Conditioner applications reduce soil cohesion, an improvement best observed as reduction in crusting and improved plant stands. This erosion plot at Ohio State shows vegetation firmly established in HPAN-treated soil (left) after two months, and erosion in untreated soil. Barrier of straw mulch separates two plots

CHEMICALS FOR SOIL

Soil conditioner chemicals greatly improve soil physical properties but their use has not been adopted as a general soil management practice

FROM THE PHYSICAL point of view the ideal soil is one that does not crust readily, can be worked easily, allows relatively rapid infiltration of rain and irrigation waters, drains quickly, and permits optimum plant root respiration and microbial activity. Some soils approach the ideal by virtue of the size distribution and shape of the individual particles which make up the soil mass. Most soils which exhibit excellent physical properties, however, do so largely because the finer soil particles are bound together into small aggregates or granules which are stable in water.

Soil aggregate formation generally involves two processes, namely, the breaking down of soil masses or lumps into favorably sized granules, and the stabilization of these granules. Breaking up of the soil mass may result from the action of insects and earthworms, tillage operations, pressures

CONDITIONING

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and differential drying caused by freezing, compression due to plant root growth, and localized shrinkage caused by removal of water by roots or by evaporation. The granules are bound into stable units by iron and aluminum oxides in some soils, but in the best agricultural soils the binding materials are primarily organic in nature. They stabilize aggregates by linking soil particles together by mutual adsorption on two or more particles and by weakening the otherwise strong cohesive bonds between clay particles, thus favoring aggregates instead of a solid mass structure.

The favorable influence of organic residues on soil tilth or aggregation has been known since the beginning of agriculture. The turning under of green manure crops, manure applications, and grass or meadow crops in a rotation are accepted practices for maintaining or improving soil tilth. Numerous investigators have demonstrated the beneficial effects of organic materials on soil aggregation. Although some complex organic materials may contain water soluble soil binding substances, the increased aggregation has been shown to be largely dependent on the decomposition of the organic residues by soil organisms. During the decomposition processes, compounds synthesized by the soil microbes and products of decomposition are formed which bind the soil particles together and tend to stabilize aggregates.

Studies designed to determine the nature of the binding substances synthesized by soil microbes have indicated that polysaccharides are probably the most active materials.

Nature of Chemicals Used for Soil Conditioners

The discovery that soil microorganisms synthesized substances which improved soil aggregation stimulated the search for compounds which would act in a similar manner to the microbial products. The alginates which are similar to some bacterial polyuronides were tried for this purpose, but proved unsatisfactory. They were not highly effective binding substances so it was necessary to add large amounts to the soil, namely, several tons per acre. The material also proved to be an excellent food source for soil organisms and was quickly destroyed in the soil. The organisms decomposing the alginates utilized ni-

Worm's eye view of grass seed in conditioner-treated soil. Seed adheres to soil surface. Exact mechanism whereby soil particles are bound into aggregates needs further clarifying, but cation and anion adsorption and hydrogen bonding at active sites on clay particles are probably involved

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trogen and other plant nutrient elements from the soil and thereby temporarily reduced some of these nutrients to deficiency levels. These observations made it clear that, in order to be successful, a conditioner material would have to be more active than the alginates and should be resistant or relatively resistant to microbial decomposition in the soil.

Other compounds which have been tried with little or no success include the silicates of potassium and sodium, stearic and abietic acid, and volatile and water-soluble silicones. All have increased aggregation but are not being used because high rates of application are needed, soils are made highly alkaline, granules are rendered waterproof, or microbial activity is retarded.

Some cellulose derivatives have been tested with fair success. These include cellulose acetate, cellulose methyl ether, methyl cellulose, carboxymethyl hydroxyethyl cellulose, and variously substituted carboxymethyl celluloses. These compounds act very much like the microbial polysaccharides and effect an immediate improvement of soil aggregation. They are, however, subject to microbial decomposition so that their effectiveness is of short duration.

