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Soil Additives and Their Effect on the Yield of Various Crops and the Physical Properties of an Agricultural Soil

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SOIL ADDITIVES AND THEIR EFFECT ON THE YIELD OF VARIOUS CROPS AND THE PHYSICAL PROPERTIES OF AN AGRICULTURAL SOIL

by

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INTRODUCTION

Importance of Problem

It is generally accepted that soil structure is very important in keeping productivity at a high level. When soils are loose and friable, mechanical impedance to root growth and seedling emergence is greatly reduced. Such soils infiltrate greater quantities of precipitation, are better aerated, and possess a more favorable temperature than puddled soils. Essential plant nutrients are also more easily available in well aggregated soil.

In the last few years, several synthetic soil additives have been placed on the market. Extravagant claims have been made about the ability of these amendments to maintain soil structure, without a sound body of research data on which to base these claims. Advertising of the products which are on the market has been extensive. Much of this advertising would lead one to believe that these additives applied to any soil will increase stand and growth of plants resulting in greatly increased yields.

As a result of this, agronomists, county agents, and other extension workers are constantly being asked by farmers and gardeners about the value of these products and for advice on whether or not to apply them. Most of the work has been done either in the laboratory or on exceptionally poor land which represents an extremely small fraction of the land used for agriculture. The data from these experiments do not indicate what results can be expected from application of additives to either average or good farm land. Therefore, the results of applying additives to our general agriculture land should be determined so that large amounts of money are not wasted on valueless products.

Scope of Research

The main objective of this investigation was to determine whether soil additives would increase farm income: (a) by increasing rate of seedling emergence or speeding up maturity so that crops could be put on the early market when prices are high and so long season crops would be in less danger of frost damage in the fall; (b) by increasing number of seedlings emerging or increasing growth so that a larger crop yield would be obtained.

It was also intended to investigate the effects of soil additives on some of the physical factors which might indirectly affect crop yield. The physical factors to be tested and the methods to be used were: (a) investigate crusting by determining the modulus of rupture; (b) investigate water holding capacity by determining one-third and 15 atmosphere percentages; (c) evaluate permeability by determining conductivity in the unsaturated soil.

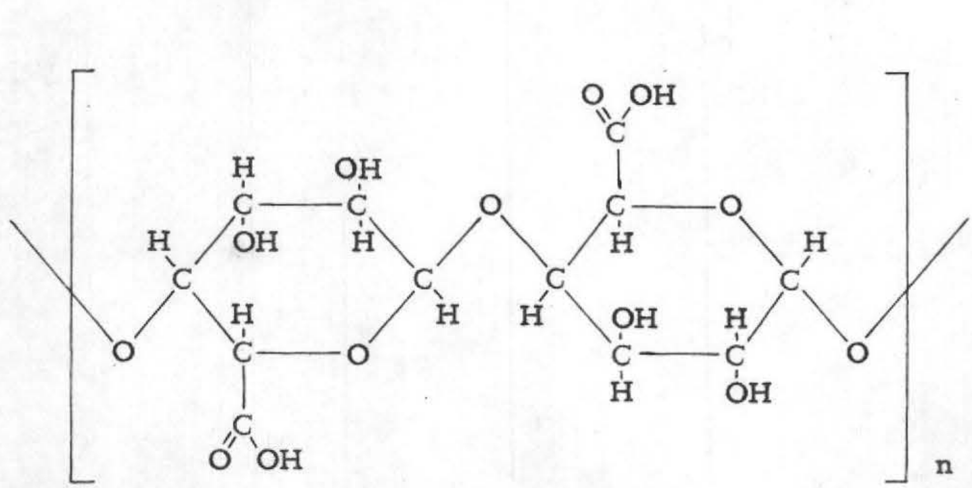
REVIEW OF LITERATURE

Development of Soil Additives

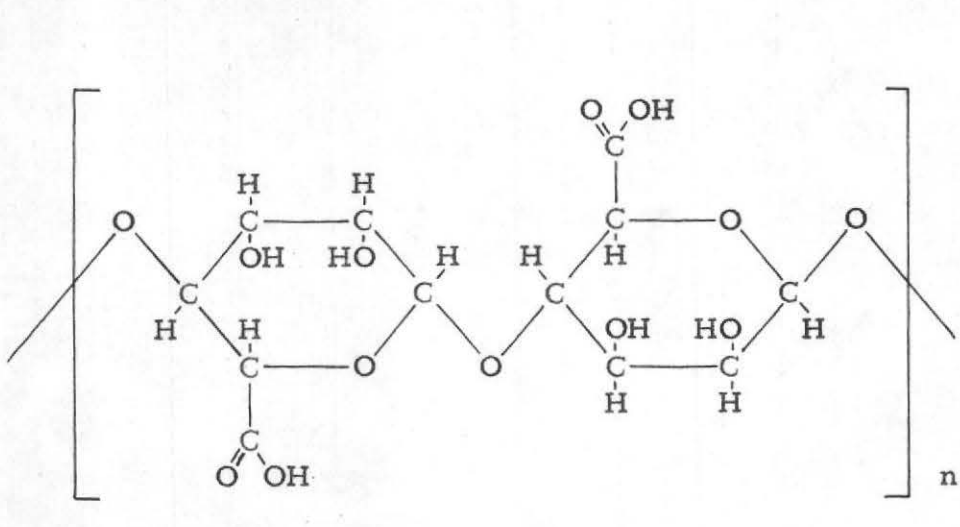
In the past, soil structure has been maintained largely by binding effects of organic matter and iron and aluminum oxides.

Organic matter is derived primarily from the decomposition of plant and animal tissue. Sugars, starches, and proteins are quickly converted into lignoproteins and polyuronides. Other portions of the plant and animal tissue, such as celluloses, hemicelluloses, waxes, and fats, are more resistant to bacterial attack. The speed of decomposition of these latter products is much slower, and they may serve as binding agents before they are converted to other products (11).

Polyuronides are much more effective soil aggregators than the other portions of organic matter and the iron and aluminum oxides. Among the polyuronides present in soils are pectic acid and alginic acid, both of which are made up entirely of uronic acid units. Pectic acid is made up of D-galato-pyruronic acid residues united by 1:4$^{\alpha}$ linkage.

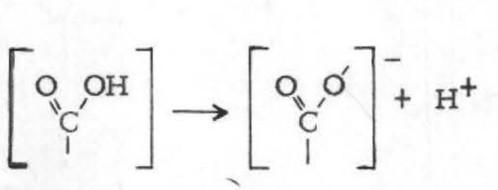


Alginic acid is D-mannopyruronic acid residues joined by 1:4β linkage.



Other polyuronides in the soil are polysaccharides which contain uronic acid units in their chain structure (10).

The development of soil additives and the method by which they improve soil structure can be understood better if the aggregating properties of polyuronides are presented first. The acid groups of the uronide ionize leaving the uronic groups with negative charges.



Clay also has a negative charge, and it is generally considered that hydrogen bonding is the major mechanism of bonding between the polyuronide molecule and the clay particle (see figure 1). Because of the importance of soil structure, many attempts have been made to apply soil aggregating agents artifically. The first attempts were to use naturally occurring polyuronic acid salts and other closely

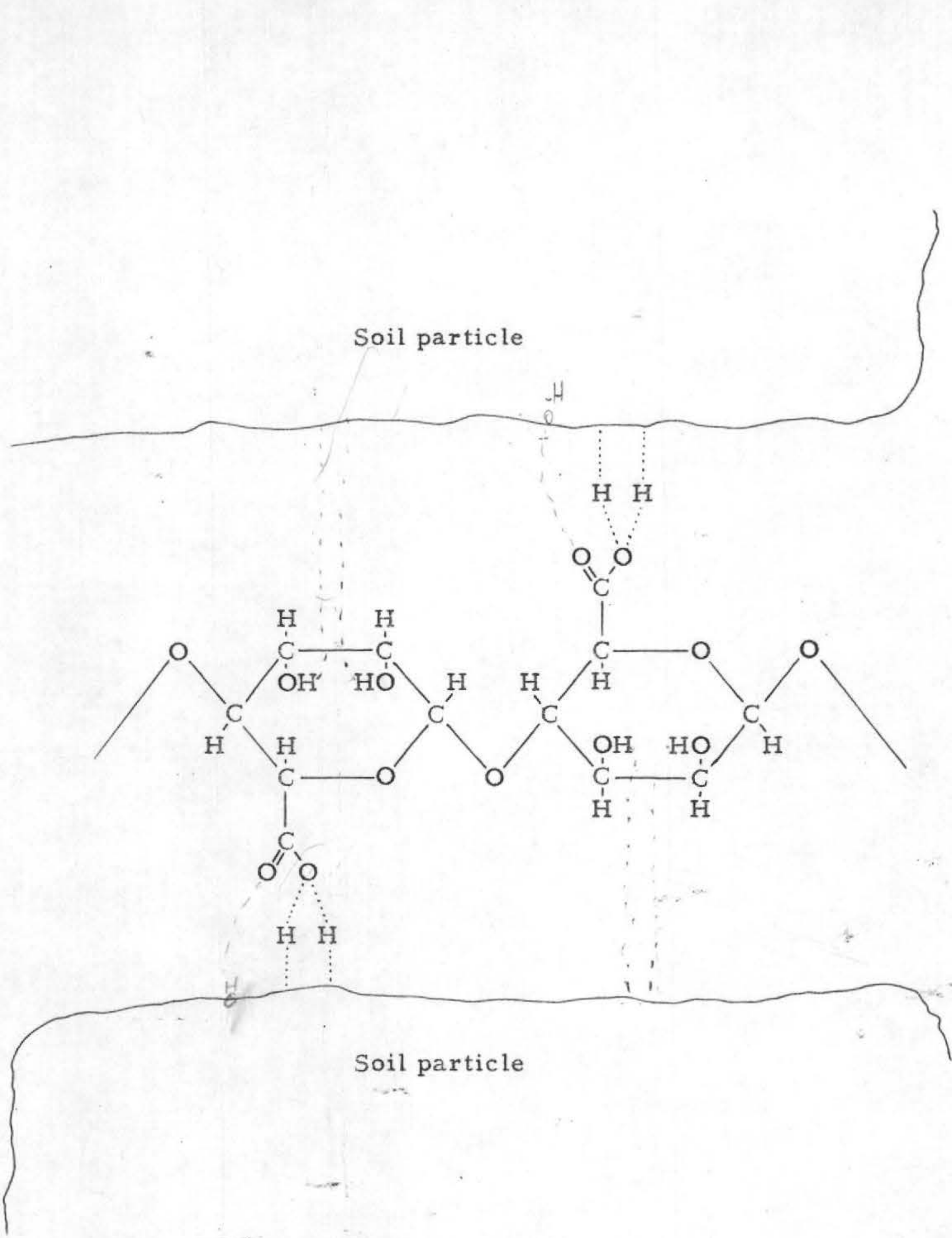


FIGURE 1: Two clay particles held together by hydrogen bonding with alginic acid

Kohl & Taylor Soil Sci. 91: 223 - 227 - 1961 related polysaccharides. Hedrick and Mowry (5) point out that they have not proved successful or practical even though soil aggregation was improved. The three reasons for this are: (a) the large amounts required for significant structure improvement (5 to 10 tons per acre) cause harmful effects to the soil by releasing large quantities of cations; (b) the rapid decomposition of the added polyuronides (2 weeks to 2 months) shortens their effectiveness to a point where they are uneconomical.

