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Determination and Evaluation of Alternative Methods for Managing and Controlling Highway-Related Dust
Phase II—Demonstration Project

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16. Abstract

The State of Iowa currently has approximately 69,000 miles of unpaved secondary roads. Due to the low traffic count on these unpaved roads, paving with asphalt or Portland cement concrete is not economical. Therefore to reduce dust production, the use of dust suppressants has been utilized for decades. This study was conducted to evaluate the effectiveness of several widely used dust suppressants through quantitative field testing on two of Iowa's most widely used secondary road surface treatments: crushed limestone rock and alluvial sand/gravel. These commercially available dust suppressants included: lignin sulfonate, calcium chloride, and soybean oil soapstock. These suppressants were applied to 1000 ft test sections on four unpaved roads in Story County, Iowa. To duplicate field conditions, the suppressants were applied as a surface spray once in early June and again in late August or early September. The four unpaved roads included two with crushed limestone rock and two with alluvial sand/gravel surface treatments as well as high and low traffic counts. The effectiveness of the dust suppressants was evaluated by comparing the dust produced on treated and untreated test sections. Dust collection was scheduled for 1, 2, 4, 6, and 8 weeks after each application, for a total testing period of 16 weeks. Results of a cost analysis between annual dust suppressant application and biennial aggregate replacement indicated that the cost of the dust suppressant, its transportation, and application were relatively high when compared to that of the two aggregate types. Therefore, the biennial aggregate replacement is considered more economical than annual dust suppressant application, although the application of annual dust suppressant reduced the cost of road maintenance by 75 %. Results of the dust collection indicated that the lignin sulfonate suppressant outperformed calcium chloride and soybean oil soapstock on all four unpaved roads, the effect of the suppressants on the alluvial sand/gravel surface treatment was less than that on the crushed limestone rock, the residual effects of all the products seem reasonably well after blading, and the combination of alluvial sand/gravel surface treatment and high traffic count caused dust reduction to decrease dramatically.

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DETERMINATION AND EVALUATION OF ALTERNATE METHODS FOR MANAGING AND CONTROLLING HIGHWAY-RELATED DUST

PHASE II—DEMOSTRATION PROJECT

IHRB Project TR-506

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EXECUTIVE SUMMARY

The State of Iowa currently has approximately 69,000 miles of unpaved secondary roads. Due to the low traffic count on these unpaved roads, paving with asphalt or Portland cement concrete is not economical. Therefore to reduce dust production, the use of dust suppressants has been utilized for decades. This study was conducted to evaluate the effectiveness of several widely used dust suppressants through quantitative field testing on two of Iowa's most widely used secondary road surface treatments: crushed limestone rock and alluvial sand/gravel. These commercially available dust suppressants included: lignin sulfonate, calcium chloride, and soybean oil soapstock. These suppressants were applied to 1000 ft test sections on four unpaved roads in Story County, Iowa. To duplicate field conditions, the suppressants were applied as a surface spray once in early June and again in late August or early September. The four unpaved roads included two with crushed limestone rock and two with alluvial sand/gravel surface treatments as well as high and low traffic counts. The effectiveness of the dust suppressants was evaluated by comparing the dust produced on treated and untreated test sections. Dust collection was scheduled for 1, 2, 4, 6, and 8 weeks after each application, for a total testing period of 16 weeks. Results of a cost analysis between annual dust suppressant application and biennial aggregate replacement indicated that the cost of the dust suppressant, its transportation, and application were relatively high when compared to that of the two aggregate types. Therefore, the biennial aggregate replacement is considered more economical than annual dust suppressant application, although the application of annual dust suppressant reduced the cost of road maintenance by 75 %. Results of the dust collection indicated that the lignin sulfonate suppressant outperformed calcium chloride and soybean oil soapstock on all four unpaved roads, the effect of the suppressants on the alluvial sand/gravel surface treatment was less than that on the crushed limestone rock, the residual effects of all the products seem reasonably well after blading, and the combination of alluvial sand/gravel surface treatment and high traffic count caused dust reduction to decrease dramatically.

CHAPTER 1. INTRODUCTION

1.1 Problem Statement

Currently the State of Iowa has approximately 69,000 miles of unpaved secondary roads in its transportation matrix (Lohnes and Coree, 2002). Due to the low traffic count of these secondary roads, paving with asphalt or Portland cement concrete is not economical. Therefore, surface treatments of crushed limestone or alluvial sand/gravel are periodically applied to maintain a stable and safe surface for rural travel. Although these unpaved secondary roads are an essential part of agricultural and rural transportation, they pose several serious threats to our safety, health, and wellbeing.

Air borne dust particles produced when a vehicle travels the unpaved surface causes impaired visibility, additional vehicle wear, inhalation hazards, stunted crop growth, and personal annoyance. The dust produced is of several sources including: degradation of coarse surface aggregate through repetitive grinding and crushing caused by vehicle traffic, default dust that is included in the original surface treatment gradation, and organic and inorganic material deposited by various sources.

Impaired visibility caused by air borne dust is a serious safety problem that can have devastating consequences. From 1991 to the present, there has been three dust related accidents in Story County, resulting in five injuries, zero fatalities, and thousands of dollars in property damage. Of the three accidents reported in Story County, all but one person involved was under 20 years of age. The main cause was obscured vision caused by following a preceding vehicle at an unsafe distance.

The health threat associated with road dust is the inhalation of microscopic particles that are able to slip through our natural respiratory air filter. Air borne dust particles less than 1 mm in diameter are considered a health hazard and median particle diameters of road dust have been reported to range from 0.002 mm to 0.049 mm (Hoover et al., 1981). Lohnes and Coree (2002) indicate that Iowa air quality standards recommend a concentration of particulates in air less than 75 mg/m^3 for human health. Other studies in Iowa have reported particulate concentrations in road dust in excess of 1.2 million mg/m^3 (Lustig, 1980). The dust produced on unpaved secondary roads is one of the major man made sources of fugitive dust, contributing up to 34%

of the particulate matter in the atmosphere (Sanders et al., 1997).

According to Hoover et al. (1973) the severity of the problems associated with dust continues to increase as:

1. traffic volume increases,
2. more people move to rural areas surrounding larger towns and cities, and
3. the current concern over air pollution increases.

To the large number of people residing in the unpaved areas, the dust produced on the unpaved surface is undesirable and causes personal annoyance. The dust settles on exterior furnishings and lawn ornaments as well as on the siding, windows, and roofs of homes. On the interior, a thin layer of dust accumulates on television screens, tables, furniture, shelves, and nearly every surface that is exposed.

Although dust poses several threats, its importance in the stability of an unpaved road is imperative. The dust that we term annoying and unhealthy acts as a binding agent for coarse aggregate particles and keeps the unpaved road surface compacted. In order to maintain compaction and this binding action, it is important to bind the dust particles together and reduce dust loss through the use of dust suppressants. There have been several quantitative field studies on dust suppression, but the search for an economical, durable, environmentally safe dust suppressant is still being pursued.

1.2 Objective and Scope

The objective of the study as proposed was to evaluate the effectiveness of two dust control additives that have been used but subjected to limited systematic study, namely, ground asphalt shingles and soap stock (a soybean oil byproduct). The evaluation was to include comparison to widely used dust palliatives as well as to untreated sections. Early on in the study it was discovered that an adverse experience with nails in ground shingles effectively prevented further consideration of this material in Iowa. This was a Phase II Demonstration Project study. Hence, in this study the effectiveness of three dust suppressants, lignin sulfonate, calcium chloride, and soybean oil soapstock, was studied through quantitative field testing on two of Iowa's most widely used secondary road surface treatments: crushed limestone rock and alluvial sand/gravel.

The study was proposed five in tasks: 1) construction of dust measuring equipment, 2) selection of field test sites and construction of demonstration sections, 3) monitoring of dust at the demonstration sites for a period of one year, 4) evaluation of previously stabilized road sections at various locations in Iowa, and 5) preparation of final report. The first three tasks are reported on herein and the fifth task is covered in this report. Task 4, the evaluation of previously stabilized road sections at various locations in Iowa, was found to be unattainable as all sections identified as potential sites had been subsequently resurfaced or otherwise remediated to make dust collection for comparison purposes a moot point.

The contents of this report are presented in several chapters. In Chapter 2 a literature review of several studies on dust suppression at Iowa State University and throughout the United States is provided. Much of the information previously presented by Lohnes and Coree (2002) in the Phase I in also presented for completeness of the report. In Chapter 3 discussion is provided of the demonstration site selection criteria, granular surface characteristics, and locations as well as the test section plans. Chapter 4 describes the three dust suppressants, application rates, and costs. Chapter 5 discusses the method used for dust measurement and the schedule of dust collection. The presentation of the results and discussions of the dust measurements is included in Chapter 6. The conclusions and recommendations based on the dust measurements are provided in Chapter 7. Following the chapters are a list of references and appendices that provide additional information on weather conditions and the dust measurement data.

CHAPTER 2. LITERATURE REVIEW

There are numerous dust control products available throughout the country including calcium chloride, soybean oil soapstock, lignin sulfonate, foamed asphalt, magnesium chloride, and many others. This review summarizes several studies on dust suppression completed at Iowa State University as well as throughout the United States.

2.1 Iowa State University Studies

Researchers at Iowa State University began studying products for both road stabilization and dust suppression in the mid 1950's under the supervision of D.T. Davidson (Lohnes and Coree, 2002). The studies conducted by Davidson and his colleagues were mainly associated with road stabilization, but additional benefits of the stabilization products were recognized as possible dust suppressants.

A study conducted by Fox (1972) is one of the earliest dust control research projects at Iowa State University. The study investigated the effectiveness of ammonium lignosulfonate and ammonium lignosulfonate in combination with calcitic lime or aluminum sulfate as additives in dust suppression on granular surfaced secondary roads. The study included laboratory and field investigations of granular surfaced secondary roads in Clinton, Linn, and Floyd Counties. Laboratory investigations concluded that the unconfined compression strength, dry density at optimum water content, and resistance to slaking increase with increase in the amount of calcitic lime or aluminum sulfate additive. Field investigations were conducted using plastic containers placed at intervals perpendicular to the roadway. The plastic containers captured a portion of the settling dust caused by vehicles traveling the roadway. The dust collected in the plastic containers confirmed that all the roadways with treatment had reduced dust production to nearly 80% compared to the untreated roadways. The results of the field studies also indicated that 1% lignosulfonate treatment was as effective as 1% lignosulfonate plus 0.5% of either calcitic lime or aluminum sulfate additives, more improvement at less cost was realized by the addition of secondary additives rather than by addition of more lignosulfonate, and although the availability of lignosulfonate is nearly unlimited, its use as a dust suppressant in Iowa will probably be limited due to the cost of delivery.

Bergeson (1972) conducted investigations on the use of cutback asphalts, latex emulsions, and cationic asphalt emulsions for use as dust suppressants and surface stabilizing agents for granular surfaced secondary roads. The study included evaluation of three cutback asphalts, two latex emulsions, and one cationic asphalt emulsion using laboratory and field testing. The laboratory tests involved unconfined compression testing and the use of a traffic simulator to evaluate stability and rutting on loess and crushed Bedford limestone mixed with the additives. Based on the results of the laboratory testing, the cutback asphalt and the cationic asphalt emulsion were recommended for field trials. The latex emulsions were not recommended for field trials due to the high cost of the latex compared to the asphalt. The results of the laboratory testing also concluded that the samples that were air-cured for 24 hours and then immersed for 24 hours provided an indication of an additives potential as a waterproofer, but did not define the additive's stability. Traffic simulator results gave valid indications of both fine material retention and waterproofing as well as indications of a material's stability under a moving load and imposed environmental condition. From the results it was concluded that fines retention and waterproofing of the cationic asphalt emulsion, cutback asphalt, and latex emulsion were essentially the same; however the latex emulsion and cationic asphalt emulsion resisted rutting better than the cutback asphalt. Field testing was conducted on a one-mile section of roadway in Poweshiek County with a traffic count of 150 vehicles per day. The one-mile section was divided into ten, 500-ft long test sections and one, 300-ft test section. The 300-ft test section served as one of the three untreated or control sections and the 10-500 ft test sections contained various percentages of cutback asphalt and cationic asphalt emulsion. The field tests concluded that dust had been reduced on all treated sections and with the exception of the 2% cationic asphalt emulsion, all treated sections had improved surface stability. Although both the 4% MC-800 cationic asphalt and the 4% Redicote E-36 cationic asphalt demonstrated excellent performance and stability characteristics, the overall recommendation for superior stability and performance is 4% Redicote E-36 cationic asphalt.

One year later, a laboratory study conducted by Denny (1973) investigated the use of polyester and thermo plastic resins as soil stabilizers and low cost dust suppressants. Various soil-chemical additives were evaluated on the basis of unconfined compression strength, durability or erosibility, trafficability, resistance to freezing and thawing, and moisture retention and density and compared with the results of untreated or control samples. In all, sixteen different additives were initially studied; however half of the additives were believed to be inappropriate for field application due to water insolubility that hindered dilution and difficulty in application. The rejected additives require the use of benzene for solution and include polystyrene, polypropylene, and several polyester resins. Benzene, due to its toxicity and volatility, was not considered practical as a solvent for field application. The remaining eight additives included several polyester resins and five proprietary chemicals of unknown chemical composition. Based on the laboratory test results, the following additives were recommended for field trials: Petro D Dust at 0.1% to 0.25% concentration, Stypol 40-5020 polyester resin at 0.5% concentration, Kelpak at concentrations ranging from 0.1% to 0.2%, and SA-1 at 0.1% concentration. Elvanol 71-30 polyvinyl alcohol provided excellent improvement over untreated samples, but was considered unsatisfactory for field trials due to the requirement of hot mixing water and extreme difficulty in mixing with soil. Clapak and Claset also were not recommended due to their inability to effectively control sub-grade moisture content.

The three preceding theses by Fox (1972), Bergeson (1972), and Denny (1973) were edited and compiled into a report to the Iowa State Highway Commission in 1973 by J.M. Hoover (Hoover et al., 1973). This compilation suggested six criteria for dust palliatives:

1. The additive must cost less than $5,000 per mile (1973 dollars) and certainly not exceed $10,000 per mile.
2. The additive must be water soluble on application but become insoluble after incorporation with the soil to provide bonding, waterproofing, or other resistance to dust production.
3. The additive must not require any special handling or construction equipment.
4. The additive must provide adequate dust control with possible strength improvement.
5. The additive must have ease of surface penetration or be easily mixed in-situ up to 6 inches in depth with existing road materials, and
6. The additive quantities must not exceed 4% to 5% by dry weight.

The use of organic cationic and sodium chloride were investigated by Butzke (1974) for use as soil stabilization additives. Although the study did not specifically study dust suppression using these additives, the effect of soil stabilization will aid in the reduction of dust. Laboratory testing was conducted on soil-aggregate samples obtained directly from the wheel track of an unpaved secondary roadway near Ames in Story County. Additives evaluated included Arquad 2HT (quaternary ammonium chloride), Armac T (tallow amine acetate), Duomac T (N-alkyl trimethylene diamine), and sodium chloride (NaCl). A screening phase was used in the laboratory testing to generate data relevant to soil stabilization characteristics and delineate the most promising concentrations to be further analyzed through more advanced testing. The samples selected for further analysis through advanced testing were concentrations of 0, 0.05, and 0.1 percent organic cationic chemicals and 0, 0.5, and 1.0 percent sodium chloride. These concentrations were evaluated on freeze-thaw performance, shear strength using consolidated undrained triaxial tests, and rutting using a traffic simulator.

Results of the untreated soil specimens indicated poor durability in erosibility and freeze-thaw testing as well as poor resistance to rutting during trafficability testing in wet environments. The samples treated with sodium chloride exhibited increased erosibility resistance, increased moisture retention, increased freeze-thaw durability, and good trafficability performance. For satisfactory field performance, recommendations of 1.0 percent sodium chloride treatment appeared to be sufficient, although the quantity may be higher or lower depending on the field conditions and soil type. Results of the organic cationic testing displayed excellent stabilization properties and were recommended for field use at concentrations of around 0.1 percent. The Arquad 2HT and Duomac T presented slightly better stabilization performance than Armac T, but differences were nearly negligible.

The control of unpaved road dust with emulsified asphalts was investigated by Lustig (1980). Laboratory studies were conducted on existing road surface materials in Plymouth, Pottawattamie (two sites), Marion, Story, Franklin, and Buchanan Counties. These road surface materials were mixed with four different CSS-1 type asphalt emulsion products including E4868, E65, E55, and E11 with asphalt contents ranging from 57% to 61% by weight. The various aggregate/asphalt emulsion mixtures were evaluated on trafficability, freeze-thaw resistance, Iowa K test parameters, and unconfined compression strength to determine which of the four asphalt emulsions would provide the best mixture with each aggregate type, as well as to determine the most appropriate asphalt content. In addition to the previous aggregate/asphalt emulsion type and content combinations, there were three curing methods utilized including plastic wrapped specimens placed in the humidity room for 24 hours, air-cured specimens at room temperature for 24 hours, and air-cured specimens at room temperature for 24 hours and immersed in distilled water for 24 hours.

Results of the laboratory testing concluded that further field evaluation should be conducted on the following: the E65 emulsion in Buchanan County with an asphalt content of 4%, the E4868 asphalt emulsion in Franklin County with special application procedures, the E4868 emulsion in Marion County with an asphalt content of 4%, the E-11 asphalt emulsion in Plymouth County with an asphalt content of 4%, the E4868 emulsion with asphalt contents of 4% in Pottawattamie County (Honey Creek), and the E65 asphalt emulsion with an asphalt content of 4% in Pottawattamie County (Neola).

The field investigations involved three types of application including surface, mixed with 4 to 6 inches of surface aggregate, and mixed with 6 inches of surface aggregate, compacted, and topped with a seal coat. Evaluation of the field sites included dust measurements, moisture-density relationships, and visual observations. The method of dust collection utilized 6.5 inch diameter plastic containers half filled with distilled water placed perpendicular to the road centerline at various distances. The plastic containers captured a portion of the settling dust caused by vehicles traveling the roadway. The laboratory and field investigations concluded that the composition of cationic asphalt emulsion affects the performance with a particular soil type and the variation of asphalt emulsion zeta potential exhibits distinct effects on the mixture compatibility as well as the required optimum asphalt content. The investigations also concluded that surface applied asphalt emulsion provides a large amount of dust suppression but does not last and asphalt emulsion mixed with the surface aggregate to a depth of 6 inches provides excellent dust control as well as improves surface stability.