The most successful synthetic soil conditioner chemicals were introduced in 1951. They are water-soluble, high molecular weight, polymeric electrolytes which resist decomposition. Numerous polymers of this type with soil aggregate stabilizing properties have been described in Monsanto Chemical Co. patents. The three most commonly used for soil improvement are: (1) hydrolyzed polyacrylonitrile (HPAN) supplied largely as sodium polyacrylate; (2) a mixture of calcium hydroxide and a copolymer of vinyl acetate and the partial methyl ester of maleic acid (VAMA); and (3) a copolymer of isobutylene and the half ammonium salt-half amide of maleic acid (IBMA) (see next page). These chemicals are markedly resistant to decomposition in the soil.

In addition to the above, various products are sold on the market as soil conditioners which appear to have little or no influence on soil aggregate stabilization, either at recommended application rates or at any other dosage. Examination of some of these products indicates that they consist of various plant or compost extracts, compost preparations, diatomaceous earth, lignite, poor quality peats, acidified beach sand, and others.

Influence on Physical Properties of Soils

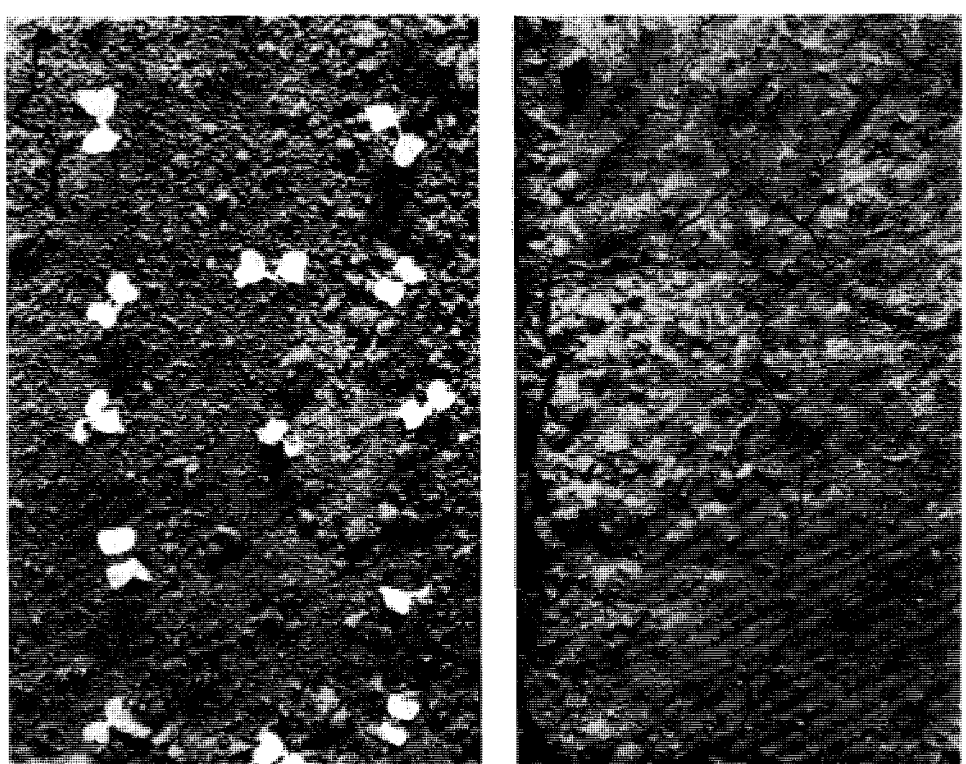
In order to stabilize soil aggregates effectively the conditioners must be applied in adequate amounts, and must be placed in contact with the soil particles on which they are to be adsorbed. Application rates generally vary from 0.02 to 0.2% on a soil weight basis. This would be equivalent to 400 to 4000 pounds per acre 6 inches in depth. Fine textured soils require the larger amounts. The soil should contain enough moisture for good workability. If too wet, the polymers will form a gum before they can be mixed with the soil. Immediately after spreading, the material should be thoroughly mixed with the soil, and, after subsequent irrigation or rainfall, remixing will generally prove helpful. Still better results are obtained if the soil is worked before the initial application of the conditioner.

