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Effect of Drilling Fluid Components and Mixtures on Plants and Soils

Shahnaz Honarvar (Asad Sangabi)

Utah State University

EFFECT OF DRILLING FLUID COMPONENTS AND MIXTURES ON PLANTS AND SOILS

by

Shahnaz Honarvar (Asad Sangabi)

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ABSTRACT

Effect of Drilling Fluid Components and

Mixtures on Plants and Soils

by

Shahnaz Honarvar (Asad Sangabi), Master of Science

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Major Professor: Dr. Raymond W. Miller

Department: Soil Science and Biometeorology

Using greenhouse pot techniques, 32 drilling mud components were tested to see if, at a high rate of addition, they reduced plant growth. Green beans and sweet corn were the test plants. The excellent black, silt loam, slightly acidic, uncultivated Dagor soil (Cumulic Haploxeroll) was used for most tests. Rates used were considered to be abnormal level (high rate) and usual (low rate) amounts that might be added in commonly used drilling muds.

Drilling mud components that caused no observable or statistically significant reductions of plant yield are the following: Super Visbestos, (Asbestos), asphalt, Ben-Ex (a vinyl acetate and maleic anhydride copolymer), bentonite, Cypan (sodium polyacrylate), DME (ethoxylated nonyl phenol), Super Lube Flow (gilsonite), paraformaldehyde, Separan-AP-273 (Dow-made, Shell-supplied polymer), sodium acid pyrophosphate, and sodium carboxymethyl cellulose.

Drilling mud components that barely caused a statistical significant (5 percent level) reduction in yield for only one of the two plant species when added to the soil only and, therefore, is of questionable

hazard to plant growth are the following: Barite ($BaSO_4$), Desco (modified tannin), Drillaid 412 (a filming amine), Drillaid 405 (diesel oil replacement), Kelzan-XC (a xanthan gum), Pipe dope, Ligno (lignite), Soltex (sulfonated asphalt?), and Witconnate 1840 (sulfonated tall oil).

Drilling mud components causing significant reduction in plant growth mostly at only the high addition rates to soil-mud mixtures are the following: Desco (modified tannin?), Dextrid (a non-fermenting starch), pregelatinized starch, Q-Broxin (an iron chromelignosulfonate), Gendril Thik (guar gum), and Kwik-Seal.

The most severe reductions in plant growth were caused by the following materials: Sodium hydroxide at the high rate (which was used in the soil-mud mixture with calcium lignosulfonate and with lignite), diesel oil and potassium chloride at both rates. The latter salt completely inhibited plant germination.

Probable causes for plant growth reductions, photographic and visual records, and a discussion of the results is presented in some detail.

(147 pages)

INTRODUCTION

Interest in maintaining a quality environment has prompted many industries to look at the effects on the environment of their activities. Does the aftermath of oil well drilling on land cause a condition harmful to plant growth? If it does, can the problem be resolved? These questions are not easily answered affirmatively or negatively. The answers depend on the drilling mud (fluid) composition, what plants one wished to grow, what residues of the drilling activity are left on the site, what site alternations are made, and even how soon after drilling it is desired or essential to grow plants.

Many variables relative to plant growth exist at the drilling site. The wastes left on the site will be mostly drilling muds (fluids) and perhaps spilled crude oil. The drilling mud is a slurry of thin mud circulated constantly from a small surface retaining pond down into the drill hole and back out. The mud carries out of the drill hole all of the rock grinding wastes produced by the drilling. The mud contains barite (barium sulfate) to increase its density and thus carrying capacity. Other additives are used to make the mud flow readily, to cause it to gel, to seal porous geologic strata, and for other purposes.

When the drilling is completed, spilled mud may occur over considerable areas. The mud-filled holding pond will be filled in and smoothed. Some of the variations in final site that exist are (1) the amount of mixing of mud with soil done by the clean-up operation, (2) the kinds of materials and their amounts put into the drilling mud,

(3) the nature of the soil on the site, (4) the final proportions of mud to soil, and (5) the climatic environment of the area.

The purpose of this study is to study a small portion of this problem, i.e., what components added to drilling muds affect plant growth and at what approximate concentrations.

Objectives

The objective of this research is to provide information which can be used to select drilling mud mixtures having minimal impact on plants used to revegetate drilling sites. This study was intended to accomplish the following:

1. To determine the harmful effects on plant growth, if any, of various drilling mud components.

2. To determine the harmful effects on plant growth, if any, of various drilling mud components in a base-mud mixture with soil.

REVIEW OF LITERATURE

The literature is very scarce concerning the growth of plants on residues of oil-well drilling activities. However, if the individual drilling fluid components tested are grouped according to chemical composition, a more meaningful approach to the literature is possible. The following categorization of the 32 components used in this study was used as a guide to the review of literature.

1. Materials that might produce soluble salt affects.

   Barite, potassium chloride, sodium acid pyrophosphate, sodium dichromate and sodium hydroxide.

2. Materials of petroleum origin

   Asphalt, diesel oil, pipe dope, Soltex

3. Minerals, coal or related natural solid deposits

   Asbestos, Barite, Gilsonite, and Lignite.

4. Organics of plant origin other than petroleum or coal-like materials

   Desco, Dextrid, Guar gum, Kelzan-XC, Q-Broxin, Kwik-Seal (partly), calcium lignosulfonate, pregelatinized starch, and Witconnate 1840.

5. Synthetic and miscellaneous organic materials

   Ben-Ex, Cypan, Desco, Dextrid, DME, Drillaid 405, Drillaid 412, Kwik-Seal, Paraformaldehyde, Separan AP-273, sodium carboxymethyl cellulose, and Torq-Trim.

The effects of soluble salts

Soluble salts retard plant growth primarily by dissolving in the soil water and, by an osmotic effect, reducing the ease with which plants can absorb the water (Richards, 1954; Thorne and Peterson, 1954; Bernstein, 1964). Although soils do vary in the salt concentration at which plant growth will be reduced, the following general guides have been widely accepted.

Electrical conductivity of the solution extracted from the soil paste made with water	Affect on plant growth on the soil
(mmhos/cm)	
0-2	No plants affected
2-4	Few plants affected
4-8	Many plants affected
8-16	Only salt tolerant plants grow
16 and greater	Few plants grow

Bernstein (1964) attempted a quantitative estimate of yield reduction for a number of crops as related to the salt concentration. He measured salt concentration by conductivity of the saturation soil extract (extract of a soil "paste"). Bernstein listed the following tolerances to salt for garden corn and garden beans:

Conductivity (mmhos/cm) at which plant yield will be reduced:	Garden beans mmhos/cm	Sweet corn mmhos/cm
10 percent	1.4	2.5
25 percent	2.0	4.0
50 percent	3.0	6.0
100 percent (plant death)	5.0	8.0

The values given are still only estimates which will change with factors of soil fertility, climate, and probably many other conditions. However, the values are the closest generalizations that are available.

Solubilities of the materials listed under grouping 1 of this review are indications of their potential as a soluble salt if added in high enough concentrations (See Table 1).

Table 1. Solubilities in cold water of various compounds used drilling-mud components as an estimate of their potential as a soluble salt hazard to plants. (After Lange, 1946)

Material	Solubility in 100 ml of cold water	Comments relative to being a salt hazard
Barite	0.00011 (5°C)	Very insoluble, not a hazard
Potassium chloride	27.6 g (0°C)	Very soluble, a definite hazard
Sodium acid pyrophosphate	4.5 g (0°C)	Soluble, a potential hazard
Sodium dichromate	238.0 g (0°C)	Very soluble, a definite hazard
Sodium hydroxide	42.0 g (0°C)	Very soluble, a definite hazard

Barite obviously does not cause a salinity problem. Sodium of sodium hydroxide will often adsorb to colloids causing a high soil pH. The hydroxide (OH^- ion) will either be neutralized by acids (carbonic) or form insoluble metal hydroxides (of iron, zinc, aluminum, others). Consequently, sodium hydroxide should not constitute a salinity hazard. If it does, the problem of soil pH or exchangeable sodium will probably be greater.

Soluble salts in the soil solution not only hinder water uptake but also may interfere with nutrient balance or uptake. Such affects are difficult to assess unless visual symptoms indicate abnormal growth. The visual symptoms of salt damage on plants or seeds are given by Reeve and Fireman (1967):

1. Slowed germination.
2. Reduced growth.
3. Deep blue-green foliage or, in more severe damage, yellowing and whitening of leaves.
4. Wilting appearance and leaf cupping sometimes followed by dying, if severe enough.
5. Leaf tip burn, necrotic areas and marginal firing of the leaves.

<u>Materials of petroleum origin</u>

The components or mixtures of petroleum origin include asphalt, diesel oil, pipe dope and Soltex. A number of authors have discussed toxicities to plants of various oils (Carr, 1919; Tucker, 1936; Crafts and Reiber, 1948; Johnson and Haskins, 1952; van Overbeek and Blondeau, 1954; Baker, 1970; and numerous others).

In general, the smaller the hydrocarbon molecule is in the "oil," the more toxic the "oil" is to plants (and presumably to seeds ready to germinate). Baker (1970) tabulates the following approximate composition of basic cuts of crude oil.

Cut or separated part	Approximate boiling range	Approximate molecular size
Refinery gases	Up to 25°C	C_3 to C_4
Gasoline cut	40 to 150°C	C_4 to C_{10}
Naptha	150 to 200°C	C_{10} to C_{12}
Kerosene	200 to 300°C	C_{12} to C_{16}
Gas oils	300 to 400°C	C_{16} to C_{25}
Residual oils	Above 400°C	Above C_{25}

Diesel oil would be a further refined, high-boiling kerosene or low-boiling gas oil in this tabulation. Both asphalt and Soltex are high-boiling residual oils (tars). The petroleum base of pipe dope is probably also material of carbon chains longer than C_{20}.

Of these four materials (diesel oil, asphalt, Soltex and pipe dope), only diesel oil has toxic carbon compounds, unless the others contain small percentages of other materials as contaminants. Hydrocarbons within the boiling range of 150-275°C, which includes much of the diesel oil fraction, are one of the most toxic petroleum fractions because of their residual nature. Gases quickly evaporate. Since fresh crude oil or newly separated fractions often contain contamination by low-boiling compounds, "aged" materials are less toxic than fresh materials.

Besides the chain length (or boiling-temperature fraction) the type of molecule affects the toxicity. Toxicity to plants increases in this series: paraffins--naphthenes and olefins--aromatics. Many compounds in the gasoline are very toxic.

The precise action of oils on growth is mostly speculation. The oil is known to penetrate cells and plant organs in general. Some scientists have speculated that the oil penetrates the "oil-miscible" cell membranes eventually destroying their semi-permeable nature. In contrast, the asphalt-like residues are not as toxic to plants and, in fact, may be somewhat beneficial to plants (Carr, 1919; Galtsoff et al., 1935; Mackin, 1950).

It seems clear that, of the materials of petroleum origin used in this study, only diesel oil should have strongly detrimental effects. The materials in diesel oil are volatile and degradable and should be dissipated within a few months or few years at the longest. The principal effect may be making the soil temporarily water-repellent.

Minerals, coal or related natural solid deposits

The minerals, asbestos and barite, and the coal-like organics, gilsonite and lignite, are included in this group. Asbestos is a common, essentially-insoluble mineral of composition $H_4Mg_3Si_2O_9$. Although its fiber-like particles have caused human health problems when inhaled into the lungs over long exposures, the material will not affect plants any appreciable amount, favorably or otherwise. Barite ($BaSO_4$) contains no known toxic elements. Gilsonite, a fossil resin, and lignite are both high-boiling-point organics and, unless they contain a small amount of some toxicant formed during degradation, they should not affect plant growth. They might be of some benefit as a source of energy to microbes and thereby promote the release of nutrients by decomposition of soil organic matter.

Organics of plant origin other than petroleum or coal-like materials

The plant-origin materials are starches, gums, extracts from woods, and a mixture of materials. (See a detailed listing of materials under Experimental Procedures, Materials and Soils.)

Starches: Pregelatinized starch, Dextrid (non-fermenting starch)

Gums: Kelzan-XC, Guar gum

Wood extract: Witconnate 1840 (resin acids and fatty acids)

Other: Kwik-Seal (black walnut shells, rubber-tire cord, and vegetable fibers); Desco (said to be a modified tannin).

Little literature about the effect of these materials on plant growth is available. It is suspected that at least some of the detrimental effects which might be shown by these materials may be the additives, preservatives, or incidental compounds produced in small amounts during processing. One suggestion of toxicity in gums was the possibility of formation of furans formed by heating.

Guar, the plant from which guar gum is obtained, has been tested as a green manure crop; it has been selected as a green manure to mix with other plants (Subbiah and Mannikar, 1964). The gum, a long-chain sugar galactose and a mannose chain called mannan will hydrolyze to simple sugars slowly and it is readily soluble. The large molecule (220,000 molecular weight) becomes highly hydrated in water, and its water solution is about four times more viscous than a similar solution of cornstarch.

Kelzan-XC is a xanthan gum produced by fermentation of a carbohydrate by the bacteria called Xanthamonase compestis. The gum compositions do not contain any known toxin. Perhaps an organic toxin is produced during xanthan gum decomposition.

Because of the tendency of starches and gums to absorb water and to swell, inadequate water availability or poor soil aeration may be a problem in the soil when those materials are present.

Kwik-Seal contains ground black walnut shells. Black walnut has been reported to be toxic to a number of plants by many investigators (Cook, 1921; Schnerderhan, 1927; Massey, 1925; Davis, 1928; and Bode, 1958).

The growth depressing effect of the black walnut tree on other plants is produced by juglone (5-OH-1,4-naphthoquinone). Juglone has been reported to inhibit the oxygen uptake by leaf discs of tomato and bean (Koeppe, 1972). Juglone also causes an inhibition of respiration.

It is presumed that ground walnut shells could be toxic to plants because of respiration. Juglone has been found in various parts of the walnut tree (Massey, 1925; Davis, 1928; and Bode, 1958). Davis (1928) reported that juglone is known to occur throughout all parts of the plant.

The other materials of this grouping are of less definite composition and the presence of even small percentages of toxic organics may exist in almost any of the materials. No data were found in the literature concerning these materials. Fatty acids, part of Witconnate 1840, are esters of glycerol; resins form when molecules produced in a reaction are too large to give ordered crystalline formation. Primarily, fatty acids and resins make up the composition of Witconnate 1840. Their effect on plants is not predictable because the material composition is only vaguely known.

Other organic materials tested

The remaining materials studied are a diverse group of substances. Ben-Ex, similar to large-polymer soil conditioners, should have no detrimental effects; Cypan and Separan AP-273 should be similar. Soil conditioners of this type have been studied extensively as materials to improve the soils physical condition. These materials are not detrimental to plant growth. The effect of vinyl acetate-maleic acid copolymer (VAMA) on growth of various plants in several kinds of soil was studied by Martin and Jones (1954). VAMA, a soil conditioner, increased growth of carrot roots and doubled growth of avacado seedlings but did not affect tomato plants, red beets or orange seedlings. VAMA-treated soils had increased sizes of aggregates.

VAMA also was used by Bernstein and Pearson (1956) as a soil conditioner. A significant ameliorative effect of VAMA occurred at the higher levels of exchangeable sodium, caused persumably by improvement in the physical condition of these soils. At the lowest level of exchangeable sodium, a slight inhibitory effect of VAMA on yields was noted.

The effect of VAMA and HPAN (hydrolyzed polyacrylonitrile) increased the aggregate stability and porosity of soils (Mortensen and Martin, 1956). Corn plants growing in soils treated with these soil conditioners, especially in combination with nitrogen fertilization, were greener, more vigorous, larger, and exhibited very little wilting during drought periods. VAMA and HPAN conditioners, when applied in amounts sufficient to provide a high state of aggregation, were about equally effective in improving water infiltration, reducing soil crusting, and increasing stand and yield of sweet corn on the high-sodium Pachoppa loam (Allison and Moore, 1956). Sherwood and Egibous (1953) reported that a preliminary study involving 0.15 percent of conditioning chemical showed decreased cation-exchange capacity in treated (Ohio) soils.

The lignosulfonates--calcium lignosulfonate and Q-Broxin--are large organic molecules and perhaps should be listed as being of plant origin. It is supposed that companion substances or hydrolysis products may exhibit some toxicities to plants. Many aromatic hydrolysis or other breakdown products may be produced. Lignosulfonates contain phenol-propane molecules which have been found to be toxic to plants (Borner, 1950; Whitehead, 1963; Wange, 1967; Takijima, 1963; and Patrick, 1971).

Drillaid 412, an amine, should adsorb to soil cation exchange sites strongly forming an organic surface coating on clay particles. This action is a common process in organic-clay bonds in all soils. Unless a toxic additive accompanies the amine, the chemical is not expected to be a problem to growing plants. Intermediate decomposition products could be toxic depending on the amine's composition. No information could be obtained from the manufacturer.

Paraformaldehyde, a polymer of formaldehyde, is probably no more toxic than are slow-release nitrogen fertilizers such as urea-formaldehyde polymers. Although formaldehyde is toxic to microorganisms, the polymer hydrolyzes or is broken down by microbial enzymes too slowly to cause a noticeable problem to growing plants.

Sodium carboxymethyl cellulose readily absorbs water. Although it absorbs less water than the gums, it may have similar though lesser swelling than the gums.

Torq-Trim, a relatively simple, water-soluble mixture of aliphatic glycerides and alcohols, should have problems only if other materials which are toxic also occur as contaminants in the material.

Other effects possible

Chromium (Cr). Soils usually contain low amounts of chromium. The higher concentrations are found in soils formed from dark-colored, igneous rocks (ultramafic or ultrabasic), in shales and clays, and in phosphorites (Committee on Biological Effects of Atmospheric Pollutants, 1974). In soils, the average Cr value is less than 100 parts per million (ppm), but values as high as 300 ppm have been found in soils from serpentines (Bowen, 1966). Values as high as 7,600 ppm in soils were found by Lyon et al. (1970).

In general, low concentrations of chromium in water or soil appear to be beneficial or possibly even essential to plants (Committee on Biological Effects of Atmospheric Pollutants, 1974), whereas higher concentrations may be toxic. The effects vary with the species and with the specific chromium compound. Although chromium at 75 ppm in soil was not harmful to orange seedlings, the addition of chromium at 150 ppm was toxic (Committee on Biologic Effects of Atmospheric Pollutants, 1974). Chromium sulfate stimulated the growth of corn seedlings in culture solutions containing chromium at 0.5 ppm, but at 5 ppm and above it inhibited growth. Chromium at 5 and 10 ppm in nutrient solutions produced iron chlorosis and ammonium to be toxic in oat plants, and at 15-50 ppm it was toxic. Chromium (chromic or chromate) at 8 and 16 ppm produced iron chlorosis in sugar beets. At 5 ppm (as chromate) it was toxic to tobacco, and at 10 ppm, it was toxic to corn. Toxicity has been associated with the chromium concentration in the plant tissues. Leaves of tobacco grown on serpentine soil, which normally has a high chromium concentration, has contained chromium at 14 ppm (dry weight) without toxic signs, but at 18-34 ppm toxic effects were visible (Committee on Biologic Effects of Atmospheric Pollutants, 1974). Toxic symptoms appeared in corn when the leaves contained 4-8 ppm and in oats when the leaves contained 252 ppm. Coupin (1900) found that chromate and bichromate salts of potassium, sodium and ammonium to be toxic, and that the bichromate was more toxic than the chromate.

The U.S. National Committee for Geochemistry (1974) reports numerous studies on the effect of Cr on plant growth. Chlorosis (plant yellowing) in citrus occurred in South Africa when it was grown on soils having 1,370 to 2,740 ppm Cr in the soil. Barley, in pot studies, exhibited toxic effects when potassium chromate levels were over 50 ppm but had growth stimulated at concentrations less than 50 ppm Cr. Oats had less tolerance. At 10 ppm Cr as potassium chromate, oat plants were small and most leaves were slightly chlorotic (yellowed); at 25 to 50 ppm, oats were stunted and had narrow, reddish-grown leaves with necrotic (dying) areas. Using water-culture solution, Cr concentrations [as $Cr_2(SO_4)_3$] of 1 ppm stimulated growth, 1 to 10 ppm reduced growth, and 100 ppm almost completely inhibited growth.

Gemmell (1974) claimed that high pH accentuated Cr toxicities but that organic materials such as peat or sewage sludge were helpful in reducing Cr toxicity. This is probably a result of the organic matter-Cr bond which reduces Cr availability for uptake by plants.

Hunter and Vergnaro (1953) suggest 10 ppm Cr in nutrient solution as a toxic level (5 ppm was not). Gemmell (1973) suggests, after plotting yield-water soluble Cr data, that yield is reduced by 20 ppm and larger of Cr.

High pH. The use of high rates of sodium hydroxide increases the mud pH to values toxic to plants. At soil pH values of about 8.5 to 9.0 (8.0 to 8.5 in 0.01 Molar $CaCl_2$), many plants exhibit growth reduction. Besides this effect, sodium causes the deflocculation of the soil producing poor physical conditions. The high soil pH also dissolves organic matter. The final result is a soil which dries into a dark, hard, massive configuration.

EXPERIMENTAL PROCEDURES

This information was collected primarily for use by personnel associated with oil well drilling. The U.S. system is preferred in oil drilling measurements. For that reason, the units "barrels," and the U.S. units are used extensively. For conversion to the metric system, the following are provided:

1 barrel (bbl) = 42 gallons = 159 liters

1 pound (lb) = 0.4536 kilogram (kg) = 453.6 grams (g)

1 pound per barrel (lb/bbl) = 2.85 grams per liter (g/l).

Materials and soils

All chemicals used, except diesel oil, were furnished from various suppliers through arrangements made by Mr. James Lummus of Amoco Products Co., Tulsa, Oklahoma. The materials and suppliers are given in Table 2.

The materials used and their rates are given in Table 3. Each material is described further with whatever detail was known to the writer about it in the following paragraphs. Some materials were not well described by the supplier; some compositions are confidential to the manufacturer. The compositions of some materials were given in handbooks and fliers sent by the companies who supplied the materials.