Hoover et al. (1981) evaluated seven different dust palliatives and stabilizing additives including asphalt emulsion, Coherex (emulsion of petroleum oils and resins), Polybind Acrylic DLR 81-03 (co-polymer resin emulsion), Amsco Res AB 1881 (styrene butadiene latex), ammonium lignosulfonate, type I Portland cement, and fly ash through laboratory and field testing. Eight different demonstration sections were located throughout the state of Iowa to represent major geographic and geologic regions. Three methods of application were utilized including surface application, mixed-in-place, and mixed-in-place with seal coat. Due to the broad range of potential application rates, laboratory trial mix screening tests were conducted to determine satisfactory products and provide a limited range of application rates. The satisfactory products were further tested in the laboratory for freeze-thaw durability, trafficability, unconfined compression strength, and Iowa K-Test. It was concluded from laboratory testing results that only mixed-in-place application with seal coat using fly ash and Portland cement were effective through a wide range of soil-aggregates and lignosulfonate, Coherex, Polybind Acrylic DLR 81-03, and Amsco Res AB 1881 additives had varying effectiveness from useless to potentially effective depending on the soil-aggregate type.

Field testing included the construction of demonstration sections and dust measurement. Dust measurement was conducted through the use of 6 in. diameter 7 in. high plastic containers half filled with distilled water placed at varying distances transverse to the roadway centerline. The plastic containers captured a portion of the settling dust caused by vehicles traveling the roadway. The field evaluations concluded that mixed-in-place applications with seal coat using type I Portland cement, fly ash, or emulsified asphalt and surface applications using Amsco Res AB 1881, Polybind Acrylic DLR 81-03, and emulsified asphalt were effective in reducing dust production. Coherex also reduced dust production, but can not be used on absorptive aggregates and is limited in use due to its high cost. Due to preferences of the county engineers, mixed-in-place application was excluded as a possible test method. Hoover et al. (1981) recommended the following procedure when deciding between dust suppressant alternatives:

1. Determine how much dust is being produced and what minimum levels are necessary to provide desirable results.
2. Identify practices currently in use.
3. Identify products and techniques currently in use.
4. Perform demonstration tests using various different materials.
5. Evaluate the test results.

A study conducted by Hoover (1986) for the Arizona Department of Transportation, investigated methods of controlling dust on construction sites in the Phoenix metropolitan area. Although water is usually used for controlling dust, water can be fairly expensive where it is not readily available, therefore alternate methods for reducing dust on construction sites were investigated. The research included two components 1) a literature review of dust control agents and processes, and 2) to consider the feasibility of selected dust control agents and/or in-situ mixed-in-place admixtures as possible alternatives to constant watering of construction sites. Estimations of the soil properties in the Phoenix area were made using United States Department of Agriculture (U.S.D.A.) soil surveys. Soils classified by the Unified Classification System ranged from GW to CH, which indicated an extreme variability in potential stability characteristics for roadway construction. The literature review conducted included material on capillary modifiers, binders, and P/E additives and their potential performance as dust suppressants. Because many dust suppressants are site/soil sensitive, the use of suppressant A in soil GW may provide excellent dust control whereas the use of suppressant B in soil GW may provide little to no dust suppression at all. Four binder and P/E agents were recommended as having the most applicability to the Phoenix metropolitan area including: CSS-I cationic asphalt emulsion, Coherex, Corexit 178, and Soil Seal. Although these four products are recommended, there availability may be questioned. Therefore the use of calcium or magnesium chloride is recommended for temporary dust control measures for the Phoenix area. It was also stated that regardless of the recommendations noted in this research, the use of dust control agents on construction sites in the Phoenix metropolitan area demands field evaluations.

Wahbeh (1990) investigated the use of sodium montmorillonite clay (bentonite) as a dust suppressant for limestone surfaced secondary roads. The research consisted of three phases: 1) laboratory screening of various percentages of bentonite to evaluate their effectiveness as soil stabilizers and dust palliatives, 2) construction of test roads, based on the results of the laboratory phase, and 3) observations and tests of the various sections performance and serviceability with respect to dust palliation and surface improvement. A final objective of the research was to evaluate the effectiveness, performance, duration, maintenance, and cost of the bentonite treated roadways in comparison to roadways treated with calcium chloride.

Crushed limestone surfaced test roads were selected in Dallas and Adair Counties with traffic counts of 75 and 80 vehicles per day, respectively. Test road construction consisted of two different methods: 1) spray application of bentonite, water and soda ash slurry to loose surface material and 2) dry blade mixing of bentonite with crushed limestone with saturating spray application of water and soda ash to follow. The test roads were divided into sections with different application rates of bentonite as well as calcium and magnesium chloride. Calcium chloride (39 % solution) and magnesium chloride (32 % solution) were spray-applied at a rate of 0.76 gal/linear foot and the bentonite slurry was spray-applied at 7.5 % solution by weight. The bentonite slurry included 1250 pounds of water, 50 pounds of soda ash, and 750 pounds of bentonite. Field testing consisted of sampling of dust generation under traffic through the use of stationary high volume air samplers developed by Hesketh and EL-Shobokshy (1985) as well as braking tests to evaluate the effects of treatment on braking and safety. Laboratory samples of the untreated and treated crushed limestone were periodically collected during the project and tested for gradation and also analyzed by Scanning Electron Microscopy (SEM).

Results of the laboratory and field testing concluded that the bentonite treated sections show no adverse effects with respect to braking distance and can be bladed according to the normal maintenance schedule without reducing effectiveness. Results also indicated that the calcium chloride treatment was very effective in the first three months of testing, but the bentonite outperformed the calcium chloride near the end of the 1.75 year testing period, as well as during dry weather (low relative humidity). Results of the cost analysis concluded that the use of bentonite is an economical treatment for dust reduction on crushed limestone surfaced secondary roads.

Research conducted by Bergeson and Brocka (1996) also investigated the use of sodium montmorillonite clay (bentonite) as a dust palliative for limestone surfaced secondary roads. Field demonstration sites were constructed in Dallas, Tama, and Adair Counties using various amounts of bentonite ranging from 0.5 to 9.0 percent by weight of aggregate. Field investigations included dust generation, crust development, roughness, and braking characteristics through quantitative and qualitative evaluation. Evaluations were conducted independently by a panel composed of personnel representing Marshall and Tama Counties, the Iowa Department of Transportation (IDOT), and Iowa State University. Results of the dust generation data indicated a uniform standard deviation of plus or minus 11 percent for dust production on all test sections. Dust generation was reduced by approximately 45 percent on demonstration sites containing three percent bentonite and 70 percent on demonstration sites containing nine percent bentonite. Therefore the use of bentonite on limestone surfaced secondary roads was considered effective in reducing dust generation. Results of the nine percent bentonite treatment also indicated good crust development, reduced roughness, and no change in braking or handling characteristics.

Economic considerations were also investigated involving nine percent bentonite and 38 percent concentration calcium chloride treatments. Results indicated that the use of bentonite costs $1750 per mile and calcium chloride costs $3200 per mile (0.25 gal/yd^2 application rate). Therefore the use of bentonite treatment is less expensive per mile by $1450 when compared to calcium chloride treatment.

The use of recycled asphalt shingles as a dust suppressant was suggested by Marks and Petermeier (1997). In 1995, Benton County recycled nearly nine hundred tons of waste asphalt shingles for use as dust suppressant. The waste shingles were ground up using a Maxigrind machine with a magnetic roller on the discharge conveyor to remove most of the nails. Benton County blade mixed five hundred tons of recycled asphalt shingles into 0.3 miles of a crushed stone granular surfaced secondary road. A second magnet attached to the motor grader removed another 3/4 pound of nails during the blade mixing process. The bitumen of the waste shingles was very effective in reducing the dust produced on the granular surface roadway as well as binding the granular surface together. The section of roadway in Benton County treated with recycled asphalt shingles remained dust free for two years and could be maintained normally without reducing effectiveness. Although the recycled asphalt shingles were examined twice for nail removal, the remaining nails created several flat tires and concerned motorists.

2.2 United States Studies

Some of the best and well known studies on dust suppression have been conducted by T.G. Sanders and his associates at Colorado State University. Sanders and Addo (1993) investigated the relative effectiveness and the environmental impact of road dust suppressants. The research project included three objectives: 1) develop a device that would provide a standard, quantitative, and reproducible method of measuring the amount of dust produced on unpaved secondary roads, 2) measure the relative effectiveness of the different dust suppressants, and 3) assess the environmental impact caused by the use of various dust suppressants. The project included five gravel surfaced test sections located in Larimer County, Colorado. Four of the test sections were treated with calcium lignosulfonate, calcium chloride, magnesium chloride, and a special kind of calcium chloride which contains no magnesium. The treated test sections were each 1.25 miles long and all were part of the same stretch of road with an average daily traffic of 400 cars per day, while the untreated test section was also 1.25 miles long it had an average daily traffic of 200 cars per day.

Construction of the test sections was completed according to most transportation literature as well as the dust suppressant supplier's recommendations. Early attempts using the dust collecting bucket method (ASTM D1739) in this project proved to be ineffective and inefficient due to several reasons including: 1) difficulty in getting permission from the landowner to install the buckets, 2) the land along the roadway being tested was grazing pasture, and 3) continuous problems with livestock destroying the buckets as well as problems with wind. Therefore a new moving, quantitative, reproducible, and portable concept of dust collection was developed called the Colorado State University (CSU) Dustometer. The Dustometer is a dust sampler that is securely attached to the rear bumper of a test vehicle and through the use of suction, collects a portion of the dust created when the test vehicle travels the roadway. A more detailed description of the Dustometer and its components is presented in Chapter 5. Dust collection was conducted once every week unless weather did not permit.

Results of dust collection indicated that all treated test sections produced less dust than the untreated test section, with calcium lignosulfonate performing superior to calcium chloride, magnesium chloride, and the special calcium chloride. Runoff from the four treated test sections was sampled by means of plastic containers installed at the shoulders of the roadway. During a rainfall event, part of the runoff from the roadway would enter the plastic containers and be collected for laboratory analysis. All runoff samples collected from the treated test sections were analyzed by measuring total dissolved solids (TDS), conductivity, total hardness, and the amount of free chloride present.

Another research project completed by Sanders et al. (1997) investigated the relative effectiveness of several common dust suppressants under field conditions. These common commercially available dust suppressants included lignosulfonate, calcium chloride, and magnesium chloride. Four, 1.25-mile long crushed gravel surfaced test sections were used to evaluate the products. Three of the test sections were treated with the three different dust suppressants and the fourth test section was left untreated as a control section. Construction of the test sections included: 1) scarification of the road surface, 2) grading and smoothing of the road surface, 3) application of the dust suppressants in sufficient quantities for effective dust control, and 4) proper road finish procedure that includes the forming of the surface crown, optimum compaction of the road surface, and proper drainage. The application rates for all three dust suppressants were identical at 0.5 gallons per square yard, although the lignosulfonate was applied with a mix-in-place procedure and the calcium and magnesium chloride were applied by a surface spray.

Field measurements included traffic counts, dust measurement, and aggregate loss. The traffic counts were conducted using stationary traffic counters installed at the beginning and end of each test section. Dust measurements were conducted using the Colorado State University Dustometer. The Dustometer is a dust sampler that is securely attached to the rear bumper of a test vehicle and through the use of suction, collects a portion of the dust created when the test vehicle travels the roadway. A more detailed description of the Dustometer and its components is presented in Chapter 5. Aggregate loss from each test section was measured through cross section elevations after construction and at the end of the testing period.

Results of the traffic counts concluded that the untreated and lignosulfonate treated sections had 515 and 538 cars per day, respectively. While the calcium chloride section had 421 cars per day and the magnesium chloride section had 448 cars per day. Results of the fifteen dust measurements on each test section indicated that all three treated test sections effectively reduced dust production. The untreated control test section averaged approximately 1.0 gram of dust, while the lignosulfonate treated section varied from 0.05 grams after treatment to 0.6 grams of dust near the end of the 4.5 month testing period. The calcium chloride treated section produced 0.4 grams of dust after treatment and 0.9 grams near the end of the 4.5 month testing period. The magnesium chloride treated section produced 0.08 grams of dust after treatment and 0.7 grams near the end of the 4.5 month testing period. Results of the aggregate loss measurements on the treated sections were 0.23 in. for lignosulfonate, 0.28 in. for calcium chloride, and 0.20 in. for magnesium chloride compared to 0.6 in. on the untreated test section. Therefore the untreated test section lost approximately two to three times more aggregate than the treated test sections. The estimated aggregate loss for the untreated test section over the 4.5 month testing period was approximately 2.6 tons per mile per year per vehicle, which is 51% more than the average lost on the treated test sections. In addition to the field investigations, a cost analysis was completed that concluded the use of dust suppressants reduced the yearly maintenance expenditures by approximately 28% to 42%.

The United States Department of Agriculture Forest Service has been using and investigating different dust suppressants for many years. A study conducted by Bolander (1997) investigated then current dust suppressant products and discussed what had been learned from their use. The dust suppressant products included: lignin sulfonate, magnesium and calcium chloride, synthetic polymer emulsions, tall oil emulsions, clay additives, and penetrating asphalt emulsions. Although the Forest Service currently only uses lignin sulfonate, calcium and magnesium chloride, synthetic polymer emulsions, and clay additives to control dust on unpaved roads, the remaining products have been used at one time and were evaluated in this study. Through years of experience, the Forest Service has found that the preparation of the roadway is a vital component to the effectiveness and longevity of the dust control product being applied. The surface of the roadway should have a good crown for water drainage, as well as be slightly damp when the products are being applied. The coarse aggregate that usually gathers near the edges of the roadway should be moved and incorporated into the surface. The Forest Service has been using lignin sulfonate for dust suppression for years and has found it to be one of the most cost-effective products available for use on roads with between 8 and 20 percent passing the 75-μm (No. 200) sieve.

According to Bolander (1997) the key to effective lignin sulfonate dust abatement is penetration into the top 25 mm, which will minimize the development of a thin crust. For increased performance and longevity, the lignin sulfonate can be mixed into the top two inches of the road surface. The performance of the chlorides depends on the percent aggregate passing the 75-μm (No. 200) sieve, with recommendations between 10 and 20 percent passing. The use of chlorides during the wet winter months west of the Cascade Mountains causes the top few inches of the road surface to soften, which leads to traction problems. The use of chlorides is recommended east of the Cascade Mountains where they are able to recover moisture during the night hours, with the exception of roads high in the mountains that are exposed to continuous sun and high winds.

The use of synthetic polymer emulsions and tall oil emulsions for dust control has been limited, but according to experiences so far the products have promise. Although the products have performed satisfactorily thus far, there are not enough consistent field or laboratory results for recommendation without caution. Clay additives have been used since 1990 by the Forest Service on approximately 25 miles of unpaved roads. Typical application rates are between 1.5 and 3.0 percent clay by dry weight of aggregate and total passing the 75-μm (No. 200) sieve should not exceed 15 percent. The clay reduced dust production and reduced aggregate throw off significantly and was recommended as a cost effective dust control product. The last dust suppressant investigated in this research was penetrating asphalt emulsions, which included products such as Coherex, DOPE 30, Asphotac, PennzSupress-D, PEP (penetrating emulsion primer), SemiPave, and DL-10 pounder emulsion. The use of these products by the Forest Service has been limited. Based on the Forest Service laboratory and field experiences, the most economical and practical products for dust suppression include lignin sulfonate, magnesium chloride brine, calcium chloride flakes, and clay additives.

A "Dust Palliative Selection and Application Guide" was compiled by Bolander and Yamada (1999) to help the employees of the United States Department of Agriculture Forest Service, its contractors, and cooperating Federal and State agencies understand, choose, and apply a dust suppressant that is right for their specific site, traffic level, and weather conditions. The guide discusses 62 commercially available dust suppressants and the advantages and disadvantages of each, as well as the products origin, expected performance, and possible environmental impacts. A list of several factors that contribute to dust production on granular surfaced roadways was presented and includes:

- Vehicle speed
- Number of wheels per vehicle
- Number of vehicles
- Vehicle weight
- Particle size distribution (gradation) or the surface material
- Restraint of the surface fines (compaction, cohesiveness/bonding, durability)
- Surface moisture (humidity, amount of precipitation, amount of evaporation)

The selection of the correct dust suppressant for a specific site includes understanding of not only the factors that produce dust but also the long term cost and environmental impact of the dust suppressant. According to Bolander and Yamada (1999) long term costs include road improvement, road preparation, application of the suppressant in conjunction with the number of times the suppressant needs to be applied, and expected change in maintenance practices. The selection and application guide divides the wide range of dust suppressant types up into seven different categories, including water, water absorbing, organic petroleum based, organic nonpetroleum based, electrochemical, synthetic polymers, and clay additives. Table 2.3.1 presents the breakdown of the seven different categories of dust suppressants and examples of each. Data from Bolander and Yamada (1999) is presented in Table 2.3.2 and includes treatment rates, limitations, application methods, and longevity of several common dust suppressants.

Table 2.3.1. Categories and examples of dust suppressants (Bolander and Yamada, 1999).

Category	Water	Water Absorbing	Organic Petroleum	Organic Nonpetroleum	Electro-chemical	Sythetic Polymers	Clay Additives
Examples	Water	Calcium Chloride, Magnesium Chloride, Sodium Chloride	Asphalt Emulsions, Cutback Asphalt, Dust Oils	Animal Fats, Lignin Sulfonate, Molasses/Sugar Beet, Tall Oil Emulsions, Vegetable Oils	Enzymes, Ionic Products, Sulfonated Oils	Polyvinyl Acetate, Vinyl Acrylic	Bentonite, Montmorillonite

The dust suppressants presented in Table 2.3.2 are ranked according to longevity of dust suppression. The guide also presented several general tips on application rates, road maintenance, and application methods including:

- Higher application rates or more frequent applications are needed if the roadway has high traffic volumes, high speeds, large truck traffic, low humidity conditions, low fines content (less than 10% passing the 75μm (No. 200) sieve), and poorly bladed or loose surfaces.
- Repair unstable surfaces, adequately drain the road surface, remove poorly graded surface material, and blade the roadway to a sufficient depth to remove potholes and ruts.
- Apply chloride based dust suppressants immediately following the wet season, if products are applied before a rain they may wash away, if the surface is extremely dry moisten it with water before application, break up and loosen hard crusts present on the

surface, and use a pressure distributor to ensure the dust suppressant is uniformly distributed on the road surface.

Table 2.3.2. Common dust suppressant treatment rates, limitations, application methods, and longevity (Bolander and Yamada, 1999).

Dust Suppressant	Treatment Rates	Limitations	Application Method	Longevity
Clay	1-3% by weight	Rutting in wet conditions	Mixed uniformly	1-5 years
Polymers	2.3 L/m^2		Mix or spray	1+ years
Electrochemical	Diluted 1/100 or 1/600	Depends on clay mineralogy	Mix w/light compaction	?
Tall Oil	2.3 L/m^2	Highly soluble	Mix or spray	1+ years
Vegetable Oils	1.1 to 2.3 L/m^2	Limited availability, becomes brittle	Mix or spray	1 year
Lignin Sulfonate	2.3 L/m^2	Potential pollution from leaching	Mix or spray	6 months
Petroleum	0.5 to 4.5 L/m^2	Rutting in weak bases, could be toxic	Mix or spray	6 months
Magnesium Chloride	1.6 L/m^2	Corrosive, potential pollution	Mix solids or spray brine	6 months
Calcium Chloride	1.6 L/m^2	Corrosive, potential pollution	Mix solids or spray brine	6 months
Water	A lot	Very short duration	Spray	1 day

Effects of dust suppressants on the environment were also discussed in Bolander and Yamada (1999). The constituents of any dust suppressant product may migrate into the environment due to carelessness in application, run-off, leaching, dust particle migration, or adhesion of product to vehicles. Bolander and Yamada (1999) recommend careful review of the product literature, material safety data sheets (MSDS), and manufacturer's instructions before application or purchase as well as compliance with federal, state, and local laws/regulations regarding dust suppressant application.