Compounds not known to occur naturally in the soil were prepared as aggregating agents. Salts of methyl cellulose and carboxymethyl cellulose had a moderately high aggregate stabilizing effect but are susceptible to rapid bacterial decomposition. Sodium and potassium silicates have been reported to give good aggregate stability. The silicates like the iron and aluminum oxides, found naturally in the soils, are required in high concentrations (0.5 to 1.0 per cent) to be effective. These large dosages are toxic to the soil microflora. Treatment with dimethyldichloro-silane gas (0.2 to 0.5 per cent) increased aggregate stability. Its use is impractical because of high animal toxicity and difficulty in application. The stability is largely a result of waterproofing action causing stability at the expense of water holding capacity. Other water-proofing chemicals, such as stearic acid and abietic acid are available but these often hinder plant growth because of unfavorable soil-moisture relationships.

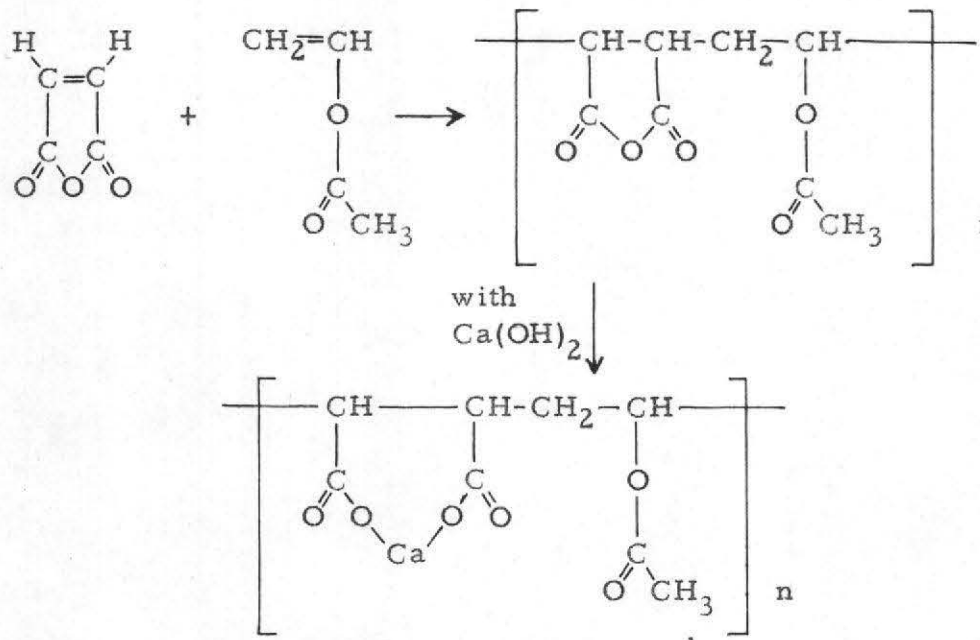
It soon became obvious that it would be necessary to find a substance that would be effective at low concentration (0.1 to 0.2 per cent) but which, unlike pectic acid and other uronides, was resistant to bacterial decomposition. The compound would also have to be non-toxic to micro-organisms, plants, and animals.

The investigations then centered around development of chemicals that closely resembled the polyuronides found in humus (5). This approach soon appeared fruitless, and the search shifted to a more empirical approach of developing and testing materials without regard to their chemical structure. As a result of testing and screening some 700 chemicals, it became apparent that high-molecular-weight poly-electrolytes would best satisfy the needs. These additives became known as soil conditioners. About this same time, research workers in the detergent industry developed some surface-active materials which affect water relations in the soil. These were called surfactants.

Soil Conditioners

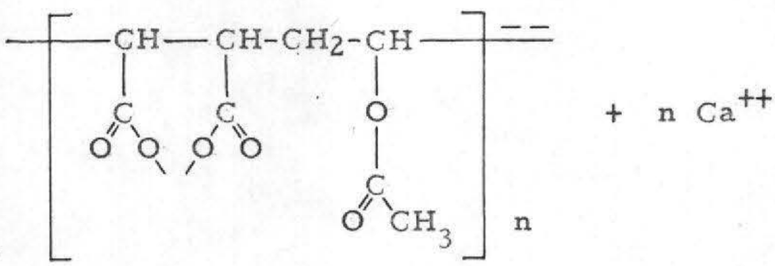
Monsanto Chemical Company developed a large number of the 700 chemicals tested. Late in 1951 this company placed a group of aggregate stabilizers on the market under the trade name of Krilium. Since then, other chemical companies have manufactured compounds the same as and similar to those sold by Monsanto. These have been made available to research workers and will be placed on the market if tests prove successful.

Chemical Compositions. The three polyelectrolytes sold as Krilium are: VAMA, HPAN, and IBMA. VAMA (CRD-186) is the calcium salt of vinyl acetate maleic acid. It can be made by copolymerizing maleic anhydride with vinyl acetate, and then saponifying with calcium hydroxide.



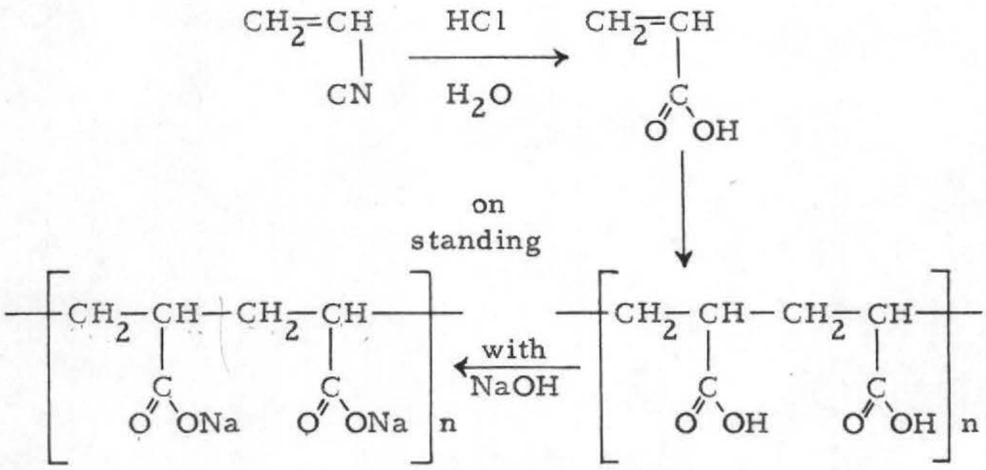
Calcium salt of vinyl acetate maleic acid.[1]

When the calcium ionizes off the acid group, the polymer is left with a negative charge.



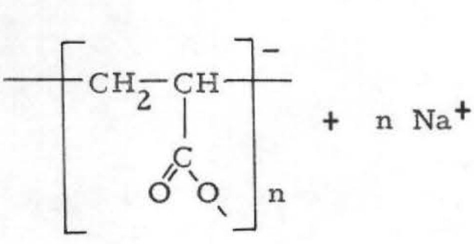
1. Approximate formula. Since two different units are being copolymerized, the resulting compound is heterogeneous and could have two or more maleic anhydride groups or vinyl acetate groups appearing together in the chain. The subscript n means this basic unit is repeated n times.

HPAN (CRD-189) is the sodium salt of hydrolyzed polyacrylonitrile. It can be made by converting acrylonitrile to an acid, polymerizing, and then saponifying with sodium hydroxide.

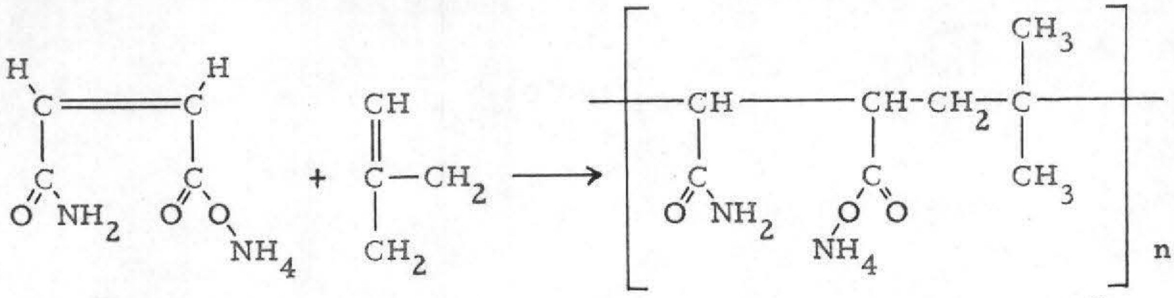


Sodium salt of hydrolyzed polyacrylonitrile

When the sodium ionizes off the acid group, the polymer is left with a negative charge.

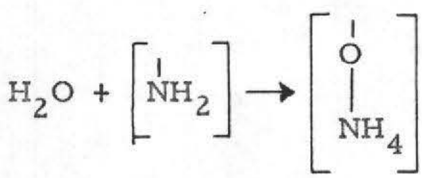


IBMA (CRD-212) is a copolymer of isobutylene and the half ammonium-half amide salt of maleic acid.