1. Asbestos or Super Visbestos[R] (chrysotile). Asbestos, a natural mineral is used to increase carrying capacity, flow properties and stabilize gelation of bentonite. The chemical composition ($H_4Mg_3Si_2O_9$) suggests that asbestos should not adversely affect plant growth. Suggested rates from suppliers are about 1 to 3

Table 2. Drilling mud components used in this study to determine possible toxicities of the components to growing plants, and the suppliers of these materials. Diesel oil was purchased locally at a Phillips 66 gas station

Material	Supplier and address
Asbestos Gilsonite	Montello Co. (Mr. Harry Wyatt), P.O. Box 130, Sand Springs, Oklahoma 74063
Ben-Ex Kwik Seal	Rotary Drilling Services, Inc. (Mr. Jerry Hall), P.O.Box 45286, Tulsa, Oklahoma 74145
Asphalt	Oil Base, Inc. (Mr. W. C. McMordie, Jr.) 3625 Southwest Freeway, Houston, Texas 77027
Barite Bentonite	Dresser, Oilfield Products Div. (Mr. R. E. McGlothlin), P.O.Box 6504, Houston, Texas 77005
Dextrid, Q-Broxin, Torq Trim	NL Industries, Baroid Div. (Mr. Jay P. Simpson), P.O. Box 1675, Houston, Texas 77001
DME, Lignite, Guar gum	Milchem (Mr. George W. Bettge), 3920 Essex Lane, P.O. Box 22111, Houston, Texas 77027
Cypan	American Cyanimid Co. (Mr. Sam I. Kohen), Refinery Chemicals Dept., Boundbrook, New Jersey 08805
Calcium lignosulfonate Pregelatinized starch Na-carboxymethyl cellulose	Imco Services (Mr. Doyle Waller), 2400 West Loop South, P.O. Box 22605, Houston, Texas 77027 (CMC was purchased from Drilling Specialties)
Separan AP-273	Bellaire Research Center (Shell Oil) (Dr. M. A. Matovich), 3737 Bellaire Boulevard, Houston, Texas
Desco Soltex	Phillips Petroleum Co. (Mr. H. M. Barrett, through Mr. J. L. Lummus of Amoco), 309 Short Street, Bartlesville, Oklahoma 74004
Kelzan_XC	Kelco Co. (through Mr. J. L. Lummus of Amoco), 8355 Aero Drive, San Diego, California 92123
Paraformaldehyde Sodium acid pyrophosphate Sodium stearate Witconnate 1840	Amoco Products Co. (Mr. James L. Lummus), 4502 East 41st Street, P.O. Box 591, Tulsa, Oklahoma 74102 (Witconnate was supplied by Witco)
Drillaid 405 Drillaid 412	Amoco Chemicals Corp. (Mr. T. L. Ashby, Chemist) Oil Production Chemicals Div., 3815 Dacoma St., Houston, Texas 77018
Sodium hydroxide Sodium dichromate Potassium chloride Pipe dope	Amoco Products Co. (Mr. James L. Lummus), P.O. Box 591, Tulsa, Oklahoma 74102

Table 3. Drilling mud components and their concentrations added to soil to determine the effects of components on plant growth. Rates are given in pounds per barrel (lb/bbl) and in grams per 1.6 liters of soil. For the test soil, about 1.8 kg of soil equalled 1.6 liters

Mud component	Component concentrations: lbs/bbl of soil (proposed)	Component concentrations: Grams/1.8 kg of soil
Asbestos (Super Visbestos^R)	2 and 5	8.18 and 20.5
Asphalt (blown)	1 and 5	4.09 and 20.5
Ben-Ex^R (vinyl acetate polymer)	0.05 and 0.2	0.21 and 0.82
Calcium lignosulfonate	3 and 20	12.28 and 81.9
Cypan^R (Sodium polyacrylate)	0.5 and 1.5	2.05 and 6.14
Desco (modified tannin)	0.25 and 3	1.02 and 12.3
Dextrid^R (starch)	1 and 10	4.09 and 40.9
DME (ethoxylated nonyl phelol)	0.5 and 3	2.05 and 12.27
Diesel oil	1* and 10*	18 and 180
Drillaid 405^R (Diesel oil replacement)	0.2 and 1	0.82 and 4.09
Drillaid 412^R (Filming amine)	0.1 and 0.3	0.41 and 1.23
Gilsonite (a fossil resin) (Super Lube Flow^R)	1 and 5	4.09 and 20.5
Guar gum (Gendril Thik^R)	1 and 6	4.09 and 24.5
Kelzan-XC^R (Xanthan gum)	0.5 and 2	2.05 and 8.18
Kwik-Seal^R	5 and 50	20.5 and 182†
Lignite (Ligco^R)	2 and 10	8.18 and 40.9
Paraformaldehyde	0.1 and 0.3	0.41 and 1.23
Pipe dope	0.1 and 0.3	0.41 and 1.23
Potassium chloride	10 and 30	40.9 and 122.7
Pregelatinized starch (corn starch)	1 and 10	4.09 and 40.9
Q-Broxin^R (a chromelignosulfonate)	3 and 20	12.28 and 81.9
Separan AP-273^R (Shell polymer)	0.5 and 2	2.05 and 8.18
Sodium acid pyrophosphate	0.1 and 0.5	0.41 and 2.05
Sodium carboxymethyl cellulose	0.5 and 1.5	2.04 and 6.14
Sodium dichromate	0.5 and 3	2.05 and 12.3
Sodium hydroxide	1 and 5	4.09 and 20.5
Soltex^R (High-molecular weight hydrocarbon)	0.5 and 2	2.05 and 8.18
Witconnate 1840^R (Sulfonated tall oil)	0.5 and 3	2.05 and 12.3
Torq Trim^R (a triglyceride)	0.5 and 1.5	2.05 and 6.14
Barite	100 and 350	364** and 955**
Bentonite	7 and 35	28.6 and 135#

*Percentage by weight.

†182 g/1.6 kg of soil.

**364 g/1.6 kg of soil and 955 g/1.2 kg of soil.

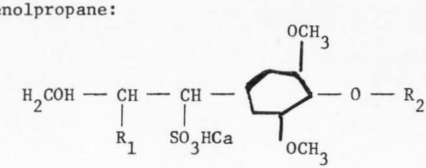
#135 g/1.7 kg of soil.

pounds per barrel (lbs/bbl) of mud or 4.14 to 12.27 g/1.6 l of soil. An oil field barrel is about 42 gal or about 350 lbs of water. Forty-two gallons of the mud mixture will, of course, weigh more.

2. Asphalt (blown). Asphalt is used as a differential sticking agent, shale stabilizer, torque reducer and fluid loss control agent. Prepared by air oxidation of petroleum residium, asphalt is composed of hydrocarbons (saturates, naphthene aromatics, polar aromatics and asphaltene) of molecular weights from 600 to over 4000. Suggested use rates are about 2 percent by weight in the mud. Its composition doesn't suggest it will be detrimental to plant growth; in fact, the small amount of N and S it contains might favor good growth.

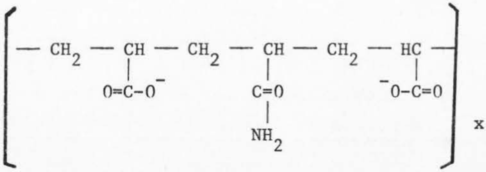
3. Ben-Ex[R]. Ben-Ex is used as a bentonite extender and selective flocculent to remove cuttings from the cycled mud. Originally marketed as a soil conditioner, Ben-Ex is a co-polymer of vinyl acetate and maleic anhydride. These are C,H,O materials with some double bonds. It should not be detrimental to plant growth. Use recommendations are 0.05 to 0.3 lbs/bbl of mud (0.21 to 1.23 g/1.6 l of soil).

4. Calcium Lignosulfonate. This material is used primarily to aid dispersion of clays. Calcium lignosulfonate is a substituted phenolpropane:



The R_1 and R_2 may be additional phelolpropane molecules which has been found to be toxic to plants (Patrick, 1971). The material may chelate (complex) zinc, iron, copper or mamganese, but this should help growth. Use rates are between 1 and 10 lbs/bbl (6.7 g/1.6 l of soil) with an average of about 4 lbs.

5. <u>Cypan</u>^{R} (Sodium polyacrylate). Cypan is used to control fluid loss by forming a clay-polymer network at the bore wall. It is a polymer of acrylonitrile made to the desired molecular weight.

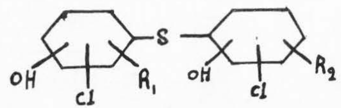


It resists microbial attack and so should not be of much benefit nor detriment to the plant growth. Use rates are 0.1 lb/bbl for flocculating clay, and up to p.25-0.50 lb/bbl, which deflocculates the clay.

6. <u>Desco</u>^{R}. The only data available is from J. L. Lummus (Amoco Products Co.) describing Desco as a "modified tannin neutralized with an alkali." Tannins are large, complex molecules containing ring alcohols, large, ring acids and many less common organics. Rates used in this study are 0.25 and 3 lb/bbl (1.02 and 12.3 g/1.6 l soil). Desco could contain toxic organic substances because of its variety of possible decomposition products.

7. <u>Dextrid</u>^{R} (non-fermenting starch). Dextrid is an adsorptive colloid designed to limit the rate of hydration of shale formations and serve as a filtration control agent for permeable formations. Its composition is described in U.S. Patent 3,256,115. It is a

microbially-stable, gelatinized, starchy flour with from 1 to 5 percent paraformaldehyde and 1 to 5 percent of a compound with the following structural formula:



where R_1 and R_2 are selected chloride (Cl) and H.

Its use rate is 0.5 to 6 lb/bbl (2.05 to 24.5 g/1.6 l of soil) with 2 lb/bbl a typical rate.

8. DME (ethoxylated nonyl phenol). DME is an oil-in-water emulsifier. Its use rate is 1 tp 3 percent (by volume?) normally.
9. Diesel oil. Common diesel oil is an intermediate molecular weight petroleum distillate. Rates used for this study are 1 percent and 10 percent by weight based on the first study, a soil weight of 1.8 kg per pot.
10. Diesel oil replacement (Drillaid 405[R]). Drillaid 405 is a private formula and is unavailable to the writer. It is said to be biodegradable and a nonpollutant. It reduces torque, drag, differential pressure, and aids in hole stability. Use rates are 0.2 to 0.8 lb/bbl (0.82 to 3.79 g/1.6 l of soil).
11. Drillaid 412[R] (Filming-amine, inhibitor). Drillaid 412 is an oil-soluble, water dispersable, organic, filming-amine inhibitor used to retard hydrogen sulfide and oxygen corrosion of drill pipe. This material's composition is a private formula and unavailable, but contains amine salts. The material is used as a coating on drill pipe rather than by treating the drilling mud. The use rate is as a 10 percent solution in water or oil,

but the amounts used depend on pipe length. Rates of 1000 ppm (about 24 lbs/bbl) may be added to mud when drilling through corrosive layers.

12. Gilsonite (Super Lube Flow[R]). Gilsonite is used for mechanical stabilization, chemical inhibition and surface hydration. It is "one of the natural fossil resins." According to information from the supplier, it is listed in "Foods and Drugs" as being safe in food-contact surfaces. It should not be detrimental to plant growth. Use rates are 3 to 5 lb/bbl (12.3 to 20.5 g/1.6 l of soil).

13. Guar gum (Gendril Thik[R]). Guar gum is used as a water viscosifier. It is ground endosperms of Cyamopsis tetragonolobus (a legume called Guar or cluster bean). The molecule is a straight-chain mannan of mannose sugar molecules having branches of single galactose molecules. Its average molecular weight is 220,000. From its composition, there is no indication that it would effect plant growth. Use rates are 0.25 to 3.0 lb/bbl (1.02 to 12.3 g/1.6 l of soil).

14. Kelzan-XC[R]. Kelzan is used as a viscosifier in drilling fluids. It is a xanthan gum produced by fermentation of a carbohydrate by the bacteria Xanthanomas campestis. Rates used in this study are 0.5 and 2 lb/bbl (2.03 to 8.18 g/1.6 l of soil). As a product resulting from bacterial action, it would not be expected to exhibit toxicity to plants.

15. Kwik-Seal[R]. A material added to seal porous geologic formations. Kwik-Seal is a blend of ground walnut shells, two vegetable fibers, two synthetic fibers, and cellophane. The use rate is up

to 25 lb/bbl (102.5 g/1.6 l of soil). Walnut leaves and root extracts have been shown to effect the growth of some plants. Whether the walnut shells, vegetable fibers or other components may be detrimental to plant growth is not predictable.

16. Lignite (Ligco^R). Lignite is used to emulsify oils in water-based drilling fluids and to control filtration rates of these fluids. Ligco is a ground lignite which is a low rank of coal classified between peat and subbituminous coal. Use rate is 1 to 8 lb/bbl (4.09 to 32.7 g/1.6 l of soil). It should not be detrimental to plants.

17. Paraformaldehyde. Paraformaldehyde is used as a preservative in conjunction with starch. It is a polymer represented by $(CH_2O)_x$. The rate used in this study is 0.1 and 0.3 lb/bbl (0.41 to 1.23 g/1.6 l of soil)

18. Pipe dope. Pipe dope is a partially refined petroleum oil thickened with a calcium soap of abietic acid with 10 percent red lead oxide dispersed in it. Rates used in thus study are 0.1 and 0.3 lb/bbl (0.41 to 1.23 g/1.6 l of soil).

19. Potassium chloride (KCl). Potassium chloride is used in combination with other chemicals, such as Separan AP-273. It helps stabilize sensitive shale formations encountered while drilling. With Separan AP-273, KCl may be used in rates of 3 to 15 percent by volume of mud. Salt is known to severely reduce plant growth at levels of a few tenths percent in soil. Retarded plant growth is expected for these KCl levels.

20. Pregelatinized starch. This starch is an amylose carbohydrate (sugar units) with 7.5 percent protein. It is used at rates of

4 to 8 lb/bbl (16.4 to 32.8 g/1.6 l of soil) as an agent to reduce fluid loss. It is not expected to retard plant growth and may even be a source of nitrogen.

21. Q-Broxin^{R} (an iron chromelignosulfonate). Q-Broxin is used primarily as a thinner or dispersant to lower the apparent viscosity and gel strength of mud. Caustic soda is usually also used giving a mud of pH 9 to 10. Additional composition is given in U.S. Patent 2,935,504. See also material 4, Calcium lignosulfonate. Use rates are 1 to 20 lb/bbl (4.09 to 81.8 g/1.6 l of soil) with a typical rate of 6 lb/bbl. The chromium and a high mud pH because of sodium hydroxide would be expected to be detrimental to plant growth. The form of sulfur might also be a problem in some soil conditions such as poor aeration.

22. Separan AP-273^{R} (Shell polymer). At low concentrations, 25-50 ppm (about 0.008-0.018 lb/bbl), Separan is a flocculant for maintaining a low-solids content. At rates 1000 to 3000 ppm (0.3 to 1.0 lb/bbl) in combination with 3 to 15 percent KCl, Separan stabilizes water sensitive shale formations encountered while drilling. It has a molecular weight of 3 x 10^6 or greater and a formula as follows:

$$\left[- \begin{pmatrix} CH - CH_2 \\ | \\ COOH \end{pmatrix}_{0.3} - \begin{pmatrix} CH - CH_2 \\ | \\ CONH_2 \end{pmatrix}_{0.7} - \right]_n$$

Separan AP-273 is a partially hydrolyzed polyacrylamide and is similar to hydrolyized polyacrylonitriles (HPAN), differing in the extent of hydrolization. HPAN has been used to form stable soil structure. Separan is manufactured by Dow Chemical Company and supplied by the Shell Development Company. It should not adversely affect plant growth.

23. Sodium acid pyrophosphate (SAPP). SAPP is used as a reducer of viscosity. Its composition, $Na_2H_2P_2O_7$, does not suggest that we should expect it to have a damaging action on plant growth. Rates used in this study are 0.1 and 0.5 lb/bbl (0.41 and 2.05 g/1.6 l of soil).

24. Sodium carboxymethyl cellulose (SCMC). SCMC is used to reduce fluid loss. Composed of 70 to 99 percent of sodium carboxymethyl celluslose, its formula is $R\text{-}O\text{-}CH_2COONa$, where R = glucose chains. Use rates are commonly 1 to 2 lb/bbl (4.09 to 8.18 g/1.6 l of soil). It should not affect plant growth.

25. Sodium dichromate. The reason for employing sodium dichromate has not been provided by the suppliers, but it is presumed to be for making the salt of lignosulfonates which help to increase clay dispersion. Its chemical composition is $Na_2CR_2O_7$. Rates used in this study are 0.5 and 3 lb/bbl (2.05 and 12.28 g/1.6 l of soil). Chromium may be toxic to plants and these higher levels should be enough to affect plant growth as a soluble salt concentration.

26. Sodium hydroxide. Sodium hydroxide, NaOH, is a strong base. It is a well-known soil dispersant and causes the breakdown of soil aggregates. It is often used in drilling muds with calcium lignosulfonite, lignite and Q-Broxin, resulting in a mud of pH 9 to 10. As such, it should constitute an undesirable additive

when spilled onto soils. Rates used in this study are 1 and 5 lb/bbl (4.09 to 20.5 g/1.6 l. of soil).

27. Soltex[R]. Soltex is a modified, high molecular-weight hydrocarbon, possibly a sulfonated asphalt. The rate actually used in the present study is 0.5 and 2 lb/bbl (2.05 and 8.18 g/1.6 l of soil). No other data is available.

28. Witconnate 1840[R] (Sulfonated tall oil). Witconnate 1840 is a mixture of resin acids (35-40 percent) and fatty acids (50-60 percent) from acid treatment of pine wood. Rates used in this study are 0.5 and 3 lb/bbl (2.04 and 12.3 g/1.6 l of soil).

29. Torq Trim[R]. Torq Trim is used to improve lubricity. It is a sulfated triglyceride containing aliphatic and short-chain alcohols. Use rates are 0.5 to 6 lb/bbl (2.04 to 24.6 g/1.6 l of soil), with 2 lb/bbl as a typical rate.

Greenhouse procedures

Part A. The soil used is the Dagor silt loam series, a dark-colored soil under "scrubby maple." The vegetation is dense, bigtooth maples about 10 to 15 feet tall. The soil is black and friable. In the U.S. Soil Classification system, Dagor silt loam is a Cumulic Haploxeroll, fine-loamy, mixed, mesic. It has a deep A1 horizon, 0 to 34 inches. Its general properties are given in Table 4 along with the characterization data on 3 other soils which were used for a pilot study in Part B. The Dagor soil has developed from calcareous sandstones and limestones on a 10 to 12 percent northwest-facing slope. It is a virgin (uncultivated) soil, high in organic matter and well aerated.

Table 4. Characterization data for soils used in this study. Dagor silt loam is the soil used for the Parts A and B. The other 3 soils are used very sparingly in Part B.

Soil identification	Textural class	Clay content	Organic matter	Soil pH		Cation exchange capacity	Moisture contents		Available P‡	Exch. K‡
				Paste	$CaCl_2$*		1/3 bar	15 bars		
		%	%			me/100 g	%	%	kg/ha	kg/ha
Dagor†	Silt loam	10	8.1	6.2	6.0	34.3	34.7	16.8	130	1150
Soil MU2-74†	Sandy loam	5	0.3	6.3	5.5	5.8	15.8	4.2	58	154
Millville†	Silt loam	8	2.1	7.7	7.0	10.4	21.2	6.5	58	470
Miamian (Ohio)†	Silt loam	19	3.3	5.8	5.2	14.5	32.7	11.0	11	223

*1:2 soil--0.01 molar $CaCl_2$.

†Dagor: Cumulic Haploxeroll, fine-loamy, mixed, mesic.
Soil MU2-74: Not surveyed, probably a Typic Cryboralf, sandy-skeletal, mixed, cryic.
Millville: Typic Haploxerolls, coarse-silty, carbonatic, mesic.
Miamian: Typic Hapludalfs, fine, mixed, mesic.

‡Adequate P or exchangeable K exists if values are larger than about 25 kg P/ha and 200 kg K/ha. For pot extractions (more intensive), higher values are necessary.

The Part A was a study of the individual mud components mixed directly into the soil. The chemicals and materials were weighed or measured, added to the dry soil, mixed by hand and added to a round, plastic "Decorator" pot (16 cm in diameter and 12 cm tall). Ammonium nitrate and treble super phosphate was mixed into the dry soil at a rate to supply 100 kg N/ha (kilograms of N per hectare) and 50 kg P/ha. An additional 100 kg of N/ha was added to pots in the irrigation water on August 12, 1974, and again on August 22 to pots of the first planting, and, on August 28, 100 kg N/ha was added to pots of the second planting. The second addition of N to the pots of the second planting was omitted by error.

All pots were planted with either eight bean (green beans--*Phaseolus vulgaris*)* or eight corn (sweet corn--*Zea mays succharate*)* seeds, wetted and allowed to germinate. Pots were thinned to 6 plants one week after emergence. No drainage was permitted. However, pots were weighed to a predetermined weight several times weekly. The amount of water required to wet the soil was determined by wetting trials of soil samples potted, wetted with different amounts of water, allowed to equilibrate about 2 hours and checked for wetness. The amount of water required, 650 ml, was 36 percent moisture; the 1/3 bar value of the soil was 31 percent. This is a good agreement for greenhouse pots. The soil used wetted easily, drained rapidly and was well structured. Periodically, the soil in the highest numbered control was carefully removed (roots held it together) and the soil checked for wetness. The water added was increased as plants increased in age and weight. Water was added to each

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*Beans were Tendergreen; corn was Northrup King 199.

pot to a specific weight two or three times weekly. During active growth of beans it was common to add daily nearly 200 to 300 ml of water per pot.

Greenhouse temperature was automatically maintained at 24°C (75°F) during the daylight hours and at about 16°C (62°F) at night. Normal daylight through a plastic covered greenhouse was the light source. The daylight hours decreased as the growth continued from July 16 to October 1.

Periodically notes were taken of plant appearance. At the end of 56 days from planting, plants were photographed and then harvested. Within 20 minutes of cutting, fresh weights were measured. Drying was first by sunlight, finally by drying ovens at 65°C. Dried plants were ground and stored.

Because of the delay in obtaining some chemicals, two planting dates were used in Part A.

First group: Planted July 16, 1974; harvested September 10, 1974. This group included all materials not below.

Second group: Planted August 5, 1974; harvested October 1, 1974. This group included Dextrid, DME, Pipe Dope, Q-Broxin, Witconnate 1840 and Torq Trim.

