are very good, and their drilling characteristics are considered excellent.

Acknowledgment

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SOIL CONDITIONERS

Dextran and Dextran Products as Soil-Conditioning Materials

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The recent prominence given to dextran and its use as a plasma extender for humans, as well as the development of techniques for making dextran products, has suggested other commercial possibilities. The presence of dextrans in many soils and their stability to influence the binding of soil particles have been noted. Additional work is reported dealing with the effect of molecular weight ranges of dextran polymers on soil conditioning, including data on the influence of the structural branching of dextran polymers. Marked stabilization of soils, up to 60% increased plant seedling emergence, and up to 70% better crop yield, have been demonstrated with soils containing specific dextran products.

Since ancient times the plow has symbolized man's agricultural efforts in tilling soils and improving their structure. Within recent times, however, it has become evident that natural agents in many soils help the farmer by imparting increased stability or permanence to soil aggregates. If this were not true, such soil aggregates would be broken down to an undesirable degree mechanically, by tillage instruments, by the action of raindrops, or by excess moisture during rainy seasons. Without such natural stabilizing agents it would be necessary to expend much more than the currently estimated one-third available draft power on the farm (*9*) for plowing.

Organic and inorganic soil colloids are believed to be largely responsible for the natural structural stability of many good soils. Unfortunately, much of the organic matter has been lost from many of our tillable soils. This continued depletion has focused attention on the development of synthetic materials, which stabilize and condition soil aggregates. Such synthetic materials, however, have not been considered complete substitutes for natural organic materials such as stable manure, nor are they economically feasible from the farmer's viewpoint.

Long before man recognized the need for tillage and the addition of plant nutrients to the soil and before the term "soil conditioner" was coined, Nature supported and sustained plant and vegetable life, by establishing a relationship between plant nutrients taken from the soil and those returned to it. Soil nutrients taken in water-soluble forms by plants are returned to the soil as organic material—dead plant and animal matter. This organic material is attacked by the multitudinous soil microorganisms and converted to forms again available to plants, and to a product of a mucilaginous nature called humus. It is this material, composed in part of bacterial polysaccharides (*3–5*, *8*, *9*, *14*), which is mainly responsible for the desirable, well drained, granular condition of typical virgin soils. Dextrans, synthesized by a number of soil bacteria (*8*), comprise one of these bacterial polysaccharidal groups.

Studies on soil-water extracts, particularly rich in organic matter, demonstrate that water-soluble, alcohol-precipitable polysaccharidal substances may be present. Certain investigators have reported the influence of bacterial polysaccharides on soils (*3–6*), but the use of bacterial dextran polysaccharides as soil conditioners has not been sufficiently investigated.

Some properties of dextran were clarified in 1869 by Scheibler (*11*) in Germany. Dextran is now known to be a polysaccharide-type polymer made up of many molecules of glucose in long chains, having definite repeating linkages and branchings, and chemically related to glycogen.

Dextrans are produced from bacteria in typical fermentation media, which may contain such materials as corn steep liquor, peptone, and inorganic salts, or may be made in cell-free media from an exocellular enzyme termed dextran sucrase. Such enzymes can be concentrated so that, when added to strong sucrose solutions, they will rapidly form enough dextran to prevent perceptible flow in the system when the container is inverted.

Leuconostoc mesenteroides NRRL-B512, produces the native dextran used for the manufacture of blood plasma volume expanders. Dextrans, as they are biosynthesized, may have molecular weights in the millions and yet many can be dissolved in water to form colloidal solutions of high viscosity. Few, if any, related materials possess such high molecular weights with concomitant water solubility.

The solubility of native dextrans is related to their molecular structures. Those having a high ratio of alpha-1,6 to non-1,6 repeating anhydroglucose unit linkages may be more water-soluble than those with a low ratio; although some dextrans are very insoluble in water, they are apparently all swollen when added to water.

Physical and chemical properties such as water solubility, viscosity, molecular weight, and structure vary widely among different types of dextrans. The number of dextran-producing organisms is large and only a few of the products made by these organisms have been investigated. At least 96 strains of bacteria may produce glucose polymers that vary in their properties (*7*).

During the past two decades, The Commonwealth Engineering Co. of Ohio has worked with dextran and dextran products. It has developed many uses for these materials, as well as a process for producing a blood plasma expander for the treatment of shock in humans.