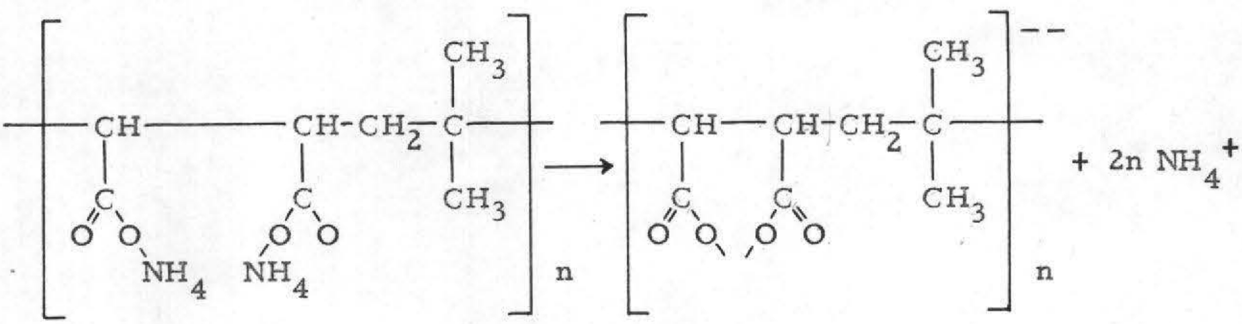


Half ammonium-half amide salt of isobutylene maleic acid.[2]

Upon entering the soil, the amide salt could react with water to form an ammonium salt.



Upon ionization it yields



If VAMA is a good aggregate stabilizer, then IBMA should also be. This can be observed by comparing the ionized form of these two compounds and observing that the active portions of the chains are both maleic acid groups.

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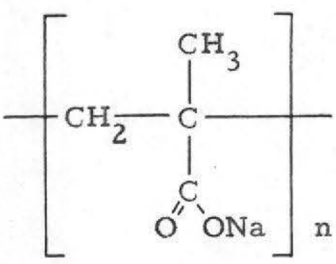
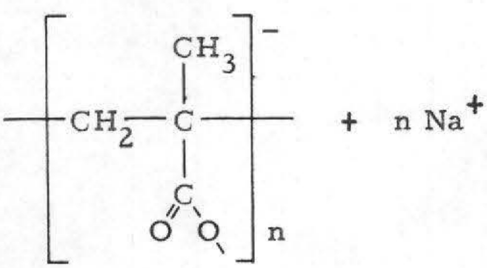
2. Approximate formula. This is a heterogeneous compound.

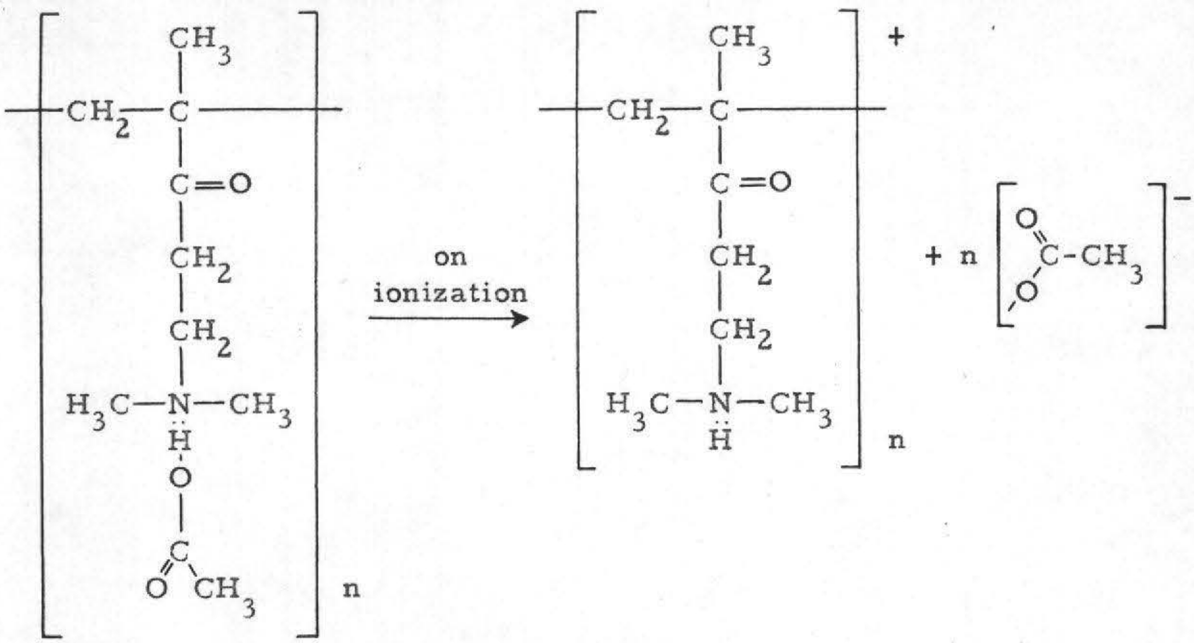
Ruehrwein and Ward (12) ran tests to determine the method by which clay particles are aggregated. Sodium polymethacrylate (SPM)



which ionizes to form sodium ions and a polyanion



was chosen as a representative polyanion for these tests. All conditioners on the market today and practically all of those used in research are polyanions. However, poly β-dimethylaminoethylmethacrylate hydroacetate (DMAEM),



a polycation, was used in the tests.

Effects on Soil. To determine how the polyelectrolytes cause aggregate stability, three types of experiments were conducted: (a) x-ray diffraction; (b) adsorption measurement; (c) flocculation studies. DMAEM was used as a representative polycation and SPM as a representative anion.

The interplanar (c-axis) spacing of montmorillonite clay is proportional to the size of the ions adsorbed; it is larger for organic than for inorganic ions. X-ray diffraction patterns were obtained on montmorillonite treated with both SPM and DMAEM.

The observed c-axis spacing is not increased by the polyanion, but is increased by the polycation. These results demonstrate that the polycation is adsorbed on the faces of montmorillonite; polyanions were not adsorbed thereon. It is not unlikely that they do adsorb on the edges of the montmorillonite layers where anion exchange sites do occur.

The adsorption of polyanions on kaolinite clay was strikingly slow, probably resulting from the rate of diffusion and orientation of the large polymer molecules. The adsorption rate was increased in the presence of extraneous electrolytes. This may be explained by positive ions forming an ion cloud around the highly negatively charged polymer. This diminishes the repulsive force between the two molecules so that they can be adsorbed closer together on the clay surface. Polyanions do not, however, flocculate a clay suspension. In fact a small addition of SPM renders the clay more peptized, and a higher concentration of sodium ion has to be added to flocculate the clay than is necessary when SPM has not been added. If the order of addition is reversed and SPM is added to a clay suspension containing a flocculating amount of sodium ion, the rate of flocculation is greatly increased.

Further work showed that clay floccules that were sedimented by addition of polyanions were resistant to redispersion. When the polymer was added first and the clay sedimented with sodium, the floccules were easily redispersed. This may be explained by assuming the formation of polymer bridges between clay particles (see figure 2). Upon addition of polyanion to a dilute, dispersed clay suspension, the clay particles are far apart; and the polymer molecule adsorbs on a single clay particle. In a flocculent suspension, clay particles are sufficiently close for the large polymer molecule to be adsorbed on more than one particle, forming a polymer bridge. When diluted, the particles bound

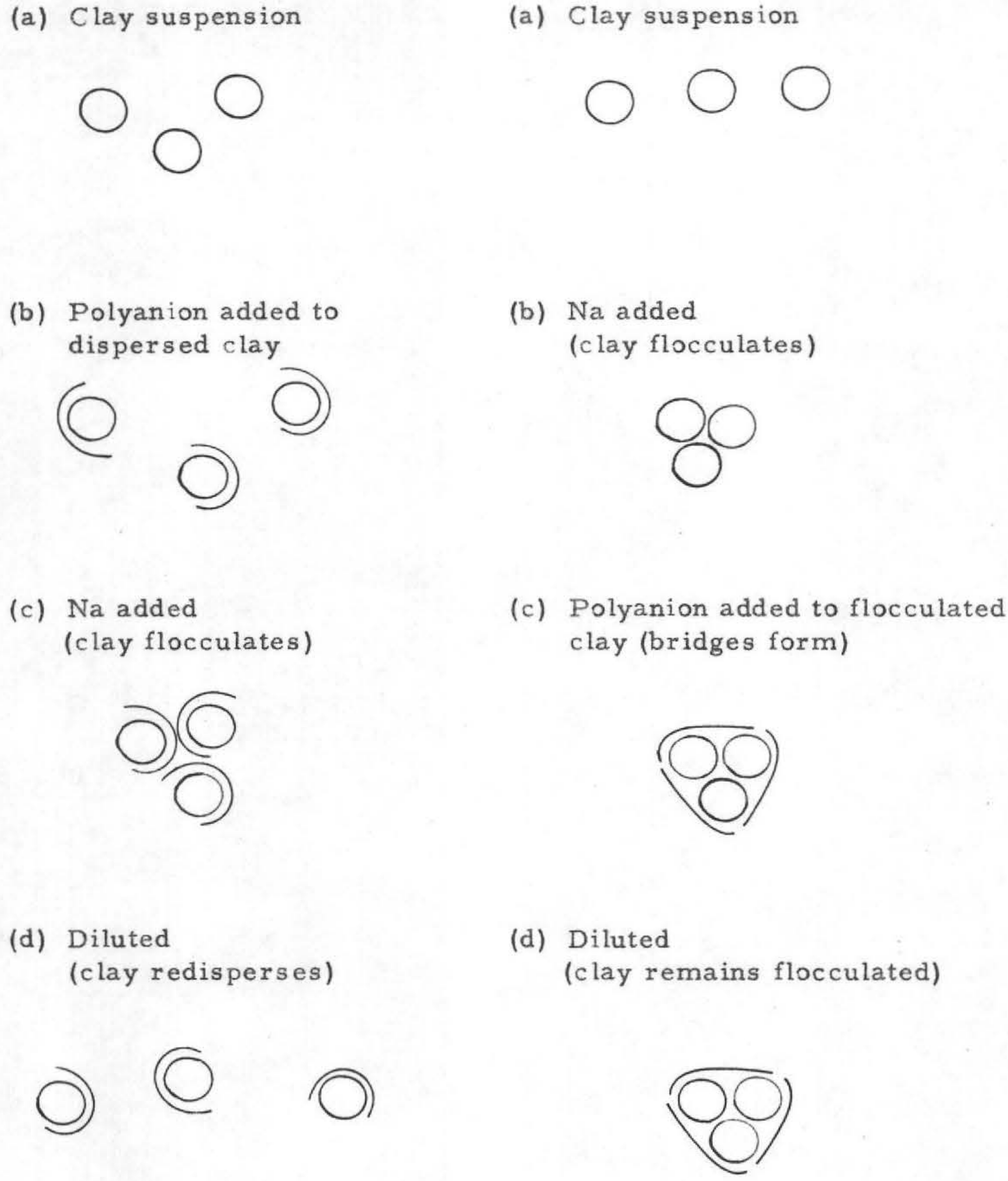


FIGURE 2. Schematic Representation of Adsorption of polyanion on dispersed and flocculated clay. Adapted from (12).

by polymer bridges remain flocculated (12).

