 'loam- $K$ ' value. The value of  $K$  obtained for the untreated samples B and C are 7.1 and  $20.4 \cdot 10^{-6} \text{ m s}^{-1}$ , respectively.

The process of conditioning any soil must be done with reference to a standard, bearing in mind the use to which the conditioned soil is to be put. In this regard we realise that conditioning a soil for agricultural and pollution-control purposes may not satisfy the requirements for civil engineering purposes or for water-harvesting purposes. Thus, we have assumed in this study that, for agricultural and, to a large extent, for pollution-control purposes, a cardinal characteristic of a soil with a good and stable structure is a  $K$  value equal to or in the close neighbourhood of the loam- $K$  value. A soil with a poor structure will, on the other hand, have a  $K$  value significantly different from the loam- $K$ .

Thus the ability of a soil amendment to prevent collapse of soil structure in water and thereby to resist changes in  $K$  away from the loam- $K$  value will be taken here as the

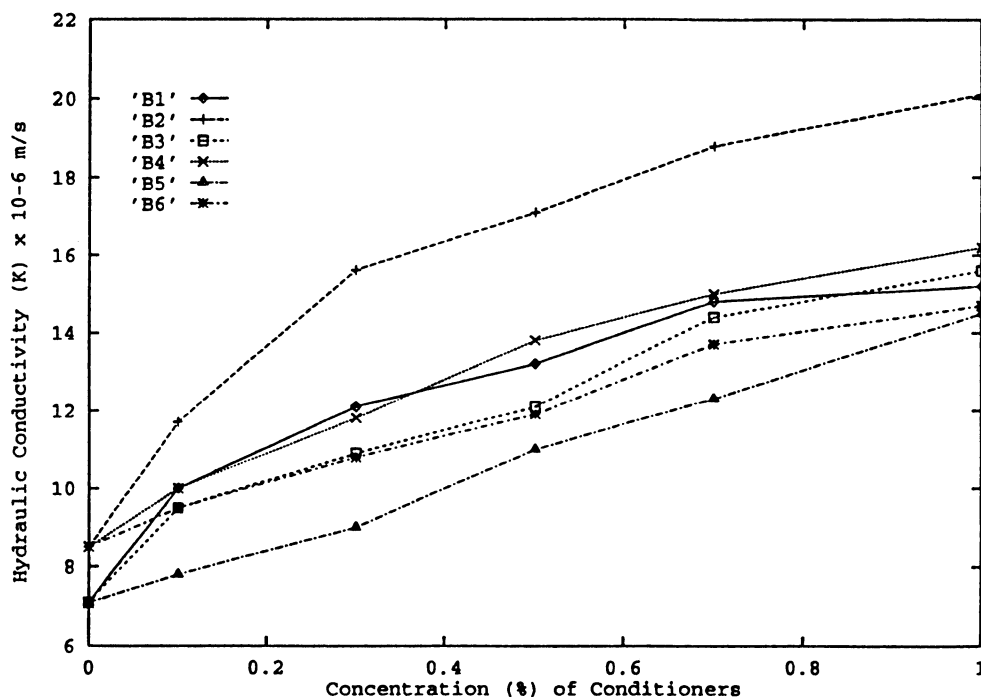


Fig. 1. Plots of hydraulic conductivity vs concentration of conditioners for sample B. B1 - *P. bicolor* without  $\text{CaCl}_2$ ; B2 - *P. bicolor* with  $\text{CaCl}_2$ ; B3 - *A. occid.* without  $\text{CaCl}_2$ ; B4 - *A. occid.* with  $\text{CaCl}_2$ ; B5 - PVA without  $\text{CaCl}_2$ ; B6 - PVA with  $\text{CaCl}_2$ .

yard-stick/criterion for soil structure stabilisation and therefore for a good soil-conditioning capacity.

By this token, the results (Figs 1 and 2) show that in the absence of the conditioners, both samples B and C undergo structural collapse in water as revealed by their  $K$  values which are significantly different from the loam- $K$  value. On application of the gum and PVA solutions, the  $K$  values of these soil samples are observed to change towards, reach, and in some cases surpass, the loam- $K$  value. It is thus concluded that the applied gums and PVA conferred structural stability to these soils.