Monlux (2003) of the United States Department of Agriculture Forest Service, Northern Region, presented stabilization results of several unpaved roads treated with calcium chloride at the Eighth International Conference on Low-Volume Roads. Although the study did not specifically study dust suppression using calcium chloride, the effect of soil stabilization will aid in the reduction of dust. The Forest Service applied heavier than normal amounts of 77% concentration calcium chloride flakes on three unpaved roads (two in Montana and one in Idaho) to increase surface stabilization. Performance of the calcium chloride stabilization was determined through four measurements: washboards, raveling, rutting, and potholes and compared to that of untreated control sections.

The first road stabilized with calcium chloride was Copper Creek Road located near Lincoln, Montana. Copper Creek Road is a 20 ft wide aggregate surfaced road with a traffic volume between 20 and 50 vehicles per day. The surface was composed of good quality crushed 3/4 in. aggregate with 12% passing the 75 μm (No. 200) sieve. This road has a reputation of being rough, even though it gets a lot of maintenance attention, and is closed from December through April due to heavy snows. In June 1998, there were 17 test sections constructed. Eight of these test sections were treated with various combinations of calcium chloride and bentonite clay and the remaining nine test sections were left untreated to serve as control sections. Results indicated that the best performing treatment was calcium chloride flakes (4.2 lb/yd^2) mixed 2.5 in. deep into the road surface. This treatment did not require any maintenance until June 2000, which was three seasons after initial treatment.

The second road treated with calcium chloride was Toll Mountain Road located near Butte, Montana. Toll Mountain Road is a 22 ft wide, two lane aggregate surfaced roadway with an average traffic volume of 120 vehicles per day and a history of maintenance problems. The surface consists of aggregate smaller than 3/4 in. with 13.6 % passing the 75 μm (No. 200) sieve. In all, eight test sections were constructed; five treated with 5.4 lb/yd^2 of 77% concentration calcium chloride flakes and three untreated or control sections. After blade mixing and compacting the first flake application, a second application of calcium chloride flake was applied at 1.1 lb/yd^2 to the compacted surface. Results of the stabilization performance indicated that the treated test sections all performed similarly and did not begin to show signs of washboarding until mid-way through the second season of testing. In June 2000, two sections of Toll Mountain

Road were treated with calcium chloride to improve surface stabilization. Due to below normal precipitation and low relative humidity of the arid environment, the stabilization did not last and produced results worse than those of the untreated test sections.

The third road treated with calcium chloride was Selway River Road, located near Fenn, Idaho with an average daily traffic count of approximately 130 vehicles per day. The road surface is composed of decomposed granite and crushed basalt with 15 % passing the 75 μm (No. 200) sieve. The road has major surface and sub-surface drainage problems, but due to the scenic designation of Selway River Road, various reconstruction plans have gone unapproved. Before calcium chloride treatment could be applied, the road under went repairs to remove large boulders from the surface and remove the top 3 in. of aggregate. To replace the 3 in. of aggregate removed, a layer of crushed basalt approximately 1 in. thick was applied and mixed into the surface. Calcium chloride 77% concentration flakes were applied to the roadway, with application rates ranging from 4.0 to 6.8 lb/yd^2, and mixed into the top 2.7 in. of the aggregate surface. Before the end of the first testing season, the test sections treated with calcium chloride needed blading due to extensive pothole development on the relatively flat surface (crown <2%).

Overall conclusions of the three stabilization projects indicate that the use of calcium chloride reduces maintenance costs, dust, aggregate loss, raveling, and washboarding. Stabilization performance is strongly subjected to weather conditions, traffic volume, and type of aggregate surface, but can be improved with high quality construction practices.

Evaluation of groundwater pollution susceptibility of dust suppressants and roadbed stabilizers was conducted by Kimball (1997). This research described techniques available for the evaluation of groundwater pollution due to the application of dust suppressants as wells as presented the results of a groundwater pollution susceptibility evaluation on Pennzoil's Pennz-Suppress D, a petroleum based road stabilizer/dust suppressant. Groundwater pollution susceptibility evaluations were carried out through subsurface fate and transport analyses. This evaluation included two phases; the first was chemical analyses, which identified constituents in the suppressant/stabilizing product that may dissolve in water and consequently leach down into the groundwater. The second phase consisted of screening-level mathematical modeling used to identify whether or not a certain concentration of constituent in the suppressant/stabilizing product has the ability to affect the safety of the groundwater used by consumers. The

Environmental Protection Agency (EPA) has developed several methods of chemical analysis including leachability testing and total constituent concentration testing, as well as screening-level mathematical modeling for targeting harmful constituents that may be released into the environment. These two phases of evaluation were used to evaluate the potential for Pennzoil's Pennz-Suppress D to affect the quality of the groundwater when applied to the ground surface. The primary evaluation included the testing of volatile organic compounds (VOCs), semi-volatile organic compounds (SVOCs), mercury, metals, and tentatively identified compounds (TICs).

Results of the total constituent concentration analysis indicated that interference caused by the high concentration of detected constituents resulted in analytical detection quantities that varied from 500 parts per million (ppm) for VOCs to 25 ppm for SVOCs. The SVOC analysis also identified 8 TICs. Metal compounds that were identified in the Penns-Suppress D did not exceed any health requirements, while concentrations of furfural exceeded the health limits. With the assumption that furfural is leachable, the concentrations detected in the Pennz-Suppress D could have adverse affects on the quality of the groundwater and could cause human health problems if consumed. Due to the interference described above, uncertainties in the analyses were reduced through additional leachate testing. Leachate analyses were completed by two methods: toxicity characteristic leaching procedures (TCLP) and synthetic precipitation leaching procedures (SPLP). Results of the TCLP method indicated that there were leachable organic constituents in the Pennz-Suppress D. Although this method indicated that the product has leachable constituents, this did not realistically model the way the product would leach in the field. Therefore SPLP analyses were conducted. Results of the SPLP analyses concluded that furfural concentrations had disappeared due to the fact that furfural volatilizes during drying, or curing of the Pennz-Suppress D petroleum based product.

In 1992 a new product called Molex was tested on several granular surfaced roads in Marshall City, Indiana and discussed briefly in an article called "Dust: Don't Eat It! Control It!" by the U.S. Roads Road Management and Engineering Journal (June 1998). Molex is a concentrated liquid extract of beet molasses. The product is very hygroscopic (absorbs moisture from the atmosphere), has a high level of potassium chloride (which could replace calcium chloride), a near neutral pH (non-corrosive), and has a freezing point below -16 ºF. Several users of Molex believe it could replace calcium chloride due to its comparative performance and lower price.

Frazer (2003) briefly discussed the use of Dust Stop, a dust suppressant that is made entirely of natural starches and is completely biodegradable. Dust Stop was discovered by a company called Cypher through experiences in hydro-seeding applications. According to Cypher, Dust Stop is identified as a modified polysaccharide that is somewhat alkaline (pH 10.8-11.5) as well as a mild skin and respiratory irritant. Cypher uses the starch as a tackifier that is mixed into slurry with water, fertilizer, seed, and mulch. The slurry is then sprayed on the ground and the starch bonds to the soil surface to keep the slurry mixture from eroding or blowing away. Cypher decided if the starch keeps the seed and mulch in place then it should perform well in dust suppression applications. According to Cypher, Dust Stop can be used on gravel, limestone, dirt, sand, or any other granular surfaced roadway but it performs more efficiently on roadways with large particle sizes rather than high fine contents. The Dust Stop product is also available in modified variations for high, moderate, and low temperature applications as well as a variation with added citronella scent for rodent repellant. Cypher claims that the citronella scent repels small animals, insects, and rodents which can significantly reduce road kill incidents around the application site. The Dust Stop product has been tested on granular surfaced roadways in China, Canada, and several other countries and is currently being tested on a heavily traveled dirt road near Prescott, Arizona. Preliminary testing has shown that Dust Stop is an efficient, environmentally friendly, and promising new product for suppression of unpaved road dust.

2.3 Summary of Literature

Research on dust suppression at Iowa State University started in the mid 1950's under the supervision of D.T. Davidson (Lohnes and Coree, 2002) and is still being studied today, a little over 50 years later. Although the early studies were concerned more with stabilization than dust suppression, additional benefits of stabilization were recognized as possible dust suppressants. The research reviewed included a variety of products and methods for dust suppression including ammonium lignosulfonate, cutback asphalts, latex emulsions, cationic asphalt emulsions, polyester and thermo plastic resins, organic cationic chemicals, sodium chloride, type I Portland cement, fly ash, sodium montmorillonite clay (bentonite), and recycled asphalt shingles.

Research reviewed on dust suppression throughout the United States was dominated by the United States Department of Agriculture Forest Service and T.G. Sanders and his associates at Colorado State University. The research reviewed included several dust suppressant products including lignosulfonate, calcium chloride, magnesium chloride, synthetic polymer emulsions, tall oil emulsions, clay additives, penetrating asphalt emulsions, modified waxes, natural starches, and beet molasses as well as over 50 other products in Bolander and Yamada (1999). The research conducted by Sanders and his associates began in 1993 and investigated the relative effectiveness of several common commercially available dust suppressants under field conditions (Sanders et al., 1997 and Sanders and Addo, 1993) as well as the impact of dust suppression on the environment (Sanders and Addo, 1993). Research conducted by Sanders and Addo (1993) introduced the Colorado State University Dustometer; a new inexpensive, quantitative, reproducible method of dust collection.

The research herein is specifically focused on dust suppression with secondary benefits of road stabilization. Results of the studies conducted at Iowa State University and throughout the United States conclude that the use of dust suppressants reduces dust production and increases surface stabilization on granular surfaced roadways when compared to untreated sections.

CHAPTER 3. DEMONSTRATION SITES AND TEST SECTIONS

In this chapter, the selection criteria, locations, granular surface characteristics, and test section plans for the demonstration sites used in this study are presented.

3.1 Selection Criteria

There are four-one mile long demonstration sites being evaluated in this study, all of which are located near Ames in Story County, Iowa. Selection of the demonstration sites was determined in cooperation with the Story County Engineer. To determine the overall effectiveness of the dust palliatives, the demonstration sites were required to successfully duplicate existing field conditions. Therefore, there are two high Average Annual Daily Traffic (AADT) sites and two low AADT sites. Each of the high AADT sites has a different granular surface and likewise with the low AADT sites. Selection of the demonstration sites was based off the following criteria: level topography and limited obstructions such as trees and buildings, average annual daily traffic (AADT), type of granular surface (rock or gravel), and location (Story County).

3.2 Location of Demonstration Sites

The locations of the final demonstration sites are presented in Figure 3.2.1 and include:

- Zumwalt Road between South 500th Avenue and 510th Avenue
- 260th Street between 510th Avenue and 520th Avenue
- South 530th Avenue between 260th Street and 270th Street
- Grant Avenue between 180th Street and 190th Street

A summary of the demonstration site characteristics is presented in Table 3.2.1.

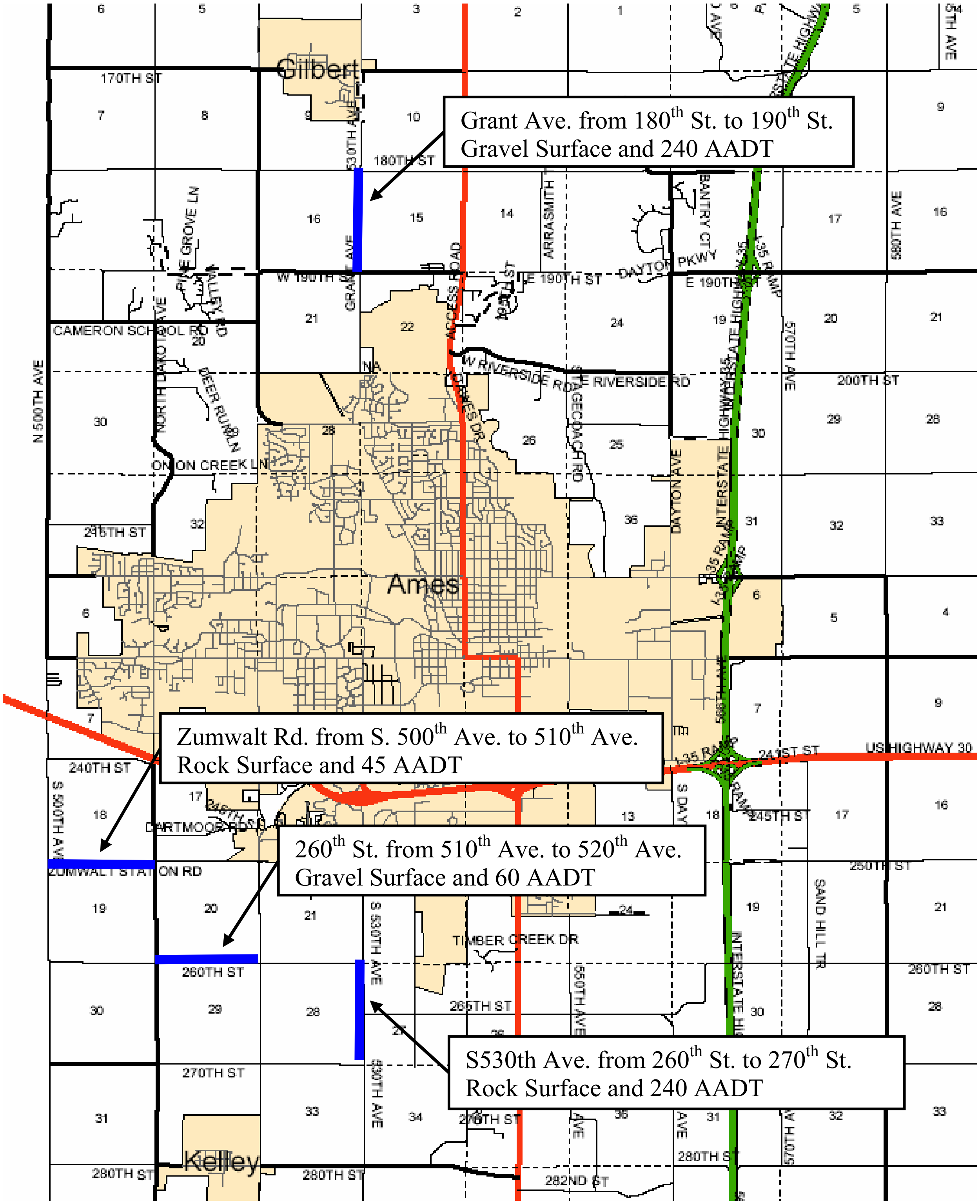

Figure 3.2.1. Location of demonstration sites.

Table 3.2.1. Summary of demonstration site characteristics.

Demonstration Site	AADT	Granular Surface	Orientation	Topography
South 530th Avenue	240	Rock	North/South	Level, 1 residential dwelling
Grant Avenue	240	Gravel	North/South	Level, 3 residential dwellings
260th Street	60	Gravel	East/West	Level, 0 residential dwellings
Zumwalt Road	45	Rock	East/West	Level, 0 residential dwellings

3.3 Granular Surface Characteristics

Virgin granular surfacing material was applied to all the demonstration sites in early April 2004 and is applied regularly every two years. The virgin rock (crushed limestone) was applied at a rate of 300 ton/mile ($14.45/ton including transport) and the virgin gravel (alluvial sand/gravel) was applied at a rate of 200 ton/mile ($9.32/ton including transport).

The rock is classified as Iowa Department of Transportation (IDOT, April 2004) Class A Crushed Stone (Division 4120.04), which is specified as a uniform mixture of coarse and fine particles produced by crushing limestone, dolomite, or quartzite. The percentage of wear, when tested according to AASHTO T 96, Grading B, shall not exceed 45% and the material shall meet the gradation requirements presented in Table 3.3.1 as well as have a maximum of 4% clay lumps and friable particles (IDOT, April 2004).

The gravel is classified as Iowa Department of Transportation (IDOT, April 2004) Class C Gravel (Division 4120.03), which is specified as natural gravel or mixture of sand with gravel or crushed stone or both meeting requirements for gradations presented in Table 3.3.1 and the following additional requirements:

- Maximum of 10% shale particles in fraction retained on No. 4 (4.75 mm) sieve
- Maximum of 15% clay lumps and friable particles and particles passing No. 200 (75 µm) sieve
- Maximum of 20% of a combination of the previous two items

Gradations were performed on the virgin gravel and rock granular surfacing materials according to the ASTM C 136-82 or AASHTO T 27-84 standard testing method and are presented in Figure 3.3.1 and Figure 3.3.2, respectively. The virgin gravel gradation results presented in Figure 3.3.1 are based on an average of 11 gradation tests in which all results met IDOT specification requirements. The virgin rock gradation results presented in Figure 3.3.2 are based on an average of 17 gradation tests in which all results also met IDOT specification requirements.

Table 3.3.1. Gradation requirements for granular surface materials (IDOT, April 2004).

		Standard Sieve Size, Percent Passing										
Material	**Intended Use**	1.5"	1.0"	3/4"	0.5"	3/8"	4	8	30	50	100	200
Class C Gravel	Granular Surface			100			50-80	25-60				15
Class A Crushed Stone	Granular Surface		100	95-100	70-90		30-55	15-40				6-16

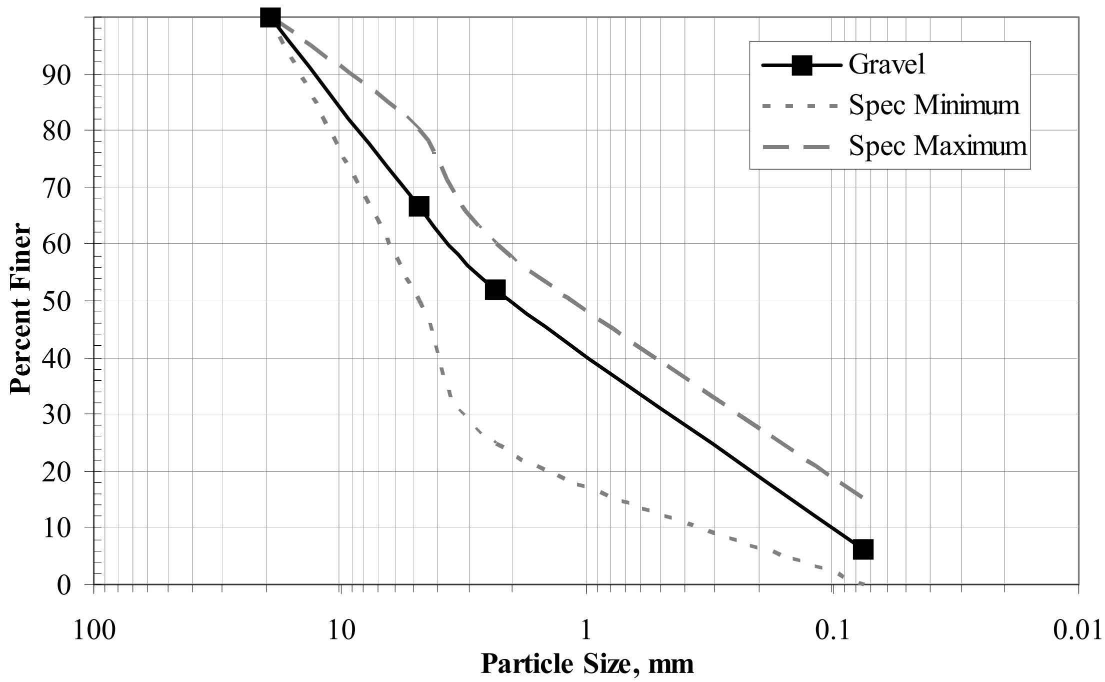

Figure 3.3.1. Gradation test results for virgin gravel.