Sedimentation studies showed that polycations are strikingly effective clay flocculating agents as compared with simple cations. Polyanions, however, do not flocculate a clay suspension (12).

It is difficult to determine the effects of conditioners on soil structure, since the physical state of the soil is the resultant of many variables and forces. Although no completely satisfactory measurement of structure exists, permeability, porosity, aggregate size distribution and aggregate stability have been used to characterize it.

Wet-sieving is the most general method of determining aggregate stability. This technique was used by Hedrick and Mowry (5) to determine the distribution of water stable aggregates as a result of treatment with HPAN. The quantity of larger soil crumbs increased directly with amounts of conditioner applied. VAMA gave similar results. Water-stable aggregates were increased on 22 of 23 structurally deficient soils. An increase in water-stable aggregates is also reported by other investigators (1, 6, 7, 8, 16).

Infiltration rate is increased by addition of conditioners to the soil (4, 5, 6, 7, 8, 16, 18). Allison (1) reports a very marked increase in permeability on alkali soil. This increase was proportional to the rate of treatment over the application range tested.

Hedricks and Mowry (5) report an increase in the moisture equivalent of the soil; however, there is no change in the wilting point. This means that the available moisture supply is increased. A later study (9) on five different types of soil showed no significant changes in either wilting point or moisture equivalent due to treatment. It is pointed out (8, 9) that plants might be able to extract more water from the soil as a result of increased infiltration rates causing more rainfall to enter the soil and/or the encouragement of a more extensive root system as an indirect affect of treatment.

Aeration is signicantly increased by adding polyelectrolytes (5). There have been some reports of increases in seed germination, seedling emergence, (8) and earliness of maturity (7, 16).

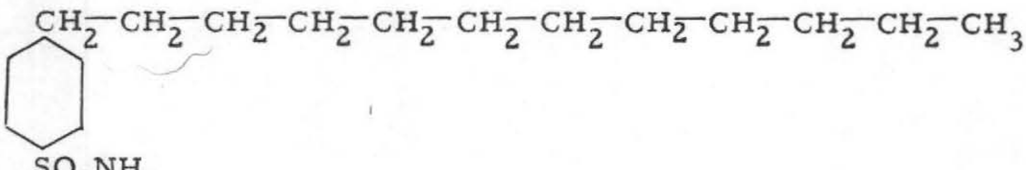
The physical state of the soil is difficult to evaluate, and no unique relationship has been found between crop yield and physical condition of the soil. Therefore, economic evaluation of conditioners must be made from production data. Greenhouse and field experiments have been carried out to determine plant responses to addition of soil conditioners (1, 4, 5, 7, 8, 16). In general the greenhouse experiments show a striking increase in yield of treated over untreated plots. Increases were not so pronounced in the field studies. It is significant to note, however, that no decreases in yield have been reported.

Two slightly modified conditioners (CRD-186-1 and CRD-189-A) were used by Weeks and Colter (18) in their studies of erosion control. Artifically prepared plots with a slope of 22° were sprinkled to simulate rain. Runoff and soil erosion were measured on each plot. The conditioners had about the same effect as a straw mulch in reducing soil losses and surface runoff.

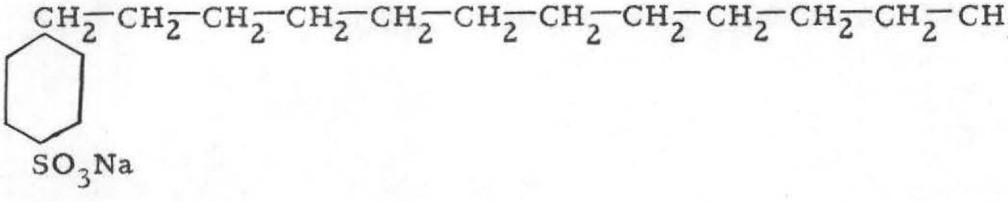
Surfactants

Surface active agents are polar molecules, containing a hydrocarbon chain of variable length and a solubilizing group. The hydrocarbon portion of the molecule is more or less hydrophobic. The solubilizing group is hydrophillic. The combination of these two groups gives a molecule which is active at interfaces in affecting a reduction of the surface tension. At the interface of two immiscible substances the hydrocarbon portion of the molecule is oriented towards the hydrophobic media; the other portion is towards the hydrophyllic material (3). The properties of surface active agents can be varied by changing the length of the carbon chain or by changing the nature of the solubilizing group. While varying the molecular structure of surface-active agents, Atlantic Refining Company found two materials which were not good washing detergents but were effective in reducing the surface tension of water in soil. These products, PR-78 and PR-51, are called surfactants.

Chemical Compositions. Both PR- 78 and PR-51 belong to the alkyl sulfonate group of compounds. PR-78 is the amine salt of dodecyl benezene sulfonate.



PR-51 is the sodium salt of dodecyle benzene sulfonate.



Effects on Soil. Work with surfactants indicates that the only effect they have on soil is to increase water permeability. Since the molecules are polar it is possible that the increase in infiltration rate is due to the soluble portion of the molecule being oriented in the water and the hydrocarbon portion sticking out from the surface as in figure 3. This results in a lowering of the surface tension.

It is also possible for the molecules to be attached to the clay crystal by hydrogen bonding (see figure 4). The sodium can ionize off to leave the molecule with a negative charge. This means that these materials could act similarly to the polyelectrolytes except that the chain of the surfactants is extremely short and only has 1 point for attaching on to the clay particles. It is, therefore, impossible for surfactants to bind clay particles together through the formation of bridges between them. A clear-cut theory on the mechanism responsible for the increased infiltration rate has not been published.

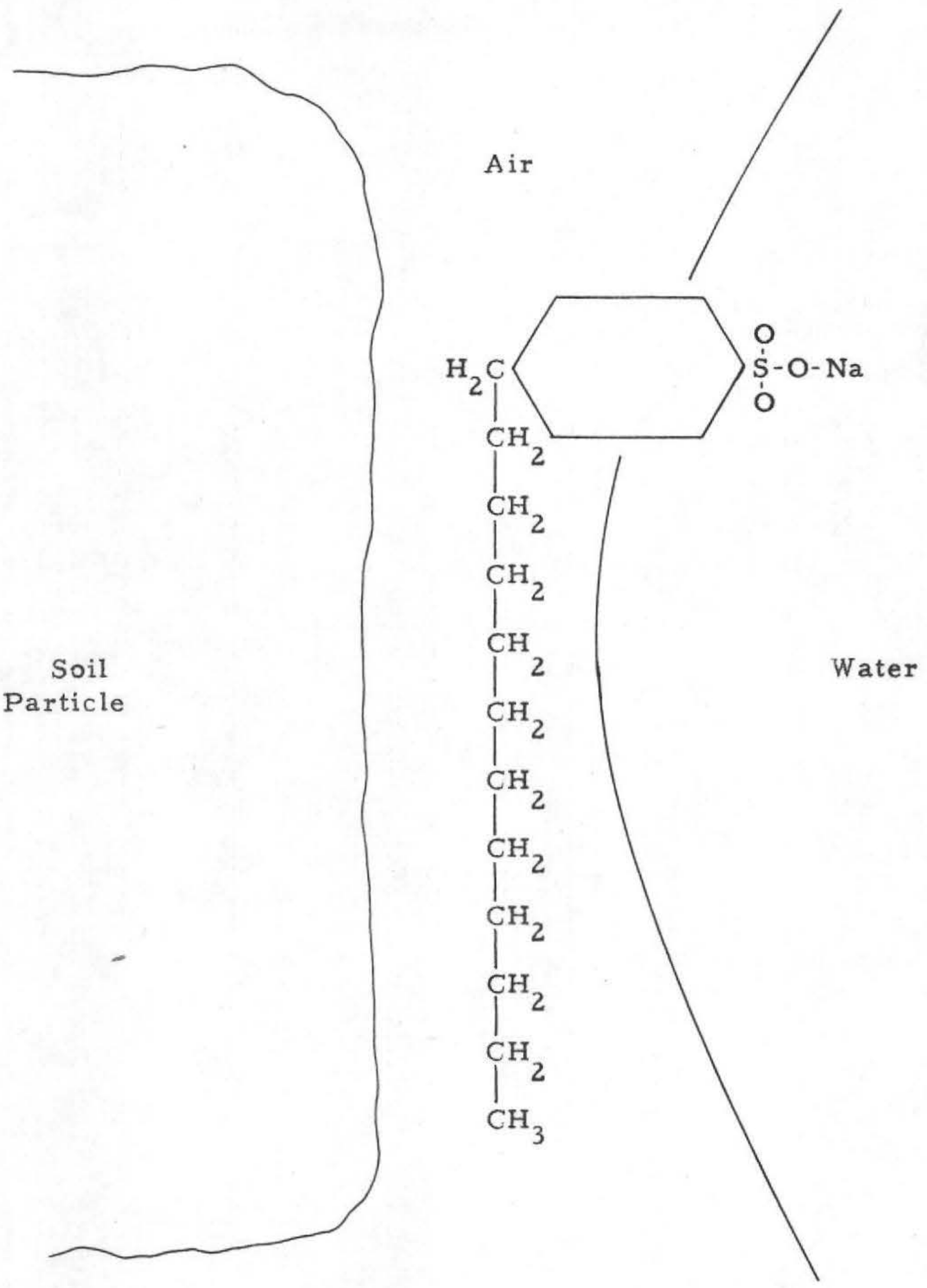


FIGURE 3. PR-51 with the solubilizing group oriented in the water and the hydrocarbon portion sticking out from the air-water interface