When applied in this manner, the polymer conditioners give very markedly increased soil aggregate stability. Probably as a consequence of improved granulation, other important soil physical properties are improved. In laboratory studies, application rates of 0.05 to 0.15% have greatly increased permeability. Under field conditions, increased permeability has contributed toward greater water intake and decreased runoff and erosion. The percentage of larger pore spaces is increased by conditioner treatment. This undoubtedly contributes to faster internal drainage and higher plant survival.

Conditioner applications reduce soil cohesion, an improvement best observed as reduction in crusting, and improved plant stands. In addition the moisture level at which soil begins to exhibit plasticity is increased.

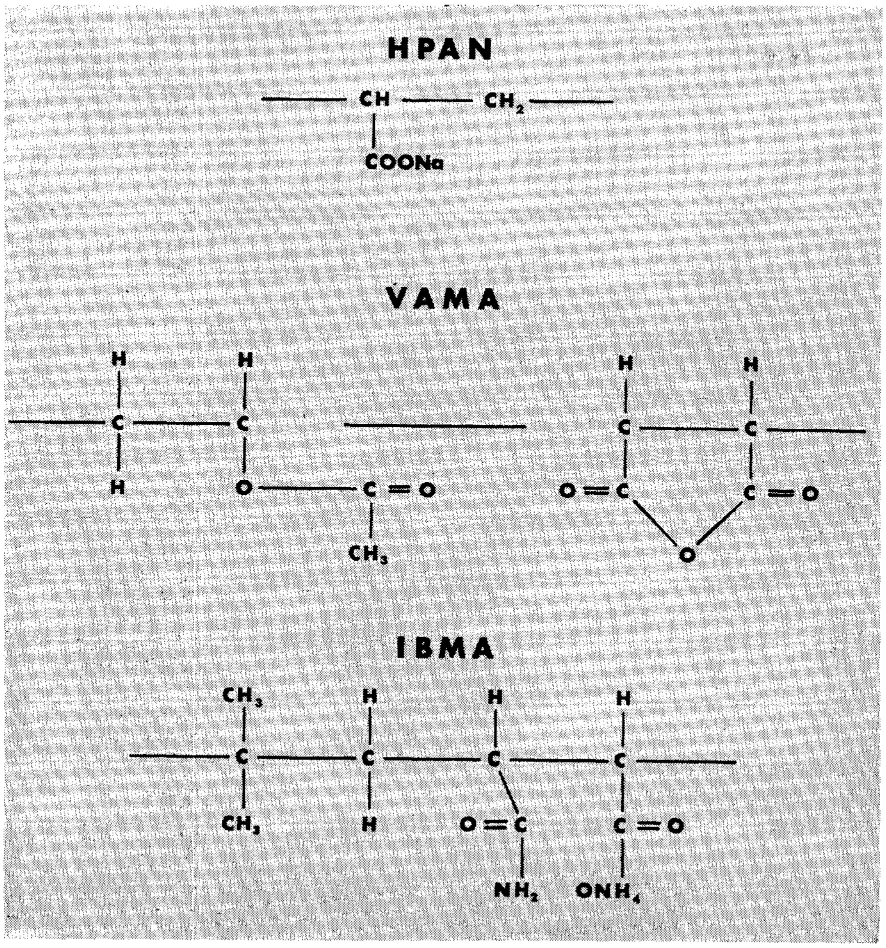
The soil conditioners may be used to stabilize a seedbed condition or prevent crusting until the seeds have germinated and sprouted through the

Radishes planted in soil treated with HPAN (left) and untreated soil (right). Better germination resulted in treated soil, which was watered in same manner as untreated soil, which shrank and dried to a hard crust from watering