Because of differences in planting dates and thus the daylight hours, and because only 100 kg of N/ha (rather than 200 kg N/ha as added to the first group) was added later in the irrigation water, the growth of the second group and its controls are of different average size. However, the individual comparisons to the controls grown with each group are still valid.

Rates of mud components used are given in Table 3. The American Petroleum Institute selected the addition rates in the units of pounds per barrel (lb/bbl). The oil field barrel volume is 42 gallons. The estimated weight of soil in 42 gallons (5.61 cu ft) was estimated to be 200 kg. (A bulk density of 1.25 x 5.61 cu ft x 28.4 kg/cu ft = 199 kg soil.) Each pot held 1.8 kg of soil (0.0090 barrel). The weights used per pot (1.8 kg of soil) are given in Table 3 also. The soils bulk density was not 1.25 as originally calculated; it is about 1.12. Therefore the weights actually used are the g/kg and the weights based on a volume of soil should be about 11 percent higher than the lbs/bbl shown in tables.

Part B. In Part B, the base mud was used with each component. The base mud consisted of 294 cm^3 of water plus 13 g of bentonite, mixed well. After allowing it to stand overnight, the mixture had 194 g of barite ($BaSO_4$) added. This mixture was used immediately as the base mud. The component was mixed with a stirrer into the amount of mud to be used for one pot (1200 ml of mud to 1.2 liters (about 1.4 kg) of Dagor soil used in Part A). This mixture was left over night.

The following day the soil was split into two parts. Half of the mud was poured onto part of the soil and the other part of soil poured onto the remaining mud. Very slight mixing with a spatula was done to wet all the soil, but also not to cause any breakdown of soil aggregation. The two pots were allowed to air dry in the sun in the greenhouse. As surface portions dried, slight turning or mixing was done to speed drying. Complete drying required 7 to 10 days. The materials were crushed by rolling with a bottle on a plastic covered board breaking the materials to particle sizes no larger than about one-quarter inch (0.8 cm) diameter, although most of the material was about 3 mm or finer. Ammonium nitrate at the rate of 300 kg N/ha and treble superphosphate at the rate of 100 kg P/ha were added and mixed through the dry soil. Higher fertilizer rates were used in Part B than in Part A, because of the lower soil weight used (part of the volume was occupied by barite and bentonite comprising the mud) and because barite lacks most nutrients. No later additions of nitrogen were given.

The planting and harvesting dates for Part B were as follows:

Beans: Planted October 25, 1974; harvested December 20, 1974.

Corn: Planted November 5, 1974; harvested December 30, 1974.

Beans and corn were selected for the test plants for various reasons: (1) The seed are large and vigorous and thus slight soil crusting and germination problems caused by slight management variation are not apt to be important. (2) The seed germinate and the plants grow rapidly, thereby putting a high stress on the soil in a relatively short time. (3) Beans are a dicotyledon and legume; corn is a monocot and related to grasses. (4) Beans are sensitive to many soil problems such as salt, wetness, and toxic elements; corn is more tolerant of salts and wetness but often shows element-unbalance stresses. (5) Considerable work in the literature has been done on beans and on either corn or grasses, thus permitting additional comparisons to other studies.

Watering the pots in Part B was more difficult than in Part A, since the material added in Part B changed the features of the soil mass. Since final soil weights with added mud except for Kwik-Seal, were nearly the same, the amount of water added was the same for all except Kwik-Seal.

Some pots had the soil carefully removed occasionally to check moisture. It was done only on pots whose plants were vigorous and had a good root system through the soil. Because of the short days in November and December, an overhead bank of flourescent lights was used to aid growth. However, the use of late fall greenhouse work was not in the original planning and optimum lighting conditions were not available.

Pots were distributed at random in one location and were mixed indiscriminately during each watering. After the first month, short stunted plants were kept in grouped areas at at the bench edges so the taller plants would not shade them from the low-angle sunlight or the overhead bank of lights.

Harvests and disposition of harvested materials was similar to that of Part A.

Analytical tests

Soluble salts were determined by electrical conductivity of the saturation paste extract (Bower and Wilcox, 1965).

Soil pH on treatment and control samples was measured on a 0.01 Molar $CaCl_2$:soil suspension which results in pH values about 0.5 pH unit lower than paste pH values (Peech, 1965). A pH of 6.5 is conveniently regarded as neutrality (Davis, 1971). Soil characterization pH values were done on a soil paste made with water (Peech, 1965).

Moisture retention values for one-third bar and 15 bars of moisture suction were obtained on pressure plates using standard procedures (done by the Utah State Soil Testing Laboratory).

Organic matter was measured by the Walkley-Black method of wet oxidation with potassium dichromate and sulfuric acid and back titration with ferrous sulfate (Allison, 1965).

Cation exchange capacity values were done by the Utah State University Soil Testing Laboratory using the standard ammonium acetate extraction and measurement of the replaced ammonium ion. Exchangeable K was measured on this extract.

Available P was done by the sodium bicarbonate extraction procedure of Olsen and Dean (1965).

Chromium was analyzed using an atomic adsorption spectrophotometer after extraction of chromium by wet digestion of plant material with nitricperchloric acid for total chromium and with a 1:10 soil to 2 N KCl extraction for exhangeable and soluble chromium from soils.

Photography

Photographic records were made of all plants before harvest. Numerous early age photographs were taken not knowing what changes might occur. Not many of the young plant photos have been included in this final report. Except for a few Kodachrome II slides of Part A, all photographs were taken using Kodacolor film. A single lens reflex Pentax Spotomatic and natural light was used for all photos.

RESULTS OF PART A

Growth observations and photographs of Part A

Of the thirty-two chemicals studied, thirteen caused reduced plant growth on beans and/or corn. In contrast to this, some treatments seemed even to favor increased growth, i.e., asphalt, Ben-Ex, gilsonite, paraformaldehyde and Shell polymer. The description of all treatments is given in the following tabulation.

1. Asbestos (Rates--5 and 2 lb/bbl; 20.5 and 8.18 g/1.8 kg of soil). No growth depression occurred.
2. Asphalt (Rates--5 and 1 lb/bbl; 20.5 and 4.09 g/1.8 kg of soil. No growth depression occurred; even some growth increase seemed to occur.
3. Barite (Rates--350 and 100 lb/bbl; 955 g/1.2 kg of soil and 364 g/1.6 kg of soil). Only at the high rate with bean plants was there a slight growth reduction (20 percent). Plants were normal in appearance but likely were somewhat deficient in some plant nutrients because of the lower soil weight needed when using the high barite levels (See Table 3).
4. Bex-Ex (Rates--0.2 and 0.05 lb/bbl; 0.82 and 0.21 g/1.8 kg of soil). Ben-Ex did not cause any visual decrease in plant growth.
5. Bentonite (Rates 35 and 7 lb/bbl, 135 g/1.7 and 28.6 g/1.8 kg of soil). Bentonite did not decrease plant growth.

6. Calcium lignosulfonate (High rate--20 lb/bbl, 81.9 g/1.8 kg of soil). Beans were one-third the height of controls and older leaves had interveinal chlorosis (yellowish-white leaves with green veins). Corn grew to half the height of controls. Older leaves reddened at the tip and the red coloring progressed downward toward the stem. Red coloring was 2.5R 6/6 on the Munsell color chips.

   (Low rate--3 lb/bbl, 12.3 g/1.8 kg of soil). Both beans and corn appeared normal; beans were even darker green than the control plants.

7. Cypan (Sodium polyacrylate) (Rates--1.5 and 0.5 lb/bbl, 6.14 and 2.05 g/1.8 kg of soil). No growth depression was clearly evident at either treatment rate.

8. Desco (High rate--3 lb/bbl, 12.3 g/1.8 kg of soil). Beans appeared to grow normally but corn plants had only 60 to 80 percent the growth of the controls. Color, however, was good.

   (Low rate--0.25 lb/bbl, 1.02 g/1.8 kg of soil). No obvious reduction of growth was evident for either beans or corn.

9. Dextrid (High rate--10 lb/bbl, 40.9 g/1.9 kg of soil). Beans had reduced plant size, leaves about one-half the normal size, and yellowed leaves (5GY 5/6). Corn grew only 25 to 35 percent as tall as control plants. Leaves were rust-colored at the tips and had at age 3-weeks considerable red mottling on the 2 lower leaves (of the 3 leaves out). See Figures 1 and 2 in the Appendix.

10. Diesel oil (High rate--10 percent of soil weight). The soil remains greasy or oily in appearance and wets with difficulty. Only a few bean seeds germinated but they died within a week or so. No corn germinated. The soil was left exposed to the sunlight for a total of 26 days after which the soil was replanted. Replanted beans had only 3 of the 8 seeds germinate. Subsequent growth was very poor. Replanted corn germinated 100 percent but grew very poorly. See Figure 3 in the Appendix.

    (Low rate--1 percent of soil weight). Germination of both beans and corn was normal but plant growth was only about 70 percent of the control plants.

11. Diesel oil replacement (Drillaid 405) (Rates--1 and 0.2 lb/bbl, 4.09 and 0.82 g/1.8 kg of soil). Generally growth of all plants was good. In the high rates, corn was a little more slender than control plants. Beans in the high rate had about 15 percent shorter growth than controls; some chlorosis (yellowing) occurred on lower leaves.

12. DME (Rates 3 and 0.5 lb/bbl, 12.3 and 2.05 g/1.8 kg of soil). Beans and corn both seemed to grow relatively normal.

13. Filming Amine--Inhibitor (Drillaid 412) (Rates0.3 and 0.5 lb/bbl, 1.23 and 0.41 g/1.8 kg of soil). No obvious affects on plant growth were observed.

14. Gilsonite (Rates--5 and 1 lb/bbl, 20.5 and 4.09 g/1.8 kg of soil). Gilsonite did not depress plant growth. Both beans and corn appeared to grow better with added Gilsonite.

15. <u>Guar Gum</u> (High rate--6 lb/bbl, 24.5 g/1.8 kg of soil). <u>Beans</u> germinated but only grew to heights of 17 to 20 cm (controls were 70 cm). Some leaves had marked interveinal chlorosis; green leaf parts were dark green and very shiny. Only a few <u>corn</u> seeds germinated; plants soon died off at the ground level. Leaves of the largest <u>corn</u> plants (20 cm tall) had the edges whiten before the leaves died completely. See Figures 4, 5, and 6 in the Appendix.

(Low rate--1 lb/bbl, 4.09 g/1.8 kg of soil). <u>Beans</u> germinated well and set large leaves which soon developed reddish speckles, then grayed and fell off the plant. New leaves appeared at growing tips and appeared green and normal; growth was only 30 percent as much as controls. <u>Corn</u> had poor germination and a 20 percent reduction in growth.

16. <u>Kelzan-XC</u> (Rates--2 and 0.5 lb/bbl, 8.18 and 2.05 g/1.8 kg of soil). No growth reductions were evident for either corn or <u>beans</u> at the treatment levels used.

17. <u>Kwik-Seal</u> (High rate--50 lb/bbl, 182 g/1.6 kg of soil). <u>Beans</u> grew only 40 percent as tall as controls. Older leaves were chlorotic (yellowed). <u>Corn</u> did even more poorly, growing only to heights of 10 to 18 cm which was about 20 percent as large as controls. Plants were slender and leaves reddened. See Figure 7 in the Appendix.

(Low rate--5 lb/bbl, 20.5 g/1.8 kg of soil). <u>Beans</u> grew only about half as tall as controls and were chlorotic (yellowed). <u>Corn</u> did grow somewhat better than beans but still was only 50 to 70 percent as tall as control pots.

18. Lignite (Rates--10 and 2 lb/bbl, 40.9 and 8.18 g/1.8 kg of soil. Lignite did not depress bean or corn growth.

19. Paraformaldehyde (Rates--0.3 and 0.1 lb/bbl, 1.23 and 0.41 g/1.8 kg of soil). Plant growth appeared to be slightly improved by the addition of paraformaldehyde.

20. Pipe dope (Rates--0.3 and 0.1 lb/bbl, 1.23 and 0.41 g/1.8 kg of soil). Pipe dope did not affect growth of beans or corn.

21. Potassium chloride (High rate--30 lb/bbl, 122.7 g/1.8 kg of soil). Beans were a week late in germinating and only grew 5 cm tall before dying. Corn germinated adequately but seedlings died within three weeks. Salt was slow to move back into the soil surface after initial watering moved it downward or the plants probably would not have germinated at all. See Figures 8 and 9 in the Appendix.

    (Low rate--10 lb/bbl, 40.9 g/1.8 kg of soil). Beans germinated well but grew only to 14 to 20 cm tall (20 percent as tall as controls) before leaves dried up and fell off. Corn grew somewhat better than beans but plants were a bluish green and appeared somewhat shrivelled even though leaves did not curl much. Colors were 7.5GY 7/2 compared to controls which were 5GY 6/8.

22. Pregelatinized starch (High rate--10 lb/bbl, 40.9 g/1.8 kg of soil). Beans appeared normal in color and shape but were only 30 cm tall (controls were 70 cm tall). Corn was very stunted (15 cm tall), had red leaf tips and was a pale green color (2.5GY 7/8). See Figure 10 in the Appendix.

(Low rate--1 lb/bbl, 4.09 g/1.8 kg of soil). Beans grew well at the low treatment level. Corn, however, was affected at low treatment levels and grew only 70 percent as large as control plants.

23. Q-Broxin (Rates--20 and 3 lb/bbl, 81.9 and 12.3 g/1.8 kg of soil). Plants at low rates had normal growth. At high rates both beans and corn had retarded growth. Beans had just over 50 percent germination and about 60 percent as much growth as the controls. Corn was similar to beans; it grew only about 70 percent as large as controls and had slight chlorosis (yellowing).

24. Separan AP-273 (Shell Polymer) (Rates--2 and 0.5 lb/bbl, 8.18 and 2.05 g/1.8 kg of soil). Separan had no visible influence on the growth of beans or corn.

25. Sodium carboxymethyl cellulose (Rates--1.5 and 0.5 lb/bbl, 6.14 and 2.05 g/1.8 kg of soil). Sodium carboxymethyl cellulose had no visible effect on the growth of beans or corn.

26. Sodium dichromate (High rate--3 lb/bbl, 12.3 g/1.8 kg of soil). Beans grew only 10 to 18 cm tall (controls were 70 cm). Their leaves curled and were more bluish than controls (Treatment, 5GY 7/6; control, 5GY 6/8). Corn also did poorly and grew only to 20 to 23 cm tall (controls were about 80 cm tall). Corn leaves had reddish mottling on leaf tips; these areas of the leaf finally dried up. See Figures 11 and 12 in the Appendix.

27. Sodium acid pyrophosphate (Rates--0.5 and 0.1 lb/bbl, 2.05 and 0.41 g/1.8 kg of soil). Sodium acid pyrophosphate had no visible effect on the growth of beans or corn.

28. Sodium hydroxide (High rate--5 lb/bbl, 20.5 g/1.8 kg of soil). The NaOH was applied to dry soil as pellets. The base was slow to disperse through the soil mass which allowed seeds to germinate before the NaOH was distributed throughout the soil. Thus, early germination is probably not representative of what would happen if dissolved NaOH was initially mixed with the soil.

Beans germinated, grew to 10 cm and died. Eventually the soil lost some of its structure, appeared more puddled and the surface crusted. Corn plants grew better than beans but were irregular in size; some plants were 20 cm tall, others were 65 cm. The corn leaves curled, as happens in drought, and the plant color was slightly more bluish than control plants.

(Low rate--1 lb/bbl, 4.09 g/1.8 kg of soil). Both beans and corn appeared to have normal growth at the low treatment level.

29. Soltex (Rates--8 and 2 lb/bbl, 8.18 and 2.05 g/1.8 kg of soil). An error was made which resulted in using lower rates than planned. Rates of 2 and 0.5 lb/bbl were used. However, during growth of Part B, the high rate of 8 lb/bbl was planted and growth observed. It was not apparently affected by the treatment. There was no evidence of treatment effects on growth of beans or corn.

30. Torq-Trim (High rate--1.5 lb/bbl, 6.14 g/1.8 kg of soil). Beans had reduced growth and were chlorotic (yellowed). Corn grew to only half the height of control plants and were also more yellow (treatment, 5GY 5/8; control 5GY 4/6).

(Low rate--0.5 lb/bbl and 2.05 g/1.8 kg of soil). The low treatment rate did not affect plant growth.

31. Witconnate 1840 (Sulfonated tall oil) (Rates--3 and 0.5 lb/bbl 12.3 and 2.05 g/1.8 kg of soil). Witconnate 1840 did not produce any obvious effect on growth of beans or corn. See Figures 13 and 14 in the Appendix.

Yields of plant materials in Part A

Bean and corn yields, fresh and oven dry, are listed in Tables 5 through 13. Oven-dry weights are after drying plants at 65°C in forced draft plant drying ovens.

Plant weight differences are results of changes in day length and treatment variations including management. The 25 materials tested first (July 16, 1974) had longer daylight periods and, by an oversight, one extra addition of nitrogen fertilizer than those tested 20 days later. These combinations resulted in lower yields for controls and treatments of the later planting. For example, day lengths at Logan on various dates are shown below.

July 25	14 hours, 34 min (sunrise to sunset)
August 10	14 hours, 0 min
August 24	13 hours, 26 min
September 10	12 hours, 43 min
October 1	11 hours, 46 min

This results in appreciable differences in growing days for the two groups.

Table 5. Oven-dry yield weights in grams per pot of sweet corn grown on Dagor soil to which various drilling mud components have been added, each at two rates. H3, H4 and L3, L4 are replicates of high and of low rates, respectively

Materials	High rate			Low rate			Total
	H3	H4	Ave.	L3	L4	Ave.	Ave.
Asbestos	47	43	45.0	42	48	45.0	45.0
Asphalt	43	41	42.0	42	48	45.0	43.5
Barite	37	39	38.0*[a]	48	45	46.5	42.3
Ben-Ex	53	48	50.5	48	49	48.5	49.5
Bentonite	44	37	40.5	41	42	41.5	41.0
Calcium lignosulfonate	13	13	13.0**[b]	42	53	47.5	30.3
Cypan (sodium polyacrylate)	48	44	46.0	45	47	46.0	46.0
Desco	34	33	33.5**	48	34	41.0	37.3
Diesel oil	1	1	1.0**	17	12	14.5**	7.3
Drillaid 405 (D. oil replacement)	31	4	17.5**	43*	45	44.0	30.8
Drillaid 412 (filming amine)	33	46	39.5*	48	32	40.0	39.8
Gilsonite	46	46	46.0	50	34	42.0	44.0
Guar gum	2	2	2.0**	29	55	42.0	22.0
Kelzan-XC	31	38	34.5**	47	47	47.0	40.8
Kwik-Seal	3	1	2.0**	22	30	26.0*	14.0
Lignite	48	42	45.0	44	52	48.0	46.5
Paraformaldehyde	46	55	50.5	49	44	46.5	48.5
Potassium chloride	1	0	0.5**	7	4	5.5**	3.0
Pregelatinized starch	2	2	2.0**	42	35	38.5*	20.3
Separan-AP273 (Shell Polymer)	41	51	46.0	47	50	48.5	47.3
Sodium acid pyrophosphate	46	45	45.5	53	44	48.5	47.0
Sodium carboxymethyl cellulose	44	47	45.5	51	40	45.5	45.5
Sodium dichromate	2	2	2.0**	38	42	40.0	21.0
Sodium hydroxide	16	26	21.0**	44	49	46.5	33.8
Soltex	34	39	36.5**	40	37	38.5*	37.5
Controls	Rep	Rep	Rep	Rep	Rep	Rep	Ave.
Nos. 31-36	49	48	47	47	48	44	47.3
Nos. 37-42	50	45	46	48	49	46	
Nos. 43-48	47	47	50	48	46	49	
Nos. 49-50	50	41					

LSD (Controls vs treatments) = 7.66 (95% confidence level)
=10.17 (99% confidence level)

[a]Statistically significant at the 95% confidence level.
[b]Statistically significant at the 99% confidence level.

Table 6. Oven-dry yield weights in grams per pot of sweet corn grown on Dagor soil to which various drilling mud components have been added, each at two rates. H3, H4 and L3, L4 are replicates of high and low rates, respectively.

Materials	High rate			Low rate			Total
	H3	H4	Ave.	L3	L4	Ave.	Ave.
Dextrid	4	0	2.0**[a]	28	29	28.5*[b]	15.3
DME	35	35	35.0	41	35	38.0	36.5
Pipe dope	21	18	19.5**	35	34	34.5	27.0
Q-Broxin	7	5	6.0**	32	20	26.0**	16.0
Witconnate 1840	17	30	23.5**	25	37	31.0	27.3
Torq-Trim	6	16	11.0**	32	19	25.5	18.3
Controls:	Rep	Rep	Rep	Rep	Rep	Rep	Ave.
Nos. 51-56	35	40	34	37	37	40	36.9
Nos. 57-60	37	40	30	39	--	--	

LSD (Controls vs treatments = 7.78 (95% confidence level).
=10.59 (99% confidence level).

[a]Statistically significant by 99% confidence level.
[b]Statistically significant by 95% confidence level.

Table 7. Fresh yield weights in grams per pot of sweet corn grown on Dagor soil to which various drilling mud components have been added, each at two rates. H3, H4 and L3, L4 are replicates of high and of low rates, respectively

Materials	High rate			Low rate			Total
	H3	H4	Ave.	L3	L4	Ave.	Ave.
Asbestos	319	296	308	288	304	296	302
Asphalt	294	289	292	310	312	311	302
Barite	186	258	221**[a]	309	296	303	262
Ben-Ex	330	345	338†[b]	328	369	349†	344
Bentonite	287	274	281	287	268	278	280
Calcium lignosulfonate	85	90	88**	257	246	252**	170
Cypan (sodium polyacrylate)	348	332	340†	307	313	310	325
Desco	238	216	227**	321	244	283	255
Diesel oil	3	2	1**	116	92	104**	52.5
Drillaid 405 (D. oil replacement)	253	294	274	290	296	293	284
Drillaid 412 (Filming amine)	192	308	250**	305	253	279	265
Gilsonite	300	309	305	314	244	274	290
Guar Gum	5	4	4.5**	239	224	232*[c]	118
Kelzan-XC	227	274	251**	314	316	315	283
Kwik-Seal	17	6	11.5**	138	176	157**	84.3
Lignite	301	290	296	311	340	326	311
Paraformaldehyde	307	352	330	306	280	293	312
Potassium chloride	3	0	1.5**	28	17	22.5**	12
Pregelatinized starch	8	11	9.5**	247	250	249**	129
Separan-AP273 (Shell Polymer)	270	328	299	307	330	319	309
Sodium acid pyrophosphate	292	307	300	324	310	317	309
Sodium carboxymethyl cellulose	304	257	281	317	290	304	293
Sodium dichromate	2	3	2.5**	240	193	217**	110
Sodium hydroxide	82	68	75**	310	144	227**	151
Soltex	254	271	263*	266	266	266*	265
Controls:	Rep	Rep	Rep	Rep	Rep	Rep	Ave.
Nos. 31-36	306	308	297	323	295	290	
Nos. 37-42	313	304	293	295	315	284	302
Nos. 43-48	314	292	320	292	298	344	
Nos. 49-50	314	244					

LSD (controls vs treatments = 29.64 (95% confidence level).
= 42.206 (99% confidence level).