In the case of sample B,  $K$  increases, and for sample C,  $K$  decreases, with increase in concentration of the applied conditioners. The concentration of the conditioners at which the loam- $K$  value is attained for each soil sample is given in Table 3.

The results further show that, except in the case of PVA on sample B, prior treatment of the soil samples with 1%  $\text{CaCl}_2$  solution produces a more dramatic change in  $K$  towards the loam- $K$  value; this treatment also caused a reduction in the amount/concentration of conditioner required to attain the loam- $K$  value. It is thus concluded that the  $\text{CaCl}_2$  enhanced the soil-conditioning capacity of the gums and PVA applied as conditioners. It is further observed that  $\text{CaCl}_2$  produced some-conditioning effect when applied on its own (i.e., in the absence of conditioner) - as is seen in the difference in  $K$  between the distilled-water-treated and the  $\text{CaCl}_2$ -treated soils. More explicitly the results plotted in Fig. 1 show that, in the absence of the tree gums, the  $K$  value for samples B after prior treatment with distilled water is  $7.1 \cdot 10^{-6} \text{ m s}^{-1}$ ; the value for the same soil sample after treatment with 1%  $\text{CaCl}_2$  solution is  $8.5 \cdot 10^{-6} \text{ m s}^{-1}$ . Thus this  $\text{CaCl}_2$ -treatment

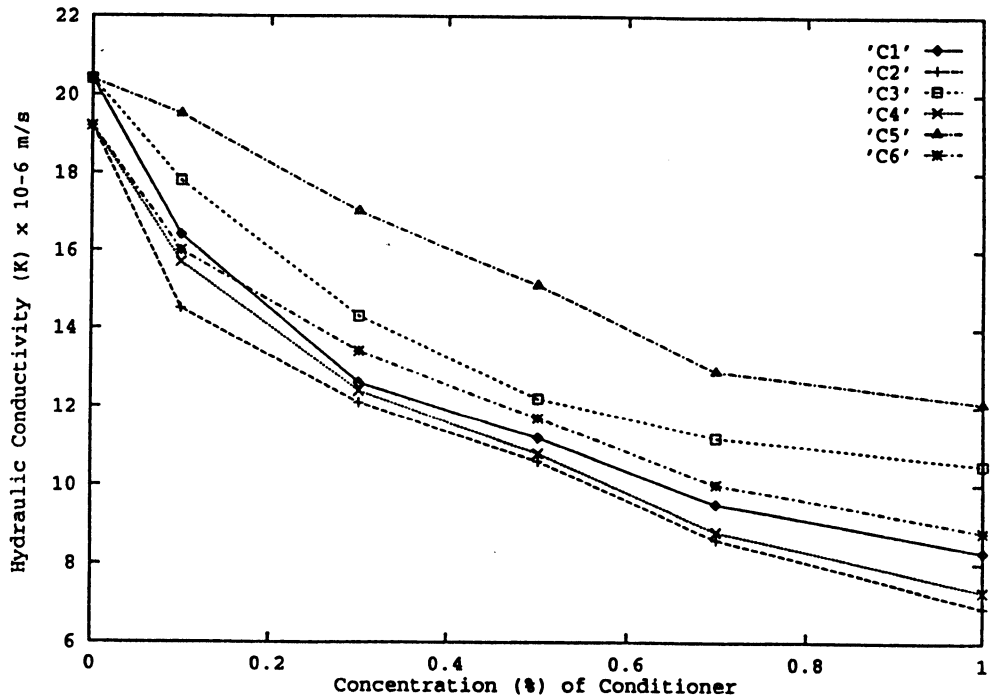


Fig. 2. Plots of hydraulic conductivity vs concentration of conditioners for sample C. C1 - *P. bicolor* without  $\text{CaCl}_2$ ; C2 - *P. bicolor* with  $\text{CaCl}_2$ ; C3 - *A. occid.* without  $\text{CaCl}_2$ ; C4 - *A. occid.* with  $\text{CaCl}_2$ ; C5 - PVA without  $\text{CaCl}_2$ ; C6 PVA with  $\text{CaCl}_2$ .