3.4 Test Section Plan

Each of the four one mile long demonstration sites was divided into four 1000 ft. and two 595 ft. sections as presented in Figures 3.4.1 through 3.4.4. The two 595 ft. sections were located at each end of the one mile long site to allow for acceleration and deceleration space. Three of the four 1000 ft. sections at each demonstration site were used to evaluate the effectiveness of the three dust suppressants in this study, calcium chloride, soybean oil soapstock, and lignin sulfonate. The fourth 1000 ft. section at each demonstration site was left untreated to be used as a control section. A 30 ft. buffer was left in between each section to help minimize the amount of tracking of one product to another, as well as to give well defined start and stop points used in testing. To keep dust produced on the buffers from drifting and accumulating on the treated sections, the suppressants on each side of the buffers were applied 15 ft. into the buffer.

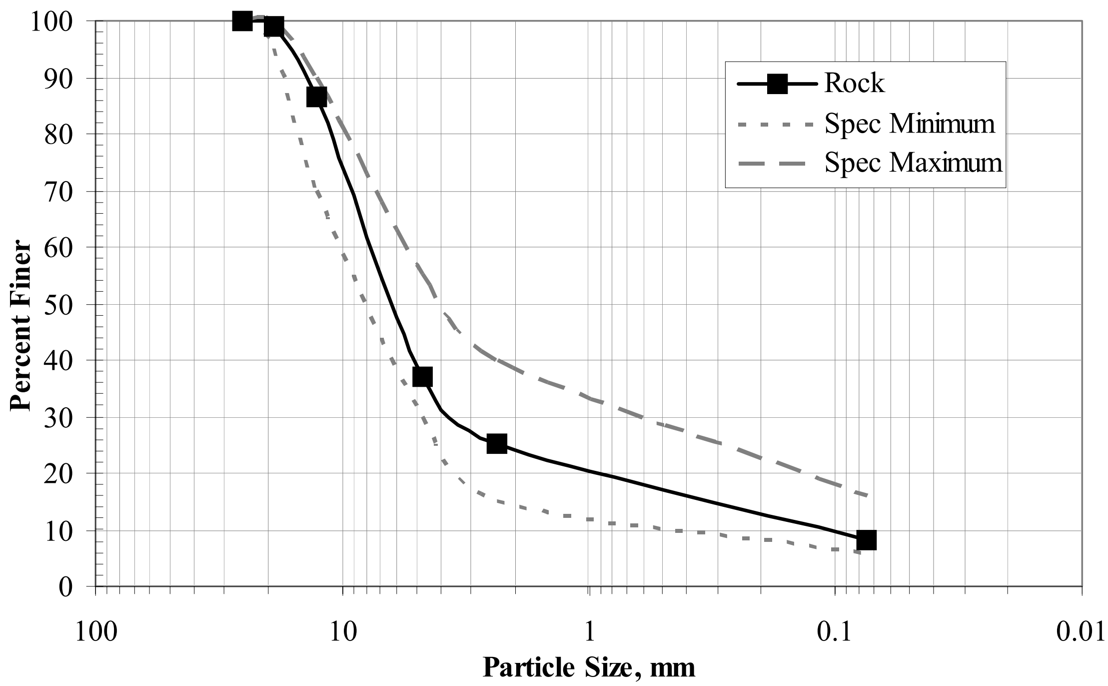

Figure 3.3.2. Gradation test results for virgin rock.

To ensure the surface of the demonstration sites were acceptable for product application, each demonstration site was bladed and shaped by county forces prior to application. To keep the project as close to field conditions as possible, the procedures used for surface preparation of the demonstration sites were the same used for preparation of any publicly requested dust control application in Story County. No special treatments were used. The regular maintenance schedule for the roads in Story County was approximately every two weeks. The untreated or control sections at each demonstration site were maintained normally every two weeks, while the treated sections at each demonstration site were maintained only if needed or if public safety started to become a concern due to extensive pothole development near the centerline of the roadway.

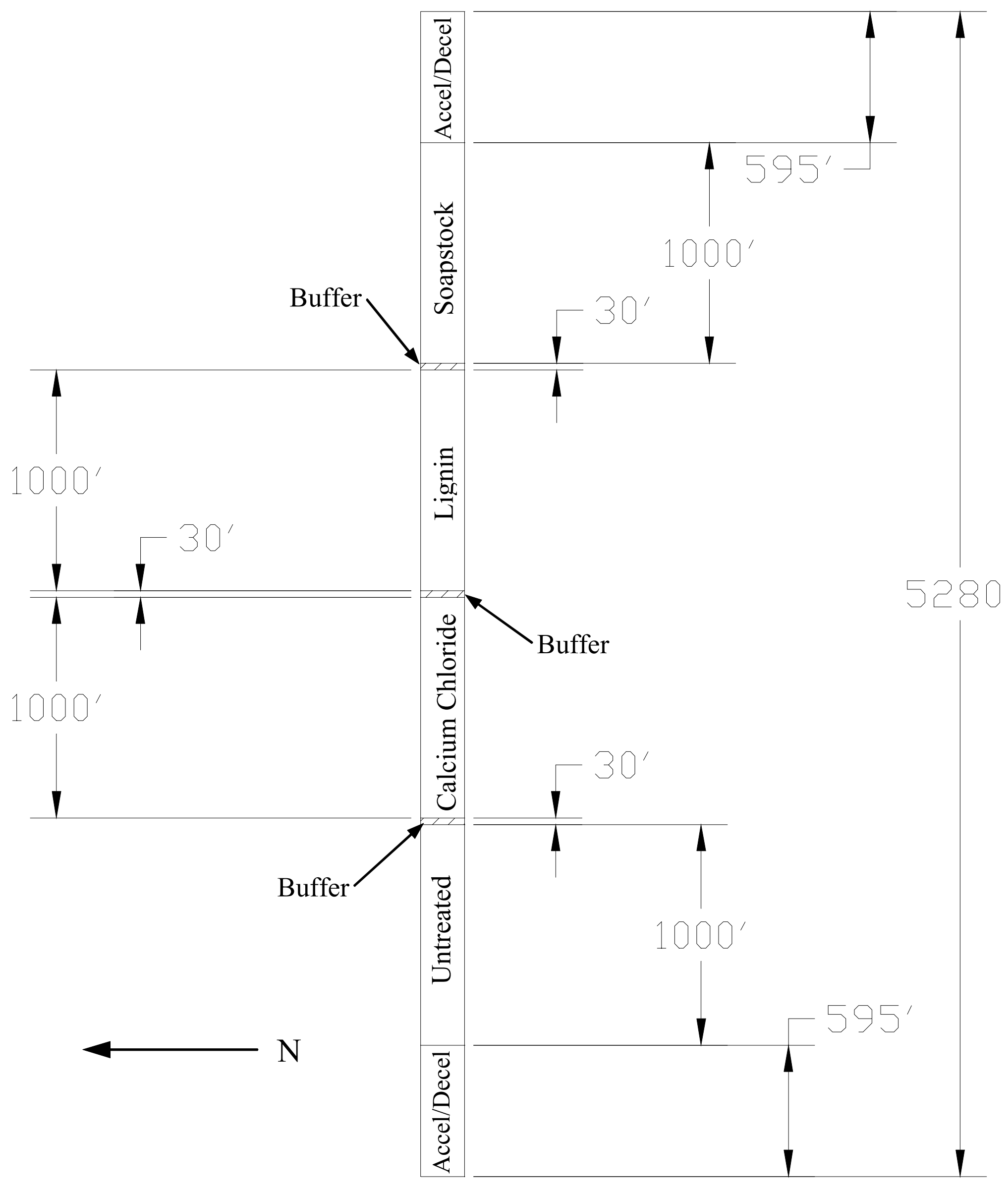

Figure 3.4.1. 260th Street test section plan.

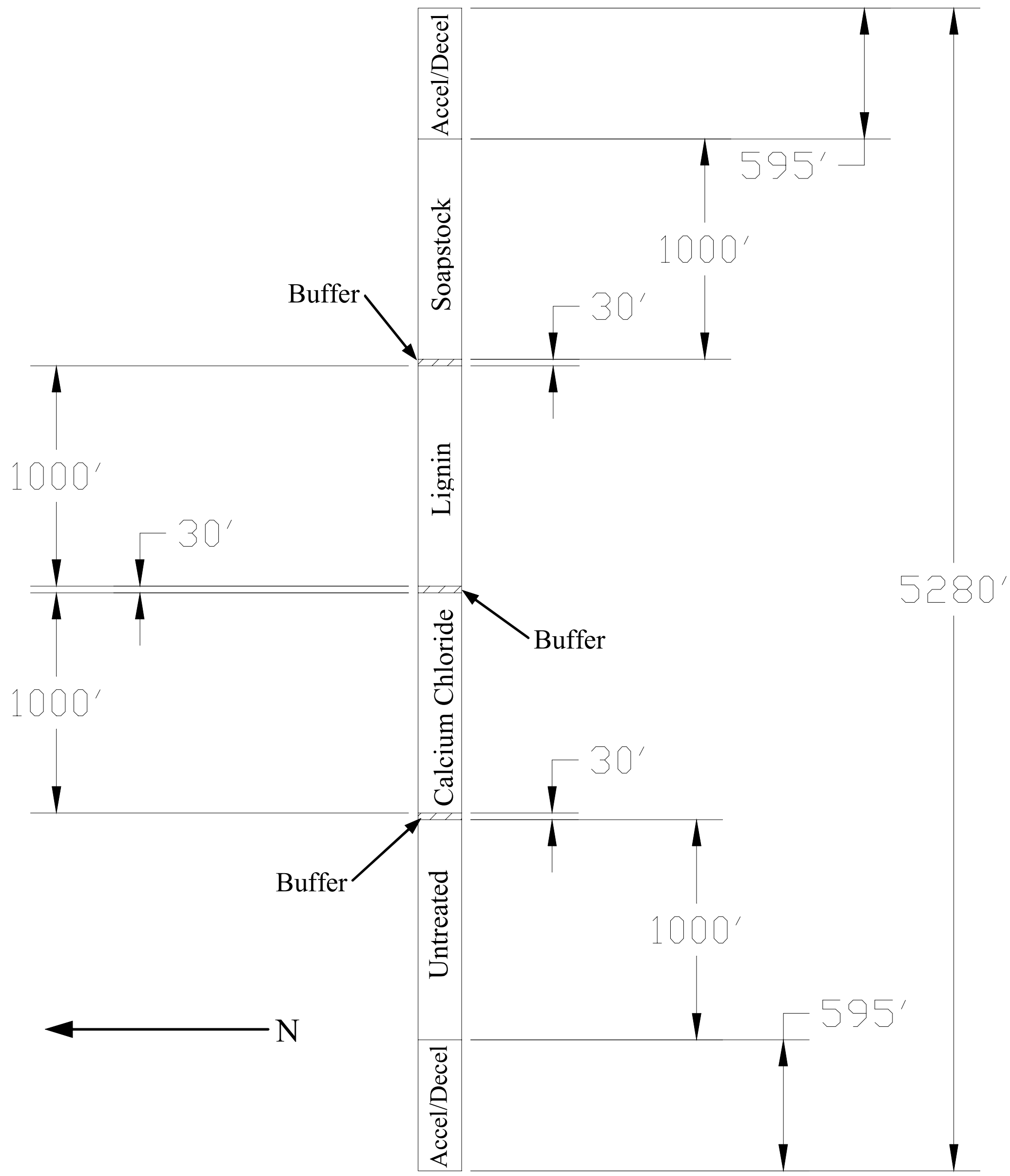

Figure 3.4.2. Zumwalt Road test section plan.

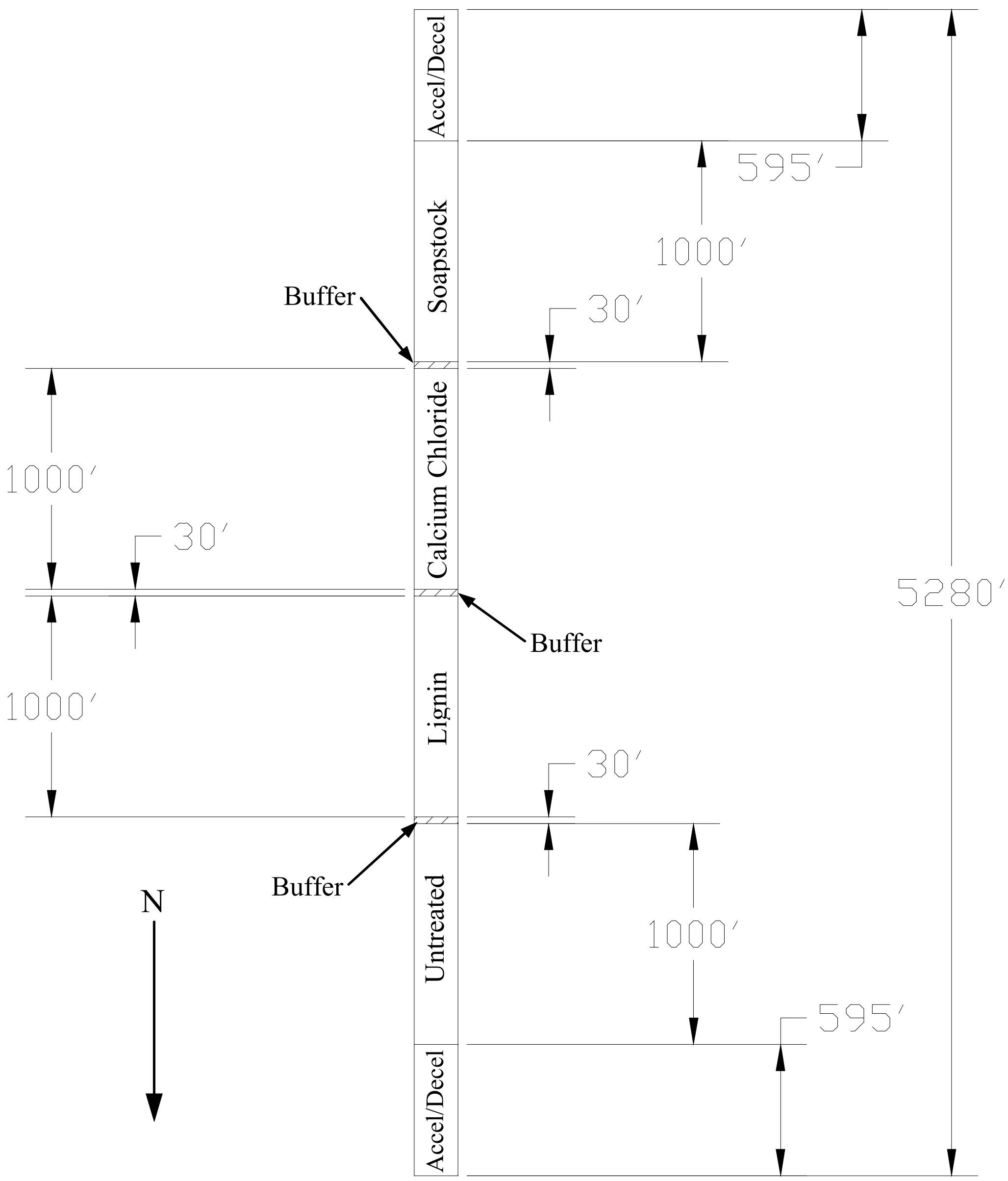

Figure 3.4.3. Grant Avenue test section plan.

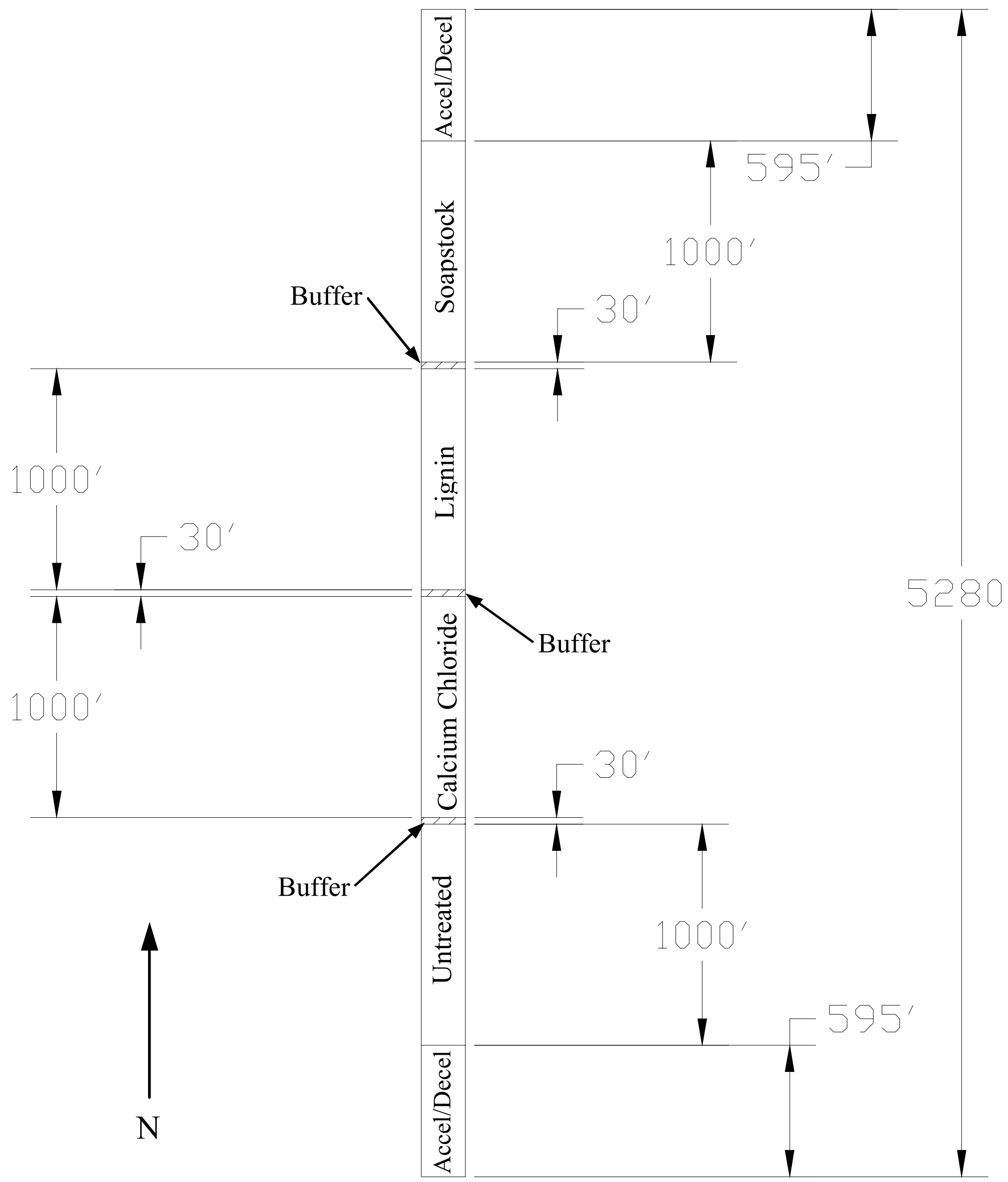

Figure 3.4.4. South 530th Avenue test section plan.