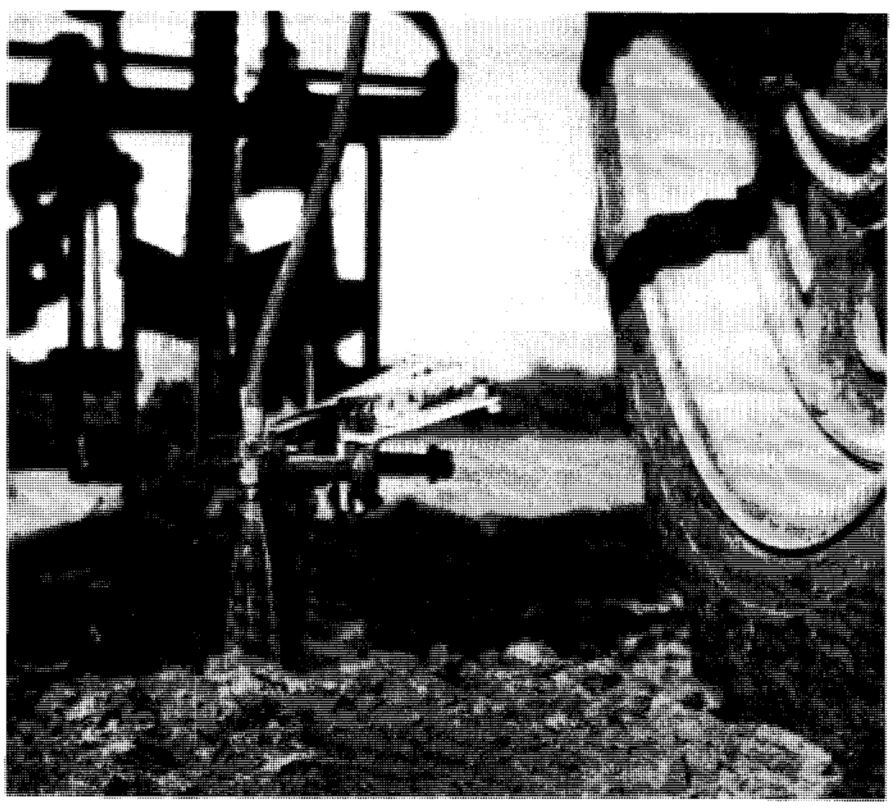
soil surface. IBMA, HPAN, and carboxymethyl cellulose in solution at 0.2 to 0.4%, sprayed or sprinkled in a band over the row, have proved successful in this respect. Only 2 to 5 pounds of conditioner per acre is needed for the treatment.

The exact mechanism whereby the organic soil conditioners bind the soil particles into aggregates needs further clarification, but it appears that cation and anion adsorption and hydrogen bonding at active sites on clay particles may be involved. The long chain conditioner molecules are adsorbed on two or more soil particles and through cross linkages bind clumps of soil together. Long chain polymers are more effective and produce larger soil aggregates than relatively short chain polymers.



Probable structures of some effective soil conditioner chemicals

Application of soil conditioner to stabilize a seed bed condition. It is sprayed (at 0.2 to 0.4% concentration) in a band directly over strip where seed has been planted. This application equipment can be attached to the planter



Effect of Soil Chemical Properties on Conditioners

Sodium and, to a smaller extent potassium, tend to disperse soil particles and, when present in relatively high concentrations in the soil, cause marked deterioration of soil physical properties. Polysaccharides containing carboxylic acid units, including the carboxymethyl cellulose type conditioners, and certain natural soil binding substances in soil humus, are also dispersed by sodium and potassium, and for this reason these materials are relatively ineffective aggregate stabilizers in highly alkaline soils. The effectiveness of IBMA is also reduced by high soil sodium and potassium percentages. The action of VAMA and HPAN type polymers, however, is apparently little influenced by these cations, although the size of the aggregate may be affected. Treatment of alkali or saline-alkali soils with these polymers should aid in their reclamation for agricultural use.

Carboxymethyl cellulose conditioners are more effective aggregate stabilizers in acid soils than in neutral or alkaline soils, while IBMA may be less effective in highly acid soils. The aggregating effect of the polymer conditioners is not appreciably influenced by fertilizer constituents.