Because of the reported presence of dextrans in soil and their influence on retention of soil moisture, discovered in preliminary experiments, it was believed that some dextrans might serve as suitable soil-conditioning materials. A series of laboratory investigations was begun in 1952.

Prior to 1954 the term "soil conditioner" was insufficiently defined. The situation was clarified by the Federal Trade Commission (*2*), which defined a soil conditioner as "any synthetic organic chemical substance, or chemically modified natural substance, which is represented as having a primary function of forming and/or stabilizing soil aggregates in soil to which it has been applied and thereby improving the resistance of such soil to the slaking action of water, increasing its water and air permeability, improving the resistance of its surface to crusting, improving its ease of cultivation, and/or otherwise favorably modifying its structural or physical properties."

Objective

An extensive program was undertaken to investigate dextran products for use in the conditioning or stabilization of soils, to obtain information on the influence of dextran-treated soils on seedling emergence, plant growth, and crop yield, and to ascertain the relative differences in activity of various types of dextran polymers with different branching structures and molecular weight ranges.

If particular dextran products were found to have significant initial soil-conditioning activity, preliminary information would be obtained on the durable or transitory action of such dextran products for soil conditioning.

Test Procedures

Soil Samples. To study this problem adequately, several classes of soil were obtained for evaluating dextran as a soil conditioner. Soils were chosen on the basis of their "need" for conditioning and their content of sand, silt, and clay particles. Sandy loam, silt loam, and clay loam soil classes were selected to obtain satisfactory ranges of soil particle size (*9*, *13*).

Soil Mechanical Analyses. Mechanical analyses of soil for sand, silt, or clay content were made as described by Puri (*10*).

Moisture Content. Soil moisture content was determined by drying weighed samples at 105° to 110° C. for 24 hours in tared aluminum weighing dishes.

Procedure for Establishing Period of Effectiveness

Air-dried silt loam soil was passed through a 20-mesh sieve and divided into three groups, each consisting of three 300-gram portions, which were placed in jars and covered with loosely fitted lids. In two groups 0.5% dry powdered dextran 60 or 21 was thoroughly incorporated. The third group served as controls.

The moisture content of each sample was brought to 20%, and then the samples were covered with loosely fitting lids and placed in an incubator set at 37° C. During incubation the soil in each container was aerated daily by removing the lids and slowly rotating the containers.

The moisture content of all samples was kept between 10 and 20%. When it had diminished to 10% in a sample, water was added to bring soil moisture content to 20%.

At periodic intervals, a wet-sieve soil stability test was run on each sample.

Method for Incorporating Dextran into Soils

Soils were passed through a 4-mesh sieve and divided into the proper number of weighed samples, and moisture was determined. The powdered, dry dextran product was then thoroughly mixed with the required soil samples, and placed in containers. Water was added to give a 30% moisture content.

The samples were allowed to stand and were weighed at periodic intervals until weight loss showed the samples to contain 15% moisture. Appropriate seeds were then planted in this soil.

The preliminary basis for evaluating the effect of dextran on laboratory soils was measurement of the stability of the soil aggregates under the influence of excess moisture.

Wet-Sieve Soil Stability Test

A modification of the wet-sieving method described by Bryant, Bendixen, and Slater (*1*) was used.

Procedure. All soil samples were prepared for treatment by sieving through a 20-mesh screen. Appropriate weighed amounts of powdered dextran were added to 100-gram samples of the soil and thoroughly mixed. The moisture content of the soil was then brought to 30%, based on the weight of dry soil. The wet soil was allowed to stand for 24 to 48 hours, when it was passed through a 4-mesh screen. Twenty-five-gram samples of soil aggregates, with diameters less than 4.7 mm. and greater than 2.0 mm., were used for determining water stability. Water stability of the soil under test was recorded as that percentage of dried soil aggregates, greater than 0.25 mm., retained on the screens after wet-sieving for 30 minutes.

Greenhouse Tests

Brookston silty clay loam soil was passed through a 4-mesh sieve. One-gallon stone jars were filled with 3000 grams of this prepared soil, 0.5% of dextran based on the oven-dry weight of the soil was added and thoroughly mixed, and the technique described above was followed. The surface soil in each jar was stirred with a spatula and ten beans were planted in each jar.

All jars were placed so that they received an equal amount of light. Four days after planting, the sprouted beans were counted and the number was recorded as seedling emergence data. All jars containing bean plants were periodically watered to maintain a moisture content of approximately 20%.