CHAPTER 4. DUST SUPPRESSANTS

The three dust suppressants evaluated in this study, calcium chloride, lignin sulfonate, and soybean oil soapstock, are used extensively throughout Story County and Iowa. In the past few years, the total number of public dust control applications in Story County increased 18 % from 2003 to 2004, as shown in Figure 4.0.1. The greatest increase was seen in calcium chloride with 140 applications in 2003 and 166 in 2004, followed by lignin sulfonate which increased slightly from 2003 with 34 applications to 52 in 2004, while soybean oil soapstock had a slight decrease from 49 applications in 2003 to 46 applications in 2004.

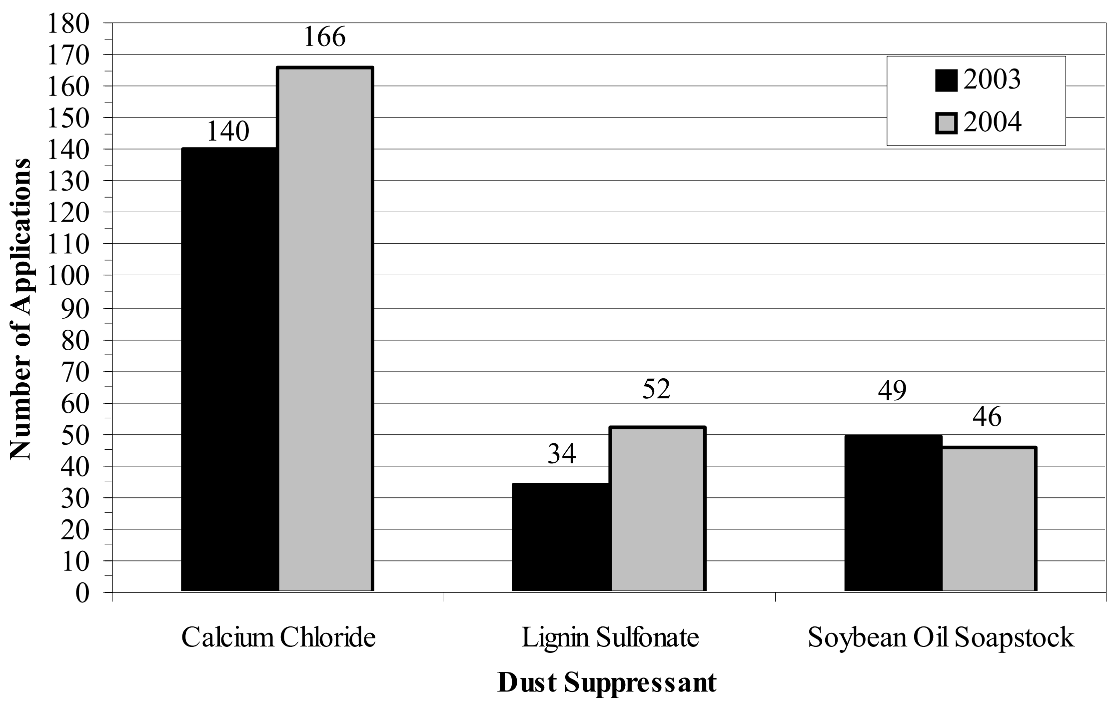

Figure 4.0.1. 2003/2004 Dust suppressant application comparison.

4.1 Product Descriptions

4.1.1 Calcium Chloride

Calcium chloride is one of the most widely used dust suppressant products in the United States and the most widely used in Story County as well as the State of Iowa (Lohnes and Coree, 2002). According to Lohnes and Coree (2002) in a survey of Iowa county engineers, 62 out of 90 reported they used calcium chloride as a dust suppressant.

Calcium chloride is a natural, readily available product found underground in natural brine deposits which is processed into a colorless, odorless liquid or white solid (Figure 4.1.1). According to Dow Chemical Company (undated) calcium chloride has three characteristics that make it useful in road maintenance applications. The first characteristic is calcium chloride is hygroscopic, which means it attracts water from the atmosphere and increases the surface tension in the pore space between the aggregate. This increased surface tension causes slower evaporation rates and a decreased amount of dust. Secondly, calcium chloride is deliquescent, which means it can be applied to the road surface as a solid and will absorb moisture from the atmosphere to become liquid. Thirdly, calcium chloride is exothermic, which means that it gives off heat as it dissolves and tries to return to its natural state. This is why calcium chloride is one of the most widely used chemical deicers for snow and ice control. Lohnes and Coree (2002) also state that calcium chloride lowers the freezing point of the pore water, which results in greater freeze-thaw resistance and benefits compaction as well as enhances coarse aggregate retention. Calcium chloride is also known for its residual effects after road maintenance and increased effectiveness from year to year.

With too much moisture and high fines content, calcium chloride can cause slippery road surfaces and can also be harmful to vegetation in large doses. Calcium chloride is also somewhat corrosive to unprotected metal and aluminum and accelerates rusting on vehicles (Borlander and Yamada, 1999).

4.1.2 Lignin sulfonate

Lignin sulfonate, or more well known as “tree sap”, is an environmentally safe and readily available water liquor product of the sulfite paper making process, which contains lignin in solution and is chloride free (Figure 4.1.1). The lignin is sold as a by-product by paper mills. The composition of lignin varies with the raw materials, which is mainly wood pulp. Lignin contains a small amount of sugar, which gives it hygroscopic ability (Borlander and Yamada, 1999). Unpaved roads treated with lignin remain slightly plastic allowing reshaping, remolding, and additional compaction of the surface aggregate.

Disadvantages to lignin are it may cause corrosion of aluminum and its alloys, due to solubility of solids in water the surface binding may be reduced in heavy rains, and it can cause slippery surfaces when wet and brittle surfaces when dry (Borlander and Yamada, 1999).

4.1.3 Soapstock

The use of soybean oil soapstock or soapstock as a dust palliative is a relatively new concept. There are no known reports in engineering or scientific journals, but according to the Indiana Soybean Board (2003) and U.S. Roads (June 1998) the product proves to be an effective, locally grown, environmentally safe, economical dust control and road stabilizer. Soapstock acts as a binding agent and stabilizes the road by keeping the dust particles bound together.

Soybean oil soapstock is a by-product of the soybean oil industry (Figure 4.1.1). The original by-product is purchased by private companies from soybean processors such as Cargill. The original by-product is processed twice by the private company, once to acquire products that can be used in the feed industry and a second time to remove unwanted stems and parts of soybeans. The end result is a by-product of a by-product and is called emulsion. The emulsion is added to a small amount of soybean oil and named DC Sealer or Dust Control Sealer. The availability of soapstock varies with the soybean market and can be difficult to obtain at certain time periods (Stensland, 2004).

Soapstock is difficult for suppliers to store and transport. The product has to be kept at a constant temperature of 155 degrees Fahrenheit and continuously or periodically agitated. As the product becomes cooler it gets thicker, making transport and pumping difficult. Soapstock also cannot be pumped using blade pumps; the blades of the pump shear the product turning it into a peanut butter like consistency. If the product is not agitated continuously or periodically, the soybean oil settles to the bottom and the emulsion is left on top (Stensland, 2004). The soapstock has an odor within the first few weeks after application that some individuals find offensive. The odor usually dissipates within a few weeks. Currently, soapstock producers are researching additives that will reduce or remove the offensive odor as well as improve dust control effectiveness (Lohnes and Coree, 2002).

Figure 4.1.1. Dust suppressant samples.

4.2 Application Rates and Costs

The construction of the treated test sections was completed by specialty contractors with experience in applying these dust suppressants. The application rates and methods were those recommended by the specialty contractors. To duplicate local application practices, the dust suppressants were applied once in early June and a second time in late August or early September. The application rates and methods were identical for the first and second applications.

Calcium Chloride

The suppliers recommended surface sprayed application rate is 0.225 gal/yd^2 of a 38% solution and costs are around $71.25 per 100 feet, which includes two applications.

Lignin sulfonate

The suppliers recommended surface sprayed application rate is 0.50 gal/yd^2 of a 50:50 lignin water mix and costs are around $65 per 100 feet, which includes two applications.

Soapstock

The suppliers recommended surface sprayed application rate is 0.70 gal/yd^2 of a 100% solution and costs are around $75 per 100 feet, which includes two applications.

CHAPTER 5. DUST MEASUREMENTS AND MONITORING

This chapter presents the method of dust collection used in this study as well as the procedure and schedule of dust collection.

5.1 Method of Dust Collection

The amount of dust produced on each of the test sections was measured using the Colorado State University Dustometer. The Dustometer is an inexpensive quantitative moving dust sampler that was developed at Colorado State University (CSU) by Sanders and Addo (2000). The device consists of (1) a fabricated steel filter box that contains a 25.40 x 20.32 cm (10 x 8 in.) glass fiber filter paper; (2) a standard high volumetric (1/3 horsepower) suction pump; (3) a steel mounting bracket attached to the bumper of the test vehicle; (4) a 5.08 cm (2 in.) flexible hose for connecting the suction pump to the filter box; (5) a 5000 Watt electric generator; (6) a 3/4 ton pickup truck used as a testing vehicle; and (7) a on/off switchbox connecting the generator to the suction pump that extends into the cab of the test vehicle.

The fabricated steel filter box is connected to the testing vehicle behind the driver's side rear wheel by means of the steel mounting bracket attached to the bumper (Figure 5.1.1). The mounting bracket consists of two pieces of 1/4 in. thick steel plate welded at a right angle with two 4 in. pieces of 1-1/4 x 1-1/4 in. angle welded to the horizontal surface, two 1/2 x 3/4 x 4 in. pieces of steel bar stock, and two 1/4 x 1-1/4 x 1-1/4 in. pieces of steel with centered 3/8 in. diameter holes welded to the vertical surface of the 1/4 in. steel plate. The mounting bracket was painted to protect against corrosion and attached permanently to the rear driver's side bumper of the test vehicle with two 1/2 in. diameter bolts. The suction pump and generator are secured in the back of the test vehicle using adjustable ratchet straps (Figure 5.1.2 and 5.1.3).

When mounted, the center of the fabricated steel filter box aligns horizontally with the center of the driver's side rear wheel and is elevated vertically 9.5 in. from the road surface. The distance from the front of the mounted fabricated steel filter box to the center and rear of the driver's side rear wheel are 52 in. and 37 in. respectively (Figure 5.1.4).

Figure 5.1.1. Steel mounting bracket and mounting bolts.

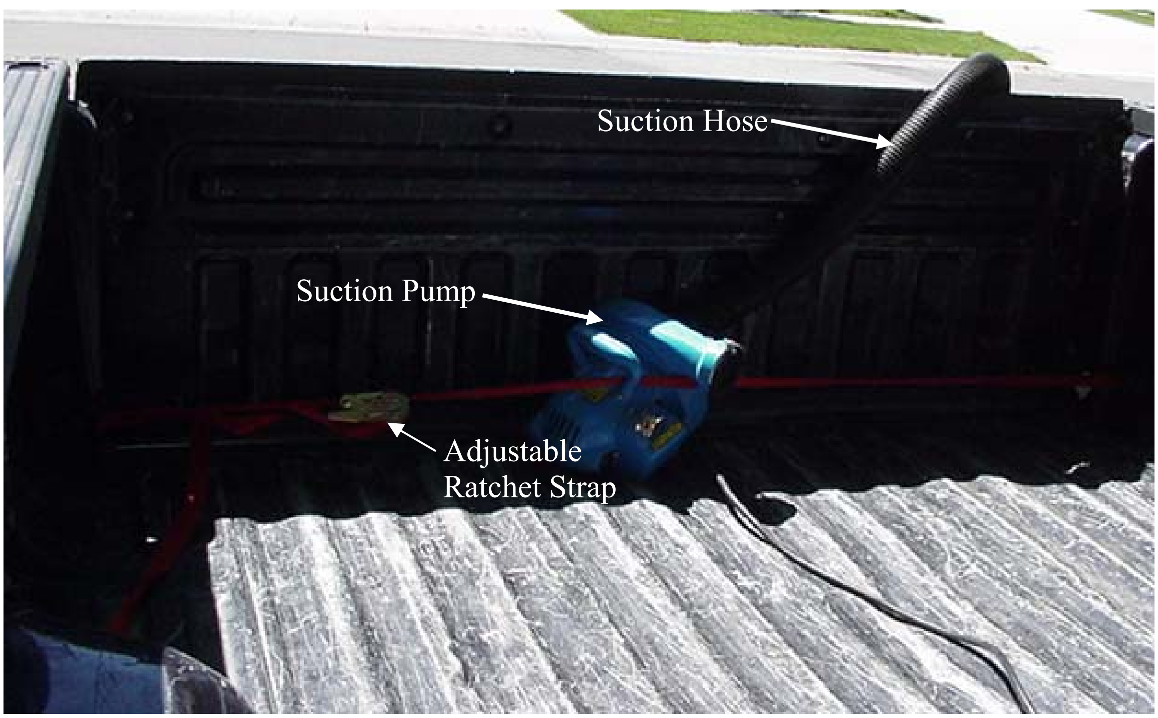

Figure 5.1.2. Suction pump secured by adjustable ratchet straps.

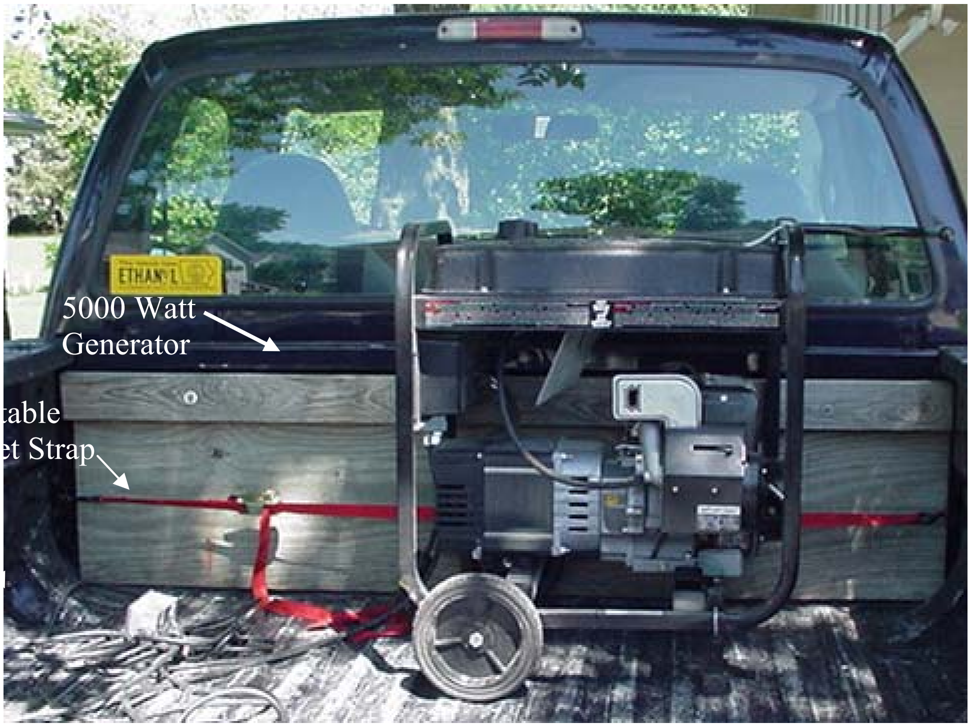

Figure 5.1.3. Generator secured by adjustable ratchet straps.

The design of the fabricated steel filter box and the steel mounting bracket allows easy removal of the steel filter box for filter replacement and storage when not in use, while the mounting bracket is permanently attached to the bumper of the test vehicle. The steel filter box is fabricated from a galvanized steel sheet and has a 25.4 x 25.4 cm. (12 x12 in.) opening facing the rear wheel covered with a 200 μm mesh sieve that prevents any large particles from entering the filter box during dust collection.

The bottom of the filter box opens to allow easy access to the filter paper (Figure 5.1.5). Inside the bottom of the filter box is another 200 μm sieve mounted horizontally for the filter paper to rest on. The bottom of the filter box is sealed with a stationary rubber/foam seal and secured with two hair pins.

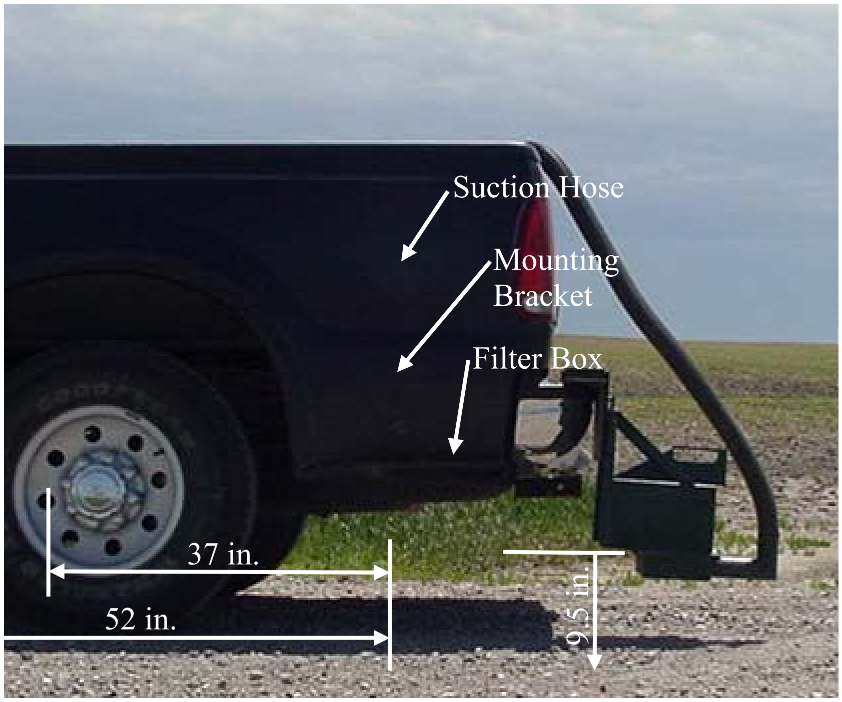

Figure 5.1.4. Mounted dustometer dimensions.