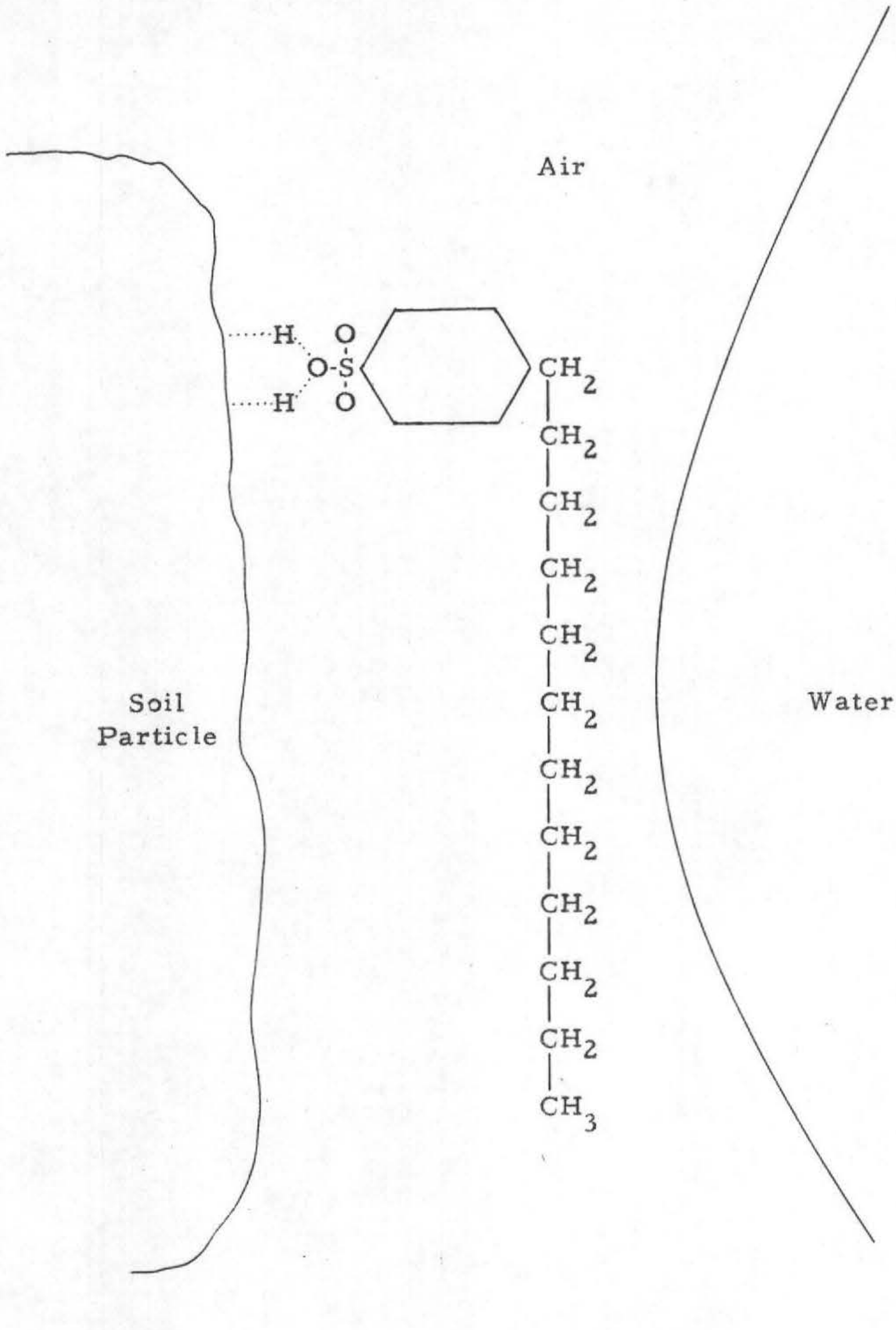


FIGURE 4. PR-51 attached to the soil particle by hydrogen bonding

EXPERIMENTAL METHODS AND RESULTS

Field Experiments

To determine the effect of soil additives on crops and physical properties of the soil, three independent field experiments were conducted.

PR-51 on Tomatoes. A tomato experiment was set out on Timpanogas fine sandy loam to test the effect of PR-51, a surfactant, on yield, earliness of maturity, and size of tomatoes. This is a deep, moderately permeable soil. It forms only light crusts and produces good crops of forages, fruits, vegetables, or grains. Tomatoes of Stokesdale type, Moscow type, and an indeterminate hybrid were treated on June 23, 1953. The plants were well established when treatments were applied. Plots were 6 feet by 32 feet and contained 14 plants (when planted) placed 3 feet apart, in rows 4 feet apart. Eight plots of Stokesdale type tomatoes were treated with 150 grams (approximately 75 lbs. /acre) of PR-51 scattered on the surface. An equal number of plots were left untreated as controls. On the same date eight similar plots of Moscow type tomatoes and three plots of indeterminate hybrid tomatoes were treated with 90 grams of PR-51 per plot (approximately 45 lbs. /acre). An equal number of plots on each of these types of tomatoes were retained as controls.

The ripe tomatoes were picked on five different dates. At each picking the tomatoes were counted and weighed. After the fifth picking the green tomatoes that remained were picked and weighed. Some plants died from disease. Consequently, yields were adjusted on the basis of an equal number of plants in each plot.

The results of this experiment are summarized in table 1.

Table 1. Effect of PR-51 on earliness, yield, and size of tomatoes on Timpanogas fine sandy loam in 1953

Item tested	Treatment	Tomato type		
		Stokesdale	Moscow	Hybrid
Weight ripe tomatoes (lbs.)	PR-51[(1)]	216	267	194
	Control	212	266	208
Weight green tomatoes (lbs.)	PR-51	55	56	97*
	Control	58	66	64*
Total weight tomatoes (lbs.)	PR-51	270	322	291
	Control	269	332	272
Number ripe tomatoes	PR-51	915	767	624
	Control	877	765	668
Average weight of ripe tomatoes (lbs.)	PR-51	0.24	0.35	0.31
	Control	0.24	0.35	0.31
Weight of ripe tomatoes in first picking (lbs.)[(2)]	PR-51	0.8	0.5	10.3
	Control	0.6	0.3	12.1

* Differences resulting from PR-51 treatment were significant at .05 level of probability

1. Applied to Stokesdale at 75 lbs. per acre; applied to Moscow and hybrid at 45 lbs. per acre
2. Used to indicate earliness of maturity

These data were compared by analysis of variance (2). The hybrid type tomato showed a significant increase in weight of green tomatoes left on the vines after the last picking. The other varieties showed no significant differences in earliness of maturity, size of ripe tomatoes, yield of ripe tomatoes, yield of green tomatoes, or total tomato yield.

PR-51 and Moisture on Tomatoes. An experiment was set out on Salt Lake silty clay loam to test the effect of PR-51 on growth and yield of tomatoes at two moisture levels. Permeability of this soil is satisfactory for agricultural production although infiltration rate does depend on the dryness of the soil when water is applied. When dry the soil shows cracks that are often an inch wide at the surface and 6 to 8 inches deep. Severe surface crusts are formed under some conditions, and soil is easily compacted. Treatment consisted of one plot 8 feet by 45 feet which was treated with PR-51 at the rate of 40 pounds per acre and another plot of equal size to which no PR-51 was applied. This treatment was replicated 6 times in a randomized block design at each moisture level. The soil was treated by broadcasting PR-51 on the surface. The treatments were made and VR-Moscow type tomato plants were set out June 26, 1953. The wet plots were irrigated when tensiometers at 6-inch depths reached a tension of 400 cms. of water. At this point about one-third of the readily available water had been removed from the root zone of the plants. The medium-dry plots were irrigated when the moisture tension reached 2 atmospheres. At this point about 60 percent of the available water had been removed. The ripe tomatoes were picked and weighed three times, and then the green tomatoes were picked and weighed.

Table 2 shows results of the PR-51 moisture experiment. The

Table 2. Effect of PR-51 and moisture on earliness, yield, and size of tomatoes on Salt Lake silty clay loam in 1953

Item tested	Treatment	Moisture treatment	
		high	medium-low
Weight ripe tomatoes (lbs.)	PR-51 (1)	68	32
	Control	68	42
Weight green tomatoes (lbs.)	PR-51	302	186
	Control	289	201
Total weight tomatoes (lbs.)	PR-51	370	218
	Control	357	243
Number ripe tomatoes	PR-51	210	130
	Control	229	165
Average weight of ripe tomatoes (lbs.)	PR-51	0.32	0.25
	Control	0.31	0.26
Weight of ripe tomatoes in first picking (lbs.) (2)	PR-51	1.0	0.5
	Control	0.7	0.1

1. Applied at 40 lbs. per acre
2. Used to indicate earliness of maturity

effects of PR-51 were not significant at either moisture level on: earliness of maturity, size of ripe tomatoes, yield of ripe tomatoes, yield of green tomatoes, or total tomato yield.

<u>Soil Additives on Various Crops</u>. A third experiment was set out on Salt Lake silty clay loam to test the effect of 14 soil additives on

the germination and yield of 11 crops. The soil is ideal for testing seedling emergence since, as previously stated, it has a tendency to form heavy crusts. The soil was not cropped in 1952 but was clean cultivated for the control of weeds. It was in good tilth and showed residual structural effects from a previous grass sod.

Thirteen soil additives and a control plot were set out at random on plots 6 feet by 16 1/2 feet. This was replicated four times. The materials were measured onto the plots in the amounts indicated in table 3, and one-half of each plot was sprayed with PR-78 at the rate of 40 pounds per acre. The plots were then double tilled with a roto-tiller to a depth of 5 inches. The entire area was disced once with a disc harrow and seeded on April 26, 1953.

The crops used were: carrots, onions, parsnips, sugar beets, lettuce, tomatoes, reed canary grass, sweet clover, ladino clover, alfalfa, and table beets. Single rows were seeded in a random order in soil that had received the previous treatments. The soil was irrigated when tensiometers at one foot depths indicated that the soil moisture was at a tension of 500 cm. of water.

The number of seedlings emerging was counted soon after planting to determine the effect of treatment on earliness of emergence. A second emergence count was taken to determine the effect of treatment on stand. Each crop was also weighed at the time of harvest to detect differences in yield resulting from treatment.