Fifty-four days after planting, the plants in each jar were harvested by cutting off at the soil level and dried for 60 hours at 120° F. in a mechanical convection oven.

Field Tests

Tests were carried out on an eroded phase of soil similar to the Russell silt loam in Greene County, near Xenia, Ohio. Dextran 60 of 40- to 100-mesh was incorporated in this soil to a depth of about 4 inches. Its concentration in the soil was calculated to be 0.3%. A garden fertilizer (Vigoro) was then applied at a rate of 2 pounds per 100 square feet.

Soybeans were drilled solid and grown in triplicate plots, which were staggered to reduce error from variation in soil fertility. Sweet corn was planted by hand in rows 3 feet wide with seeds spaced 8 inches apart in the row. Soybean crop yield was determined 88 days after planting by cutting down the plants in the plot with a scythe and drying as described under greenhouse tests.

Experimental Findings

Influence of Dextran on Stabilization

In order to determine whether or not dextran has any effect on certain soil classes and to establish its range of soil-stabilizing influence as well as the concentration required, a series of experiments was carried out. It was established that dextran stabilizes different classes of soils to different degrees and that varying percentages of a dextran, control soil stabilization in some ratio to the amount added.

Table I presents a typical set of determinations resulting from the water-stability test with dextran 60–stabilized soils. The data show that dextran is effective in stabilizing certain classes of soil from the coarse-textured through the fine-textured ones. It is particularly interesting to note the stabilizing effect

Table I. Effect of Native Dextran 60 Concentration on Stabilization of Soils as Determined by Wet-Sieve Soil Stability Test

Soil Class	Dextran, %	Stability, %
Clay loam	0.0	42.2
	0.3	69.8
	0.6	83.4
Silty clay loam	0.0	61.7
	0.3	78.2
	0.6	78.6
Silt loam	0.0	29.3
	0.3	53.0
	0.5	98.4
Sandy loam	0.0	33.0
	0.5	76.2

on the sandy loam. Both soil classes are improved by addition of dextran.

Influence of Molecular Structure on Stabilization

The molecular structure of native dextrans of different types varies widely. It was of particular importance early in this work to establish which types were most efficient for practical soil stabilization.

Using test procedure described above, certain facts were established for later use in the program. A typical set of findings showing the degree of stabilization of one class of soil produced by 0.3% dextrans differing in molecular structure is given in Table II. These dextrans all had molecular weights above 1,000,000. Tests represent averages of at least duplicate analyses.

Table II. Effect of Native Dextrans Differing in Molecular Structure on Increase in Stabilization of a Clay Loam Soil

Treatment	Ratio of Dextran Molecular Anhydroglucose 1,6 Linkages to Non-1,6 Linkages	Soil Stability, %
Control	. . .	51.5
Dextran 61	3 to 1	62.8
Dextran 21	8 to 1	65.4
Dextran 60	18 to 1	68.5

The results show that a native dextran with a high ratio of 1,6 to non-1,6 anhydroglucose linkages may be superior as a conditioning agent for this particular soil. Such dextrans are more water-soluble and in forming colloidal solutions they are not influenced by differences in solution pH as much as less soluble dextrans with lower ratios of 1,6 to non-1,6 anhydroglucose linkages.

Dextrans such as Type 61 may, however, form true colloidal solutions at pH values above 7.0. In the presence of constant soil moisture content, the soil pH (or free acid or alkali content) may therefore be related to the degree of soil stabilization obtained for a particular dextran product.

The pH of the soil used in these experiments was determined to be 6.0. The results, therefore, substantiate the belief that acid soils may be stabilized more efficiently with the more water-soluble dextrans having higher ratios of 1,6 to non-1,6 anhydroglucose linkages.

Influence of Molecular Weight Ranges on Stabilization

It was of importance to establish any relationships between the molecular weight ranges of a suitable dextran and increased stability for particular soil classes.

During the last decade considerable progress has been made toward the preparation of dextrans having particular molecular weight ranges. This has been due principally to improved fractionation techniques and methods for determining molecular weight of such "polyglucoses," either before or after controlled acid hydrolysis (*12*).