[a]Significantly smaller than controls by 99% confidence level.
[b]Significantly larger than controls.
[c]Significantly smaller than controls by 95% confidence level.

Table 8. Fresh yield weights in grams per pot of sweet corn grown on Dagor soil to which various drilling mud components have been added, each at two rates. H3, H4 and L3, L4 are replicates of high and of low rates, respectively

Materials	High rate			Low rate			Total
	H3	H4	Ave.	L3	L4	Ave.	Ave.
Dextrid	22	0	11.0**[a]	170	185	178	94.5
DME	194	198	196	224	206	215	206
Pipe dope	125	122	124**	206	187	197	161
Q-Broxin	25	43	34.0**	191	125	158*[b]	96
Witconnate 1840 (Sulfonated oil)	125	171	148*	171	204	188	168
Torq-Trim	44	103	73.5**	170	126	148*	111
Controls:	Rep	Rep	Rep	Rep	Rep	Rep	Ave.
Nos. 51-56	194	195	196	201	213	206	201
Nos. 57-60	208	212	175	208	---	---	

LSD (controls vs treatments) = 39.61 (95% confidence level).
= 52.620 (99% confidence level).

[a]Statistically significant by 99% confidence level.
[b]Statistically significant by 95% confidence level.

Table 9. Oven-dry weights in grams per pot of green beans grown on Dagor soil in which various drilling mud components have been added, each at two rates. H1, H2 and L1, L2 are replicates of high and of low rates, respectively

Materials	High rate			Low rate			Total
	H1	H2	Ave.	L1	L2	Ave.	Ave.
Asbestos	25	25	25.0	30	29	29.5†[a]	27.3
Asphalt	27	27	27.0	27	27	27.0	27.0
Barite	24	25	24.5	27	23	25.0	24.8
Ben-Ex	30	30	30.0†	30	29	29.5†	29.8
Bentonite	24	22	23.0	26	28	27.0	25.0
Calcium lignosulfonate	14	6	10.0**[b]	28	25	26.5	18.3
Cypan (sodium polyacrylate)	28	25	26.5	29	21	25.0	25.8
Desco	22	23	22.5	26	30	28.0	25.3
Diesel oil	2	4	3.0**	12	14	13.0*[c]	8.0
Drillaid 405 (D. oil replacement)	23	22	22.5	19	24	21.5*	22.0
Drillaid 412 (Filming amine)	25	27	26.0	25	26	25.5	26.8
Gilsonite	29	29	29.0	29	26	27.5	28.3
Guar gum	5	8	6.5**	10	8	9.0**	7.8
Kelzan-XC	26	24	25.0	27	28	27.5	26.3
Kwik-Seal	9	12	10.5**	18	15	16.5**	13.5
Lignite	24	25	24.5	24	19	21.5*	23.0
Paraformaldehyde	23	26	24.5	24	32	28.0	26.3
Potassium chloride	0	0	0**	3	3	3.0**	1.5
Pregelatinized starch	15	17	16.0*	19	22	20.5*	18.3
Separan-AP273 (Shell Polymer)	23	23	23.0	30	25	27.5	25.3
Sodium acid pyrophosphate	32	22	27.0	27	25	26	26.5
Sodium carboxymethyl cellulose	24	24	29.0	20	25	22.5	25.8
Sodium dichromate	3	2	2.5**	24	35	29.5†	16.0
Sodium hydroxide	4	4	4.0**	23	28	25.5	14.8
Soltex	30	28	29.0	24	25	24.5	26.8
Controls	Rep	Rep	Rep	Rep	Rep	Rep	Ave.
Nos. 1-6	27	25	25	25	25	27	
Nos. 7-12	27	23	--	30	23	28	25.6
Nos. 13-18	24	27	26	19	27	27	
Nos. 19-20	22	29	--	--	--	--	

LSD (controls vs treatments) = 3.89 (95% confidence level).
= 5.185 (99% confidence level).

[a]Significantly larger than control.
[b]Significantly smaller than controls by 99% confidence level.
[c]Significantly smaller than controls by 95% confidence level.

Table 10. Oven-dry yield weights in grams per pot of green beans grown on Dagor soil to which various drilling mud components have been added, each at two rates. H1, H2 and L1, L2 are replicates of high and of low rates, respectively

Materials	High rate			Low rate			Total
	H1	H2	Ave.	L1	L2	Ave.	Ave.
Dextrid	7	7	7.0**[a]	18	29	23.5	15.3
DME	22	25	23.5	23	13	18.0	21.5
Pipe dope	20	20	20.0	22	21	21.5	20.7
Q-Broxin	4	8	6.0**	15	19	17.0	11.5
Witconnate 1840	18	14	16.0	18	25	21.5	18.8
Torq-Trim	13	7	10.0**	18	21	19.5	14.8
Controls:	Rep	Rep	Rep	Rep	Rep	Rep	Ave.
Nos. 21-26	16	23	20	--	20	25	21.1
Nos. 27-30	24	25	20	17	--	--	

LSD (controls vs treatments) = 6.051 (95% confidence level).
= 8.253 (99% confidence level).

[a]Significantly smaller than controls by 99% confidence level.

Table 11. Fresh yield weights in grams per pot of green beans grown on Dagor soil to which various drilling mud components have been added, each at two rates. H1, H2 and L1, L2 are replicates of high and of low rates, respectively

Materials	High rate			Low rate			Total
	H1	H2	Ave.	L1	L2	Ave.	Ave.
Asbestos	197	220	209	183	189	186	197.3
Asphalt	208	232	220†[a]	193	186	190	205
Barite	167	164	166	176	174	175	171
Ben-Ex	201	210	206	226	188	207	207
Bentonite	131	149	140	161	124	143	142
Calcium lignosulfonate	92	36	64**[b]	170	207	189	127
Cypan (sodium polyacrylate)	232	199	216	180	191	186	201
Desco	122	94	108**	135	177	156	132
Diesel oil	5	5	5**	73	125	99**	52
Drillaid 405 (D. oil replacement)	196	150	173	155	187	171	172
Drillaid 412 (filming amine)	182	176	179	168	200	184	182
Gilsonite	211	137	174	236	183	210	192
Guar gum	38	52	45**	43	44	43.5**	44.3
Kelzan-XC	175	184	180	191	186	189	185
Kwik-Seal	68	96	82**	114	70	92**	87
Lignite	175	207	191	196	208	202	197
Paraformaldehyde	204	198	201	220	226	223	212
Potassium chloride	0	0	0**	5	3	4**	2
Pregelatinized starch	101	118	110*[c]	159	186	173	142
Separan-AP273 (Shell Polymer)	147	153	150	221	202	212	181
Sodium acid pyrophosphate	222	196	209	181	202	192	201
Sodium carboxymethyl cellulose	179	221	200	127	172	150	175
Sodium dichromate	4	8	6**	177	212	195	101
Sodium hydroxide	5	5	5**	123	197	160	83
Soltex	180	170	175	148	148	148	162
Controls:	Rep	Rep	Rep	Rep	Rep	Rep	Ave.
Nos. 1-6	215	204	202	170	184	178	
Nos. 7-12	199	176	---	206	126	204	170
Nos. 13-18	150	127	144	83	218	129	
Nos. 19-20	65	253					

LSD (controls vs treatments) = 45.76 (95% confidence level).
= 60.98 (99% confidence level).

[a] Significantly higher than controls.
[b] Significantly lower than controls by 99% confidence level.
[c] Significantly lower than controls by 95% confidence level.

Table 12. Fresh yield weights in grams per pot of green beans on Dagor soil to which various drilling mud components have been added, each at two rates. H1, H2 and L1, L2 are replicates of high and of low rates, respectively

Materials	High rate			Low rate			Total
	H1	H2	Ave.	L1	L2	Ave.	Ave.
Dextrid	43	51	47**[a]	126	155	141	94
DME	169	179	174	176	156	166	170
Pipe dope	180	167	174	176	147	162	167
Q-Broxin	24	48	36**	168	136	152	94
Witconnate 1840 (Sulfonated oil)	136	147	142	176	194	185	164
Torq-Trim	119	48	84**	167	167	167	126
Controls:	Rep	Rep	Rep	Rep	Rep	Rep	Ave.
Nos. 21-26	135	149	173	---	180	154	156
Nos. 27-30	154	149	168	143	---	---	

LSD (controls vs treatments) = 29.34 (95% confidence level).
= 40.018 (99% confidence level).

[a]Significantly smaller than controls by 99% confidence level.

Table 13. Oven-dry yield weights in grams per pot of green bean pods grown on Dagor soil to which various drilling mud components have been added, each at two rates. H1, H2 and L1, L2 are replicates of high and of low rates, respectively

Materials	High rate			Low rate			Total
	H1	H2	Ave.	L1	L2	Ave.	Ave.
Asbestos	12	16	14.0†[a]	7	6	6.5	10.3
Asphalt	11	12	11.5	11	6	8.5	10.0
Barite	8	6	7.0	7	6	6.5	6.8
Ben-Ex	9	9	9.0	11	7	9.0	9.0
Bentonite	4	6	5.0	4	5	4.5	4.8
Calcium lignosulfonate	3	1	2.0**[b]	7	12	9.5	5.8
Cypan (sodium polyacrylate)	9	10	9.5	13	9	11.0	10.3
Desco	6	0.54	3.3*[c]	2	4	3.0*	3.2
Diesel oil	3	0	1.5**	3	3	3.0*	2.3
Drillaid 405 (D. oil replacement)	11	11	11.0	6	8	7.0	9.0
Drillaid 412 (filming amine)	7	8	7.5	7	8	7.0	7.3
Gilsonite	9	2	5.5	14	12	13.0†	9.3
Guar gum	0.4	0.13	0.35**	0.35	1	0.7**	0.51
Kelzan-XC	4	7	5.5	8	7	7.5	6.5
Kwik-Seal	2	3	2.5*	4	1	2.5*	2.5
Lignite	6	11	8.5	2	13	7.5	8.0
Paraformaldehyde	11	10	10.5	11	10	10.5	10.5
Potassium chloride	0	0	0**	3	3	3.0*	1.5
Pregelatinized starch	3	3	3.0*	7	8	7.5	5.3
Separan-AP273 (Shell Polymer)	4	6	5.0	9	11	10.0	7.5
Sodium acid pyrophosphate	5	7	6.0	8	9	8.5	7.3
Sodium carboxymehtyl cellulose	7	10	8.5	3	5	4.0	6.3
Sodium dichromate	3	2	2.5*	7	14	10.5	6.5
Sodium hydroxide	4	4	4.0	4	8	6.0	5.0
Soltex	5	2	3.5*	3	2	2.5*	3.0
Controls:	Rep	Rep	Rep	Rep	Rep	Rep	Ave.
Nos. 1-6	10	12	9	12	10	5	
Nos. 7-12	9	7	12	11	1	10	8.1
Nos. 13-18	3	14	2	4	13	1	
Nos. 19-20	3	14					

LSD (controls vs treatments) = 4.44 (95% confidence level).
= 5.897 (99% confidence level).

[a]Significantly larger yield than control.
[b]Significantly lower than control by 99% confidence level.
[c]Significantly lower than control by 95% confidence level.

However, since controls are included for each planting, differences in length of daylight and other variables which affect all pots also affect treated pots and controls alike. Errors in reproducibility of growing plants in any one grouping are expected to be up to about 15 percent, with 10 percent or less error considered about normal. This anticipation in growth variance was the reason such a large number of the treatment control plants were used--to be able to statistically estimate growth variability in similar pots.

Plant growth in treatments that reduce growth may vary even more than growth in replications having normal growth. The effect of "toxic" materials seldom reacts equally on all plants in a system unless the effect is quite severe. Thus, drilling mud components that have only a slight to moderate effect on plant growth may result in greater yield variations between the two replications than will occur between control plants.

The yield data clearly identify many drilling mud components that reduce plant growth. "Average" values with a single or double asterisk are those which statistically (at the 95 and 99 percent confidence levels, respectively) are lower than the average yield from control plants. Although the statistical significance does not prove the two averages are different, it does indicate that only 5 times or 1 time out of 100 would one expect such a difference to occur by normal "chance." The Least Significant Difference (LSD) is the difference of yield averages required to say that the treatment average is statistically different than the average of the controls (at the 95 or 99 percent confidence level). LSD values have in recent years been thought to be too lenient, but is considered by Dr. D. Sisson as his preference for comparisons such as this study.[1] He based his conclusion on a recent paper he had studied. The LSD has been considered to be too lenient on type 1 (alpha) errors which say, in effect, that too many treatments were said to be significant when, if fact, they were not. However, other tests used are now thought to be too harsh on type 2 (beta) errors, i.e., some treatments that are different are not said to be significant when, if fact, they were. The LSD test is considered to be a good, if not the best, convenient test when considering both alpha and beta type errors.

Drilling mud components varied enoumously in their effects on plant growth. These materials are grouped according to the degree in which they reduce plant growth. Using only the dry-weight yields, the materials are grouped as below (numbers indicate average yield in grams per pot at high and low rates, respectively):

Corn (First planting date)

1. No statistical growth reduction (at the 5 percent level) on corn growth at either high or low addition rates.

Control (47 g) (LSD = 7.66)

Asbestos (45 and 45)	Asphalt (42 and 45)
Ben-Ex (50 and 48)	Bentonite (40 and 41)
Cypan (46 and 46)	Gilsonite (46 and 42)
Lignite (45 and 48)	Paraformaldehyde (50 and 46)
Separan-AP 273 (46 and 48)	Sodium acid pyrophosphate (45 and 48)
Sodium carboxymethyl cellulose (45 and 45)	

2. Slight growth reduction only at the high addition rates.

[1]Personal communication, Dr. Donald Sisson, Department of Statistics, Utah State University.

Control (47 g) (LSD = 7.66)

Barite (38* and 46) | Desco (33* and 41)

Drillaid 412 (39* and 40) | Kelzan-XC (34* and 47)

Sodium hydroxide (21* and 46)

3. Moderate growth reduction at the high rate; low addition rate caused only slight or no growth reduction.

Control (47 g) (LSD = 7.66)

Kwik-Seal (2* and 26*) | Pregelatinized starch (2* and 38*)

Soltex (36* and 38*)

Sodium dichromate (2* and 40) | Drillaid 405 (17* and 44)

4. Severe growth reduction at both rates used.

Control (47 g) (LSD = 7.66)

Diesel oil (1* and 14*) | Potassium chloride (0.5* and 5*)

Corn (Second planting date)

1. No statistical growth reduction (at the 5 percent level) on corn growth at either high or low addition rates.

Control (37 g) (LSD = 7.78)

DME (35 and 38)

2. Slight growth reduction only at the high addition rates.

Control (37 g) (LSD = 7.78)

Witconnate 1840 (sulfonated tall oil) (23* and 31)

3. Moderate growth reduction with the low addition rate having only slight or no growth reduction.

Control (37 g) (LSD = 7.78)

Dextrid (2* and 28*) | Pipe dope (19* and 34)

Q-Broxin (6* and 26*) | Torq-Trim (11* and 25*)

Beans (First planting date)

1. No statistical growth reduction (at the 5 percent level) on bean growth at either high or low addition rates.

Control (26 g) (LSD = 3.89)

Asbestos (25 and 29)

Barite (24 and 25)

Bentonite (23 and 27)

Desco (22 and 28)

Gilsonite (29 and 27)

Paraformaldehyde (24 and 28)

Sodium carboxymethyl cellulose (29 and 22)

Soltex (29 and 24)

Asphalt (27 and 27)

Ben-Ex (30 and 29)

Cypan (26 and 25)

Drillaid 412 (26 and 25)

Kelzan-XC (25 and 27)

Separan-AP273 (23 and 27)

Sodium acid pyrophosphate (27 and 26)

2. Slight growth reduction only at the high addition rates.

Control (26 g) (LSD = 3.89)

Drillaid 405 (22 and 21*)

Lignite (24 and 21*)

3. Moderate growth reduction with the low addition rate having only slight or no growth reduction.

Control (26 g) (LSD = 3.89)

Calcium lignosulfonate (10* and 26)

Kwik-Seal (10* and 16*)

Pregelatinized starch (16* and 20*)

Sodium dichromate (2* and 29)

Sodium hydroxide (4* and 25)

4. Severe growth reduction at both rates used.

Control (26 g) (LSD= 3.89)

Diesel oil (3* and 13*)

Guar gum (6* and 9*)

Potassium chloride (0* and 3*)

Beans (Second planting date)

1. No statistical growth reduction (at the 5 percent level) on bean growth at either high or low addition rates.

Control (21 g) (LSD = 6.051)

DME (23 and 18)

Pipe dope (20 and 21)

Witconnate 1840 (16 and 21)

2. Slight growth reduction only at the high addition rates.

Control (21 g) (LSD = 6.051)

None

3. Moderate growth reduction with the low addition rate having only slight or no growth reduction.

Control (21 g) (LSD = 6.051)

Dextrid (7* and 23)

Torq-Trim (10* and 19)

Q-Broxin (6* and 17)

4. Severe growth reduction at both rates used.

None

From these tabulations it is easy to pick out the materials causing severe growth problems. However, materials causing marginal plant yields are not clearly defined. For example, on the basis of statistics, the following materials reduce plant growth. However, reductions in plant yields are barely significant. Thus, the reduced yield of any one or all of these treatments might be a result of chance for reasons other than the added component.

Barite	Drillaid 412
Kelzan-XC	Drillaid 405
Lignite	Desco
Pipe dope	Witconnate 1840

The drilling mud components which when added to only soil clearly reduce growth of beans and corn are summarized in decreasing order of "toxicity" in the following:

Potassium chloride--inhibits most plant growth

Diesel oil

Guar gum

Kwik-Seal

Pregelatinized starch

Sodium dichromate

Q-Broxin

Dextrid

Torq-Trim

Sodium hydroxide

Calcium lignosulfonate

Drillaid 405 (?)

Desco (?)

Witconnate 1840 (?)

Compare this order of materials with tests on most of these components when added to soil-mud mixtures as given later in the "Yield" section of Part B results.

Statistical analyses of Part A

The yield data were analyzed statistically. The results were mostly predictable--there are differences between the growth on some treatments and the controls, between growth on some treatments at high application rates but not at low rates, and between different treatments. The 1 percent level of significance is indicated by a double asterisk (**); the 5 percent level is indicated by a single asterisk (*).

The statistical tables (Tables 14 through 21) show that yield variations occur and indicate the variations which are due to the added components (treatments) and their rates. The following identifications are for the "Source" in each table. Numbers before items indicate subdivision patterns as the tests in lower parts of each table are for more specific items.

1. Treatments refers to all pots to see if the differences between different additives including controls are greater than differences between duplicate samples.

   1.1 Controls vs treatments compares yield averages of added components to yield averages of the controls.

   1.2 Among treatments compares yield averages of individual treatments and rates to see if variation there is greater than differences between replications.

      1.21 Materials is a subdivision of "Among treatments" to compare differences between materials where both rates are lumped together in the material yield average.

      1.22 Rate compares differences in yields of the two rates but summing over all materials.

Table 14. Summary of statistical analysis of oven-dry yields of sweet corn, Phase I, Part A. Drilling and components were added directly to dry Dagor soil. Early group planting

Source	df	SS	MS	F-test[a]	F-Table $\alpha = 0.05$
Treatments	50	27569.2	551.4	20.54**	1.545
Control vs treatments	1	2356.2	2356.2	87.79**	3.999
Among treatments	49	25213.0	514.5	19.17**	1.548
Among materials	24	17151.5	714.6	26.62**	1.698
Between rates	1	3069.2	3069.2	114.35**	3.999
Materials x rates	24	4992.3	208.0	7.75**	1.698
Error	69	1851.8	26.84		
Total	119	29421			

LSD (soil control vs treatments) at 95% = 7.66, at 99% = 10.17

[a]Asterisks refer to the level of significance. *means the sources are different with a 95% level of confidence. **means the confidence level is even higher, at 99%; there is only one chance in a hundred that the differences are chance rather than the effect of the item listed.

[b]Degrees of freedom in this table and the other tables that follow, are unequal numbers of samples. Treatments have 2 replications; controls have more. In Phase I, Part A, the number of controls varied and ranged from 9 to 20 replications. The actual number can be known by looking at the respective tables on yields.

Table 15. Summary of statistical analysis of oven-dry yields of sweet corn, Phase I, Part A. Drilling mud components added directly to dry Dagor soil. Later group planting

Source	df	SS	MS	F-test[a]	F-Table $\alpha = 0.05$
Treatments	12	4282.4	356.9	15.31**	2.255
Control vs treatments	1	1291.2	1291.2	55.41**	4.327
Among treatments	11	2991.1	271.9	11.67**	2.285
Among materials	5	1387.3	277.5	11.90**	2.687
Between rates	1	818.3	818.3	35.12**	4.327
Materials x rates	5	785.5	157.1	6.74**	2.687
Error	21	489.4	23.3		
Total	33	4771.8			

LSD (soil control vs treatments) at 95% = 7.78, at 99% = 10.59

[a]Asterisks refer to the level of significance. * means the sources are different with a 95% level of confidence. ** means the confidence level is even higher, at 99%; there is only one chance in a hundred that the differences are chance rather than the effect of the item listed.