The effect of fourteen soil additives on earliness of germination,

Table 3. Description of soil additives used on Salt Lake silty clay loam in 1953

No.	Symbol	Chemical constitution	Physical condition	Application	
				Method	Rate
1	B	Sodium salt of styrene maleic anhydride copolymer	Water soluble powder	Spray	0.025
2	WVA	Sodium salt of tall oil	Paste	Spray	0.1
3	BRQ 12582	Phenol-formaldehyde copolymer	Insoluble powder	Dust	0.1
4	BRQ 12583	Phenol-formaldehyde copolymer	Insoluble powder	Dust	0.1
5	M-1	Ethyl methoxy polysiloxane	Viscous fluid	Spray	0.025
6	C	Hexenyl alkenyl succinate	Insoluble fluid	Spray in rows	0.1
7	K700WF	Salt of polyacrilic acid	Wettable flake	Spray	0.05
8	K700S	Salt of polyacrilic acid	20 percent solution	Spray	0.25
9	PR-51	Sodium salt of dodecyl benzene sulfonate	Soluble powder	Dust	0.002
10	PR-78 & sawdust	Amine of dodecyl benezene sulfonate, mostly cellulose	Moist granules	Hand in rows	0.2
11	VAMA	Vinyl acetate maleic acid copolymer	Dry powder	Dust	0.1
12	HPAN	Hydrolyzed poly acrilonitrile	Dry powder	Dust	0.1
13	IBMA	Half ammonium-half amide salt of isobutylene maleic acid	Dry powder	Dust in rows	0.1
14	Control				
P	PR-78	Amine of dodecyl benzene sulfonate	Viscous	Spray	0.002

is shown in table 4. Analysis of variance (2) showed significant differences in rate of germination for only 2 crops, sweet clover and ladino clover. An L. S. D. was computed for each crop, and each conditioner was compared with the control. The following differences in rate of germination were significant: B increased parsnips and retarded lettuce; BRQ 12583 retarded onions ladino clover, and alfalfa; C retarded onions and ladino clover; K700WF increased reed canary grass; VAMA retarded ladino clover. This makes 2 increases and 7 decreases in rate of germination as a result of additive treatment.

Table 5 shows the effect of soil additives on final emergence to be somewhat different. Significant effects of treatments were observed on reed canary grass, ladino clover and carrots. An L. S. D. showed significant differences in stand between the control and the following additives: BRQ 12582 decreased onions; BRQ 12583 decreased carrots, reed canary grass, and ladino clover; M-1 decreased ladino clover; C decreased ladino clover; K700WF increased reed canary grass and decreased ladino clover; K700S decreased ladino clover; VAMA decreased carrots. Additives caused one increase and nine decreases in the final number of seedlings emerging.

The stand of all crops except tomatoes was excellent and adequate for maximum growth on all plots. The reason for the excellent stand was probably related to the weather conditions. On May 18, two days after seeding, a period of wet, cool weather began and lasted until May 29. During this period adequate water was always available and

Table 4. Effect of soil additives on the number of seedlings emerged soon after planting for various crops grown on Salt Lake silty clay loam [1]

Soil additives	Crops										
	Carrots	Onions	Parsnips	Sugar Beets	Lettuce	Tomatoes	Reed Canary Grass	Sweet Clover*	Ladino Clover*	Alfalfa	Table Beets
B	1.8	1.6	3.3*	4.9	22.3	Not	3.9	14.8	5.9	5.6	0.4
WVA	0.6	1.4	2.3	4.6	22.7	Counted	5.5	9.2	6.9	3.8	0.3
BRQ 12582	2.1	5.5	0.6	4.2	27.5		2.3	8.3	4.4	3.8	0.4
BRQ 12583	0.4	0.4*	0.1	2.6	11.4		0.4	12.8	1.9*	1.8*	0.0
M-1	2.4	1.2	1.1	4.9	28.4		2.1	15.8	7.4	4.8	0.1
C	2.6	0.5*	1.3	4.0	19.4		3.8	9.2	3.3*	5.5	0.1
K700WF	2.4	1.8	0.9	5.3	22.6		6.4*	10.7	7.3	3.2	0.3
K700S	2.6	1.6	1.4	5.7	24.0		5.1	18.3	11.1	7.3	0.4
PR-51	3.5	2.4	0.9	5.4	24.0		5.0	15.9	7.8	5.3	0.5
PR-78 & sawdust	2.9	0.9	0.1	5.8	20.6		5.2	19.4	9.0	5.8	0.3
VAMA	0.8	1.0	0.2	5.4	25.6		1.1	5.1	3.1*	7.0	0.0
HPAN	3.4	1.2	0.9	5.8	24.4		4.9	15.7	6.6	5.7	0.2
IBMA	1.9	2.3	0.7	6.9	14.3		2.7	13.9	6.3	6.1	0.1
Control	0.8	2.3	0.4	4.9	26.2		2.3	15.9	8.1	7.2	0.3
Average	2.0	1.4	1.0	5.0	22.4		3.6	13.6	6.4	5.2	0.2
Standard error	1.6	0.8	1.1	1.3	8.1		1.9	5.3	2.3	1.8	0.2

* Differences resulting from additives are significant at .05 level of probability

1. Average number of plants per foot of row

Table 5. Effect of soil additives on the final number of seedlings that emerged for various crops grown on Salt Lake silty clay loam in 1953 [(1)]

Soil additives	Crops										
	Carrots*	Onions	Parsnips	Sugar Beets	Lettuce	Tomatoes	Reed Canary Grass*	Sweet Clover	Ladino Clover*	Alfalfa	Table Beets
B	13.1	4.9	8.4	6.1	25.0	5.0	11.9	40.4	24.8	11.2	2.2
WVA	9.9	4.6	6.0	4.2	25.5	5.3	11.4	38.0	24.5	11.6	2.1
BRQ 12582	14.3	4.2*	6.4	4.9	35.3	4.3	11.1	32.6	21.9	12.3	2.4
BRQ 12583	8.6*	3.7	3.9	4.0	14.8	5.1	6.3*	38.8	12.3*	7.3	1.4
M-1	10.2	4.3	4.7	6.4	28.7	4.9	8.9	40.7	19.9*	10.7	1.7
C	11.3	4.5	5.1	3.7	17.6	5.0	13.1	39.1	19.1*	9.2	1.1
K700WF	11.9	5.4	5.6	6.6	24.6	5.4	18.2*	36.5	18.2*	12.7	1.4
K700S	14.1	4.8	5.6	7.9	20.4	5.8	12.3	43.9	18.6*	12.1	1.4
PR-51	14.0	6.2	4.8	5.5	30.6	5.5	14.8	38.9	22.8	13.4	2.1
PR-78 & sawdust	11.6	5.4	4.0	5.5	15.6	5.9	9.6	47.8	22.3	12.1	1.8
VAMA	8.6*	5.5	3.8	6.3	24.6	7.5	10.3	32.9	21.3	13.4	2.0
HPAN	15.0	5.7	4.4	6.2	23.1	5.1	14.2	43.8	24.8	10.6	0.6
IBMA	11.4	5.7	6.1	6.5	22.6	7.3	11.3	39.3	22.4	9.9	1.4
Control	13.3	7.2	5.8	5.6	27.9	5.8	11.5	39.4	26.3	12.4	1.9
Average	11.9	5.1	5.4	5.7	24.0	5.6	11.8	39.4	21.4	11.4	1.7
Standard error	2.4	1.5	2.5	1.2	8.2	0.9	2.1	4.9	3.2	2.8	0.7

* Treatment differences are significant at .05 level of probability

1. Average number of plants per foot of row

the formation of surface crusts were effectively prevented. Under conditions of this kind excellent germination and emergence of all the crops except tomatoes could be expected. The poor germination of tomatoes probably resulted from the cool weather.

In Utah and other parts of the arid west, rain is not uncommon in early spring. However, later in the season there are few rain storms. Since stand on the early planted plots was uniform, they were ideal for determining the effect of additives on yield. However, a second set of plots should have been treated and planted in late spring or early summer to determine the effects of additives on rate of germination and total emergence. A crust could easily have been obtained at this season by sprinkling and allowing the soil to dry.

Table 6 shows the effect of additives on yield. Ladino clover was the only crop that showed a significant difference in yield as a result of additives treatment. The additives which caused a yield significantly different from the control when compared by an L. S. D. were: B decreased reed canary grass and increased ladino clover; C decreased sugar beets and table beets; HPAN increased sweet clover and ladino clover; IBMA increased lettuce. Treatment with additives caused four increases and three decreases in yield. Table 7 shows a decrease in the yield of reed canary grass as a result of PR-78 treatment.

The plots used in this experiment were so small (having only one 6-foot row of each crop) that the variation among treatments was larger than is desirable. It would have been much better to have

Table 6. Effect of soil additives on yield of various crops grown on Salt Lake silty clay loam in 1953

Soil additives	Crops[1]										
	Carrots	Onions	Parsnips	Sugar Beets	Lettuce	Tomatoes	Reed Canary Grass	Sweet Clover	Ladino Clover*	Alfalfa	Table Beets
B	5.29	3.84	4.58	12.56	6.89	8.75	0.93*	2.81	0.83*	4.34	3.75
WVA	6.43	3.22	5.06	12.41	6.08	3.51	1.15	2.71	0.41	2.81	3.48
BRQ 12582	8.11	3.22	6.63	12.73	6.13	4.51	1.26	2.68	0.53	3.37	3.50
BRQ 12583	7.25	2.82	4.88	12.98	6.55	8.86	1.34	2.84	0.38	3.03	2.63
M-1	5.44	3.59	3.75	14.09	6.05	5.14	1.25	2.79	0.52	3.79	3.43
C	7.74	2.47	3.39	10.93*	5.54	9.86	1.61	2.19	0.38	2.72	1.93*
K700WF	6.36	2.98	3.85	12.98	7.84	8.02	1.49	2.79	0.52	4.27	3.71
K700S	7.29	3.22	5.11	13.69	6.84	7.10	1.54	2.56	0.64	3.95	2.28
PR-51	8.55	3.66	3.44	14.14	6.04	4.04	1.13	2.90	0.63	4.58	3.53
PR-78 & sawdust	8.33	2.31	3.78	14.34	7.65	7.37	1.53	3.11	0.52	4.54	3.95
VAMA	7.60	3.90	3.46	13.10	6.88	4.67	1.26	3.18	0.56	3.50	3.15
HPAN	8.91	3.68	5.01	14.83	7.50	5.81	1.38	3.51*	0.93*	4.85	2.80
IBMA	9.88	4.61	4.99	13.84	7.98*	7.26	1.29	2.86	0.59	4.44	3.56
Control	7.04	2.95	4.56	14.59	6.09	7.01	1.78	2.93	0.53	4.18	3.80
Average	7.44	3.31	4.46	13.37	6.72	6.57	1.35	2.85	0.57	3.88	3.25
Standard error	1.66	1.00	1.33	1.08	0.86	3.23	0.38	0.27	0.14	1.07	0.72

* Treatment differences are significant at .05 level of probability

1. Yield in pounds per plot

Table 7. Effect of PR-78 on yield of crops grown on Salt Lake silty clay loam in 1953

Crops	Yield		Standard error
	PR-78	Control	
	(lbs.)	(lbs.)	(lbs.)
Carrots	7.39	7.50	0.23
Onions	3.31	3.35	0.17
Parsnips	4.31	4.61	0.19
Sugar beets	13.58	13.16	1.90
Lettuce	6.55	6.89	0.61
Tomatoes	6.75	6.37	0.55
Reed canary grass	1.30	1.41*	0.05
Sweet clover	2.84	2.85	0.02
Ladino clover	0.55	0.58	0.03
Alfalfa	3.85	3.90	0.05
Table beets	3.13	3.37	0.21

* Treatment differences are significant at .05 level of probability

deleted some of the additives from the experiment and had larger plots of the additives remaining.