Water-soluble dextran 60 was chosen for these experiments. By acid hydrolysis, and/or selective fractionation with methanol and drying, pure dextran 60 samples were obtained with weight average molecular weight ranges by light scattering of 3 × 10[4], 20 × 10[4], and

Figure 1. Influence of molecular weight ranges of 0.5% dextran 60 on wet aggregation stability of soil classes

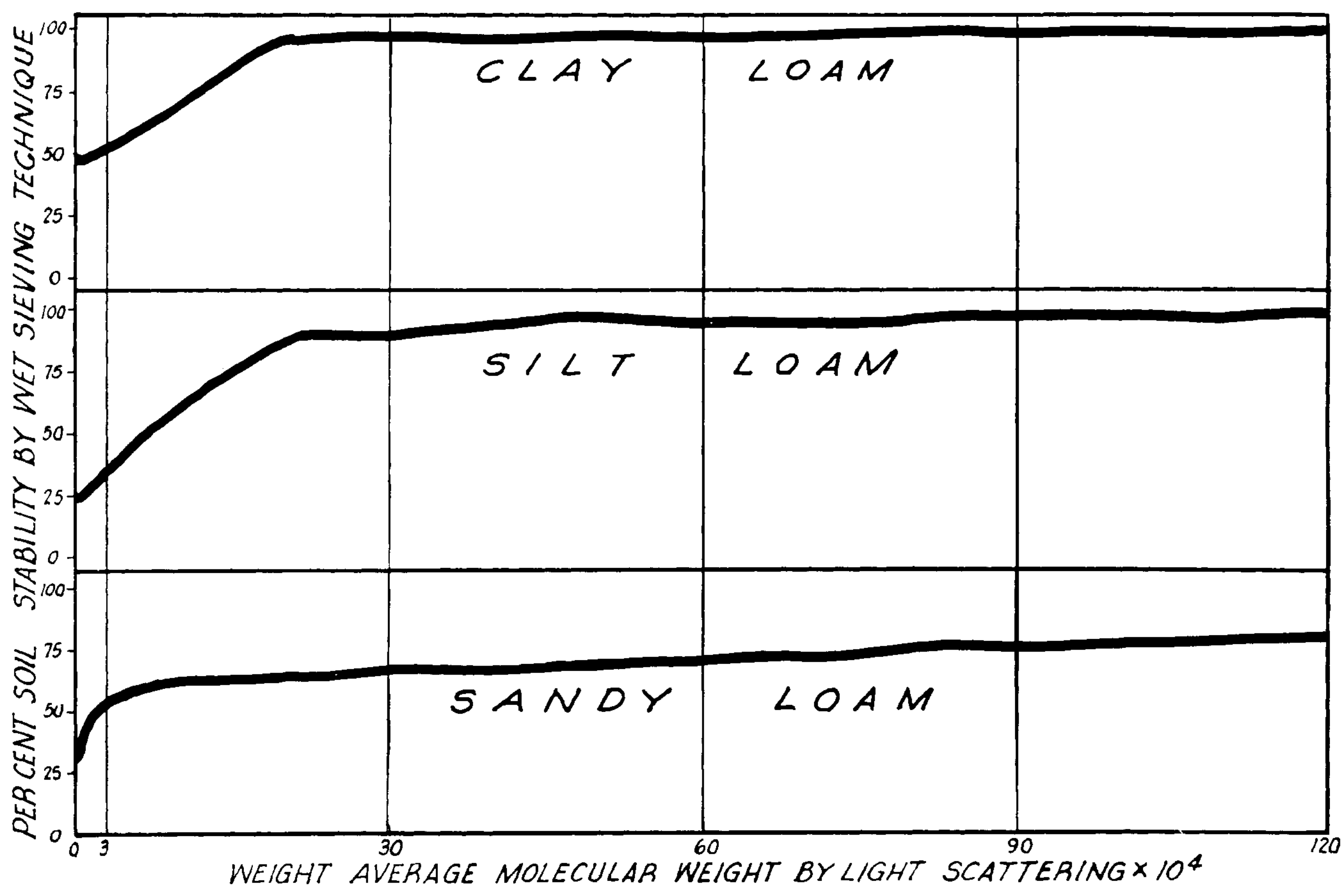

Table III. Influence of Storage Time at 37° C. on Silt Loam Soil Stabilized with 0.5% Dextran

Treatment	% Stability of Silt Loam Soil after 3 days	10 days	51 days
Control	33.6	39.2	51.7
Dextran 60	53.0	74.4	81.2
Dextran 21	57.8	75.4	89.7

Table IV. Stability of Brookston Silty Clay Loam in Greenhouse Work 69 Days after Treatment with 0.5% Dextran

Type	Stability, %
Control	70.0
Dextran 60	93.3
Dextran 21	91.5

over 1×10^6. Such samples were incorporated into three classes of soils according to the laboratory test procedures given above.