Figure 5.1.5. Opened filter box with and without filter paper.

Sanders and Addo (2000) determined the precision of the CSU Dustometer by running nine replicate dust measurements on a one mile untreated test section at a speed of 45 mph. A mean of 2.74 g. of dust was obtained with a standard deviation of 0.21, a variance of 0.04, and a coefficient of variation of 7 %. The data gathered showed that the Dustometer is quite precise for a field measurement device. A second set of dust measurements assessed the influence of test vehicle speed on the amount of dust collected. Sanders and Addo (2000) conducted dust measurements at 20, 30, 40, and 50 mph and observed a linear relationship ($r^2 = 0.98$) between speed and the amount of dust collected. The amount of dust collected varied from slightly over 2 g. at 20 mph to 7.3 g. at 50 mph.

To run a dust measurement, the CSU Dustometer is set up as presented in Figure 5.1.4. A filter is inserted into the filter box, the filter box is attached to the test vehicle by means of the mounting bracket, the flexible hose is attached to the filter box and to the suction pump, the suction pump is plugged into the on/off switch box, and the on/off switch box is plugged into the generator and operated inside the cab of the test vehicle. The ability of the on/off switch box to be inside the cab of the test vehicle allows the dust collection procedure to easily be completed by a single person. After the equipment is set up, the generator can be started with the suction pump on and the switch box off.

The test vehicle is positioned far enough away from the test section for smooth acceleration up to the testing speed. Due to the short acceleration distance of 595 ft. and from previous studies by Sanders and Addo (2000), the most appropriate testing speed was determined to be 45 mph. Once the front tires of the test vehicle entered into the section being tested, the switch box was turned on. As the test vehicle is traversing the 1000 ft. test section, the suction pump collects a portion of the dust produced by the driver's side rear tire onto the filter. When the front tire of the test vehicle reaches the end of the 1000 ft. test section, the switch box is turned off and the test vehicle decelerated slowly to a stop. For larger and more measurable quantities of collected dust, this process is repeated twice, for a total testing length of 2000 ft. At the end of the second 1000 ft. the test vehicle was decelerated slowly and brought to a stop. The flexible hose is released from the filter box and the filter box transported carefully and level into the cab of the test vehicle. The filter is carefully removed and placed in the appropriate pre-weighed plastic bag. To get a quantifiable, accurate depiction of the amount of dust produced, this collection process is repeated three times. The average of the three collections is used for comparison to determine the effectiveness of the three dust suppressants.

The dust collection procedure described above was adopted from Sanders (2004) and is presented in a detailed step by step format below.

5.1.1 Dust Collection Procedure

1. Plug the suction pump into the on/off switchbox, plug switchbox into generator, and run on/off switchbox into the truck cab.
2. Turn the pump on but leave the switchbox off.
3. Attach end of flexible hose to suction pump.
4. Start the generator with switchbox in off position.
5. Open the Dustometer and place a filter on the wire mesh and close the Dustometer.
6. Make sure Dustometer is closed tight to create a seal.
7. Place the Dustometer in the bracket on the back of truck.
8. Attach the other end of the hose to the Dustometer.
9. Position the truck enough ahead of the test section to get up to the desired speed (45 mph) before entering the test section.
10. Accelerate towards the test section.
11. When front wheels cross into the test section, turn on the switchbox, which will turn on the pump.
12. Maintain testing speed.
13. When front wheels exit the test section turn off the switchbox.
14. Decelerate smoothly.
15. Disconnect flexible hose from Dustometer and remove Dustometer from truck.
16. Carry Dustometer to the truck cab, keeping it level as it is carried.
17. Set the Dustometer down and open it up.
18. Carefully lift the filter from the wire mesh.
19. Place filter in designated plastic bag and place in notebook.
20. Wipe excess dust off the inside of the Dustometer with a paper towel and place a new filter on the wire mesh.
21. Close the Dustometer.
22. Repeat procedure starting with step 6.

To keep all the filters organized, a method similar to that utilized by Sanders (2004) was developed. The filters to be used for dust collection were placed in 10x12 in. plastic ziploc bags, the bag and filter were weighed before dust collection and after dust collection. The difference between the before and after weights was the amount of dust collected in grams. Each demonstration site has its own three ring binder containing 2 mil. sheet protectors. To keep the three filters for each test section together, each test section has its own 2 mil. sheet protector. The sheet protector was marked with the filter numbers, date of dust collection, name of demonstration site being tested (i.e. Zumwalt Road), distance test was being conducted (2000 ft.), test being conducted and on which section (i.e. 4 week soapstock test), speed at which the test was conducted (45 mph), dust weights for each of the three tests, and an average dust weight.

In addition to the CSU Dustometer, the ASTM Standard Test Method for Collection and Measurement of Dustfall (ASTM D-1739) was proposed as a method of dust collection. The ASTM standard (ASTM D-1739) was projected to provide a means of comparison to the CSU Dustometer. Unfortunately, due to time constraints as well as anticipated problems with local farmers, the ASTM standard (ASTM D-1739) was not conducted during this study.

Follow up testing was also proposed on several secondary road sites in Benton County, Iowa. These sites were used by Marks and Petermeier (1997) to determine the effectiveness of using ground up asphalt shingles as a dust suppressant. Marks and Petermeier (1997) determined that the ground up asphalt shingles were effective in reducing dust production and increasing stability shortly after initiation as well as two years after application. Unfortunately due to subsequent aggregate applications, the asphalt shingle demonstration sites have been buried under several layers of aggregate and have disappeared.

5.2 Schedule of Dust Collection

The schedule of dust collection was coordinated with the application schedules of the specialty contractors. To be highly effective, the dust suppressants are applied in early spring and again in mid summer, with approximately eight weeks in between the applications. Therefore the schedule of dust collection consisted of two eight week data sets for a total of 16 weeks of dust collection. Dust collection was performed at 1, 2, 4, 6, and 8 weeks after the first application and repeated after the second application.

Weather conditions were recorded daily throughout the collection schedule and are presented in Appendix A. The application dates and dust collection dates were kept as close to the schedule as weather permitted. For reliable data, the collection procedure could not be carried out in windy or wet conditions. All testing procedures, as well as the test vehicle, driver, and speed were kept constant throughout the testing schedule. The activities for the first and second 8 weeks of testing are presented in Tables 5.2.1 and 5.2.2, respectively.

Table 5.2.1. Activities for the first eight weeks of testing.

Date	Action	Weather Observations
4/14/2004	Rock applied	NA
4/20/2004	Gravel applied	NA
6/11/2004	Soapstock applied	Rained 0.5 in. day before
6/18/2004	Soapstock 1 week test	Rained 0.22 in. 2 days before
6/22/2004	Lignin applied	Rained 0.31 in. day before
6/23/2004	Calcium chloride applied	Rained 0.31 in. 2 days before
6/29/2004	Lignin 1 week test	Rained 0.36 in. 2 days before
6/29/2004	Soapstock 2 week test	Rained 0.36 in. 2 days before
6/30/2004	Calcium chloride 1 week test	Rained 0.36 in. 3 days before
7/12/2004	All sections on S. 530th Ave. bladed	Rained 1.2 in. day before
7/12/2004	Lignin 2 week test	Rained 1.2 in. day before
7/12/2004	Calcium chloride 2 week test	Rained 1.2 in. day before
7/13/2004	Soapstock 4 week test	Rained 1.2 in. 2 days before
7/19/2004	All sections on Grant Ave. bladed	Rained 0.09 in. 3 days before
7/19/2004	Lignin 4 week test	Rained 0.09 in. 3 days before
7/19/2004	Calcium chloride 4 week test	Rained 0.09 in. 3 days before
7/26/2004	Soapstock 6 week test	Rained 0.02 in. 2 days before
8/9/2004	Soapstock 8 week test	Rained 2.37 in. 6 days before
8/10/2004	Calcium chloride 6 week test	Rained 2.37 in. 7 days before
8/10/2004	Lignin 6 week test	Rained 2.37 in. 7 days before
8/17/2004	Lignin 8 week test	Rained 0.03 in. day before
8/23/2004	Calcium chloride 8 week test	Rained 0.48 in. 5 days before

Table 5.2.2. Activities for the second eight weeks of testing.

Date	Action	Weather Observations
8/9/2004	Soapstock second application	Rained 2.35 in. 6 days before
8/17/2004	Soapstock 1 week test	Rained 0.06 in.
8/20/2004	Lignin second application	Rained 0.48 in. 2 days before
8/30/2004	Soapstock 2 week test	Rained 0.03 in.
8/30/2004	Lignin 1 week test	Rained 0.03 in.
8/31/2004	Calcium chloride second application	Rained 0.03 in. day before
9/8/2004	Calcium chloride 1 week test	Rained 1.42 in. 3 days before
9/8/2004	Lignin 2 week test	Rained 1.42 in. 3 days before
9/8/2004	Soapstock 4 week test	Rained 1.42 in. 3 days before
9/16/2004	Calcium chloride 2 week test	Rained 0.24 in. day before
9/16/2004	Soapstock 6 week test	Rained 0.24 in. day before
9/16/2004	Lignin 4 week test	Rained 0.24 in. day before
9/21/2004	S. 530th Ave. Soapstock bladed	Rained 0.02 in. 4 days before
9/21/2004	S. 530th Ave. Calcium chloride bladed	Rained 0.02 in. 4 days before
9/30/2004	Calcium chloride 4 week test	Rained 0.03 in. 7 days before
9/30/2004	Lignin 6 week test	Rained 0.03 in. 7 days before
9/30/2004	Soapstock 8 week test	Rained 0.03 in. 7 days before
10/11/2004	All sections on Grant Ave. bladed	Rained 0.28 in. 4 days before
10/19/2004	All sections on Grant Ave. bladed	Rained 0.21 in. day before
10/25/2004	Calcium chloride 6 week test	Rained 0.01 in. 3 days before
10/25/2004	Lignin 8 week test	Rained 0.01 in. 3 days before
10/25/2004	Calcium chloride 8 week test	Rained 0.01 in. 3 days before

CHAPTER 6. RESULTS AND DISCUSSIONS

6.1 Dust Measurement Results

The results of the dust measurements conducted on the four demonstration sites are presented individually in sections 6.1.1 through 6.1.4. Raw data from the dust measurements for the first and second eight weeks of testing are presented in Appendices B and C, respectively. As discussed in section 5.1, each data point on the following graphs represents an average of three identical test runs over the specified test section. Each test run consisted of two passes of the 1000 ft test section for a total of 2000 ft at a nominal speed of 45 mph. The schedule consisted of dust measurements taken at 1, 2, 4, 6, and 8 weeks after the first application of the suppressants, followed by dust measurements taken at 1, 2, 4, 6, and 8 weeks after the second application of the suppressants for a total testing period of 16 weeks.

Due to differences in the application schedule of each suppressant, the untreated test results are not identical for each 16 week testing period. For instance, the untreated test results in Figures 6.1.1 and 6.1.2 are identical for the first 8 weeks since the suppressants were applied on the same day, while the untreated test results differ in the second 8 weeks due to differences in application times.

6.1.1 Zumwalt Road

The granular surface of Zumwalt Road consists of crushed limestone rock with an AADT of 45 vehicles per day (IDOT, 2000). Results of the dust measurements on Zumwalt Road indicate that all three dust suppressant products were effective in reducing dust production when compared to the untreated or control section, as shown in Figures 6.1.1 through 6.1.3.

Dust measurement results of the lignin sulfonate treated test section presented in Figure 6.1.1 indicate decreases in dust production compared to the untreated test section. The amount of dust measured on the lignin sulfonate treated test section gradually increased from week 1 to week 6 and slightly decreased from week 6 to week 9, followed by a relatively identical amount of dust measured after the second application of product from week 9 to week 14 and ending with an increase from week 14 to week 16. The amount of dust measured on the untreated test section shown in Figure 6.1.1 was highly erratic with small amounts of dust collected in weeks

2, 8, 9, 12, and 14 and large amounts collected in weeks 4, 6, 10, and 16.

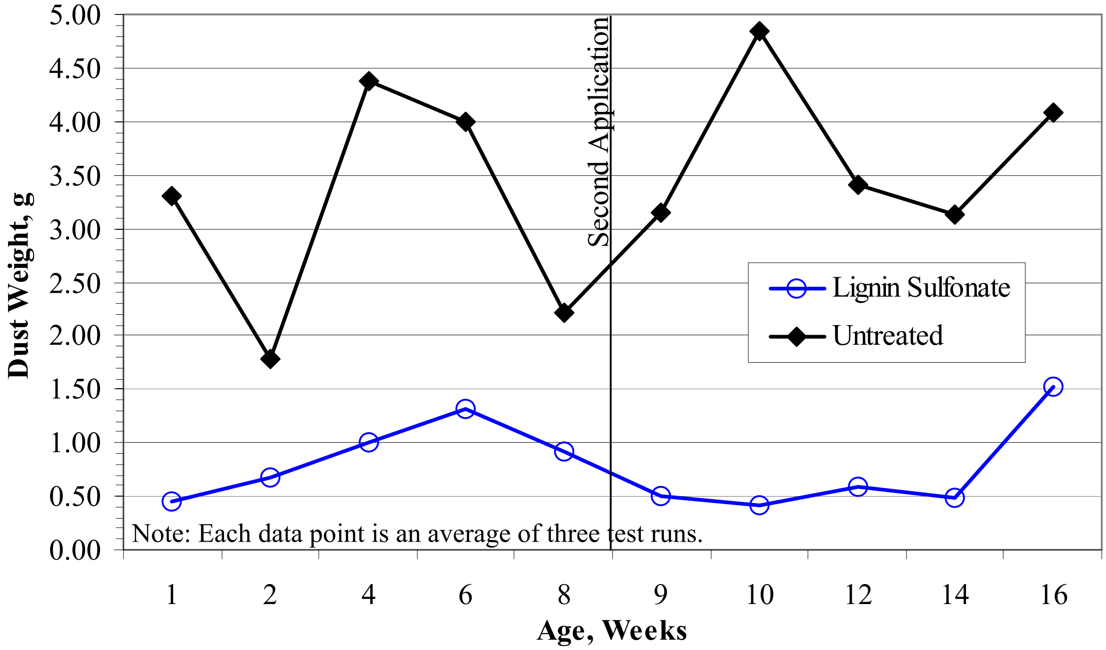

Figure 6.1.1. Zumwalt Road 16 week lignin sulfonate dust measurement results.

Dust measurement results of the calcium chloride treated test section presented in Figure 6.1.2 indicate decreases in dust production compared to the untreated test section. The amount of dust measured on the calcium chloride treated test section varied slightly in weeks 1 through 10 followed by a significant increase from week 10 to week 14 before leveling off in weeks 14 to 16. The amount of dust measured on the untreated test section shown in Figure 6.1.2 was highly variable with small amounts of dust collected in weeks 2, 8, 10, and 12 and large amounts collected in weeks 1, 4, 6, 9, 14, and 16.

Dust measurement results of the soapstock treated test section presented in Figure 6.1.3 indicate decreases in dust production compared to the untreated test section, especially in weeks 9 and 10 after the second application of the suppressant. The amount of dust measured on the soap-stock treated test section was nearly constant throughout the first 8 weeks of testing with slightly less collected in weeks 1 and 2, followed by a considerable reduction in measured dust in weeks 9 and 10 and a spike in week 12. The amount of dust measured on the untreated test section shown in Figure 6.1.3 was also highly variable with relatively small amounts of dust collected in weeks 1 through 6 as well as weeks 9, 10, 14, and 16 and large amounts collected in weeks 8 and 12.

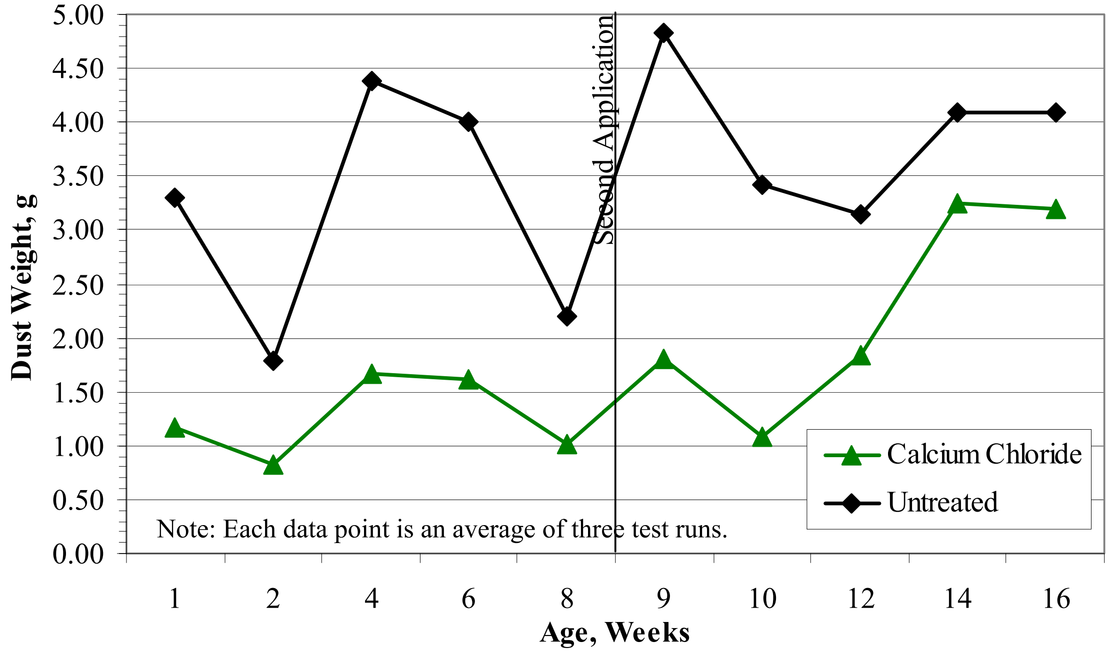

Figure 6.1.2. Zumwalt Road 16 week calcium chloride dust measurement results.