Effect on Plant Growth

Use of the synthetic soil conditioners on some soils has effected marked improvement in plant growth and yield but in other soils yields have not increased, although marked improvement in soil aggregate stability has been brought about. Rather extensive field trials have been carried out at the Ohio Agricultural Experiment Station. Aggregate stability was increased in all trials, but plant yield increases occurred in only about half of the tests. The most striking yield increases occurred on soils which were recognized problem soils from the physical point of view.

One of these soils is Paulding clay which has 65 to 75% clay in the top two feet and which is very poorly drained. Tomato stands were one-third greater and yields were doubled by conditioner treatments. The apparent cause of the higher stand and yield was faster internal drainage during a period of high spring rainfall which followed plant emergence. Stand differences were largely due to plant losses immediately following these rains. In the same experiment, sweet corn and table beets were established in August and made considerably greater growth on conditioner-treated plots. Since the latter crops were growing during a period of low soil moisture, it was apparent that the conditioners influenced growth through factors other than improved drainage.

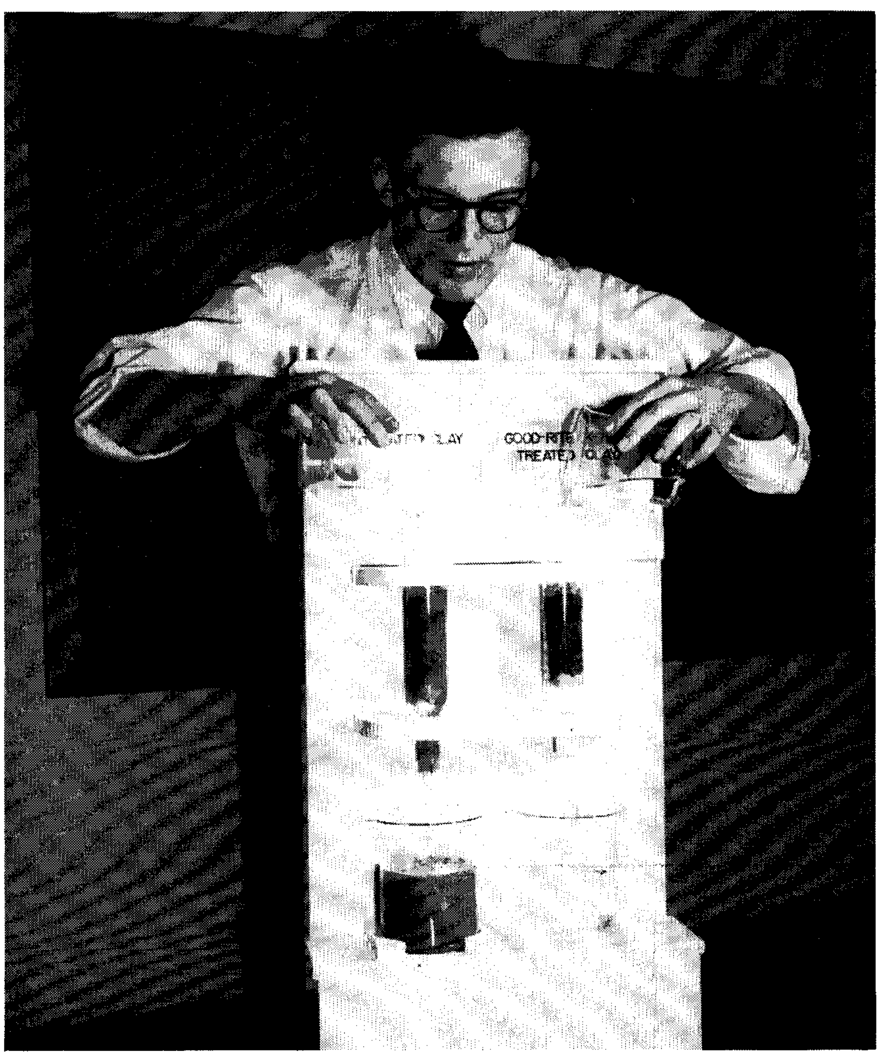
Several of the Ohio field studies have shown that yield increases from conditioner treatment are related to soil moisture availability. Corn yields were increased by 27 bushels on sloping Muskingum silt loam which had 1.12 inches less runoff during the growing season than untreated soil. Soil moisture contents were higher in conditioner-treated plots and were most probably related to greater infiltration rates.