The results shown in Figure 1 indicate that dextran 60 with a weight average molecular weight range of 3×10^4 or greater increases the stability of the three soils tested. Dextran 60 with a low weight average molecular weight range of 3×10^4 is more effective for increasing the per cent stability of the coarser textured sandy loam than of the silt loam and possibly the clay loam soils. A weight average molecular weight range greater than 20×10^4 does not significantly increase the effectiveness of dextran 60 for stabilizing the soils tested.

The results indicate that as the soil particle size range decreases, the percentage increase of soil stability may be less for dextran 60 of low weight average molecular weight. As the weight average molecular weight range increases from 3×10^4 to 20×10^4, the soil-stabilizing effectiveness of the dextran 60 becomes greater for the finer textured soils tested.

Influence of Time Although it is of secondary importance that a conditioning agent remain effective for a number of seasons or years, because of the necessary tillage and cultivating activity, a good conditioner will reduce the necessary periodic tillage. Good economics should be applied and the cost of one conditioning treatment be divided by the number of years a conditioner remains effective. It was therefore of interest to determine whether dextrans have a durable or a transitory influence on the stabilization of soil. To answer this question a series of studies along these lines was initiated, using the test procedures described.

Table III presents a typical stability report for the treated and untreated soil at 3, 10, and 51 days after treatment. Results show that the stabilizing influence of dextran on the silt loam soil aggregates is not a transitory phenomenon, as might be anticipated if the added dextran had been destroyed by the microorganisms present.

As it has been demonstrated (Figure 1) that the reduction in molecular weight of added dextran 60 from over 1×10^6 to 20×10^4 does not significantly reduce the stability of the three classes of soil studied, it can be assumed that, even if particular microorganisms slowly attack particular dextrans in a treated soil, considerable time could ensue before dextran degradation would cause a reduction in the soil stabilization initially attained.

As a further check on the permanency of dextrans in soil, this series of experiments was carried over into the greenhouse work. Table IV reports on a Brookston silty clay loam treated with 0.5% dextran for use in growing soybeans in the greenhouse. This soil still had superior stability over the control 69 days after treatment.

It may be concluded that added dextran increases the stability of soil aggregates for at least one growing season in temperate climates. The total effect of this soil-stabilizing activity over a number of growing seasons remains to be determined.

Influence of Dextran-Treated Soils

Influence on Plants. After laboratory data and information on the character of dextrans and their utility in conditioning soils had been secured, it was necessary to consider the influence of dextran products as soil stabilizers on the growth of plants. A series of tests on soybeans and mung beans in the greenhouse was undertaken. The procedure for controlled growth and test conditions is outlined above.

The soil used for greenhouse tests was slightly acid (pH 6.58). Chemical analysis showed that available phosphorus was high (105 pounds per acre), while potassium was low (89 pounds per acre). The Soil Conservation Service classes this soil as a Brookston silty clay loam. Analysis showed this soil to be 55.6% water stable.

Typical growth and yields of crop from these greenhouse tests are presented in Table V. The figures reported are the average of triplicate tests.

Four days after planting more beans had sprouted in the dextran-treated soil. Prior to harvesting the plants from the treated soil were larger and superior in appearance to the controls. The soybean plants were harvested 54 days after planting, at the hay-cutting stage. The bean pods had formed, but the plants had not completely matured.

The consistent increase of plant yield up to 70% for soybeans and 78.9% for mung beans reflects the marked influence of dextran in soils on plant growth.

Figure 2 shows a typical improvement in soybean seedling emergence after soil treatment with 0.5% dextran 60.

Influence on Crops. As dextran was shown to increase soil stability in laboratory experimentation, to improve plant seedling emergence and plant yield in controlled greenhouse tests, and to resist bacterial degradation, it was decided to initiate limited field tests on plots in Greene County, near Xenia, Ohio, to obtain additional information of possible practical value on dextran products for soil conditions.

The pH of the soil used was 5.75. Analysis showed that it contained 42 pounds per acre of available phosphorus (P_2O_5) and 166 pounds of potassium (K_2O). The wet-sieve stability of this soil was 73%, as determined by wet-sieve analysis. The relatively high stability is attributed mostly to the effects of a great deal of green plant material plowed under in the spring.