resulted in a 19.7 % change in the value of  $K$  towards the loam- $K$  value. Again the results plotted in Fig. 2 show that, in the absence of the tree gums, the distilled water-treated sample C has a  $K$  value of  $20.4 \cdot 10^{-6} \text{ m s}^{-1}$ ; the  $K$  for the  $\text{CaCl}_2$ -treated sample of the same soil is  $19.2 \cdot 10^{-6} \text{ m s}^{-1}$ . This amounts to a 6.2 % change in the value of  $K$  (towards the loam  $K$ ) caused by the  $\text{CaCl}_2$ -treatment.

Analysis of the data by linear regression showed that the variation of  $K$  vs  $c$  (i.e., concentration of the conditioners) for the application of PVA to soil sample B (with and without prior treatment with  $\text{CaCl}_2$ ) is a first degree linear relationship. The rest of the data clearly show a quadratic relationship between  $K$  and  $c$ ; with the value of  $K$  approaching a maximum (in the case of sample B) and a minimum (in the case of sample C) as  $c$  increases to the maximum value of 1 %. This points to an optimal concentration for the application of the conditioners beyond which ap-

plication is not economical. The optimal application concentration (corresponding to the onset of the curvilinear sections, i.e. minimum slope of the curves) for each conditioner/soil-sample combination is given in Table 3.

For a particular soil sample, logic dictates that an inverse relationship should exist between the amount/concentration of conditioner required to attain loam- $K$  value and the overall effectiveness of that conditioner as a soil structure stabilising agent; surely the smaller the amount of conditioner required to attain the loam- $K$  value, the more effective that conditioner. In this regard it is concluded from Table 3 that the effectiveness of the conditioners after prior treatment of the samples with  $\text{CaCl}_2$  is in the order: gum from *P. bicolor* > gum from *A. occidentale* > PVA for both soils. The same relative performance was observed on sample C without prior treatment with  $\text{CaCl}_2$ . In the case of sample B, the level of effectiveness (in terms of attainment of the

Table 3. Relative performance data for conditioners on samples B and C

Conditioner treatment	Performance indices		
	Loam- <i>K</i> value ( $10^{-6} \text{ m s}^{-1}$ )	$\Delta K/\Delta c \cdot 10^{-6}$	Optimal application concentration (%)
Sample B			
<i>P. bicolor</i> without CaCl <sub>2</sub>	1.0	22.8	0.3
<i>P. bicolor</i> with CaCl <sub>2</sub>	0.3	27.8	0.3
<i>A. occid.</i> without CaCl <sub>2</sub>	1.0	10.4	0.5
<i>A. occid.</i> with CaCl <sub>2</sub>	0.8	12.2	0.5
PVA without CaCl <sub>2</sub>	1.0	7.2	-
PVA with CaCl <sub>2</sub>	1.0	8.4	-
Sample C			
<i>P. bicolor</i> without CaCl <sub>2</sub>	0.15	-31.6	0.3
<i>P. bicolor</i> with CaCl <sub>2</sub>	0.08	-35.5	0.3
<i>A. occid.</i> without CaCl <sub>2</sub>	0.25	-23.1	0.3
<i>A. occid.</i> with CaCl <sub>2</sub>	0.10	-28.8	0.3
PVA without CaCl <sub>2</sub>	0.45	-8.8	0.3
PVA with CaCl <sub>2</sub>	0.15	-23.5	0.3

loam-*K*) observed when the conditioners were applied without prior treatment with CaCl<sub>2</sub> is the same for the three conditioners.

When the performance of the conditioners is measured in terms of the average change in *K* produced per unit concentration, i.e.,  $\Delta K/\Delta c$  (this corresponds to the average slope over the linear sections of the curves), the relative performance of the conditioners on both soil samples with and without prior treatment with CaCl<sub>2</sub> is again in the order: gum from *P. bicolor* > gum from *A. occidentale* > PVA.