Table 16. Summary of statistical analysis of fresh yields of sweet corn, Phase I, Part A. Drilling mud components added directly to dry Dagor soil. Early group planting

Source	df	SS	MS	F-test[a]	F-Table $\alpha = 0.05$
Treatments	50	1234286.84	24685.74	43.41**	1.545
Control vs treatments	1	80759.20	80759.20	112.56**	3.999
Among treatments	49	1153527.60	23541.38	32.80**	1.548
Among materials	24	896346.14	37347.75	52.056**	1.698
Between rates	1	93757.44	93757.44	130.68**	3.999
Materials x rates	24	163429.10	6809.33	9.49**	1.698
Error	69	49503.90	717.44		
Total	119	1283790.79			

LSD (soil control vs treatments) at 95% = 39.609, at 99% = 52.62

[a]Asterisks refer to the level of significance. * means the sources are different with a 95% level of confidence. ** means the confidence level is even higher, at 99%; there is only one chance in a hundred that the differences are chance rather than the effect of the item listed.

Table 17. Summary of statistical analysis of fresh yields of sweet corn Phase I, Part A. Drilling mud components added directly to dry Dagor soil. Later group planting

Source	df	SS	MS	F-test[a]	F-Table $\alpha = 0.05$
Treatments	12	98716.87	8226.40	20.24**	2.255
Control vs treatments	1	1460.41	1460.41	359.37**	4.327
Among treatments	11	97256.46	8841.50	21.75**	2.285
Among materials	5	41357.7	8271.54	20.35**	2.687
Between rates	1	41085.37	41085.37	101.100**	4.327
Materials x rates	5	14183.39	2962.68	7.29**	2.687
Error	21	8534.10	406.38		
Total	33	107250.97			

LSD (soil control vs treatments) at 95% = 29.64, at 99% = 44.21.

[a]Asterisks refer to the level of significance. * means the sources are different with a 95% level of confidence. ** means the confidence level is even higher, at 99%; there is only one chance in a hundred that the differences are chance rather than the effect of the item listed.

Table 18. Summary of statistical analysis of oven-dry yields of green beans Phase I, Part A. Drilling mud components added directly to dry Dagor soil. Early group planting

Source	df	SS	MS	F-test	F-Table $\alpha = 0.05$
Treatments	50	7337.3	146.74	21.29**	1.558
Control vs treatments	1	260.5	260.46	37.80**	3.989
Among treatments	49	7076.8	144.42	20.96**	1.555
Among materials	24	5257.8	214.07	31.79**	1.688
Between rates	1	368.6	368.64	53.50**	3.989
Materials x rates	24	1450.4	60.43	8.77**	1.688
Error	68	468.6	6.89		
Total	118	7805.9			

LSD (soil control vs treatments) at 95% = 3.89, at 99% = 5.18

[a]Asterisks refer to the level of significance. * means the sources are different with a 95% level of confidence. ** means the confidence level is even higher, at 99%; there is only one chance in a hundred that the differences are chance rather than the effect of the item listed.

Table 19. Summary of statistical analysis of oven-dry yields of green beans Phase I, Part A. Drilling mud components added directly to dry Dagor soil. Later group plantings

Source	df	SS	MS	F-test[a]	F-Table $\alpha = 0.05$
Treatments	12	1261.6	105.13	7.62**	2.28
Control vs treatments	1	72.2	72.15	5.24*	4.35
Among treatments	11	1184.5	108.13	7.85**	2.31
Among materials	5	513.2	102.64	7.45**	2.71
Between rates	1	392.0	392.04	28.47**	4.35
Materials x rates	5	284.2	56.84	4.13**	2.71
Error	20	275.4	13.77		
Total	32	1537.0			

LSD (soil control vs treatments) at 95% = 6.051, at 99% = 8.25

[a]Asterisks refer to the level of significance. * means the sources are different with a 95% level of confidence. ** means the confidence level is even higher, at 99%; there is only one chance in a hundred that the differences are chance rather than the effect of the item listed.

Table 20. Summary of statistical analysis of fresh yields of green beans Phase I, Part A. Drilling mud components added directly to dry Dagor soil. Early group planting

Source	df	SS	MS	F-test[a]	F-Table $\alpha = 0.05$
Treatments	50	431490.30	8629.81	9.06**	1.558
Control vs treatments	1	6682.30	6682.30	7.11**	3.989
Among treatments	49	42480.80	8669.55	9.10**	1.555
Among materials	24	322745.00	13447.71	4.12**	1.688
Between rates	1	17582.76	17582.76	18.46**	3.989
Materials x rates	24	84480.24	3520.01	3.70**	1.688
Error	68	64761.57	952.37		
Total	118	496251.87			

LSD (soil control vs treatments) at 95% = 45.768, at 99% = 60.98

[a]Asterisks refer to the level of significance. * means the sources are different with a 95% level of confidence. ** means the confidence level is even higher, at 99%; there is only one chance in a hundred that the differences are chance rather than the effect of the item listed.

Table 21. Summary of statistical analysis of fresh yields of green beans Phase I, Part A. Drilling mud components added directly to dry Dagor soil. Later group planting

Source	df		SS	MS	F-test[a]	F-Table $\alpha = 0.05$
Treatments	12		67236.13	5603.01	17.305**	2.28
Control vs treatments	1		9747.005	9747.005	30.10**	4.35
Among treatments	11		57489.105	5226.28	16.13**	2.31
Among materials		5	26218.37	5243.67	16.195**	2.71
Between rates		1	16695.37	16695.37	51.56**	4.35
Materials x rates		5	14575.365	2915.073	9.003**	2.71
Error	20		6475.39	323.27		
Total	32		73711.52			

LSD (soil control vs treatments) at 95% = 29.342, at 99% = 40.02

[a]Asterisks refer to the level of significance. * means the sources are different with a 95% level of confidence. ** means the confidence level is even higher, at 99%; there is only one chance in a hundred that the differences are chance rather than the effect of the item listed.

1.23 M x R tests whether in some cases the effect of the particular material is related to rates of addition, whereas in other materials rates don't differ.

2. Error includes all variations between replications. If all pots had the same yield, the error would be 0.

It is evident, looking at the statistical data, that (1) there are greater differences in treatment yields than between duplicates, (2) there are differences between treatments, rates and materials, and (3) there are differences in reactions of plant growth to addition rates between materials (a high rate does not always result in reduced growth, etc.). In comparison of yields of edible beans picked, all comparisons were not significant. Beans varied in extent of flowering, insects were absent from the flowers, and pollination was not likely to be uniform. A lack of consistency in edible bean yields is not surprising.

In this study where most differences on a gross basis were obvious and yields varied from nothing up to normal for the controls, statistics are not very helpful. The primary value of the statistical analysis in this study is to obtain the Least Significant Difference (LSD) values so individual treatment yields can be compared with the control samples. These values were discussed in the previous section, "Yield of Plant Materials."

Analytical data of Part A

Few analytical analyses were done on the soils of Part A. The major interest was in the effects of the components in a mud-soil mixture. Table 22 lists the soil pH run on selected samples. Soluble salt values for two materials were run. The results for soluble salts determined on saturated paste were:

Control soil . . . . 038 mmhos/cm

Sodium dichromate, low rate 0.44

Sodium dichromate, high rate 1.46

Kwik-Seal, high rate 0.68

Potassium chloride is known to be excessive (See Part B discussion on salt)

Values less than 2 mmhos/cm are considered as normal, non-salt affected soils. Above 4 mmhos/cm, salt becomes an increasing problem.

The pH values ranged from 5.8 to 6.7 in 0.01 M $CaCl_2$ solution (would approximate pH of 6.3 to 7.2 in water-made soil paste). The control pH was 6.1 and most materials were ± 0.3 pH of that value. These values indicate that the components measured did not greatly affect the soil.

Little pH change was expected in the other samples, so few analyses were done. More detail and replicated analyses were done on samples of Part B and are discussed in a later section.

Chromium

Tables 23 and 24 list chromium contents in plant and soils treated with sodium dichromate. The oven-dry weight of plants grown in pots treated with the high rate of sodium dichromate is much less than the oven-dry weight of plants grown in pots treated with the low rate of sodium dichromate and controls, respectively, for both beans and corn. The variation in chromium content of plants is extreme and is related to yield. Extremely high values occur where yields were very low. The multiplication factor becomes excessive with these small samples. No material was available for further replication. Chromium is absorbed in large amounts in some treatments.

Table 23. Total content of chromium and oven-dry weight of plant material treated with sodium dichromate. Phase I, Part A

Treatment rate*	Beans						Corn					
	Chromium content			Oven-dry weight			Chromium content			Oven-dry weight		
	Rep 1	Rep 2	Ave.	Rep 1	Rep 2	Ave.	Rep 1	Rep 2	Ave.	Rep 1	Rep 2	Ave.
	ppm	ppm	ppm	g	g	g	ppm	ppm	ppm	g	g	g
High	2.2	126	64.1	8.4	0.8	4.6	6.6	527	263.8	1.7	0.06	0.88
Low	1.4	0.1	0.75	7.9	8.2	8.05	0	0	0	2.7	2.0	2.4
Control-S	1.3	1.0	1.2	10.7	11.5	11.1	3.0	0.8	1.9	5.8	10.7	8.25

*High and low refers to high rates and low rates of sodium dichromate added to soil only. Control-S refers to soil without any added treatment.

Table 24. Chromium extracted by 2N potassium chloride solution from soils treated with sodium dichromate. Phase 1, Part A

Treatment rates*	Beans		
	Chromium content		
	Rep 1	Rep 2	Ave.
	ppm	ppm	ppm
High	24.0	24.5	24.25
Low	-0.5	NA†	0.5
Control-S	-1.0	-0.5	-0.75

*High and low refer to high rates and low rates of sodium dichromate added to soil only.
Control-S refers to soil without any added treatment. Negative values result when sample reads less than the reference zero.
†Sample not analyzed.

Replantings on treated soils of Part A

Some of the original soil samples, planted first on July 16 or August 5, 1974, were replanted October 28 to see if toxic conditions still existed after nearly three months of good moisture and temperature regimes during the first growing period and following harvest. Both beans and corn were planted in each pot. Almost all pots used were those with high treatment rates. There were 41 treatment pots and 4 control pots. No fertilizer was added before this replanting. The observations are tabulated below. Generally the growth rate of corn was low because of short days, no supplemental light, and a lack of nitrogen. (See Figures 15 and 17 in the Appendix).

1. Calcium lignosulfonate (without any sodium hydroxide). (High rate--20 lb/bbl, 81.9 g/1.8 kg). The soil was very hard and cloddy and difficult to make into a fine seedbed. Both corn and beans were near normal except for more

brownish-white, necrotic splotches on the leaves and more of the older leaves paling or dead than was observed in control plants.

2. Desco (High rate--3 lb/bbl, 12.3 g/1.8 kg). Corn and beans were about 80 percent of the growth of the control plants. Color was generally good but corn was slightly pale and older leaf tips were yellowed.

3. Diesel oil (High rate--10% of soil weight of 1.8 kg). Germination was only 65 to 75 percent. At 15 days after planting, beans were only 20 percent as high as control plants, had curled leaves, and had dead spots on the leaves. At 15 days old corn was only 40 to 75 percent as large as controls. Two of the seven plants were deformed and the leaf sworl (unfolding leaves) would not uncurl. Corn grew to 12 cm (controls were 40 cm) and had burned leaf tips. Beans at 46 days old were only 6-7 cm tall (controls were 40 cm) and leaves were mostly drying and falling off.

   (Low rate--1 percent of soil weight of 1.8 kg). At low treatment rates, beans and corn grew well but had a green to light green, mosaic color pattern on leaves.

4. Diesel oil replacement (Drillaid 405). (High rate--1 lb/bbl, 4.09 g/1.8 kg). Both beans and corn appeared to grow normally.

5. Guar gum (High rate--6 lb/bbl, 24.5 g/1.8 kg). The dried soil seemed to repel water and wetting initially was slow. Effects on corn growth are not obvious but beans still have very chlorotic leaves (green veins, yellow interveinal) and dead spots occurring

in interveinal areas, especially on older leaves. Plant size is similar to control plants.

6. Kwik-Seal (High rate--50 lb/bbl, 182 g/1.8 kg). Beans grew about as well as control plants but were pale green in early growth periods. Corn still grew poorly reaching a height of about one-half of the control and had older leaves dried.
7. Pregelatinized starch (High rate--10 lb/bbl, 40.9 g/1.8 kg). Neither beans nor corn exhibited any growth deficiencies compared to control plants.
8. Q-Broxin (High rate--20 lb/bbl, 80.9 g/1.8 kg). Crusting of the soil was similar but less severe than that observed with the calcium lignosulfonate treatments. Bean growth was about 75 percent as large as controls; some leaves were pale green but most appeared normal. Corn was chlorotic in older leaves and grew half as tall as control plants.
9. Sodium dichromate (High rate--3 lb/bbl, 12.3 g/1.8 kg). Corn grew poorly at 15 days after planting. Some beans were just emerging (a week late) and corn was stunted and had reddish leaves and stems. At 46 days old, corn had a maximum height of 5 cm and had died. Beans survived but half the plants still had seed coats covering the cotyledons and leaf growth was poor. Some plants were still just emerging from the soil. Plant heights were 2 to 12 cm, most of them less than 10 percent as tall as control plants.

(Low rate--0.5 lb/bbl, 2.05 g/1.8 kg). There were no obvious growth retardant effects on either beans or corn at the low treatment rates.

10. Sodium Hydroxide (High rate--5 lb/bbl, 20.5 g/1.8 kg). The soil is black, hard and crusted. Corn emerged but soon shrivelled and died before sending out the first leaf. Beans, after 15 days, were just emerging. However, all plants were dead within one month.

11. Torq-Trim (High rate--1.5 lb/bbl, 6.14/g/1.8 kg). Both corn and beans seemed to be similar to control plants. Some yellowing of older corn leaves occurred in the treated soils.

Discussion of Part A

The soil used (Dagor) was a silt loam, high in organic matter, fertile, and of excellent physical condition. Even the additions of the gums and starch did not seem to cause a visually evident physical problem in the soil. Sodium hydroxide, originally added as pellets was slow to disperse through the soil mass. Thus, early growth seemed good. Later growth showed the effects of aggregate breakdown and the dispersion of colloidal organic matter. As was indicated in the planting of a second crop on this material, both corn and beans died within a few weeks. The physical condition of the soil was very poor, drying into black, hard crusts.

The diesel oil inhibited plant growth at the beginning of the study. The soil was wet and very oily at the high rate. Replanted pots three months later had plants germinate and grow, although poorly. The loss of many of the volatiles of the diesel oil was evident from the soil's appearance, and plant growth in the treated soil improved.

Although in Part B it will be mentioned that sodium dichromate inhibits plant growth in many soils, this material was not very detrimental in this soil. It has been suggested that chromium bonds very strongly to organic matter. The high organic matter and high exchange capacity of the Dagor soil probably "adsorbs" large portions of the chromate and sodium. This would reduce the salt affect discussed later in Part B and would also lower any chromium toxicity that might otherwise have occurred.

Guar gum, pregelatinized starch, Dextrid, and Kwik-Seal seem to be anomalies; they were not expected to affect plant growth. There are no clues yet discovered to explain their effects on plant growth. Certainly the visual symptoms of plants suggest organic toxins, but the identity of the toxins or other cause is unknown.

RESULTS OF PART B

Growth observations and photographs of Part B

Part A considered only single mud components added to soil. Part B added these components first to a mud base and then to the soil so that the final mixture was "component-mud base-soil." Also, only thirteen chemicals were studied in Part B. All of these materials had reduced plant growth to some extent in Part A. Sodium hydroxide at the levels used in Part A was combined with each of calcium lignosulfonate and lignite because it is normally used in that manner in drilling muds. At the end of two weeks after planting beans, there was either no emergence or no evidence of germination in the following treatments:

	Rate of addition of chemical		
Material	Level	lb/bbl	g/1.6 l
Calcium lignosulfonate	High	20	81.9
Lignite	High	10	40.9
Potassium chloride	High	30	122.7
Potassium chloride	Low	10	40.9
Sodium dichromate	High	3	12.3

Pots with high rates of guar gum and diesel oil (6 lb/bbl and 10 percent of 1.6 l volume, respectively) had very poor growth. Bean heights on diesel oil or guar gum were only 10 to 12 cm compared to heights on controls of 35 to 40 cm.

In treatments planted to corn, only pots with potassium chloride at both levels and the high rate of diesel had no emergence.

Details of the effects on beans and corn of each treatment is itemized in detail in the following pages.

1. Calcium lignosulfonate. (High rate--20 lb/bbl, 81.9 g/1.6 l)* The presence of sodium hydroxide (5 lb/bbl) results in soil dispersion and organic coating of the soil. As the soil surface dried it became very black and hard, even though it was wet and gelatinous at a depth of 1 to 3 cm below the surface. No beans emerged within the 55 days. About 20 percent of the corn plants emerged but grew to less than 5 cm tall, died and dried by the end of 55 days. After two weeks of drying beyond harvest time and without wetting, the soil 5 cm below the surface was still quite sticky and wet. See Figures 18 and 22 in the Appendix.

   (Low rate--3 lb/bbl, 12.3 g/1.6 l). The sodium hydroxide level (1 lb/bbl) is lower here. The soil and the growth of beans appeared near normal at the low rate. The dispersed soil reduced the water lost by evaporation and transpiration (evapotranspiration, E_T). Pot L4 seemed to have an aeration problem even though the pots were weighed. Corn plants in L4 were smaller than in the other replication.

2. Desco (High rate-- 3 lb/bbl, 12.3 g/1.6 l). Beans at age 18 days were about 70 percent as large as control plants. Some leaves cupped and the tips curled at right angles to the plane of the leaf blade. Numerous leaves had deformed portion. Water

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*The abbreviations used should read: 20 pounds per barrel or 81.9 grams per 1.6 liters of soil-mud-chemical mixture.

infiltrates slowly into the soil and foams at the soil surface. Beans seem to grow out of any problem. At harvest, both beans and corn seemed to be about normal. Roots penetrated the soil mass well. (See Figure 24 in the Appendix.)

(Low rate--0.25 lb/bbl, 1.02 g/1.6 l). Both beans and corn appeared to grow normally.

(Double high rate--6 lb/bbl, 24.6 g/1.6 l). A double high rate sample, because of a weighing error, was used for corn to see what an extra high rate would do. New leaves coming out of the corn plant swirl were limp and without turgidity. The top halves of the newer leaves shrivelled and died. However, plants were near normal size.

3. Dextrid. (High rate--10 lb/bbl, 40.9 g/1.6 l). Beans yellowed and had slight height reductions compared to controls. Color became more pale with age; veins were green, interveinal areas paler. Corn grew poorly; plants were 10 cm tall after 35 days, only one-fourth as tall as controls. Stems were red-purple and older leaves were chlorotic and dying. Plants in Dextrid treatment eventually reached about half the height of control plants. (See figures 21 and 24 in the Appendix.)

   (Low rate--1 lb/bbl, 4.09 g/1.6 l). Both beans and corn did as well as controls at the low treatment rates.

4. Diesel oil (High rate--10 percent of 1.8 kg). Beans germinated but when 18 days old they were only 10 to 12 cm tall, less than one-third the size of control plants. By 55 days, beans were only 15 to 18 cm tall (one-third of control plants) and many leaves had fallen off. Few roots had penetrated the soil; most roots

were along the soil-pot contact surface. No corn germinated in the high-treatment rate pots. (See Figures 19, 21 and 23 in the Appendix.)

(Low rate--1 percent of 1.8 kg). Beans grew normally but grew only about 75 percent as large as controls. Corn did not grow quite as well. Corn in treated plots grew about 60 percent as large as controls, were spindly, had a reddish medvein in the leaves and generally yellow coloring (chlorosis) on older leaves.

5. Diesel oil replacement--Drillaid 405 (High rate--1 lb/bbl, 4.09 g/1.6 1). Beans and corn seemed to grow normally. Roots penetrated the soil well. (See Figure 22 in the Appendix.)

   (Low rate--0.2 lb/bbl, 0.82 g/1.6 1). Both beans and corn appeared to grow as well as controls.

6. Guar gum (High rate--6 lb/bbl, 24.5 g/1.6 1). Beans grew 12 to 14 cm tall and ceased growth. Leaves curled, cupped, puckered, and became dark green with burned or yellowed edges. Roots penetrated the soil throughout but were few in number. Corn plants also were spindly but with normal color and many older leaves dying. Few corn roots penetrated into the soil mass; most grew at the pot-soil boundary. (See Figures 20, 21 and 23 in the Appendix.)

   (Low rate--1 lb/bbl, 4.09 g/1.6 1). Beans appeared near normal but were slightly shorter than control plants. Corn plants appeared normal.

7. Kwik-Seal (High rate--50 lb/bbl, 182 g/1.6 1). Beans on Kwik-Seal were only about 75 percent as tall as beans in control

pots. The plants were yellowed and had a mosaic color pattern on new leaves. At an age of 30 days, corn was slightly yellowed with red-purple stem coloring and a height of only 10 to 12 cm tall, one-half the height of control plants. Several small toad stools (mushroom fungi) (0.5-1.5 cm diameter) grew in all high treatment rate pots for a few days before dying. Corn plants were spindly, older leaves were dried and only three leaves per plant had unfurled. At age 55 days, corn had not changed much and were only 20 cm tall. Bean root penetration throughout the soil mass was extensive. Large nitrogen-fixing bacterial nodules were obvious. Corn roots did not do as well as beans and the soil mass exterior seemed quite wet. (See Figures 21 and 23 in the Appendix.)

(Low rate--5 lb/bbl, 20.5 g/1.6 l). Both beans and corn grew nearly normal at low treatment rates. Many older corn leaves were drying up.

8. Lignite (High rate--10 lb/bbl, 40.9 g/1.6 l). Soil was crusted and the lack of bean or corn emergency is almost identical with observations on the calcium lignosulfonate treatments. Four corn plants emerged in the two pots but soon died after reaching a height of 2 to 5 cm. (See Figure 22 in the Appendix.)

(Low rate--2 lb/bbl, 8.18 g/1.6 l). Beans grew nearly normal but seemed a little smaller than controls. Corn plants were of unequal size ranging from 25 to 50 cm tall. In early growth some leaf tips blackened and died. At harvest, corn plants were dark green and appeared normal.