The dextran 60 was a 40/100 mesh, light tan, free-flowing powder which did not cake when stored for several weeks in air-tight fiber drums. It flowed freely and evenly from the mechanical distributor onto the soil. Just before seeding, the wet sieve stability of the soil was determined to be 90%.

Observations were made periodically on seedling emergence, crop appearance, and crop yield. Some of the typical data are produced in Table VI. Figure

Table V. Crop Yields (Dry Basis) of Beans Grown in Greenhouse Brookston Silty Clay Loam Treated with Native Dextran

Treatment	Amount, %	Average Plant Weight, Grams	Increase in Yield, %
	Soybeans		
Control	0.5	2.0	. . .
Dextran 60	0.5	2.5	25
Dextran 21	0.5	3.4	70
	Mung Beans		
Control	. . .	0.109	. . .
Dextran 60	0.3	0.160	46.8
Dextran 60	0.6	0.170	56.0
Dextran 61	0.6	0.190	74.3
Dextran 21	0.6	0.195	78.9

Table VI. Corn Seedling Emergence 20 Days after Planting on Field Plots in a Silt Loam Soil Treated with 0.3% Dextran 60

No. of Plants per Control Row	No. of Plants per Dextran Row	Increase in Plant Emergence, %
15	20	44
12	15	25
12	16	33

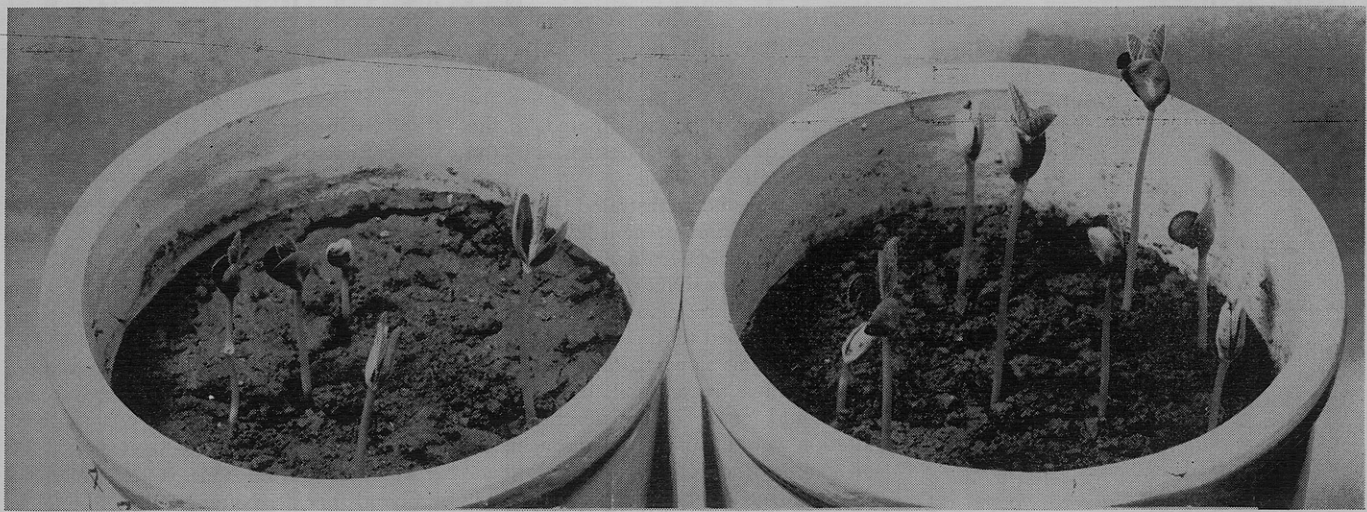

Figure 2. Emergence of soybean seeds in untreated and dextran-treated silty clay loam soil, 4 days after planting

Left. Untreated, 50% seedling emergence. *Right.* Treated with dextran 60, 80% seedling emergence

3 is a photograph of two of the test rows of corn taken 34 days after planting. The left row is the control. An average increase of 16.5% in total yield of soybean plants at the hay-cutting stage was observed from the dextran-treated plots by comparison with the control plots.

Discussion

The preceding results, as well as other work on dextrans conducted over the past few years, indicate certain advantages when dextrans are used for soil conditioning.