Laboratory Experiments

A series of experiments were carried out in the laboratory to test the effect of soil additives on various physical properties of the soil.

Preparation of Materials. Five cores 6 inches long and three-fourths inch in diameter were taken from each row. The 55 cores from each plot were combined to form a soil sample. These samples were taken the first week in August, dried, passed through an ore crusher, and sieved through a 2 mm. round hole sieve. The samples were stored and physical measurements were made on them in 1954.

Aggregates were prepared in the laboratory in 1954. Many of the additives used in the field studies in 1953 were no longer being manufactured; so aggregates were prepared from only part of these materials.

Salt Lake silty clay loam was used in preparing the aggregates. Since the soil was well aggregated it appeared necessary to grind it so that the effect of the conditioners would be masked by the structure already present. Four kilograms of soil were saved so that the natural aggregates might be compared with the artificially prepared aggregates. The structure of the remaining soil was destroyed by grinding it fine enough to pass through a 0.6 mm. sieve. The conditioners -- B, K700WF, VAMA, HPAN, and IBMA -- were added to 4 kilogram portions of the ground soil by the methods and rates shown in table 3.

The sprays were applied with an atomizer while the soil was continuously stirred. The powders were thoroughly mixed with 50 grams of soil. This was added to 500 grams of soil and thoroughly combined before mixing with the remainder of the 4 kilograms. This soil was then wet with an atomizer while being stirred. Artificial aggregates were also prepared by the same procedure except that no conditioner was added. After the sample had been wet to approximately field capacity, they were allowed to dry in a constant temperature room at $24 + 1/2^{\circ}$ C.

Crusting. Determining the modulus of rupture of soil briquets prepared in the laboratory has been suggested as a possible index of the crusting which might occur in the field (17). Modulus of rupture was, therefore, determined on briquets made from field samples using L. A. Richards technique (17). Table 8 shows there were some differences, but the variability was so high that none of the differences were significant.

Table 8. Effect of soil additives on modulus of rupture of Salt Lake silty clay loam

Soil Additives	Modulus of Rupture (dynes/sq. cm.)	
	PR-78	Control
B	420	435
WVA	551	568
BRQ 12582	635	605
BRQ 12583	645	547
M-1	487	413
C	559	640
K700WF	517	584
K700S	508	555
PR-51	536	412
PR-78 & sawdust	350	589
VAMA	537	459
HPAN	461	545
IBMA	500	459
Control	534	523

Briquets were also prepared from the 1-2 mm. fraction of laboratory-prepared aggregates. L. A. Richards technique (17) was used except the briquets were wet by spraying them with an atomizer kept at a distance of 6 cm. from the soil surface.

Modulus of rupture data were not obtained, however, since the crusts formed on the VAMA and natural briquets were so thin that they were too fragile to pick up. The IBMA did not crust at all and when the form was removed from the briquet, aggregates rolled out on the edges just as if the soil had never been wet. Artificial, B, HPAN, and K700WF all formed similar crusts except the crusting appeared a little more severe on artificial. Figure 5 shows six disks of the 2-3 mm. fraction of the laboratory samples. These disks received the same treatment as the briquets. The differences in crusting mentioned above can easily be observed in this figure.

Water Holding Capacity. To test whether the quantity of water available to plants was affected by field treatment, 1/3-atmosphere and 15-atmosphere percentages were determined on the field samples. The 1/3-atmosphere percentage was run on a porous plate (13) and the 15-atmosphere percentage was run on pressure membrane apparatus (15) using the techniques described by L. A. Richards. Table 9 shows the results of this study. There were no differences resulting from treatment.

Permeability. An experiment was designed to evaluate the moisture conductivity in unsaturated soil. A system was set up following Sterling Richards procedure (15) with the following modification. In filling the plastic tube the lower part of the assembly was placed on a table with the plastic tube in a vertical position, and rubber stoppers were placed in the holes made for tensiometers. A tremie was rested on the bottom

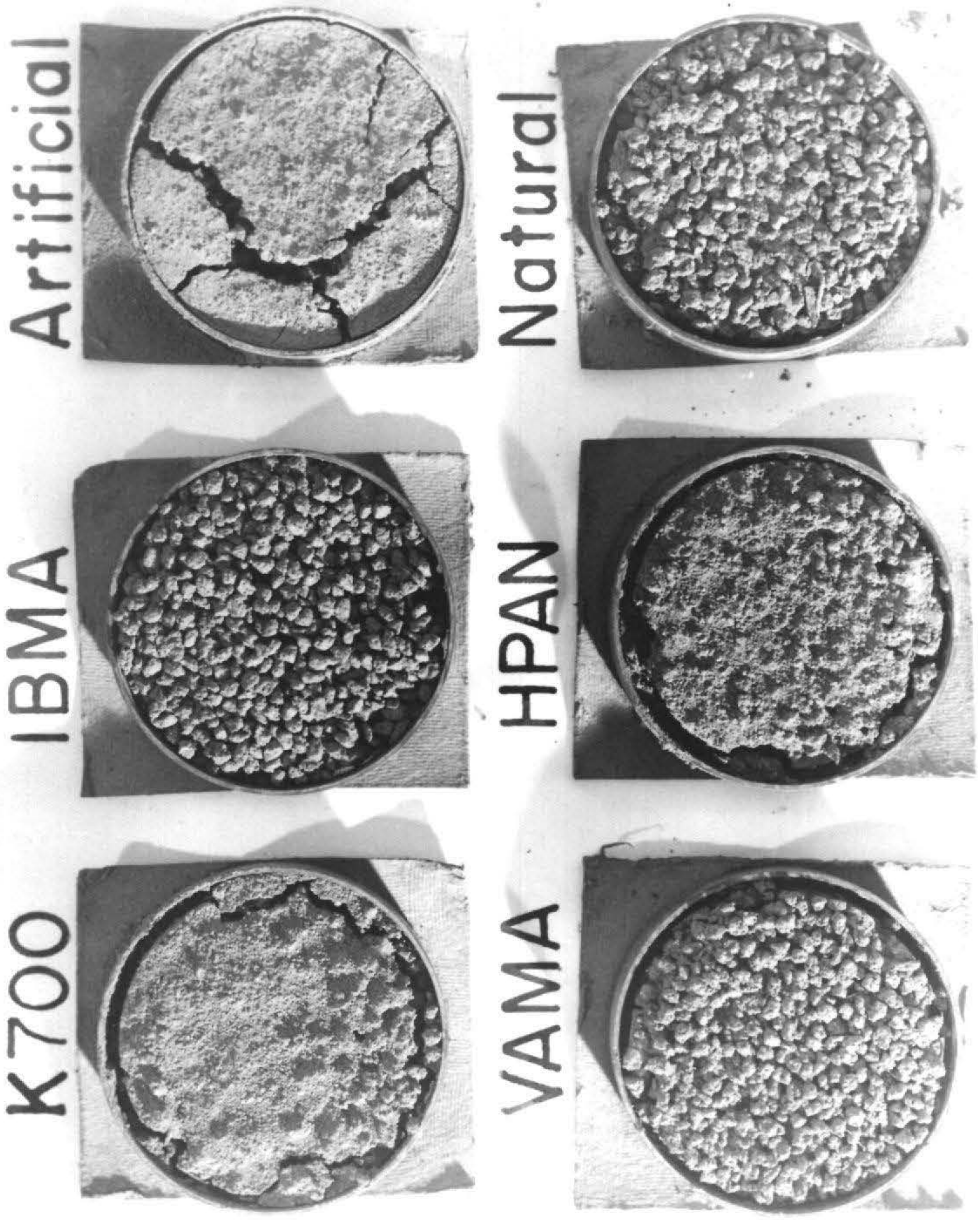


FIGURE 5. Crust developed on 1-2 mm. aggregates after spraying with an atomizer

Table 9. Effect of soil additives on 1/3-atmosphere and 15-atmosphere percentages from Salt Lake silty clay loam

Soil Additives	1/3-atmosphere		15-atmosphere	
	PR-78	Control	PR-78	Control
B	28.64	28.56	15.23	15.32
WVA	28.91	28.96	15.55	15.92
BRQ 12582	29.32	28.75	15.70	15.46
BRQ 12583	28.84	28.98	15.45	15.71
M - 1	28.20	29.26	15.38	15.54
C	29.50	29.06	15.55	15.54
K700WF	28.80	28.93	15.54	15.56
K700S	29.24	28.91	15.35	15.48
PR-51	28.93	28.92	15.35	15.25
PR-78 & Sawdust	29.14	28.90	15.17	15.53
VAMA	29.18	29.25	15.94	15.94
HPAN	29.04	28.64	15.46	15.54
IBMA	29.14	28.92	15.62	15.75
Control	29.17	29.15	15.64	15.62

of the assembly and filled with an air-dry field sample. The tremie was then moved around inside the plastic tube while rising continuously so that a uniform, smooth filling was obtained. The assembly was then dropped once onto the table from a height of three-fourths inch. Soil was then added to fill and the surface was struck off level with the top of the plastic tube. An unglazed ceramic plate was placed on top of the soil, and the cover was tightened on. The entire assembly was tipped end for end and tapped twice on the side of the plastic tube with the palm of the hand. This was done to insure good contact between the soil and the ceramic plate. The assembly was then placed in a horizontal position and allowed to wet under a tension of 5 cm. of water. After 2 days the wetting was proceeding so slowly that it was decided to wet under a head of 30 cm. of water. The wetting still progressed slowly; it was estimated that 12 days would be required to wet the sample. Since the transmission of the ceramic plate was slow, there was a possibility that the rate of transmission of the soil would be limited by the plate; and the conductivity value thus obtained would not be representative of the soil.