9. Potassium chloride (High rate--30 lb/bbl, 122.7 g/1.6 l). Neither beans nor corn germinated. Salt is excessive. (See Figure 22 in Appendix.)

(Low rate--10 lb/bbl, 40.9 g/1.6 l). Beans germinated late, grew to about 10 cm tall, wilted and died within 30 days of planting. Corn responded as the beans to the KCl. Few seeds germinated and they soon died.

10. Pregelatinized starch (High rate--10 lb/bbl, 40.9 g/1.6 l). Beans grew to two-thirds the size of controls and were pale green. Corn responded similarly to beans. Older leaves of corn were pale green as if corn had nitrogen deficiency, and plants grew only 45-50 cm tall compared to 70 cm for controls. (See Figure 24 in the Appendix.)

(Low rate--1 lb/bbl, 4.09 g/1.7 l). Beans had some growth reduction compared to controls. A yellow-green mosaic color pattern on younger leaves was apparent. Corn plants seemed about normal.

11. Q-Broxin (High rate--20 lb/bbl, 81.9 g/1.6 l). Beans 18 days old had dark green leaves, were two-thirds as large as control plants, had leaf edges that were puckered and leaves that curled parallel to the midrib. By harvest time, nearly all leaves had scorched and fallen off. Plants were half as tall as controls.

Almost no roots penetrated the soil deeper than halfway (10 cm) and no nitrogen-fixing nodules were evident. The soil surface was dark, hard, and crusty, much like soil with calcium lignosulfonate treatments. Corn (40-50 cm) was only two-thirds the size of controls and had a darker green color than controls. Its soil was also crusted and root penetration into it was limited. (See Figures 22 and 23 in the Appendix.)

(Low rate--3 lb/bbl, 12.28 g/1.6 l). Both beans and corn appear to grow normally at low rates.

12. Sodium dichromate (High rate--3 lb/bbl, 12.3 g/1.6 l). Beans germinated slowly (15-25 days) but never emerged fully. Only the bent stem broke the soil surface; the seed never lifted out of the soil. Corn had just a few plants emerge and die.

(Low rate--0.5 lb/bbl, 2.05 g/1.7 l). Beans were a little darker green color than control plants and growth was about 80 percent as much as controls. Corn plants were slightly darker green and had a slight wilted appearance. Growth seemed about normal, otherwise.

13. Torq-Trim (High rate--1.5 lb/bbl, 6.14 g/1.7 l). Bean growth seems to be normal but yellowing of older leaves is more common than on leaves of controls. Roots permeated the soil well. Corn grew well, but perhaps only 90 percent of the control plants. Appearance was normal. (See Figure 24 in the Appendix.)

(Low rate--0.5 lb/bbl, 2.05 g/1.6 l). Both beans and corn appeared to grow normally.

Yields of plant materials of Part B

The yields of fresh and dried (65°C) plant material are given in Tables 25 through 28. All pots with treatments of potassium chloride were without any plants at harvest time. Salts completely inhibited germination. At the high treatment levels, pots containing materials with added sodium hydroxide (calcium lignosulfonate and lignite) and containing the sodium dichromate salt had no plant production. Of the thirteen materials tested, only plants in Drillaid 405 (diesel oil replacement) and Torq-Trim did not exhibit growth statistically different from the control plants. In order of decreasing hazard to plant growth (based on average of bean plus corn yields at both treatment rates), the 13 materials are given below. (Total average dry weight yield per pot in grams is given in parentheses):

Potassium chloride (0)--most inhibitory to plant growth

Sodium dichromate (2.2)

Diesel oil (2.8)

Lignite + sodium hydroxide (3.0)

Calcium lignosulfonate + sodium hydroxide (3.8)

Kwik-Seal (6.7)

Guar gum (6.9)

Q-Broxin (7.2)

Pregelatinized starch (8.3)

Dextrid (a starch) (9.1)

Desco (11.3)

Torq-Trim--(11.2)--no obvious growth inhibition

Drillaid 405 (diesel oil replacement) (11.9)

Control (mud + soil) (12.7)

Relative sensitivity of beans and corn was not always consistent. Beans, which should be more sensitive to salt than the corn actually did better on sodium dichromate (low rate) than did corn (Tables 25, 26, 27 and 28). The effect of the dichromate could be both a problem with chromium and a problem of soluble salt. Beans also did better on the

Table 25. Oven-dry weight yields of sweet corn grown in soil-drilling mud base with various added drilling mud components. Weights are in grams per pot. Dagor soil, Phase I, Part B

Materials	High rate			Low rate			Total
	MH3	MH4	Ave	ML3	ML4	Ave	ave
Calcium lignosulfonate	0	0	0**[a]	9.7	1.5	5.7**	2.8
Dextrid	3.9	0.5	2.2**	15.2	14.2	14.2	8.2
Desco	8.5	8.8	8.6*	12.3	15.9	14.1	11.3
Diesel oil	0	0	0**	3.6	3.6	3.6**	1.8
Drillaid 405	9.6	12.8	11.2	11.2	12.5	11.8	11.5
Guar gum	1.2	1.0	1.1**	13.9	12.2	13.0	7.1
Kwik-Seal	0.6	0.1	0.3**	9.7	9.0	9.3**	4.8
Lignite	0	0	0**	5.1	0.8	2.9**	1.5
Potassium chloride	0	0	0**	0	0	0*	0
Pregelatinized starch	2.9	4.9	3.9**	12.4	14.8	13.6	8.7
Q-Broxin	3.5	4.1	3.8	12.0	10.8	11.4	7.6
Sodium dichromate	0	0	0**	0	0	0**	0
Torq-Trim	10.6	11.9	11.2	15.8	13.3	14.5	12.8
	Rep	Rep	Rep	Rep	Rep	Rep	Ave
A. Soil only controls							
Nos. S13 to S18	8.2	12.1	10.1	5.8[b]	10.9	11.6	10.1
Nos. S19 to S24	10.7	10.6	10.7	8.3	9.2	13.7	
B. Mud + soil controls							
Nos. M31 to M36	11.3	14.0	14.2	9.0	15.2	15.5	12.8
Nos. M37 to M42	12.8	15.7	12.8	11.9	12.5	9.6	

[a]A treatment average is significantly different from the mud control average at the 5% level (95% confidence level based on LSD values) if it has one asterisk. Two asterisks indicate significant at the 1% level.

LSD (mud control vs treatments) at 95% = 3.49, at 99% = 4.667.
LSD (soil control vs treatments) at 95% = 3.52, at 99% = 4.698.

[b]Was not planted as thought; was planted 10 days later; not used.

Table 26. Fresh weight yields of sweet corn grown in soil-drilling mud base with various added drilling mud components. Weights are in grams per pot. Dagor soil, Phase I, Part B

Materials	High rate			Low rate			Total
	MH3	MH4	Ave	ML3	ML4	Ave	Ave
Calcium lignosulfonate	0	0	0**[a]	94.4	11.1	52.7**	26.4
Dextrid	44.1	4.3	24.2**	130	129	129.5	76.8
Desco	92.0	79.4	85.7*	128	145	136.5	111.1
Diesel oil	0	0	0**	33.3	36.5	34.9**	17.4
Drillaid 405	98.9	128	113.5	92.9	123	107.9	110.7
Guar gum	11.4	7.6	9.6*	134	97.2	110.6	60.1
Kwik-Seal	4.2	3.8	4.0**	94.6	89.0	91.8*	47.9
Lignite	0	0	0**	66.9	6.4	36.6**	18.3
Postasium chloride	0	0	0**	0	0	0**	0
Pregelatinized starch	27.3	56.6	41.9**	116	132	74.0**	57.9
Q-Broxin	30.9	41.2	36.0**	114	112	113	74.6
Sodium dichromate	0	0	0**	89.9	99.7	94.8*	47.4
Torq-Trim	98.6	114	106.3	140	136	138.0	122.1
	Rep	Rep	Rep	Rep	Rep	Rep	Ave
A. Soil only controls							
Nos. S13 to S18	93	128	105	59[b]	107	115	107.1
Nos. S19 to S24	102	106	117	90	100	115	
	Rep	Rep	Rep	Rep	Rep	Rep	Ave
B. Mud + soil controls							
Nos. M31 to M36	110	129	137	103	139	146	123.1
Nos. M37 to M42	128	143	116	118	115	93	

[a]A treatment average is significantly different from the mud control average at the 5% level (95% confidence level based on LSD values) if it has an asterisk. Two asterisks indicate significant at the 1% level.

LSD (mud control vs treatments) at 95% = 29.84, at 99% = 39.825.
LSD (soil control vs treatments) a5 95% = 30.03, at 99% = 40.083.

[b]Was not planted as thought; was planted 10 days later; not used.

Table 27. Oven-dry weight yields of green bean plants grown in soil-drilling mud base with various added drilling mud components. Weights are in grams per pot. Dagor soil, Phase 1, Part B.

Materials	High rate			Low rate			Total
	MH1	MH2	Ave	ML1	ML2	Ave	Ave
Calcium lignosulfonate	0	0	0**[a]	11.6	8.0	9.8	4.9
Dextrid	6.8	6.7	6.7**	14.9	11.7	13.3	10.0
Desco	8.8	6.9	7.8**	13.9	16.1	15.0	11.4
Diesel oil	1.6	1.2	1.4**	5.9	6.7	6.3**	3.8
Drillaid 405	12.2	13.3	12.7	12.3	11.8	12.0	12.3
Guar gum	1.5	0.9	1.2**	--	12.4	12.4	6.8
Kwik-Seal	6.8	6.3	6.5**	11.0	10.4	10.7	8.6
Lignite	0	0	0**	10.0	8.5	9.2	4.6
Potassium chloride	0	0	0**	0	0	0**	0
Pregelatinized starch	5.9	5.9	5.9**	11.0	8.9	9.9	7.9
Q-Broxin	2.7	4.7	3.7**	9.7	10.3	10.0	6.8
Sodium dichromate	0	0	0**	7.8	10.0	8.9**	4.4
Torq-Trim	12.8	5.4	9.1	8.9	11.9	10.4	9.7
	Rep	Rep	Rep	Rep	Rep	Rep	Ave
A. Soil only controls							
Nos. S1 to S6	9.8	8.0	10.3	10.7	11.8	10.4	10.7
Nos. S7 to S12	11.5	12.3	11.1	11.0	11.0	10.9	
	Rep	Rep	Rep	Rep	Rep	Rep	Ave
B. Mud + soil controls							
Nos. M1 to M6	14.3	10.6	13.7	--	10.0	13.0	12.2
Nos. M7 to M12	10.2	14.2	11.2	10.8	11.9	13.5	

[a]A treatment average is significantly different from the mud control average at the 5% level (95% confidence level based on LSD values) if it has an asterisk, two asterisks indicate significance at the 1% level.

LSD (mud control vs treatments) at 95% = 2.43, at 99% = 3.242.
LSD (soil control vs treatments) at 95% = 2.416, at 99% = 3.227.

Table 28. Fresh weight yields of green bean plants grown in soil-drilling mud base with various added drilling mud compounds. Weights are in grams per pot. Dagor soil, Phase I, Part B

Materials	High rate			Low rate			Total
	MH1	MH2	Ave	ML1	ML2	Ave	Ave
Calcium lignosulfonate	0	0	0**[a]	64.4	51.0	57.7**	28.8
Dextrid	37.0	35.7	36.3**	84.1	66.9	75.5	55.9
Desco	57.5	42.7	50.1**	81.7	79.3	80.5	65.3
Diesel oil	4.0	3.3	3.6**	29.6	46.5	43.0**	23.3
Drillaid 405	78.8	71.0	69.9	72.2	67.1	69.7	69.8
Guar gum	9.5	5.9	7.7**	--	71.3	71.3	39.5
Kwik-Seal	39.4	32.8	36.1**	58.1	53.9	56.0**	46.0
Lignite	0	0	0**	59.3	53.6	56.4**	28.2
Potassium chloride	0	0	0**	0	0	0**	0
Pregelatinized starch	30.4	30.7	30.5**	60.0	46.1	53.1**	41.8
Q-Broxin	9.9	9.4	9.6**	57.4	61.3	59.4*	34.5
Sodium dichromate	0	0	0**	50.1	57.0	53.6**	26.8
Torq-Trim	76.1	29.1	52.6**	45.6	61.9	53.7**	53.1
	Rep	Rep	Rep	Rep	Rep	Rep	Ave
A. Soil only controls							
Nos. S1 to S6	60.2	55.8	62.3	64.2	71.9	63.2	62.8
Nos. S7 to S12	57.9	68.2	61.9	61.8	64.9	61.5	
	Rep	Rep	Rep	Rep	Rep	Rep	Ave
B. Mud + soil controls							
Nos. M1 to M6	78.7	62.6	76.2	--	57.5	70.0	70.4
Nos. M7 to M12	63.3	84.1	65.0	63.5	69.1	73.0	

[a]A treatment average is significantly different from the mud control average at the 5 percent level (95% confidence level based on LSD values) if it has an asterisk. Two asterisks indicate significance at the 1 percent level.

LSD (mud control vs treatment) at 95% = 9.06, at 99% = 12.099.
LSD (soil control vs treatment) at 95% = 9.00, at 99% = 12.022.

low rates of calcium lignosulfonate and lignite than did corn. An explanation for this is not presently evident.

Plant growth is affected by factors other than the added drilling mud component. Since the pots are without drainage, watering has been done by predetermining the wetted weight of soil in the pot and watering to that weight several times weekly. As the plant grew, estimates of the weight of plant material were added to the original weight for a final weight to water to. Effectiveness of this procedure was checked periodically by lifting the soil from selected pots, mostly one of two controls, and observing its wetness after watering it 30 to 60 minutes earlier. This part of the greenhouse technique was more an art than a science and was biased by the researcher's concepts of what constitutes, from visual inspection, the best conditions for growing plants in the greenhouse.

It is possible that some pots could have been overwatered. The author does not believe this occurred nor that overwatering is the cause of the observed plant growth reductions. However, it is true that the water retention characteristics of the soil-mud mass was changed by some component additions. Table 29 lists the moisture retention values for soil-mud mixtures treated with a starch, a gum, and two lignosulfonate materials and are compared to controls. Pregelatinized starch caused the greatest increase in the water held at 1/3 bar suction (approximately field capacity; the amount of water a wetted soil will hold against gravity drainage). The amount of water held in these samples when suction has reached the approximate permanent wilting percentage (15 bars suction) is also doubled over that water held by the soil-mud control.

Table 29. The effects of selected drilling mud components on the water held at 1/3 and 15 bars suction (approximately maximum wetting called field capacity and plant permanent wilting percentage, respectively). All on soils plus base mud, except the control soil

Treatment	Water retained at suctions of: 1/3 bar	15 bars
	%	%
Untreated soil (Dagor)	34.7	16.8
Soil plus mud base	30.2	11.2
Calcium lignosulfonate, high rate	40.0	23.5
Calcium lignosulfonate, low rate	34.3	14.9
Guar gum, high rate	30.5	12.8
Guar gum, low rate	29.9	11.4
Pregelatinized starch, high rate	41.6	19.9
Pregelatinized starch, low rate	30.1	11.2
Q-Broxin, high rate	32.2	12.2
Q-Broxin, low rate	31.1	13.1

When deficient water levels in soils planted to beans occurs, beans readily wilt. Yield is not as affected by early stages of wilting in beans as it is in many plants. Few occasions of more than earlier stages of wilting occurred. If a problem of growth from water occurred, it would result from excess water. The only known case of possible overwatering occurred at mid-growth on Q-Broxin beans in Part B. Over wetness did not occur at the time of, nor thought to be the cause of, the sudden bean wilting which occurred on the Q-Broxin treatment. The soil condition of this treatment, nevertheless, did appear to be undesirable for growth (lost structure, massive).

Statistical analyses of Part B

The least significant difference (LSD) allows some comparison of controls with individual treatments. The LSD values in Tables 30 through 33 are given at the 95% and 99% confidence levels. Unfortunately, the treatment difference can be more than just the added chemical; it can be variations in greenhouse watering, greenhouse location affects if they occur, seed differences, and so on.

The data in the tables on growth (Tables 25 through 28) illustrate that both levels of diesel oil, lignite + NaOH, potassium chloride, and sodium dichromate reduced plant growth. Only Torq-Trim and Drillaid 405 did not reduce growth at either addition rate.

Analytical data of Part B

Soluble salts. Soluble salt analyses were measured only on the materials thought to possibly have a soluble salt problem--potassium chloride, sodium dichromate, and Kwik-Seal. Sodium hydroxide would have its greatest affect on pH and soil dispersion, so it was not included in this study.

The soluble salt values of the saturation extracts, given in mmhos/cm of electrical conductivity, are given in Table 34. An approximate relationship of conductivity to weight of salt is:

Milligrams of salt per liter of liquid = 640 times mmhos/cm conductivity

(Bower and Wilcox, 1965). It is evident from Table 34 that potassium chloride at both high and low addition rates is many-fold too concentrated for plant growth (see reference values in the Review of Literature). Kwik-Seal does not have any appreciable amount of soluble salts, apparently.

Table 30. Summary of statistical analysis of dried corn yields of Phase I, Part B. All materials except soil controls had drilling mud base mixture plus added component added to Dagor soil.[a]

Source	df	SS	MS	F-test	F-Table
Treatments	27	2043.23	75.675	14.6**	1.733
Controls vs treatments	1	521.85	521.85	100.74**	4.052
Soils vs muds	1	35.43	35.43	6.83*	4.052
Among treatments	25	1485.95	59.438	11.47**	1.748
Among materials	12	867.25	72.271	13.95**	1.972
Between rates	1	405.45	405.45	78.27**	4.052
Materials x rates	12	213.25	17.771	3.43*	1.972
Error	47	243.51	5.18		
Total	74	2266.74			

LSD (mud control vs treatments) at 95% = 3.49, at 99% = 4.667
LSD (soil control vs treatments) at 95% = 3.52, at 99% = 4.698

[a]Asterisks refer to the level of significance. * means the sources are significant at the 5 percent level. ** means the sources are significant at the 1 percent level.
[b](See footnote b at bottom of Table No. 14, page 58).

Table 31. Summary of statistical analysis of fresh corn yields of Phase I, Part B. All materials except soil controls had drilling mud base mixture plus added component added to Dagor soil.[a]

Source	df	SS	MS	F-test	F-Table
Treatments	27	174626.62	6467.65	17.14**	1.733
Controls vs treatments	1	40115.05	40115.05	106.36**	4.052
Soils vs muds	1	1283.49	1283.49	3.40	4.052
Among treatments	25	133228.08	5329.12	14.13**	1.748
Among materials	12	64529.58	5377.46	14.25**	1.972
Between rates	1	52228.92	52228.92	138.48**	4.52
Materials x rates	12	16469.58	1372.46	3.64*	1.972
Error	47	17725.73	377.14		
Total	74	192352.35			

LSD (mud control vs treatments) at 95% = 29.84, a 99% = 39.825
LSD (soil control vs treatments) at 95% = 30.03, at 99% = 40.083

[a]Asterisks refer to the level of significance. * means the sources are significant at the 5 percent level. ** means the sources are significant at the 1 percent level.

Table 32. Summary of statistical analysis of dried green bean yeilds of Phase I, Part B. All materials except soil controls had drilling mud base mixture plus added component added to Dagor soil.[a]

Source	df	SS	MS	F-test	F-Table
Treatments	27	1488.42	55.126	22.31**	1.738
Controls vs treatments	1	332.69	332.69	134.69**	4.056
Soils vs muds	1	20.42	20.42	8.26*	4.056
Among treatments	25	35.31	43.37	17.55**	1.753
Among materials	12	567.87	47.32	19.16**	1.976
Between rates	1	369.56	369.56	149.62**	4.056
Materials x rates	12	170.88	14.24	5.67**	1.976
Error	46	113.68			
Total	73	1602.1			

LSD (mud control vs treatments) at 95% = 2.43, at 99% = 2.474
LSD (soil control vs treatments) at 95% = 2.42, at 99% = 3.227

[a]Asterisks refer to the level of significance. * means the sources are significant at the 5 percent level. ** means the sources are significant at the 1 percent level.

Table 33. Summary of statistical analysis of fresh bean plant corn yields of Phase I, Part B. All materials except soil controls had drilling mud base mixture plus added component added to Dagor soil.[a]

Source	df	SS	MS	F-test	F-Table
Treatments	27	51334.81	1901.29	55.44**	1.738
Controls vs treatments	1	11747.84	11747.84	342.60**	4.056
Soils vs muds	1	365.22	365.22	10.65*	4.056
Among treatments	25	39221.75	1568.87	45.75**	1.753
Among materials	12	17373.22	1447.77	42.72**	1.976
Between rates	1	14422.24	14422.24	42.06**	4.056
Materials x rates	12	7426.29	618.85	18.04**	1.976
Error	46	1577.38	34.29		
Total	73	52912.19			

LSD (mud control vs treatments) at 95% = 9.06, at 99% = 12.099
LSD (soil control vs treatments) at 95% = 9.00, at 99% = 12.022

[a]Asterisks refer to the level of significance. * means the sources are significant at the 5 percent level. ** means the sources are significant at the 1 percent level.

Table 34. Electrical conductivity of soil saturation (paste) extracts for soil with drilling mud components added and for soil with both base mud and drilling component added. Dagor soils for most pots; soil MU2-74 and Millville for two treatments at bottom of table

Treatment	Electrical conductivity in mmhos/cm				
	Rep 1	Rep 2	Rep 3	Rep 4	Ave
Soil only with added chemical					
Control (soil only)	0.85	0.43	0.35	--*	0.38
Sodium dichromate, low rate	0.44	0.44	--	--	0.44
Sodium dichromate, high rate	1.30	1.30	1.80	--	1.46
Kwik-Seal, high rate	0.72	0.72	0.60	--	0.68
Soil plus mud base with added chemical					
Soil control	0.35	0.43	0.35	--	0.38
Soil + mud control	0.81	1.20	--	--	1.01
Sodium dichromate, low rate	1.36	--	1.52	1.12	1.33
Sodium dichromate, high rate	4.00	3.70	5.40	6.00	4.76
Kwik-Seal, low rate	0.90	0.80	1.13	1.16	0.98
Kwik-Seal, high rate	0.66	0,81	1.16	1.52	1.04
Potassium chloride, low rate	52.2	59.1	52.5	48.0	52.9
Potassium chloride, high rate	133.0	140.8	--	119.4	131.1
Millville soil, sodium dichromate, high rate	13.6	NA†	NA	NA	13.6
Soil MU2-74, sodium dichromate, high rate	12.8	NA	NA	NA	12.8

*Sample not analyzed.