Corn yields have also been 8 to 15 bushels greater on conditioner-treated Hoytville silty clay during drouthy years but not during years of more adequate precipitation. Since the Hoytville soil has almost level topography, greater infiltration rates on treated plots are apparently not the major reason for yield increases. There were no differences in soil moisture contents during July and August sampling dates; however, larger root systems were evident, and wilting symptoms were less evident on conditioner-treated soil.

For improving plant emergence, the Ohio tests have shown that stabilizing the top half-inch of soil is equally as effective as incorporating the conditioner to a depth of 4 to 6 inches.

Effect of VAMA on growth of sweet orange seedlings in Yolo loam soil containing various sodium concentrations. Treatments were: two pots on left, 9% exchangeable sodium; center two pots, 14% exchangeable sodium; and the two on right, 26% exchangeable sodium. The second, fourth, and sixth pots (from left) each got 0.15% VAMA

Treatment of soil with conditioners greatly increases permeability, which, under field conditions, contributes to greater water intake and decreased run-off and erosion. Untreated soil (left) allows very slow water penetration



In greenhouse studies, growth of avocado seedlings was doubled by VAMA treatment of a poorly aggregated soil, but was not affected by treatment of a relatively well aggregated soil.

In summarizing the studies by various investigators concerning the soil conditioners and plant growth, it appears that the root systems of crops are more extensive following conditioner application. Yield increases are more likely to occur with vegetable and root crops than with agronomic crops such as wheat, barley, and grasses. Rather consistent yield increases occur with sweet corn. With field corn, barley, and other crops, early growth is often stimulated but at harvest time increases in crop yield may not be realized. Tests with tomatoes and potatoes have been erratic.

It should be pointed out that the conditioners are not fertilizers, but that they serve only to improve soil physical conditions. Their effect on plant growth cannot be compared with that of manure or other organic

▼ Soil conditioners are poured into a tank mounted on a tractor. Properly mixed, they do not clog spray nozzles or corrode herbicide or insecticide spray equipment

materials unless equivalent fertilizer applications are made with the conditioners.

Sodium disperses the soil. In relatively high sodium soils, plant growth may be reduced by the sodium ion, by poor soil physical conditions, or both. The use of VAMA or HPAN which improve soil aggregation in the presence of sodium offers a tool to differentiate the two effects. Studies of this nature indicate that below a certain critical sodium level, plant growth is usually improved by treatment of the soil with conditioner.

Use of Conditioners in Present Day Agriculture

The synthetic soil conditioners, primarily HPAN, VAMA, and IBMA, greatly increase aggregate stability of the soil, thereby improving physical properties and, in some soils, increasing plant stands and yields. In spite of these beneficial effects, widespread use is not being made of the conditioners in present day agriculture. One may wonder why. Probably the main factor is the cost of the material and cost of application. To treat adequately an acre of an average soil to a depth of 6 or 8 inches would require approximately 2000 pounds of active material. At 50 cents a pound, this would mean an investment of $1000 per acre, which for most agricultural enterprises would be prohibitive. In addition, the cost of application may be high.

Another probable factor is that the physical condition of many, if not most, of our agricultural soils has not deteriorated sufficiently to decrease yields of most crops appreciably.

In spite of the apparent obstacles to the widespread use of soil conditioners, there is a place for them in certain phases of our agricultural economy. They are being used, and could be used to greater advantage, by nurseries for plant seedling production and for potting mixtures; for turf establishment on golf courses and athletic fields; for home gardens and flower beds; and, for highly specialized agricultural pursuits near large population centers. In arid sections of the world they might be used to advantage in the reclamation of alkali spots or soils. In agricultural research they represent a valuable tool for use in differentiating physical and nutritional, and structural and microbiological relationships with respect to plant growth. If in the future the price is drastically reduced or if cheaper compounds are found, their use will spread to vegetable and other crop production enterprises on soils which tend to have poor physical properties.