## DISCUSSION

### Sample B

The structural stability manifested by the increase in *K* on the application of the soil conditioners to sample B would have entailed the establishment of interparticle bonds strong enough to withstand the water disruptive forces (due to hydration and double-layer repulsive forces) which normally cause slaking and dispersion in water. This would consequently have involved the 'aggregation' of the soil particles - the resulting increase in inter-

particle pores would have led to an increase in water flux and therefore in the observed increase in *K*. The samples used in this study were taken from soils which have been reported<sup>5</sup> (see also Sutton *et al.* [28]) to be dominated by kaolinite clay minerals which have relatively greater edge-thickness (than expanding-layer clay minerals) and usually composed of a mixture of platy and equidimensional particles [4]. While the platy particles are prone to associate into domains, the equidimensional particles are more likely to associate randomly and form tactoids. It should be reasonable to assume, therefore, that the clay minerals in the soil samples used in this study existed both as domains and as tactoids. It has been suggested that the formation of domains takes several weeks and even months [8]. In this study the maximum time between application of the conditioner and the measurement of *K* was only 5 days. It is therefore unlikely that domains would have formed during this period. Although tactoid formation during this period is probable, it is more reasonable to assume that the role of the conditioners in creating macroaggregates in this soil

<sup>5</sup>T.B.R. Yormah, 1981. The composition and properties of selected samples from a tropical soil profile. Ph.D. Thesis, University of Birmingham, U.K.

was simply to act as bonding/binding agents between domains and/or between tactoids that were already present in the soil prior to the application of the conditioners.

### Sample C

Soil-conditioning in sample C was manifested by a decrease in *K*; the relatively higher *K*-value for the untreated sample being indicative of the preponderance of wider interaggregate pores in this sample. This means that the pore channels were made narrower as a result of the treatment with the conditioners. Similar findings have been reported by De Boodt [8] from his work with sandy desert soils. He observed that the application of hydrophillic polymeric soil conditioners to sandy soils leads to aggregation and to a diminishing of pore size whereby the larger transmission pores are replaced by the smaller storage pores (with e.c.d. in the range 500 nm - 50  $\mu$ m). He attributes this effect to the ability of the conditioners to modify the surface tension of water - presumably so that on wetting and on drying the sand particles are not pulled together too strongly to the point of structural collapse (i.e., prevents slumping) but yet close enough to permit aggregation and granulation. It is also possible in this soil with weak structure (0.8 % OM and 0.3 % iron oxide) that some amount of pore sealing (whereby finer particles fell off from larger crumbs and then partially clogged some pores) took place during treatment and the resulting structure was subsequently stabilised by the action of the conditioners; this could also be another cause of the decrease in *K* which followed the treatment of this soil with the conditioners.

### Soil-polymer interactions

The interactions between polysaccharides and soil particles leading to soil structure stabilisation has been variously discussed in the literature; the emphasis being put on the structural properties (especially the conformations and the nature of the functional groups) of the polysaccharides, the pH of the medium, the electrical charge status of soil surface, and the

nature of the resident cations, as crucial factors in determining the mechanism involved. Because of the double layer effect the pH measured in 1M KCl is more representative of the environment at (or close to) the soil particle surface than that measured in distilled water. For sample B this pH was 5.6. At this pH the carboxyl and hydroxyl - the major functional groups of the polysaccharide monomer units which constitute the gums used in this study - are undissociated and therefore unlikely to be repelled by the net negative charge (CEC=3.1 and 2.7 meq/100 g for samples B and C, respectively) at the soil surface [7]. Under this circumstance the polysaccharides will interact with the soil surface mainly by H-bonding between the carboxyl groups and the water molecules coordinated to the resident cations [26] but also by coordination between the resident cations and the carboxyl groups of the polymer molecules [22], and possibly by H-bonding between the carboxyls and the clay surface. The current popular view is that this interaction takes the form whereby only a few segments of the polymer strands are anchored to the surface and the major portion of each strand extends and dangles in the bulk of the solution in the form of loops and tails. In the case of PVA, the short-range two-dimensional surface net-work via which it is believed to bind soil particles together at low surface-coverage/solution-concentration [6,19, etc.] could involve only a few adjacent particles per polymer strand. Such binding would be less effective (than that involving polysaccharides) in aggregating and stabilising soil particles and this would explain the observed inferiority of PVA to the plant gums as a soil conditioner. At high surface-coverages PVA is, on the other hand, reported (authors quoted above) to be sorbed on the surface in the form of 'loops-and-tails' (like in the case of polysaccharides) - such configuration would clearly make for greater interparticle contacts and would lead to an enhanced soil-conditioning effect. Against this background the present authors note the observation from their study that, unlike the situation which obtained at lower concentrations,