†No replicates were set up and thus not available (NA).

Sodium dichromate is more variable. In the high-organic-matter soil, conductivity at the high sodium dichromate rate was 4.76 mmhos/cm. In the other two soils of low organic matter content, the high rate of sodium dichromate additions produced conductivities of 12.8 and 13.6 mmhos/cm, both too high for most plants. Chromium is known to bond strongly to organic compounds. Perhaps this phenomenon is important in this situation. Bonding to organic matter in the Dagor soil would reduce the concentration of chromate in solution.

Fortunately, soluble salts in humid and subhumid areas usually are washed from the soil by rainfall. Salt accumulations as found in these treatments may not be as formidable in natural settings as it appears at first sight. On dry area sites, however, the salt would remain unless washed out by irrigation, and would be a permanent problem until washed away.

Soil pH. No problem of soil pH was expected except for treatments having sodium hydroxide added. At high rates, soil pH is in the range at which many plants are affected (pH 8.5-9.0 with the $CaCl_2$ procedure). (See Table 35 and 36). There is no reason to suggest that any of the other materials were causing toxicities because of their pH. Notice that even though the soil control's pH is only 6.0, the soil + mud control's pH is considerably higher, 6.7. Most of the treatments maintained a pH similar to that of the soil + mud control.

Similar results were obtained with other soils including the acid Miamian soil and the strongly calcareous Millville soil (see Table 36). Although alkalinity can be corrected quite easily, the problem of exchangeable sodium and resultant soil dispersion is the more damaging effect when sodium hydroxide is added.

Table 35. Soil pH* values of soils-plus-base-mud mixture and with drilling mud components added. Beans and corn were grown for 56 days before soils were sampled for analysis. Each value is an average of four measurements. Soil was Dagor.

Treatment	Treatment rate	pH*	Treatment	Treatment rate	pH
Control, soil only	0	6.0	Kwik-Seal	Low	6.9
Control, soil + mud	0	6.7	Kwik-Seal	High	6.9
Calcium lignosulfonate†	Low	7.4	Lignite (+ NaOH)	Low	7.3
Calcium lignosulfonate	High	8.7	Lignite (+ NaOH)	High	9.0
Desco	Low	6.6	Pregelatinized starch	Low	7.0
Desco	High	6.9	Pregelatinized starch	High	6.9
Dextrid	Low	6.9	Q-Broxin	Low	6.8
Dextrid	High	6.9	Q-Broxin	High	6.7
Diesel oil	Low	7.1	Sodium dichromate	Low	6.9
Diesel oil	High	7.1	Sodium dichromate	High	7.4
Diesel oil replacement‡	Low	7.0	Torq-Trim	Low	6.9
Diesel oil replacement	High	6.9	Torq-Trim	High	7.0
Guar gum	Low	7.2			
Guar gum	High	7.2			

*Soil pH was done on a 1:2 soil weight-volume of 0.01 M $CaCl_2$. These pH values are probably about 0.3 to 0.6 pH unit lower than paste pH values would be.
†Calcium lignosulfonate in soil-plus-mud treatments also had the sodium hydroxide additions.
‡Same as Drillaid 405.

Table 36. Soil pH* values of soils-plus-base-mud mixtures only and with drilling mud components added. Corn was grown for 56 days before soils were sampled for analyses. Most values shown are single treatments without replication

Soil used	Treatment	Treatment rate	Soil pH*
	Control (plus mud base)	0	5.3
	Calcium lignosulfonate†	High	8.9
Miamian	Diesel oil	High	7.3
(Ohio)	Guar gum	High	7.6
	Pregelatinized starch	High	7.4
	Q-Broxin	High	7.1
	Sodium dichromate	High	7.6
	Control (Plus mud base)	0	7.1
	Calcium lignosulfonate†	High	9.7
	Diesel oil	High	7.6
Millville (Utah)	Pregelatinized starch	High	7.4
	Q-Broxin	High	7.6
	Sodium dichromate	High	7.4
	Control (Plus mud base)	0	5.6
Soil MU2-74	Q-Broxin	High	7.4
	Sodium dichromate	High	7.2

*Soil pH was done on a 1:2 soil weight-volume of 0.01M $CaCl_2$. These pH values are probably about 0.3 to 0.6 pH unit lower than the paste pH values would be.

†Plus the high rate of sodium hydroxide.

Chromium

Tables 37, 38 and 39 list the chromium content in plants and in soil treated with sodium dichromate.

The amount of chromium in plants, even those treated with the low rate of sodium dichromate, is higher than chromium in plants on the mixture of soil and mud (Table 37). The sensitivity of analytical procedure was poor at these concentrations. The variation shown is partly instrumentation variation.

In Table 38 the content of chromium in soils treated with a high rate of sodium dichromate is shown to be much higher than it is in controls and in the low treatment rates.

The oven-dry weight of plants grown in soil with the low rate of sodium dichromate is about half that of plants grown in a mixture of soil and mud without sodium dichromate.

The pots treated with sodium dichromate in Part A replanted without any other additional sodium dichromate to see the effect of time on chromium content in soil. Then the chromium content of plant material was measured and it was 502 ppm.

Growth observations on other soils
in Part B

This simple pilot study was done to compare corn growth on different soils but using only a few of the chemicals causing growth problems. As in the main study of Part B, 300 kg of N per ha as ammonium nitrate and 100 kg P per ha as treble superphosphate were added to the soil-mud material before planting. Three additional soils were used (see Table 4 for characterization data), and the following treatments were set up:

Table 37. Chromium content and oven-dry weight of plant material grown in pots treated with sodium dichromate. Phase 1, Part B

Treatment rate*	Beans						Corn					
	Chromium content			Oven-dry weight			Cromium content			Oven-dry weight		
	Rep 1	Rep 2	Ave	Rep 1	Rep 2	Ave	Rep 1	Rep 2	Ave	Rep 1	Rep 2	Ave
	ppm	ppm	ppm	g	g	g	ppm	ppm	ppm	g	g	g
Low	3.6	2.6	3.1	7.8	10.8	8.9	4.7	1.5	3.1	10.0	11.2	10.6
Control-S	1.3	1.0	1.2	10.7	11.5	11.1	3.0	0.8	1.9	5.8	10.7	8.25
Control-M	0	0.8	0.4	14.3	10.8	12.6	3.0	3.3	3.15	15.2	15.7	15.45

*Low refers to mixture of mud and soil and low rate of sodium dichromate. No plant grew in high rates of sodium dichromate addition. Control-S refers to soil without any added treatment. Control-M refers to mixture of soil and mud without any added treatment.

Table 38. Total content of chromium in soils treated with sodium dichromate. Phase I, Part B

Treatment rate	Beans			Corn		
	Rep 1	Rep 2	Ave	Rep 1	Rep 2	Ave
	ppm	ppm	ppm	ppm	ppm	ppm
High	1930	1840	1885	1645	1875	1760
Low	276	297	286.5	268	276	272
Control-M	19	17	18	--†	--	--

*High and low refer to high rates and low rates of sodium dichromate added to nurture the soil and mud.
Control-M refers to mixture of soil and mud without any added treatment.
†Sample not analyzed.

Table 39. Potassium chloride-extractable chromium in soils-plus-mud treated with sodium dichromate. Phase 1, Part B

Treatment rate*	Chromium content extracted from soil				
	Rep 1	Rep 2	Rep 3	Rep 4	Ave
	ppm	ppm	ppm	ppm	ppm
High	160	226	256	261	225.75
Low	2.5	6.5	13	8.5	7.525
Control-S	0	-0.5	-1.0	0.0	-0.375
Control-M	-1.0	0.0	0.0	0.0	-0.25

*High and low refer to high rates and low rates of sodium dichromate added to the mixture of soil and mud.
Control-S refers to soil without any added treatment.
Control-M refers to mixture of soil and mud without any added treatment.

Soil and its properties	Material added (high rates)
MU2-74: Sandy loam, strongly-acid, low organic matter, low nutrient level	Calcium lignosulfonate (+NaOH) Guar gum Q-Broxin Sodium dichromate
Millville series: Silt loam moderately alkaline, moderate organic matter, high lime content	Calcium lignosulfonate (+NaOH) Diesel oil Diesel oil replacement (Drillaid 405) Pregelatinized starch Q-Broxin Sodium dichromate
Miamian series: Silt loam, strongly acid, 3.3 percent organic matter, low nutrient level	Diesel oil Guar gum Pregelatinized starch Q-Broxin Sodium dichromate

Soil MU2-74. This Northern Utah soil was screened to material less than 2 mm from a gravelly, leached (A2 horizon) soil under lodgepole pine. It is low in clay, organic matter and nutrients. The soil also has a high bulk density and the weight of soil used resulted in a mud-soil mixture of only about 1.4 to 1.5 liters. The visual observations of corn growth on these treatments follow.

1. Calcium lignosulfonate (High rate--20 lb/bbl, 81.9 g/1.5 l). No corn emergence. The soil was black, dried very hard on the surface, and appeared to be puddled soil.

2. Guar gum (High rate--6 lb/bbl, 24.5 g/1.5 l). Corn emerged and grew to 5 cm tall, then died. The soil dried very slowly; it seemed to be very wet because of a sponge-like soil mass.
3. Q-Broxin (High rate--20 lb/bbl, 81.9 g/1.5 l). Corn had only 5 to 6 seeds germinate. Two plants grew to 5 cm and died; the other 3 grew to 12-15 cm, only about 40 percent as large as the control plants, and the leaf tips burned. The soil was coated by black, dispersed humus and dried hard.
4. Sodium dichromate (High rate--3 lb/bbl, 12.3 g/1.5 l). No corn emerged.

Millville soil. The Millville soil is a loam soil of the Utah State Experimental Farm, with about 2 percent organic matter, pH of 7.7 and 30 percent lime (calcium carbonate equivalent). The visual observations of corn growth on these treatments follow.

1. Calcium lignosulfonate (High rate--20 lb/bbl, 81.9 g/1.8 l). The soil is coated with black humus and crusts were very hard when the soil dried. No corn emerged.
2. Diesel oil (High rate--10 percent of diesel oil based on soil weight of 1.8 kg/pot). No corn germinated.
3. Diesel oil replacement (Drillaid 405) (High rate--1 lb/bbl, 3.09 g/1.8 l). Corn grew well and appeared normal compared with controls.
4. Pregelatinized starch (High rate--10 lb/bbl, 40.9 g/1.8 l). The soil was very gelatinous and seemed to remain too wet. Corn looked fair except for tip burn on leaves and growth was only 10 to 15 cm, one-third the height of controls.

5. Q-Broxin (High rate--20 lb/bbl, 81.9 g/1.8 l). The soil surface is black and dries to a hard crust. Corn emerged well and color was normal but plants grew only to half the height of controls.
6. Sodium dichromate (High rate--3 lb/bbl, 12.3 g/1.8 l). No corn emerged.

Miamian soil (Ohio). The Miamian silt loam is formed from calcareous loam till, but has a pH of about 5.6, is under beech, oak, hickory and maple forest, has about 5.5 percent organic matter and about 29 me/100 g exchange capacity.

1. Diesel oil (High rate--10 percent oil based on a soil weight of 1.8 kg per pot). No corn emerged.
2. Guar gum (High rate--6 lb/bbl, 24.5 g/1.8 l). The soil was spongy and seemed to stay quite wet. Corn emerged but 2 of the 6 plants wilted and died. The other plants were only 10 to 12 cm tall (one-fourth of the controls) and leaf tips died.
3. Pregelatinized starch (High rate--10 lb/bbl, 4019 g/1.8 l). The corn plants appeared quite normal but were only 15 cm tall, one-third the height of control plants, and there was slight interveinal chlorosis.
4. Q-Broxin (High rate--20 lb/bbl, 81.9 g/1.8 l). The soil was black and dried to a hard crust. Corn was half as large as controls, and its color was darker green with purple coloration on stems that progressed up the older leaves.
5. Sodium dichromate (High rate--3 lb/bbl, 12.3 g/1.8 l). Some soft surface crusting occurred on the soil. No corn emerged, but not because of crusting.

Discussion of Part B

The sections on "Growth Observations" and "Yields" discuss most of the growth observations. The causes of growth reductions are several. Probably there are also some unrecognized affects active. It is believed that the greenhouse procedures and results were suitable to select the drilling mud components which reduce plant growth enough to be severe problems in site revegetation.

The causes of growth reductions are believed to fall into the following general classes:

1. Soluble salts: Potassium chloride and sodium dichromate.
2. Toxic low-boiling-point organics: Diesel oil.
3. High pH from sodium hydroxide: Calcium lignosulfonate and lignite.
4. Organic toxins of unknown composition: Kwik-Seal, Guar gum, Torq-Trim, Q-Broxin, pregelatinized starch, Dextrid, and Desco.
5. Other: Sodium dichromate as a toxic level of chromium(?).

The mixture of drilling-mud base with soil alters appreciably the basic features of the soil matrix due to the large dilution affect by barite and bentonite. The physical condition of this "new soil" is altered and seems to have reduced porosity.

Marked changes in the soil physical condition occurred with several materials. Additions of sodium hydroxide (with calcium lignosulfonate and with lignite) caused the soil to lose much of its aggregation. Upon drying the soil formed very hard, large clumps or surface crust. Yet at a shallow depth it was moist and slightly gelatinous in appearance. Guar gum, Dextrid and pregelatinized starch formed gelatinous-acting soil masses which, however, seemed to take water well, thus suggesting adequate pore space. Q-Broxin had the slowest water intake. The poor root penetration observed after harvesting these treatments suggested poor aeration in the lower soil mass, although organic toxins could hinder root penetration also.

Kwik-Seal with its light-weight bulk and synthetic plus vegetable fibers results in a soil mass similar to a mixture of soil plus peat moss. The soil seems high in porosity but yet to hold considerable water. The fungus mushrooms grew about two to three weeks after planting. They grew rapidly, were about 3/4 inch diameter, and died within two or three days. No new ones grew. These growths occurred in the high-addition-rate pots. Such fungi grow when dead vegetable material is present in a moist, warm, fertile soil; the fungi are saprophytes.

Detrimental effects of diesel oil, which were observed when the oil was added to only soil (Part A), were reduced when oil was added to the mud mixture. The seeds in the soil-mud mixture were able to germinate and maintain some growth. The detrimental effects of diesel oil were still strongly evident, however. With time the toxins should slowly dissipate.

DISCUSSION AND CONCLUSIONS

This greenhouse study of drilling mud components as they might affect plant growth of green beans and sweet corn clearly identifies some problem components. The study was preliminary in nature. Only two replications of each treatment were used; this is a minimum number possible. Generally two, widely-divergent treatment levels were used for each component (material). The low addition rates are the more extensively used concentrations and are typical of muds presently used.

The use of undrained pots permits speculation that overwatering in some instances might occur. Although careful observations and experienced judgement was used to determine the amount of water needed and the weight to which pots should be wetted, the extreme variations in the soil's physical condition occurring with different components in Part B make overwatering errors a distinct possibility. For example, measurements of field capacity moisture (1/3 bar suction) and permanent wilting percentage moisture (15 bars suction) varied widely, as indicated by these values in treatments of soil plus mud base.

Treatment	1/3 bar %	15 bar %
Untreated soil (Dagor	35	17
Soil plus mud base	30	11
Calcium lignosulfonate, high rate	40	23
Guar gum, low rate	30	11

Treatment	1/3 bar %	15 bar %
Pregelatinized starch, high rate	42	20
Q-Broxin, high rate	32	12

Drained pots could have been employed, but such a technique results in leaching losses or exposure of leachate (which must finally be re-added daily to the pot) to the atmosphere. Small pots seldom drain as dry as 1/3 bar moisture unless they have their soil in contact with some type of absorbent material beneath them.

The general similarity of plant appearance and growth in replicate pots encourages confidence in the results. It is possible to obtain similar results, however, if both pots have the same error applied to them. This would occur if overwatering because of mistaken judgement was made in the final wetted pot weight to use.

Another restriction on extrapolation of the data to other conditions is the fixed soil-mud-component ratios used in this study. Although components were added at two fixed rates, the final dilution of the waste mud by mixing with soil on the site can be extremely variable. Also, as shown by the pilot study using three different soils, even the soil properties will greatly alter the detrimental effects of a given concentration of added component. Obviously, extrapolation of these results to field conditions of different kinds of soils is limited.

Climate and time will be critical environmental factors. Porous soils in humid climates could lose those toxic levels of potassium chloride by washing (leaching) in a single, heavy rainfall. Possibly the removal of much of the problem caused by sodium dichromate could also be accomplished by leaching. Warm, humid areas could have rapid microbial inactivation of organic toxins. Dry sandy soils would have the toxic affects magnified because of a lack of deactivating constituents--organic matter, clays, and high microbial activity.

A final precaution in interpreting these results is related to the test plants used. Although beans and corn are convenient and suitable test plants, they are not representative of all kinds of plants. They are not likely to represent forest tree responses or responses of certain dry rangeland plants. Plants differ greatly in growth rate, tolerance to salt and acidity, and tolerance to certain kinds of toxins. Thus, the rapid greenhouse growth, warm climate and extensive root extractions from the soil are not similar to many conditions that will be encountered in the field; no limited greenhouse study could be.

With these cautions on the indescriminant extrapolation of the results of this study, the following conclusions seem justified.

1. The following tested materials at both rates used were inhibitory or almost inhibitory to plant growth.

   Potassium chloride: Entirely a soluble salt concentration problem.

2. The following tested materials caused severe reductions in plant growth at the high rates and also appreciable reductions at the low rates.

   Lignite plus sodium hydroxide: High pH and soil dispersion problem.

   Calcium lignosulfonate plus sodium hydroxide: High pH and soil dispersion problem.

   Diesel oil: Toxicities of low-boiling-point hydrocarbons.

   Sodium dichromate: Likely both a soluble salt and toxic chromate problem.

3. The following tested materials caused moderate to severe reductions in plant growth at the high rates but rather limited reductions in growth at the low rates.

   Guar gum: Cause is unknown. It is presumed to be organic toxins because symptoms are similar in both soil and in soil-mud mixtures.

   Kwik-Seal: Cause unknown; believed to be organic toxin(s).

   Pregelatinized starch: Cause unknown; believed to be organic toxin(s).

   Q-Broxin: Cause unknown; believed to be organic toxin(s). It contains phenol propane which is known to be toxic to plants (Patrick, 1971).

   Dextrid: Cause unknown; believed to be organic toxins.

4. The following tested materials caused statistically significant reductions in plant growth but the reductions were not great.

   Desco: Cause unknown; believed to be organic toxin(s).

   Torq-Trim: Cause unknown; believed to be organic toxin(s).

   Drillaid 405: Cause unknown; believed to be organic toxin(s).

5. The following tested materials caused no growth reduction when they were added to soil alone, or the growth reduction was so small it is questionable. These were not tested in Part B.

Asbestos (super visbestos)	Drillaid 412
Asphalt	DME
Barite	Gilsonite
Ben-Ex	Kelzan-XC
Bentonite	Lignite
Cypan	Paraformaledhyde

Pipe dope

Separan-AP-273

Sodium acid pyrophosphate

Sodium carboxymethyl cellulose

Soltex

Witconnate 1840

6. The following tested materials were found to be statistically significant at the 5 percent level in <u>increasing</u> plant growth above yields of the control plants.

Asphalt

Ben-Ex

Gilsonite

Paraformaldehyde

Shell polymer (Separan AP-273)

In general, drilling mud components can reduce plant growth in several ways.

1. The materials added to soil can increase the soluble salt content and the osmotic pressure in soil solution. This detrimental effect can be reduced by leaching the salts from the profile.
2. The materials, particularly sodium hydroxide, develop a high pH in the soil. The pH can be reduced by additions of gypsum, sulfur, or iron sulfate combined with leaching the profile.
3. The materials may contain or may form during decomposition organic toxins. It is expected that a variable length of time (a few months to maybe one or two years) plus leaching will alleviate this problem. Organic toxins will gradually be deactivated by microbial breakdown. Many of the toxins should be water soluble and thereby leachable. Thus, the next approach seems to be to obtain some knowledge about the longevity of the toxic nature and the leachability of some of these materials.

   A summary table (Table 40) itemizes the materials studied in Part B of Phase I. These were most of the materials causing growth reductions in Part A and lists the suggested approach to reduce the problem of each material.

Table 40. Oil drilling-mud components which reduced bean and/or corn growth, the application rate that was detrimental, the probable cause for the effects on plant growth, and the probable effective methods of reclamation

Mud component	Rates reducing plant growth	Probable cause for the effect of component on plant growth	Methods likely to be effective in reducing the effect of retarding growth
Calcium lignosulfonate	20 lb/bbl	Toxic aromatic from hydrolysis or decomposition; high pH if added	Time for microbial decomposition; reduce pH and replace sodium with sulfur or gypsum and leach soil
Desco (tannin?)	3 lb/bbl	Unknown. Toxic organic?	Time for microbial decomposition change should be rapid (few weeks or months), leaching
Dextrid (starch)	10 lb/bbl	Unknown. A non-starch component or preservative or/and effect on soil physical state?	Unknown. Higher soil:component ratio and time for microbial decomposition, leaching
Diesel oil	1% and 10% by weight	Toxic aromatics and aliphatics; hindrance of soil wetting and water retention	Evaporation of volatile portions; physically mix with uncoated soil; time for microbial decomposition
Drillaid 405	1 lb/bbl	Composition not available. Perhaps there is no toxicity; it is marginal	Time for microbial decomposition, leaching
Guar gum	6 lb/bbl 1 lb/bbl	Toxic organics, possibly some furans; affect on soil physical condition and soil water	Time for microbial decomposition (one year?); dilute with more soil, leaching
Kwik-Seal	50 lb/bbl 5 lb/bbl	Toxic organics	Time for microbial decomposition, leaching

Table 40. Continued

Mud component	Rates reducing plant growth	Probable cause for the effect of component on plant growth	Methods likely to be effective in reducing the effect of retarding growth
Lignite	10 lb/bbl	High pH and exchangeable sodium because of sodium hydroxide added with lignite	Reduce pH with sulfur or iron sulfate, replace sodium with gypsum or sulfur (on calcareous soils), and leach profile
Potassium chloride	30 lb/bbl 10 lb/bbl	Soluble salt (osmotic) affect	Leach salt from profile (rainfall in humid area; irrigation in dry area)
Pregelatinized starch	10 lb/bbl 1 lb/bbl	Unknown. A non-starch component or preservative or/and effect on the soil physical state or soil water relations	Unknown. Higher soil:component ratio and time for microbial decomposition, leaching
Q-Broxin	20 lb/bbl	Toxic organics from hydrolysis or decomposition; toxic chromium, possibly pH?	Time for microbial decomposition, leaching, application of high phosphate levels
Sodium	8 lb/bbl 0.5 lb/bbl	Soluble salt (osmotic) affect at high rate; toxic chromium at both rates?	Leaching to remove salts; high phosphate or organic material additions to reduce chromium activity
Torq-Trim	1.5 lb/bbl	Unknown. Low percentage additive or contaminant? May not have any toxin at all	Short time for microbial decomposition, leaching

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APPENDIX

Figure 1. Dextrid at the following concentrations: high rate = 10 lb/bbl (40.9 g/1.8 kg of soil); low rate = 1 lb/bbl (4.09 g/1.8 kg of soil). Phase 1, Part A, Beans. High treatment levels reduced bean growth.