Dextrans are produced by biosynthetic fermentation processes which require particular but inexpensive compounds rich in nitrogen, phosphorus, and potassium for maximum production yields. The principal raw material — sugar — is cheap, in free supply, and available in tonnage quantities. Dextran products which can be economically produced not only function as soil conditioners but also contain appreciable amounts of nitrogen, phosphorus, and potassium, which then may also serve as source of plant nutrients. In the work heretofore described, however, no fertilizer elements were added to the natural dextran products used in the laboratory, greenhouse or field tests. Dextrans are natural substances, and are nontoxic to plants grown in soils containing them. Undesirable overstabilization of the soil is not easily accomplished.

Figure 3. Influence of 0.3% native dextran 60 on growth of sweet corn

A range of dextrans can be produced which vary considerably in their stabilizing effects on a variety of soil classes. Results of experimental work indicate that a correlation among soil texture, dextran molecular weight, and dextran structure undoubtedly exists. It suggests that one dextran might be used for a soil class such as a sandy loam, another for silt loam, and yet another for clay soil, for maximum effectiveness.

The dextran products described are free flowing, relatively dense, finely divided powders which are easily applied to the surface of the soil, and can be incorporated in it by the use of conventional farm implements.

Conclusions

Certain dextrans when added to test soils, in concentrations not exceeding 0.6%, have increased the wet-sieve stability of the soils studied, per cent seedling emergence, rate of plant growth and crop yield for the plants used. Experiments have been successfully concluded on soybeans, mung beans, and corn.

A relationship is indicated among dextran type, dextran structure, dextran molecular weight, and the degree of soil stabilization achieved for particular soil classes.

The over-all work on which this paper is based may serve as an interesting new wedge for examination of the effects of of molecular structure and molecular weight relationships of polymers on the properties of soils. That there is a definite influence on the binding of different particle sizes in soils by the various dextrans should prompt other investigators to examine this action further. This paper has been concerned primarily with studies leading to the relative effects produced and not to their causes.

Acknowledgment

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PEPPERMINT OIL

Relation of Maturity and Curing of Peppermint Hay to Yield and Composition of Oil

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The yield of peppermint oil per acre is higher in the lower Yakima Valley of south central Washington than in any other known area. Peppermint plants bloom profusely and give maximum yield at time of full bloom. Oils contain an appreciable portion of blossom oil, high in menthofuran, and some practical method is needed to reduce the number of blossoms at harvest time. Retiming of irrigation and fertilizer application and clipping of blossoms might be of value. Harvest at an early stage of plant development might improve odor and flavor, but at the expense of total yield. Total menthol and esters increase with plant development. The optical rotation of the oil may or may not decrease to a minimum at the time of maximum yield. Length of curing after cutting has only a minor effect on composition.

PEPPERMINT OIL is obtained by the steam distillation of the peppermint plant (*Mentha piperita*). The Pacific Northwest is the source of about 60% of the oil produced in the United States; about 21% comes from the state of Washington (7).

Peppermint is grown on muck soils in the midwestern states of Michigan and Indiana, and on somewhat lighter soils in the states of Washington and Oregon. There are two main areas in the West which, according to the buyers, produce somewhat different peppermint oils, although the same plant, *Mentha piperita*, is grown in both areas, as well as in the Midwest.

In the older production area in Washington and Oregon, west of the Cascades in the Willamette and lower Columbia valleys, peppermint is grown on heavy alluvial soils which are high in organic matter. There is occasional irrigation during the dryer parts of the growing season. The peppermint oil produced there is somewhat similar to that produced in the Midwest.

The second area, located in south central Washington, is in the lower Yakima Valley and along the Columbia River immediately below its junction with the Yakima River. Peppermint is grown on mineral soils that have developed under semiarid conditions, in an environment characterized by wide temperature fluctuations and more hours of sunlight of much higher intensity than in the other areas. Cultural conditions and practices in south central Washington may vary from those in other areas. This is the only known area growing peppermint entirely under irrigation. Irrigation is principally by furrow, but sprinklers are used to some extent.

There has been a rather rapid increase of peppermint oil production in this area. The yield of oil per acre in south central Washington is over three times that obtained in the Midwest and almost twice that of Oregon and western Washington.

Plant diseases and insect damage have decreased both acreage and yield in Indiana and Michigan. Rust has become a problem in Oregon and western Washington. As yet the lower Yakima Valley in Washington is free of these plant diseases and has only a small infestation of the mint flea beetle.