at the maximum application concentration of 1 %, the measured  $K$  for PVA application to sample B (viz.,  $14.8 \cdot 10^{-6}$ ) is not significantly ( $P \leq 0.01$ ) different from the values ( $15.6$  and  $15.2 \cdot 10^{-6}$  for *A. occidentale* and *P. bicolor*, respectively) obtained for the tree gums at the same concentration. This strongly buttresses the above suggestion that at high concentrations, the same sorption mechanism operates for PVA as well as for the tree gums.

In the case of sample C, substantial ionisation of the carboxyl groups on the polysaccharide strands would be expected to take place at the measured pH of 7.6 (in 1M KCl) [7]. Thus interaction between the carboxylate groups and the negatively charged soil surface will be focussed on the charge-neutralising cations resident at the surface.

Soil oxides, especially iron oxides which were present in substantial quantity in sample B, would have interacted with the conditioning polymers in a manner exemplified by that observed between PVA and gibbsite - in the form of loops and tails projecting from the surface [16].

#### Role of the charge-neutralising $\text{Ca}^{2+}$ ions

The observation that the conditioners (except for PVA on sample B) were more effective after the soil surfaces were exchanged with charge-neutralising  $\text{Ca}^{2+}$  ions prior to the application of the conditioners, emphasizes the role of the resident cations in the binding of the polymers to the soil colloids. Under this condition, the weaker H-bonding via which some conditioner molecules held the soil particles together (in the absence of the  $\text{CaCl}_2$ -treatment) would be replaced by the relatively stronger bonds involving cation-bridging. One possibility which has been suggested by Mortensen [18] is that the polyvalent resident cations, by their ability to suppress the double-layer around the soil colloids, will allow the conditioner molecules to approach the surface much closer. This greater proximity, he argues, will increase the chances for soil-surface/conditioner interactions.

The clear trend in effectiveness (indicat-

ing the gum from *P. bicolor* to be the most effective soil conditioner, followed by the gum from *A. occidentale*, and PVA being the least effective) which emerged after the soil surfaces had been uniformly exchanged with  $\text{Ca}^{2+}$  ions could (also) be a result of differences in the molecular weights of the conditioners. Actual molecular weights of the tree gums were not determined (due to practical difficulties). However, an indication of the relative molecular weights can be obtained from values of the relative viscosities reported in Table 2; there is a direct relation between relative viscosity and molecular weight. By this token, the molecular weight of the gum from *P. bicolor* would be higher than that of the gum from *A. occidentale*, which in turn would have a higher molecular weight than PVA - the molecular weight of the gum exuded by *P. bicolor* growing in Nigeria has been reported as  $3 \cdot 10^6$  [1]; that for PVA was given as  $1.4 \cdot 10^4$ . Results obtained here are therefore in agreement with conclusions arrived at by Williams *et al.* [27] and by Carr and Greenland (cited by [6]), viz., that although polymer penetration into the inter-aggregate pores is greatest for the lowest molecular weight material, the lesser amounts of the highest molecular weight fraction that is sorbed confers the greatest aggregate stability. Schamp *et al.* [23] reported similar findings from their work with poly (acrylamide).