Figure 2. Dextrid. High rate = 10 lb/bbl (40.9 g/1.8 kg of soil). Phase I, Parr A, close-up of high rate. Beans are small (large ones are control plants). Notice deformed beans just to right of the number 30.

Figure 3. Diesel oil at the following concentrations: high rate = about 35 lb/bbl (10% of soil weight); low rate = 3.5 lb/bbl (1% of soil weight). Phase I, Part A, Corn. Both treatment levels reduce corn growth. No germination the first planting at high rate; poor growth on replants one month later.

Figure 4. Guar gum at the following concentrations: high rate = 6 lb/bbl (24.5 g/1.8 kg of soil); low rate - 1 lb/bbl (4.09 g/1.8 kg of soil). Phase I, Part A, Beans. Both treatment levels reduced growth. Notice internal chlorosis, edge burn and puckered leaves at high rate.

Figure 5. Guar gum at the following concentrations: high rate = 6 lb/bbl (24.5 g/1.8 kg of soil); low rate = 1 lb/bbl (4.09 g/1.8 kg of soil). Phase I, Part A, Beans. Notice the reddish-brown color pattern of leaves in low rate. Leaves soon died and fell in the high rate, leaves puckered, were brilliant, shiny green, and had internal chlorosis.

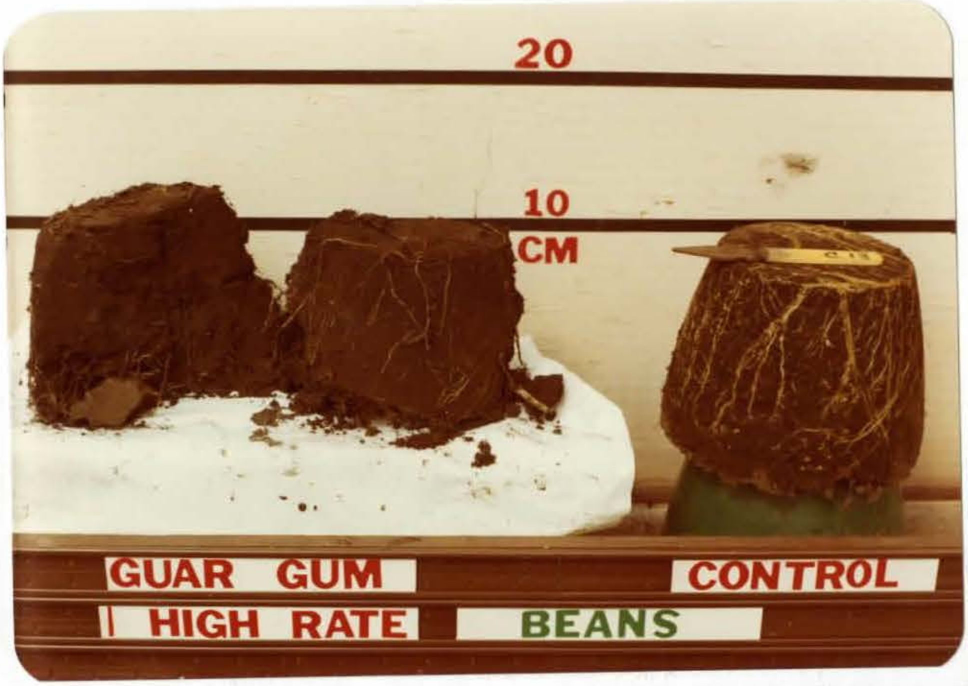

Figure 6. Guar gum treatment. High rate = 6 lb/bbl (24.5 g/1.8 kg of soil). Phase 1, Part A, Beans. Root distribution was scattered and roots penetrating into soil were few and coarse.

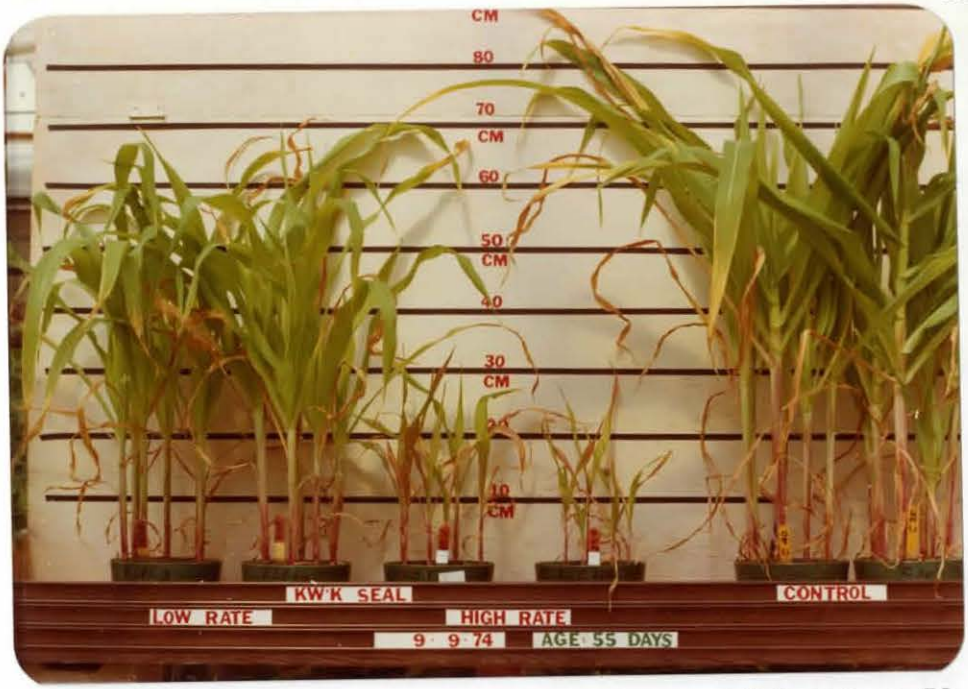

Figure 7. Kwik-Seal at the following concentrations: high rate = 50 lb/bbl (186 g/1.6 kg of soil); low rate = 5 lb/bbl (20.5 g/1.8 kg of soil). Phase I, Part A, Corn. Both treatment rates caused reduced plant growth. At the high rate, plants were very small and plants had prominent yellow and red coloring.

Figure 8. Potassium chloride at the high rates (30 lb/bbl or 122.78/ 1.8 kg of soil). Accumulation of salt occurred on top of the soil.

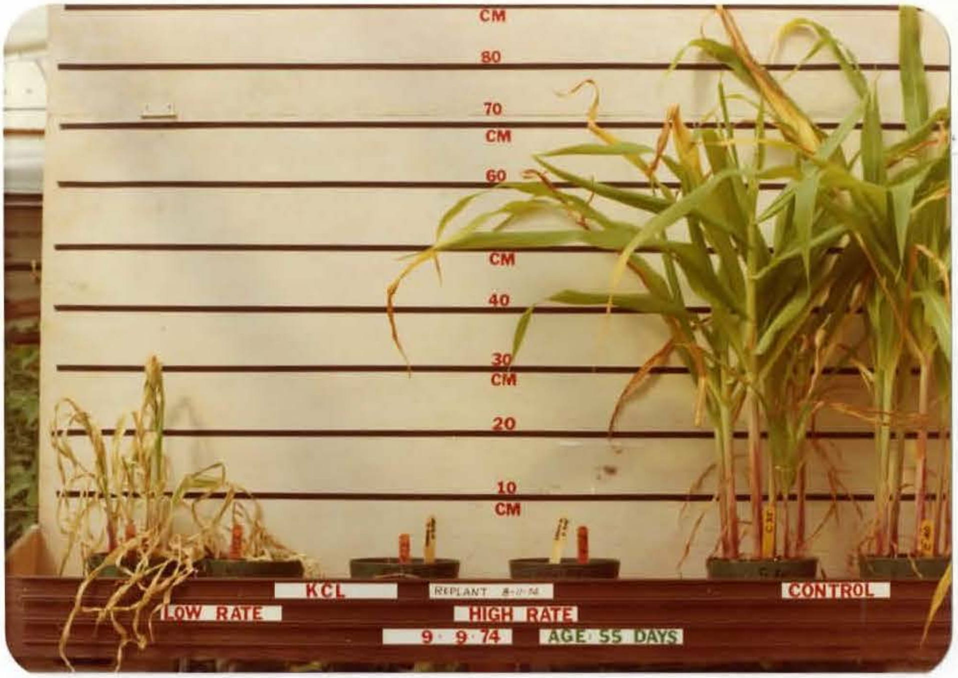

Figure 9. Potassium chloride at the following concentrations: high rate = 30 lb/bbl (122.7 g/1.8 kg of soil); low rate = 10 lb/bbl (40.9 g/1.8 kg of soil). Phase I, Part A, Corn. No germination occurred on high rate treatments; plants finally died on low rate treatment.

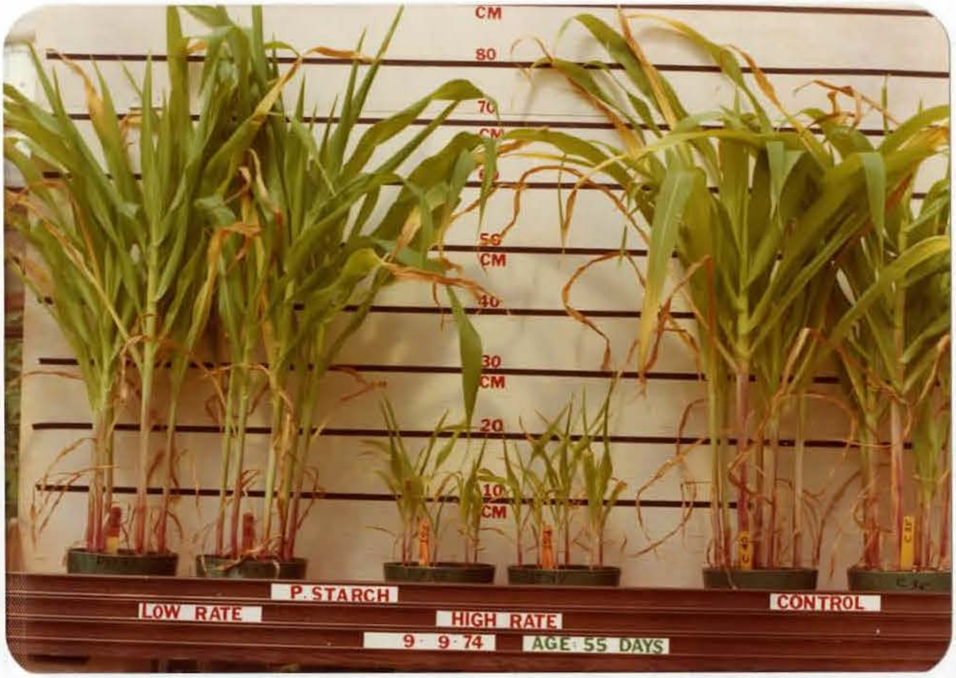

Figure 10. Pregelatinized starch at the following concentrations: high rate = 10 lb/bbl (40.9 g/1.8 kg of soil); low rate = 1 lb/bbl (4.09 g/1.8 kg of soil). Phase I, Part A, Corn. Growth in the high rate treatments is very poor.

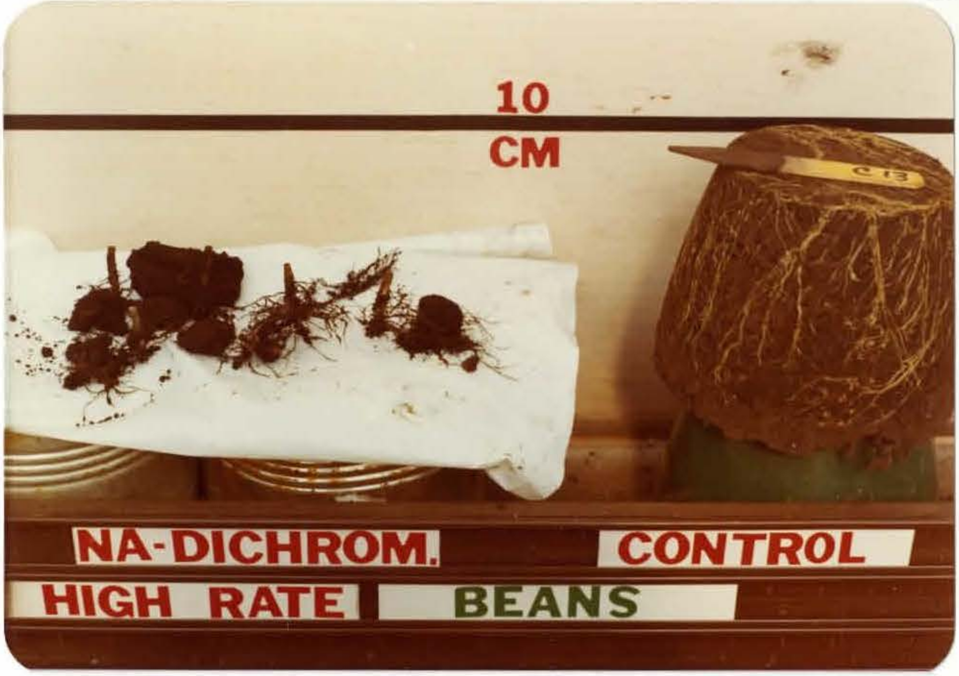

Figure 11. Sodium dichromate treatment. High rate = 3 lb/bbl (12.3 g/1.8 kg of soil). Phase I, Part A, Beans. Roots grew mostly in the top inch of soil; a few grew along the pot wall.

Figure 12. Sodium dichromate at the following concentrations: high rate = 3 lb/bbl (12.3 g/1.8 kg of soil); low rate = 0.5 lb/bbl (2.05 g/1.8 kg of soil). Phase I, Part A, Corn. High treatment rates almost hindered plant growth. Plants had reddish coloration and were almost dried at the age of 55 days old.

Figure 13. Example of four materials and their affect on bean growth. Phase I, Part A, Beans. Torq-Trim, Dextrid and Q-Broxin all reduced bean growth. Pipe dope had a slight effect on plant growth.

Figure 14. Example of four materials and their affect on corn growth. Phase I, Part A, Corn. Torq-Trim, Dextrid and Q-Broxin all reduced plant growth. The effect of pipe dope was small.

Figure 15. Second planting of some Part A soil treatments. Phase I, Part A-2. Of the materials shown, only Guar gum is still hindering normal bean growth. Torq-Trim appears to affect corn growth slightly. Torq-Trim, diesel oil replacement, and pregelatinized starch did not reduce plant growth.

Figure 16. Second planting of some Part A soil treatments. Phase I, Part A-2. All materials shown still reduce corn growth. Kwik-Seal did not appear to reduce bean growth. The most serious growth retardation was by diesel oil and sodium dichromate treatments.

Figure 17. Second planting of some Part A soil treatments. Phase I, Part A-2. Sodium hydroxide hindered any germination. Q-Broxin still hinders growth of both beans and corn. The effect of calcium lignosulfonate and Desco were less obvious.

Figure 18. Calcium lignosulfonate and Q-Broxin treatments at high treatment rates. Phase I, Part B, Corn. Only a few seedlings emerged in the calcium lignosulfonate treated soil and few roots developed. Q-Broxin caused slight root penetration into the interior of the soil-mud mass.

Figure 19. Diesel oil at the following concentrations: high rates = 10% by soil weight (180 g); low rate = 1% by soil weight (18.0 g). Phase I, Part B, Beans. Growth in the low treatment level was fair, but at the high rate growth was very poor. The soil-mud mixture stayed greasy in appearance.

Figure 20. Guar gum at the following concentrations: high rate = 6 lb/bbl (24.5 g/1.6 l); low rate = 1 lb/bbl (4.09 g/1.6 l). Phase I, Part B, Beans. Slight growth reductions occurred in low treatment rates. Severe growth retardation occurred in high level treatment rates. Leaf-edge scorch was typical on older levels.

Figure 21. Selected treatments at high addition rates. Dextrid, Guar gum, Kwik-Seal and diesel oil Phase I, Part B, Beans.

Figure 22. Selected treatments at high addition rates. Lignite (+ sodium hydroxide), Q-Broxin, calcium lignosulfonate (+ sodium hydroxide), diesel oil replacement (Drillaid 405), and Potassium chloride. Phase I, Part B, Beans.

Figure 23. Selected treatments at high addition rates. Guar gum, Kwik-Seal, diesel oil, and Q-Broxin. Phase I, Part B, Corn.

Figure 24. Selected treatments at high addition rates. Torq-Trim, Desco, Dextrid, and pregelatinized starch. Phase I, Part B, Corn.

Figure 25. Corn growth in selected treatments in Millville soil (a strongly calcareous silt loam). Rates of addition per pot are the same as given in Part B for the Dagor soil. Phase I, Part B. No growth occurred in calcium lignosulfonate, pregelatinized starch, and Q-Broxin (after 55 days).

Figure 26. Lignite (plus sodium hydroxide) and sodium dichromate in Millville soil. High treatment rates. Phase I, Part B. Few seedlings emerged; those that did emerge soon died. Lignite caused black, crusted soil.

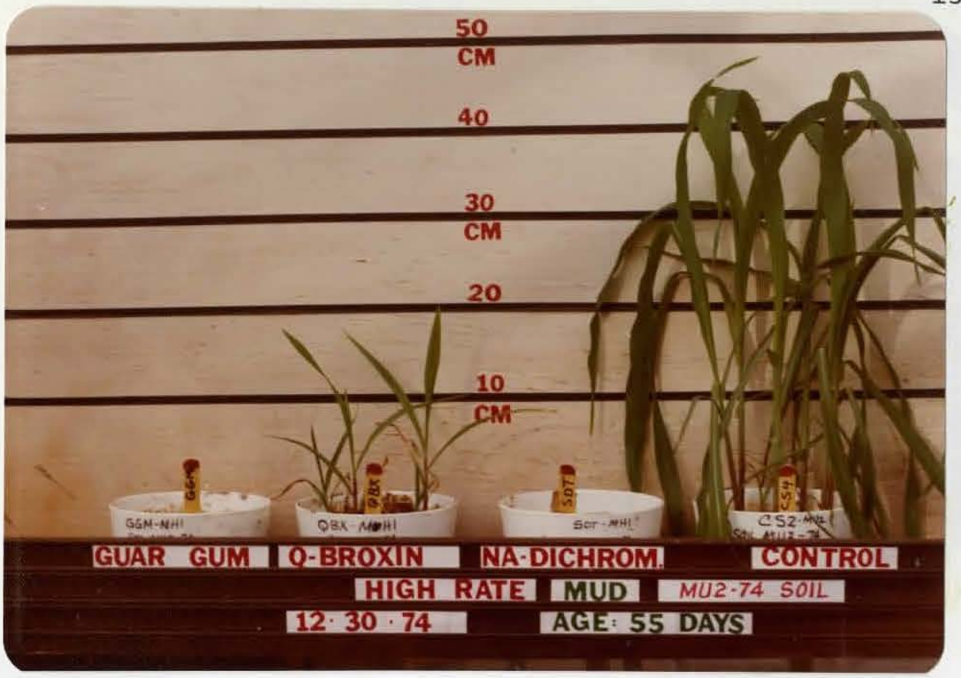

Figure 27. Corn growth in selected treatments (high rate) in soil MU2-74 (acid, sandy loam). Phase I, Part B. No growth occurred in Guar gum or sodium dichromate treatments. Greatly reduced growth occurred in Q-Broxin.

Figure 28. Q-Broxin and Guar gum treatments (high rate) in MU2-74 sandy loam. Phase I, Part B. Notice the few plants which emerged but died while very small (after 55 days).

Figure 29. Soil appearance of Miamian (Ohio) soil treated with high rates of calcium lignosulfonate (+ sodium hydroxide) and Guar gum. Phase I, Part B. Note crusting of the soil mass caused by calcium lignosulfonate which resulted from the added sodium hydroxide.

Figure 30. Plant growth in selected treatments (high rate) on the acid Miamian (Ohio) soil. Phase I, Part B. No growth of corn occurred in calcium lignosulfonate (+ sodium hydroxide), diesel oil or sodium dichromate. Growth was successively better in Guar gum, pregelatinized starch, and Q-Broxin.

VITA

Shahnaz Honarvar (Asad Sangabi)

Candidate for the Degree of

Master of Science

Thesis: Effect of Drilling Fluid Components and Mixtures on Plants and Soils.

Major Field: Soil Science and Biometeorology (Soil Fertility)

Biographical Information:

Personal Data: Born in Shiraz, Iran, June 8, 1945. Daughter of Samad and Ehteram (Mirab) Asad Sangabi, married Samad Honarvar February 7, 1969. Daughter, Bita, born May 29, 1971.

Education: 1975 M.S. in Soil Science and Biometeorology (Soil Fertility) Utah State University; 1967, B.S. in Soil and Irrigation, Pahlavi University of Shiraz, Iran; 1962, graduated from Nazemieh High School, Shiraz, Iran; and 1955 graduated from Hedaiat Elementary school.

Professional Experience: 1967-1969 teaching Biology in Shahnaz High School, Fasa, Iran.