A second soil column was then set up by the above technique using a disk of wet millipore filter[3] to replace the ceramic plate. The millipore was backed by a disk of blotter paper and a disk of 80 mesh copper screen. The soil was wet under a tension of 5 cm. of water until the wetting front was within one cm. of the end (requiring about 2 days). The tension was then increased to 30 cm. of water. After 12 hours at the new tension, the rubber stoppers were removed and holes cut in the soil with a cork borer for insertion of tensiometer cups. When the soil water was at a tension of approximately 30 cm. of water, as shown by the

3. Millipore filter is a sheet material approximately 140 microns thick composed of cellulose esters. The structure defines uniform pores of a volume equal to between 80 and 85 percent of a total volume. It was chosen to replace the ceramic plate used by Richards because of its extremely high water transmission (approximately 72 ml. of distilled water at 21° C will pass each square cm. per minute at a differential in pressure of 70 cm. Hg.) It was also considered that the small pores (0.45 microns) would provide a barrier to air, due to surface tension, when filled with water. The material was very brittle and cracked when the cover was tightened down on the dry material. When wet, the millipore filter becomes somewhat elastic and is easily handled. The millipore filter was obtained from Lovell Chemical Co., 36 Pleasant Street, Watertown 73, Mass.

tensiometers, the tensiometer readings were recorded and a drying cycle was begun. The tension at the millipore water interface was created by connecting the water reservoir to a vacuum of 510 ± 5 mm. of mercury. The vacuum was maintained by connecting the vacuum pump to a Thermocap Industrial Control Relay[4]. The control electrode consisted of a copper wire loop placed around one arm of a mercury manometer inserted in the vacuum line. The Thermocap Relay was adjusted so that, when the mercury level of the manometer reached the wire, the relay turned off the vacuum pump, when the mercury level dropped below the wire the relay turned the vacuum pump on.

The millipore was sealed to the water chamber between two rubber gaskets. When the top was tightened on the assembly, the rubber gaskets stretched the millipore between them. After a few days the millipore filter dried out between the rubber gaskets and became brittle and cracked. This broke the seal and caused leaks.

A third system was then tried in which the soil was wet to within 1 cm. of the end of the tube using millipore filter. The millipore and

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4. The Thermocap Relay is a measuring and controlling instrument that is extremely sensitive to minute changes in electrical capacity. When materials move in the proximity of a fixed electrode there is a change in capacity. The Thermocap can be used to measure these motions or effect the control of electrical power from their movement without contacting the materials. The Thermocap Relay was obtained from Niagara Electron Laboratories, Andover, New York.

backing were then replaced with a ceramic disk. The tension was reduced to 30 cm. of water and the above procedure was followed. The tensiometer cups had been cemented to the copper section of the tensiometer with 3-M Super cement. Upon drying, small air bubbles developed in the cement and as the tension in the tensiometers increased the cemented joints leaked air. No data were obtained from this run and lack of time prevented further runs.

It appeared that some other difficulties might have been encountered. The Salt Lake silty clay loam used in the experiment shrinks when it dries. As the soil dried it shrunk away from the sides of the tube and appeared to have shrunk away from the ceramic plate causing the contact to be poor. One soil column formed a crack and the tensiometers indicated that contact was poor between the two sections of the column.

Stability. Recently an alcohol-water method of measuring soil aggregate stability was developed by W. H. Gardner[5]. His work indicated that the method was as good if not better than the wet-sieving technique.

The modified procedure used to measure the stability of laboratory prepared aggregates involves placing twelve 3-5 mm. aggregates from the same treatment in the depressions of a spot plate. Twelve different alcohol-water mixtures of concentrations shown in Table 10 are then dropped into the depressions. The aggregates are allowed to sit in this mixture for 10 minutes. Then the first mixture in which the aggregate

5. Unpublished report of Western Region Soil Conditioner Conference Pullman, Washington, June 21, 1954

Table 10. Alcohol-water mixtures used in measuring aggregate stability in 1954 laboratory experiment

Mixture number	Percent C_2H_2OH	Percent water
1	0	100
2	6	94
3	12	88
4	18	82
5	24	76
6	30	70
7	36	64
8	48	52
9	59	41
10	71	29
11	83	17
12	95	5

remains flocculated is used to indicate the aggregate stability, a higher water-alcohol ratio indicating more stability.

Seven spot plates were set out containing aggregates from the seven treatments. Solution 1 was added to each spot plate in succession. Solution 2 was then added and so on to Solution 12. This procedure required 2 1/2 minutes. During the interval from 7 to 15 minutes after the last solution was added, there was no detectable difference in aggregate breakdown. It was, therefore, assumed that the difference in time between adding alcohol-water solutions of different concentrations did not affect the observations. The procedure was replicated 8 times with time of application being the variable between replicates.

The results of the alcohol-water method were highly significant. It is somewhat surprising to note the high reproducibility of this technique since one 4 mm. aggregate is used to represent the entire population. A divergence did appear in the natural aggregates in replicate 2. The aggregates in solutions 1 and 3 were dispersed but the aggregate in solution 2 remained stable. Table 11 shows that IBMA

Table 11. Alcohol-water ratings of soil aggregates which were treated with soil additives

Soil additive	Ratings (1) **								
	Replicates								
	1	2	3	4	5	6	7	8	Mean
Artificial	10	9	10	9	10	9	10	10	9.6
B	8	9	9	10	9	9	10	9	9.1
HPAN	9	9	9	9	9	9	9	8	8.9
K700WF	8	8	8	8	9	8	9	9	8.4
VAMA	1	2	4	3	3	1	2	2	2.3
Natural	1	4	1	2	3	2	3	1	2.1
IBMA	1	1	1	1	1	1	1	1	1.0

** Treatment differences significant at .01 level of probability
1. Ratings are based on mixture numbers shown in table 2.

is the only conditioner that formed more stable aggregates than those which occur naturally in the field. The VAMA treated aggregates were about equal in stability with the aggregates occurring naturally. Aggregates prepared with B, HPAN and K700WF were only slightly better than those prepared without any conditioner.

DISCUSSION AND CONCLUSIONS

There were 26 significant differences among additive treatments in the field experiments. Of these, seven were increases and 19 were decreases. However, 429 comparisons were made; and at the 0.5 level of probability 21.5 of these comparisons would be expected to appear significant when no actual differences exist. This means that most of the differences were a result of random variations. This is also borne out by the fact that most of the additives did not consistantly cause increases or decreases. However, any difference that did exist would have to be attributed to BRQ 12583 and C since they were the only additives which showed consistant results. BRQ 12583 caused six decreases, and C caused five decreases. Neither additive showed an increase. These decreases may have resulted from plant toxicity.

The alcohol-water studies are valuable in interpreting the reason why so little difference was observed in the field studies. IBMA was the only conditioner tested which caused more stability than was already present in the field aggregates. Therefore, increased stability could not have been expected from incorporation of additives with the soil.

It would be very rare indeed if moisture conditions in the field were ideal for additive application. When conditioners are applied in the laboratory they are thoroughly mixed with dry soil; the optimum moisture is added; and aggregates are carefully formed. This would explain why such large improvements in yield and physical factors have been observed by other workers in carefully controlled laboratory experiments.

The experiments show that additives are valueless and may even be detrimental on soil where structure is not lacking. Further experiments are needed to determine whether they would be of value on a structureless soil. Two things indicate that they would be of little value: (a) although the plots used in the experiments reported here were rototilled in two directions, after the first rain storm there were gelatinous balls of additives with soil particles on the outside; this would indicate that mixing was extremely poor and that thorough mixing in the field would be almost impossible; (b) additives do not form structure; the soil would therefore be stabilized in a puddled mass rather than in aggregates.

If future experiments show that field application of additives can improve a structureless soil, further work would be needed to develop a good soil test that would characterize structure so that soil could be tested and advice given, with a high degree of probability attached, as to whether a soil would respond to additive treatment. The modulus of rupture apparatus will not meet these requirements, but the alcohol-water method has some possibilities.

Although soil structure is generally accepted as being important in crop production, it is quite possible that its importance depends on moisture level, fertility level, etc. Therefore, field tests should be designed to test the effects on crop yields of the interactions between soil additives and other chemical and physical soil factors.

SUMMARY

Soil structure is important in keeping productivity high. In the past, structure was primarily maintained by bacterial decomposition of organic matter in the soil and by the binding action of iron and aluminum oxides. Later, attempts were made to develop synthetic soil conditioners. Of those tested, only the high-molecular-weight polyelectrolytes met the required standards.

Polycations are good flocculation agents but are only moderately effective stabilizers. Polyanions form polymer bridges between molecules by hydrogen bonding. They are not flocculating agents but do bind floccules once they are formed. All conditioners on the market today are of this type. Surfactants, similar to detergents, have proved to be very effective in increasing the rate of water infiltration.

PR-51 showed no differences in yield, size, or earliness of maturity of ripe tomatoes. Tests were also run to determine the effect of 14 soil additives on rate of germination, stand, and yield of 11 small seeded crops. Only two crops showed difference in rate of germination; three crops showed difference in stand; and one crop showed a difference in yield. An L. S. D. was computed for each crop, and each additive was compared with the control. The L. S. D. comparisons showed two increases and seven decreases in rate of germination, one

increase and nine decreases in stand, and four increases and three decreases in yield. Stand was adequate on all crops except tomatoes.

Soil samples from these plots were used to determine modulus of rupture and water holding capacity. Differences were not significant on either of these tests. An experiment was designed to evaluate conductivity values of these samples but no data were obtained.

Aggregates were made using five conditioners. These were compared to natural aggregates and aggregates prepared without conditioner. The evaluations were made by an alcohol-water method, and differences were highly significant.

Most of the differences observed in the field experiments were a result of random variations; however, BRQ 12583 and C appeared to be detrimental. Structure was not lacking in the soil but it is questionable if positive results would have been obtained in a field experiment if the soil had been puddled.

Further work is needed to develop a satisfactory method of evaluating structure and to determine whether field application of additives is effective on structureless soil.

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