The performance of PVA on sample B with and without  $\text{CaCl}_2$  pre-treatment was the same as judged by the index based on the concentration of conditioner required to attain the loam- $K$  value; by the same token, the performance of all the conditioners on sample B in the absence of  $\text{CaCl}_2$  is the same. These observations would be difficult, if at all possible, to rationalise due to lack of a knowledge of the nature of the native resident cations on the surface of the soil colloids during application of the conditioners.

In addition to the above rationale, it is also probable that reaction between the resident  $\text{Ca}^{2+}$  ions and the carboxylate (and similar functional) groups on the polysaccharide strands can lead to the production and deposition of

water-insoluble salts/complexes in the pores between the soil particles. As the soil dries out, these precipitates will also act to cement the particles together and thereby subsequently render the resulting aggregates resistant to water disruptive forces. From results of the ash content (Table 2) of the conditioners, this type of reaction will be more pronounced in the case of the gum from *P. bicolor* (which has the highest ash content) than for the gum from *A. occidentale*. Ash content in plant gums arises from the presence of inorganic ions (mainly  $\text{Fe}^{3+}$ ,  $\text{Al}^{3+}$ ,  $\text{Ca}^{2+}$ , and  $\text{Mg}^{2+}$ ) which function as bridging/cross-linking agents between polysaccharide strands; these inorganic ions interact via carboxylic, phenolic, etc. groups present on the polymer chains. The ash content in plant gums is therefore indicative of functionality (and to large extent, of the degree of cross-linking) present in the constituent polymers. Such precipitation reactions are unlikely between  $\text{Ca}^{2+}$  ions and PVA (which contains only hydroxyl functional groups); this could also explain the greater soil-conditioning effectiveness of the tree gums relative to the PVA.

It was not thought appropriate to attempt to compute the relative response/susceptibility of the two soils to treatment with a given conditioner since the mechanism of conditioning which operated in one soil was quite different from what obtained in the other.

#### CONCLUSIONS

All the three polymers used were observed to have a positive soil-conditioning effect on the soil samples; the conditioners were (in almost all cases) also found to be more effective after the soil samples had been treated with 1 %  $\text{CaCl}_2$ . The conditioning strength (after prior treatment of the soils with  $\text{CaCl}_2$ ) was in the order: gum from *P. bicolor* > gum from *A. occidentale* > PVA. The action of the conditioners on sample B would have involved the aggregation of the soil particles and the subsequent stabilisation of the resulting structure, and was manifested by an increase in  $K$  with increase in conditioner concentration. The ac-

tion of the conditioners on sample C could have involved a modification of the surface tension of water and therefore of the soil-particle/water/soil-particle associations during drying - this would have led to a modification of pore-size distribution and to stabilisation of soil structure against slaking and slumping in water. The overall effect was manifested by a decrease in the  $K$  of the sandy soil.

The observed trend in effectiveness of the conditioners has been interpreted here as a result of differences in the molecular weights and functionality of the conditioners as inferred, respectively, from results of relative viscosity and ash content measurements.

The observed enhanced effectiveness of the conditioners in the presence of the charge-neutralising  $\text{Ca}^{2+}$  ions has been attributed to two reasons. First, is the established effect of the polyvalent  $\text{Ca}^{2+}$  ions in suppressing the double-layer around the soil colloids, making possible greater proximity between the conditioner molecules and the soil-colloid surface and thereby increasing the chances for conditioner/soil-surface interactions. Second, is the possibility of chemical reactions between the  $\text{Ca}^{2+}$  ions resident at the soil-surface and carboxylate (and similar) groups on the polysaccharide strands of the plant gums; this would lead to the production of water-insoluble precipitates within the inter-aggregate pores, thereby helping to cement and hold the aggregates together and thus make them water-stable.

#### ACKNOWLEDGEMENTS

P.O. Egbenda would like to acknowledge, with gratitude, the award of a two-year scholarship by the European Economic Community, through the National Authorising Office in Freetown, Sierra Leone, which made possible the experimental work and the completion of his M.Sc. programme at the University of Sierra Leone. T.B.R. Yormah is grateful for the award of an Associateship by the International Centre for Theoretical Physics (funded by the Swedish Agency for Research and Cooperation with Developing Countries -