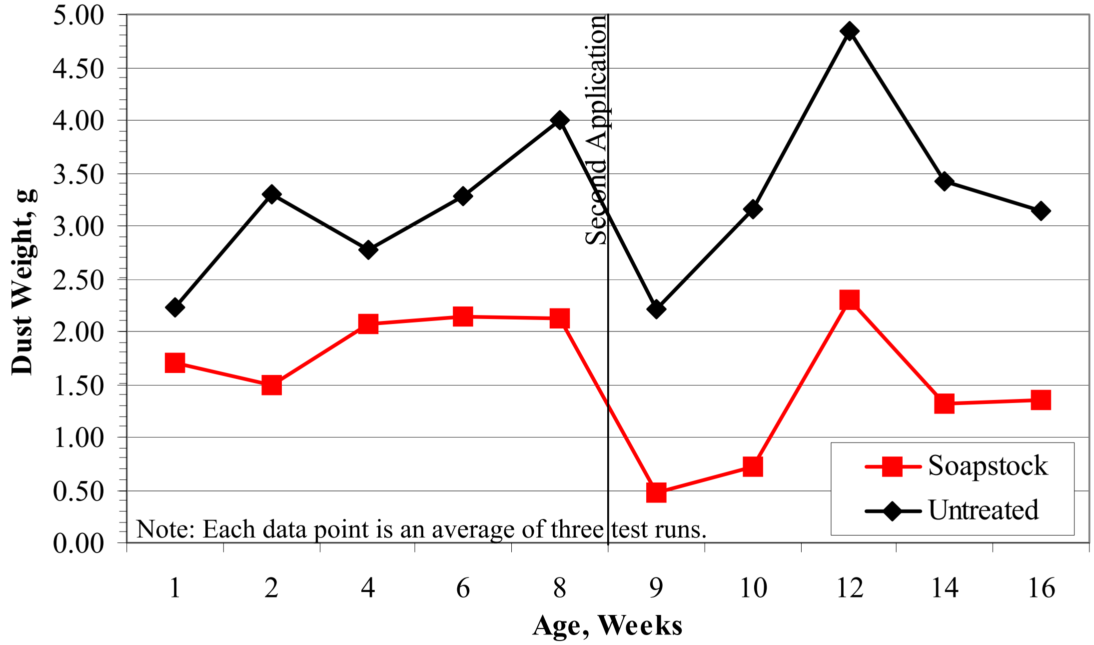

Figure 6.1.3. Zumwalt Road 16 week soapstock dust measurement results.

6.1.2 260th Street

The granular surface of 260th Street consists of alluvial sand/gravel with an AADT of 60 vehicles per day (IDOT, 2000). Results of the dust measurements on 260th Street indicate that all three dust suppressant products were effective in reducing dust production when compared to the untreated or control section as shown in Figures 6.1.4 through 6.1.6.

Dust measurement results of the lignin sulfonate treated test section presented in Figure 6.1.4 indicate reductions in dust production compared to the untreated test section. The amount of dust measured on the lignin sulfonate treated test section decreased initially in week 2 and then slightly increased from week 2 to week 8, followed by a gradual reduction after the second application from week 8 to week 12 and then an increase from week 12 to week 16. The amount of dust measured on the untreated test section shown in Figure 6.1.4 was somewhat variable with relatively small amounts of dust collected in weeks 2, 8, 10, 12, 14, and 16 and large amounts of dust collected in weeks 1, 4, 6, and 9.

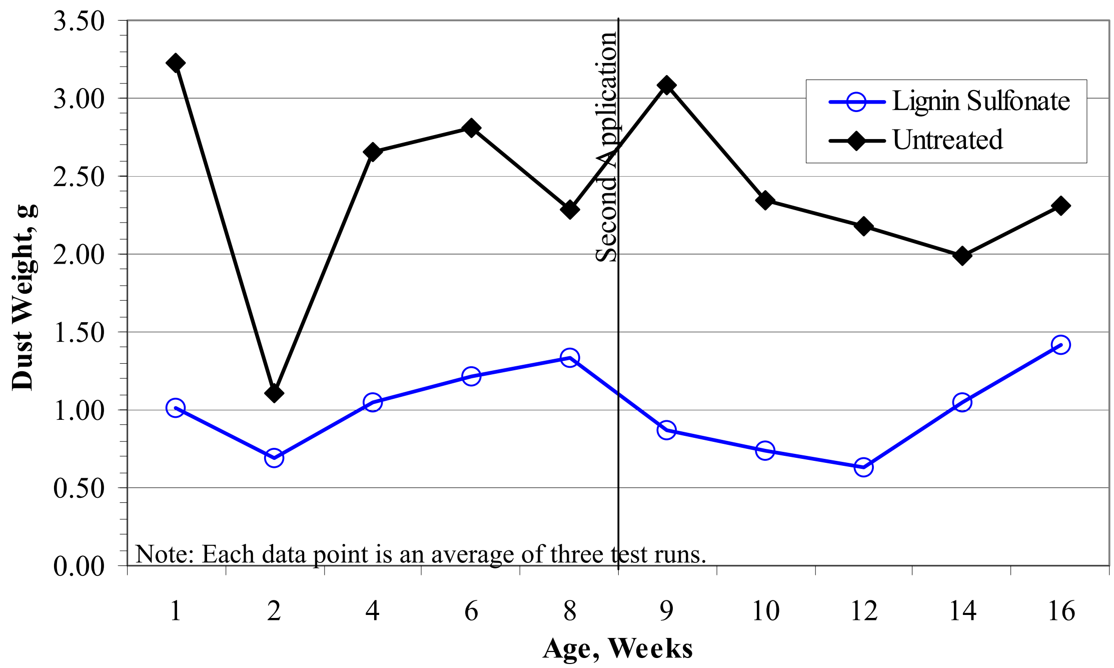

Figure 6.1.4. 260th Street 16 week lignin sulfonate dust measurement results.

Dust measurement results of the calcium chloride treated test section presented in Figure 6.1.5 show decreases in dust production compared to the untreated test section. The amount of dust measured on the calcium chloride treated test section decreased from week 1 to week 2 and then increased slightly from week 2 to just after the second application in week 9, followed by a decrease from week 9 to week 10 and a gradual increase between weeks 10 and 16. A similar trend in the amount of dust collected on the calcium chloride treated test section can be seen between weeks 1 through 8 and weeks 9 through 16. The amount of dust measured on the untreated test section shown in Figure 6.1.5 was relatively consistent, with the exception of weeks 1 through 6, where there was a drastic drop in dust from week 1 to week 2 and an increase from week 2 to week 6.

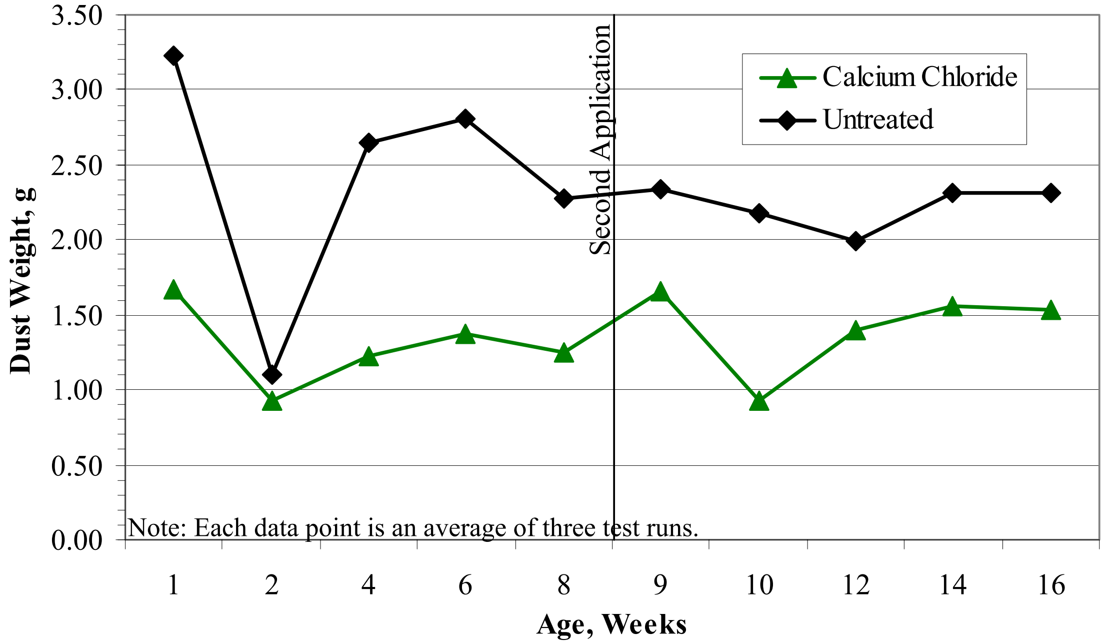

Figure 6.1.5. 260th Street 16 week calcium chloride dust measurement results.

Dust measurement results of the soapstock treated test section shown in Figure 6.1.6 verify decreases in dust production compared to the untreated test section especially in weeks 9 and 10 after the second application of the suppressant. The amount of dust measured on the soapstock treated test section initially increased from week 1 to week 2 and remained rather constant from week 4 to week 8, followed by a decrease after the second application of the suppressant in week 9 and a gradual increase between weeks 9 and 14 before decreasing slightly in week 16. The amount of dust measured on the untreated test section shown in Figure 6.1.6 varied, with small amounts of dust collected in weeks 1, 4, 6, 9, and 12 through 16 and large amounts collected in weeks 2, 8, and 10.

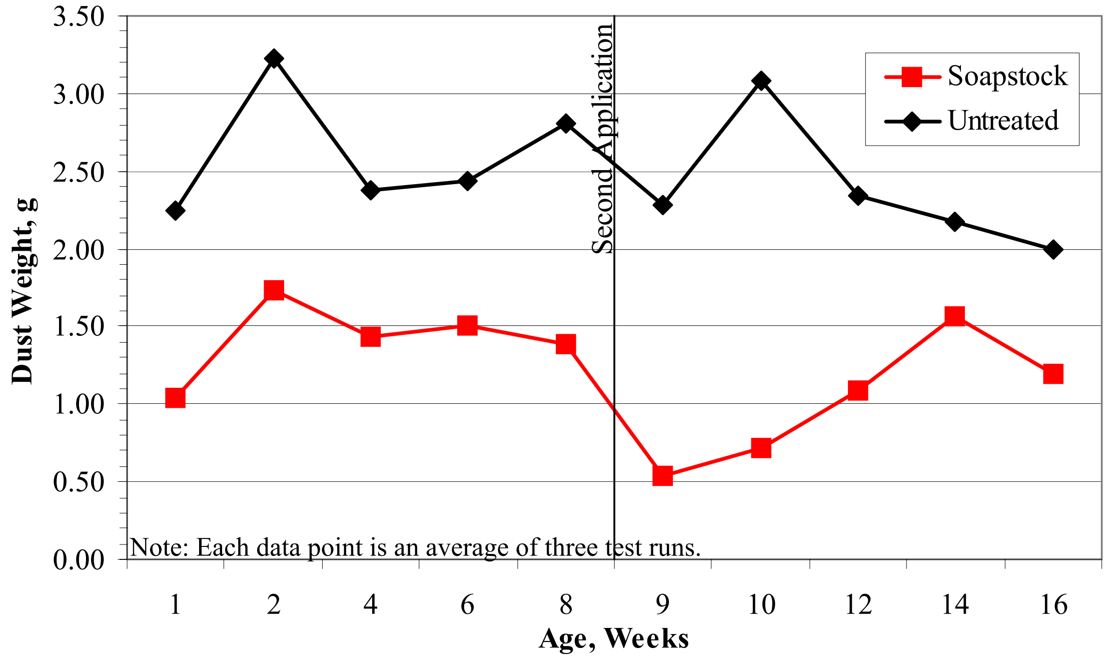

Figure 6.1.6. 260th Street 16 week soapstock dust measurement results.

6.1.3 South 530th Avenue

The granular surface of South 530th Avenue consists of crushed limestone rock with an AADT of 240 vehicles per day (IDOT, 2000). Results of the dust measurements on South 530th Avenue indicate that all three dust suppressant products were effective in reducing dust production when compared to the untreated or control section as shown in Figures 6.1.7 through 6.1.9.

Dust measurement results of the lignin sulfonate treated test section presented in Figure 6.1.7 shows decreases in dust production compared to the untreated test section. The amount of dust measured on the lignin sulfonate treated test section remained reasonably constant throughout the 16 week testing period, with the exception of a slight increase in week 2. The amount of dust measured on the untreated test section shown in Figure 6.1.7 increased from week 1 to week 2 and decreased gradually from week 2 to week 8, followed by a steady increase between weeks 8 and 10 as well as high and low peaks in weeks 12 and 14, respectively.

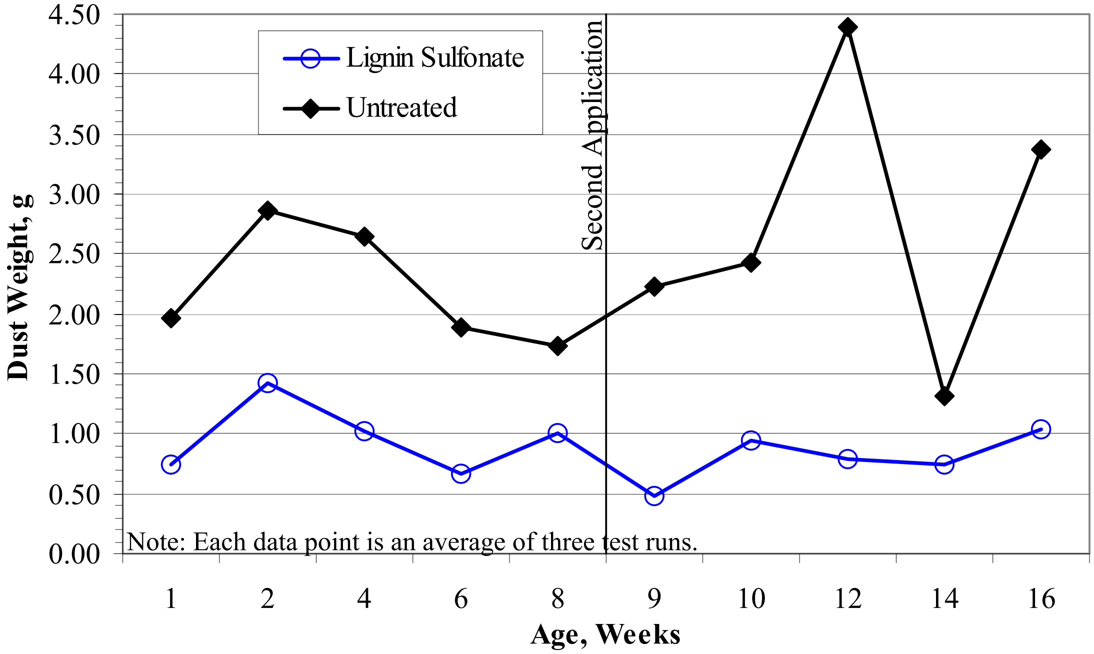

Figure 6.1.7. South 530th Avenue 16 week lignin sulfonate dust measurement results.

Dust measurement results of the calcium chloride treated test section shown in Figure 6.1.8 indicate decreases in dust production compared to the untreated test section. The amount of dust measured on the calcium chloride treated test section increased dramatically from week 1 to week 2 and decreased steadily between weeks 2 and 8, followed by an increase from week 8 to week 9 and a slow decrease from week 9 to week 16. The amount of dust measured on the untreated test section shown in Figure 6.1.8 increased dramatically from week 1 to week 2 and decreased steadily between weeks 2 and 8, followed by a large increase from week 8 to week 10 and a substantial decrease between weeks 10 and 12 before increasing from week 12 to week 14 and leveling off in weeks 14 and 16.

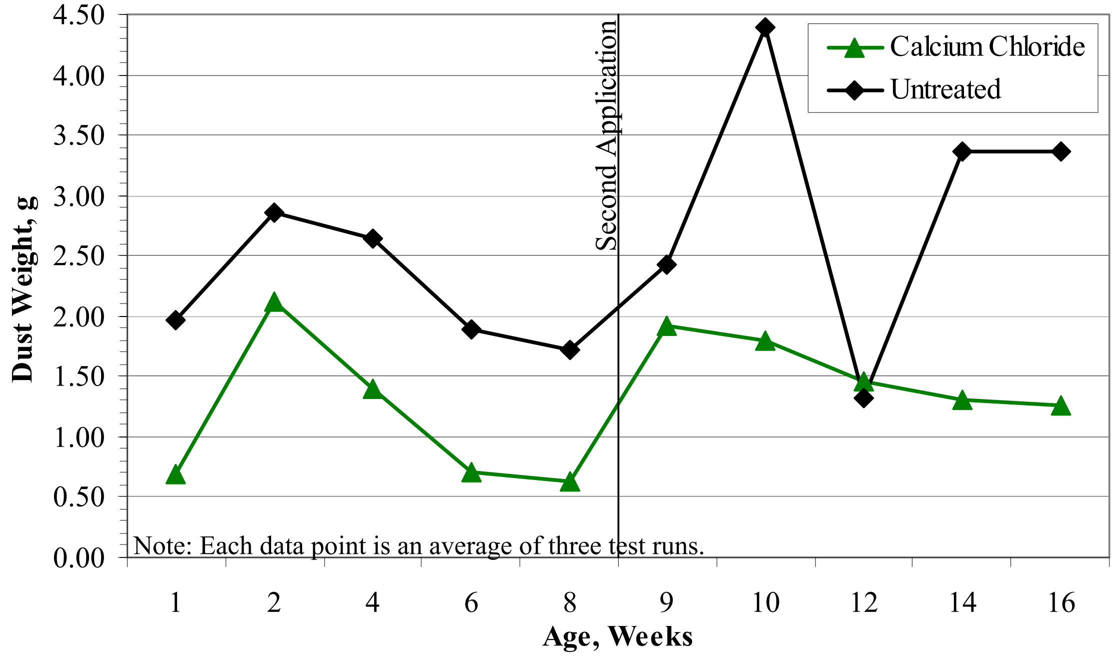

Figure 6.1.8. South 530th Avenue 16 week calcium chloride dust measurement results.

Dust measurement results of the soapstock treated test section presented in Figure 6.1.9 show little reduction in dust production compared to the untreated test section, especially in weeks 8 and 16 at the ends of the first and second 8 weeks of testing. The amount of dust measured on the soapstock treated test section increased slightly from week 1 to week 2 and increased intensely from week 2 to week 4, followed by a slow decrease between weeks 4 and 9 and slow increase between weeks 9 and 14, before decreasing from week 14 to week 16. The amount of dust measured on the untreated test section shown in Figure 6.1.9 decreased slightly from week 1 to week 2 and increased from week 2 to week 4, followed by a slow decrease between weeks 4 and 9 and slow increase between weeks 9 and 12, before increasing dramatically from week 12 to week 14 and decreasing dramatically between weeks 14 and 16.

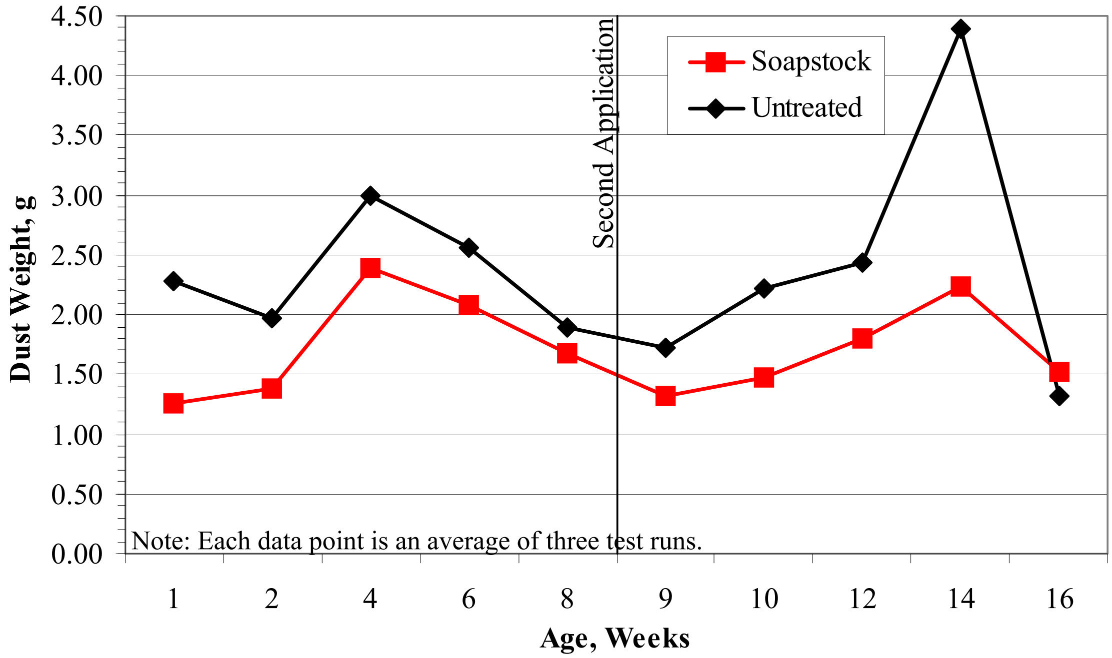

Figure 6.1.9. South 530th Avenue 16 week soapstock dust measurement results.

6.1.4 Grant Avenue

The granular surface of Grant Avenue consists of alluvial sand/gravel with an AADT of 240 vehicles per day (IDOT, 2000). Results of the dust measurements on Grant Avenue indicate that the lignin sulfonate treated test section was effective in reducing dust production compared to the untreated test section, while the calcium chloride and the soapstock treated test sections were not, with periods of dust measurements greater on the treated test sections than on the untreated test sections as shown in Figures 6.1.10 through 6.1.12.

Dust measurement results of the lignin sulfonate treated test section shown in Figure 6.1.10 indicate slight decreases in dust production compared to the untreated test section. The amount of dust measured on the lignin sulfonate treated test section decreased slightly in week 2 and increased sharply in week 4, followed by a decrease between weeks 4 and 12, with the exception of week 9 which had a minor increase, and gradually increased from week 12 to week 16. The amount of dust measured on the untreated test section shown in Figure 6.1.10 was slightly greater than that measured on the lignin sulfonate treated test section, but followed nearly the exact same trend as the lignin sulfonate.

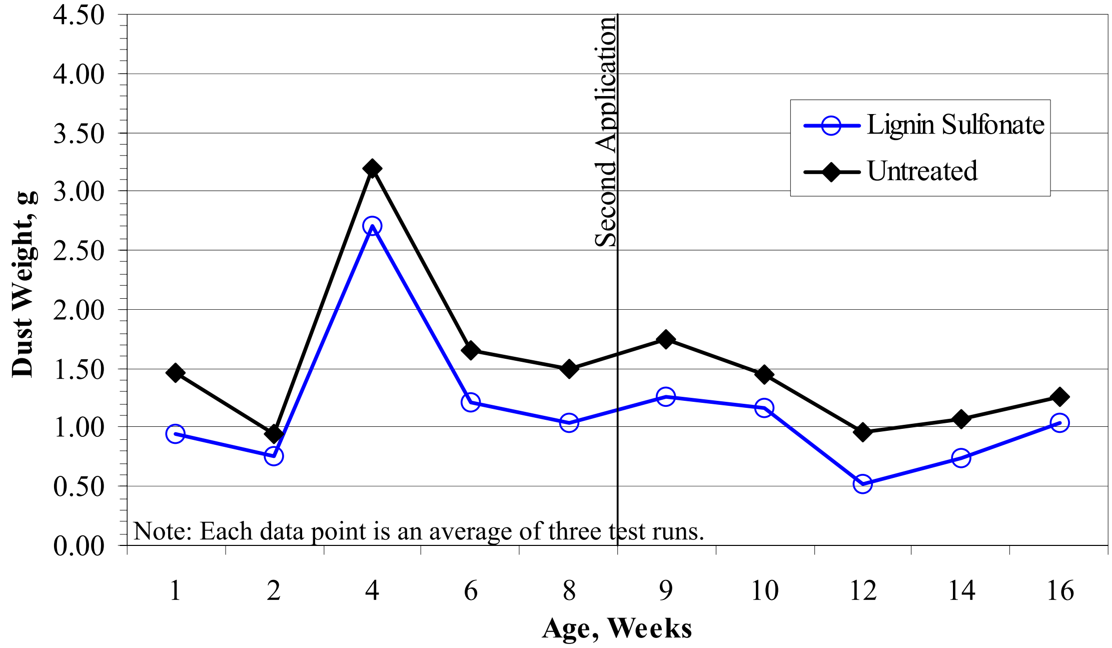

Figure 6.1.10. Grant Avenue 16 week lignin sulfonate dust measurement results.

Dust measurement results of the calcium chloride treated test section presented in Figure 6.1.11 show erratic decreases and increases in dust production compared to the untreated test section. The amount of dust measured on the calcium chloride treated test section was nearly equal in weeks 1 and 2 but rose sharply above the untreated in week 4 and decreased back down below the untreated in weeks 6 and 8, followed by a brief increase above the untreated in week 9 and decrease below the untreated in weeks 10 and 12 before increasing back above the untreated in weeks 14 and 16. The amount of dust measured on the untreated test section shown in Figure 6.1.11 was relatively invariable throughout the 16 week testing period with the exception of weeks 4 and 6.

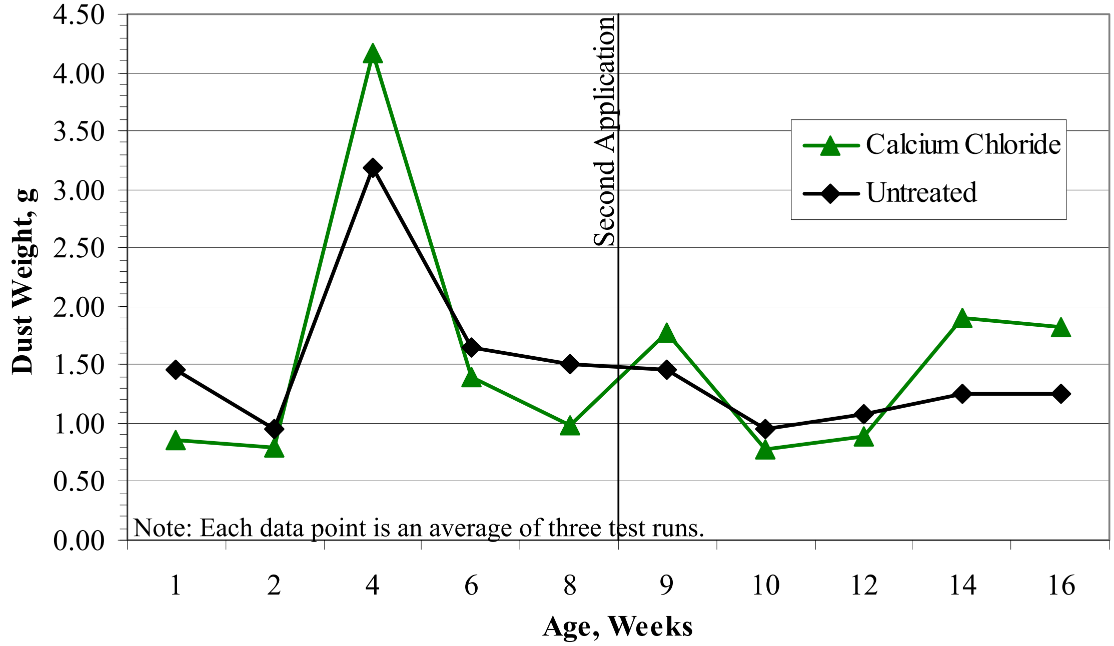

Figure 6.1.11. Grant Avenue 16 week calcium chloride dust measurement results.

Dust measurement results of the soapstock treated test section shown in Figure 6.1.12 indicate unreliable increases and decreases in dust production compared to the untreated test section. The amount of dust measured on the soapstock treated test section was relatively invariable throughout the 16 week testing period but increased above the untreated dust measurements in weeks 4 through 8 and weeks 12 through 16. The general trend indicates that the soapstock became ineffective 4 weeks after the first application and 4 weeks after the second application. The amount of dust measured on the untreated test section shown in Figure 6.1.12 was rather consistent from week 1 through week 12 and decreased from week 12 to week 14, followed by a small increase from week 14 to week 16.

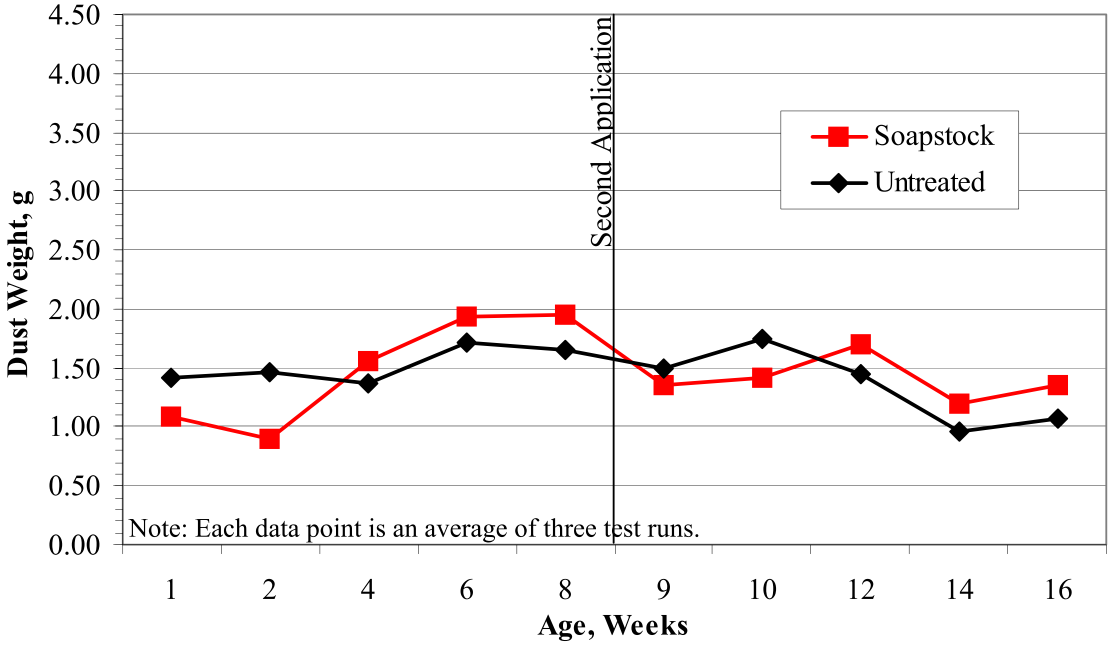

Figure 6.1.12. Grant Avenue 16 week soapstock dust measurement results.

6.1.5 One Year Follow Up Tests

To determine the long term residual effects of the three dust suppressants, a one year follow up test was completed. Results of the one year follow up test are presented in Table 6.1.1. Raw data from the dust measurements for the one year follow up tests as well as figures for each demonstration site showing dust weights for weeks one through 16 and week 52 are presented in Appendix D.

Table 6.1.1. One year follow up test results.

	52 Week Dust Weights, g			
Suppressant	260th Street	Zumwalt Road	South 530th Avenue	Grant Avenue
Untreated	2.91	5.36	6.87	2.08
Soapstock	2.10	4.99	5.87	2.65
Calcium Chloride	2.39	4.74	8.52	2.62
Lignin	2.09	4.18	6.15	*
Note: All data is an average of three test runs.				
* New gravel on lignin section, therefore no test.				

6.2 Discussion of Results

Discussion of the dust measurements conducted on the four demonstration sites are presented in sections 6.2.1 through 6.2.5. The dust measurement results of the treated test sections presented in Section 6.1 are normalized against the results of the untreated test sections to express the percent dust reduction and are shown in Figures 6.2.1 through 6.2.4.

Activities and precipitation observations for the first and second eight weeks of testing are shown in Tables 5.2.1 and 5.2.2, respectively. The performance of the dust suppressants was based on a rating system with excellent representing dust reductions of 80 % or more, good representing dust reductions of 60 %, fair representing dust reductions of 40 %, and poor representing dust reductions of 20 % or less.

6.2.1 Zumwalt Road

The percent dust reduction for each of the treated test sections on Zumwalt Road are shown in Figure 6.2.1. The lignin sulfonate treated test section performance was excellent with dust reduction near 88 % at the beginning of the first 8 weeks of testing, followed by a slight decrease in week 2 due to 1.2 inches of precipitation the day before testing. After drying out, the dust reduction increased in week 4 and then slowly decreased from week 4 to week 8, followed by a large increase in weeks 9 and 10, due to the cumulative effects of the second application, before slowly decreasing from week 10 to week 16.

The calcium chloride treated test section performance was good to fair with dust reduction near 65 % in the first week of testing, followed by a decrease in week 2 due to 1.2 inches of precipitation the day before testing. From week 4 to week 8, the calcium chloride treated test section had very similar dust reductions at around 55 % to 60 %, before increasing to nearly 70 % in week 10 due to cumulative effects of the second application. Drastic decreases in dust reduction on the calcium chloride treated test section occurred between weeks 10 and 14 due to lack of moisture for hygroscopic action.

The soapstock treated test section performance was fair in the first eight weeks of testing, but improved to good in the second eight weeks due to the cumulative effects of the second application. In week 1, the soapstock treated test section had a dust reduction near 25 % and increased sharply to around 55 % in week 2, followed by a decrease in week 4 due to 1.2 inches of precipitation two days before testing. From week 4 to week 8, the percent dust reduction slowly increased before drastically increasing in week 9 due to the cumulative effects of the second application of soapstock. After the second application, the percent dust reduction slowly decreased from week 9 to week 16, with a larger decrease in week 12 due to 1.42 inches of precipitation three days before testing.

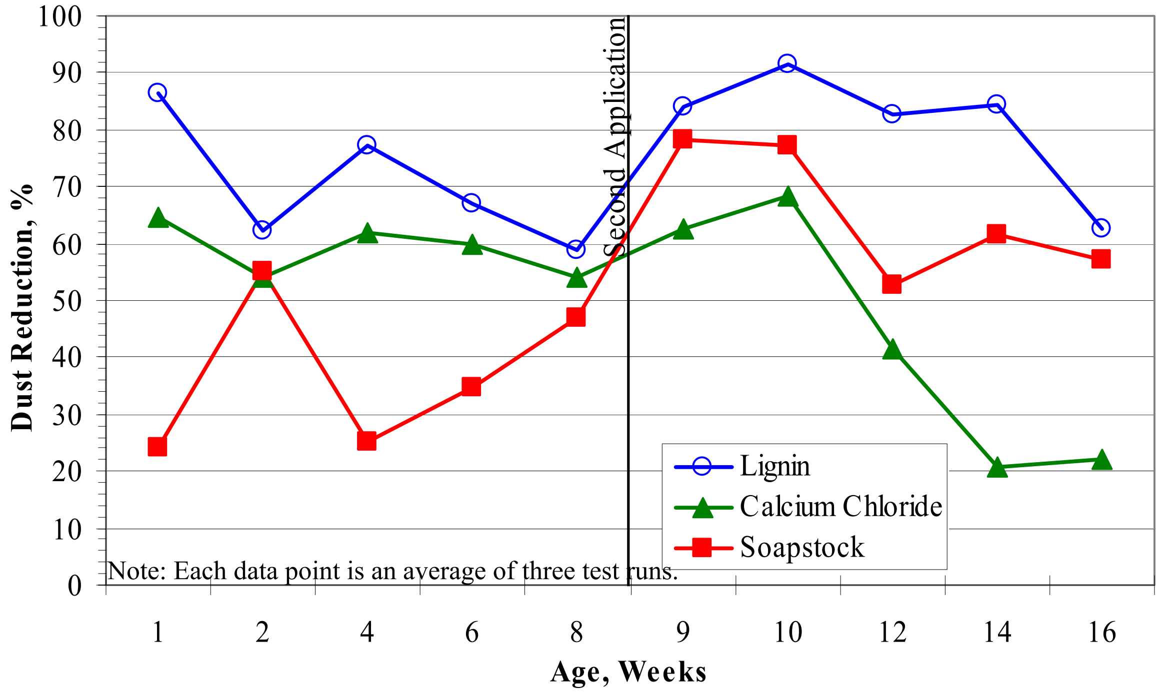

Figure 6.2.1. Zumwalt Road 16 week dust reduction results.

6.2.2 260th Street

The percent dust reduction for each of the treated test sections on 260th Street are shown in Figure 6.2.2. The lignin sulfonate treated test section performance was good to fair throughout the 16 week testing period with dust reduction near 70 % in week 1. A drastic decrease in dust reduction occurred in week 2, due to 1.2 inches of precipitation the day before testing, followed by an increase in dust reduction from week 2 to week 4 and a slow decrease from week 4 to week 8. Following the second application, the percent dust reduction increased considerably in week 9 and remained nearly constant through week 12, before decreasing rapidly from week 12 to week 16 due to relatively dry conditions.

The calcium chloride treated test section performance was good to fair with an initial dust reduction near 50 % in week 1, but due to 1.2 inches of precipitation the day before testing, the 2 week dust reduction decreased significantly to near 15 %. In week 4, dust reduction on the calcium chloride treated test section increased to near 55 %, followed by a slight decrease from week 4 to week 8. After the second application, the dust reduction decreased in week 9, due to 1.42 inches of precipitation three days before testing and increased significantly in week 10 due to a small amount of precipitation the day before testing that caused reactivation of the calcium chloride's hygroscopic action. The dust reduction decreased from week 10 to week 12 and remained nearly constant from week 12 to week 16 during a relatively dry period that lacked moisture for hygroscopic action.

The soapstock treated test section performed good to fair with dust reduction near 55 % in week 1 and a slight reduction from week 1 to week 6 due to small amounts of precipitation, followed by an increase in dust reduction in week 8 as well as weeks 9 and 10 after the second application of soapstock. The drastic increase in dust reduction on the soapstock treated test section in weeks 9 and 10, after the second application, was caused by a miscommunication between the lignin contractor and myself. Consequently, the second application of lignin was applied on top of the one week old second application of soapstock and caused large decreases in dust production and large increases in dust reduction. After recognizing the second application of lignin had been applied on the wrong test section, a second application was applied to the lignin sulfonate treated test section as well. Although the soapstock treated test section had two applications of soapstock and one application of lignin, the amount of dust reduction significantly decreased after week 10, indicating that the soapstock/lignin combination did not increase the longevity of the soapstock suppressant.

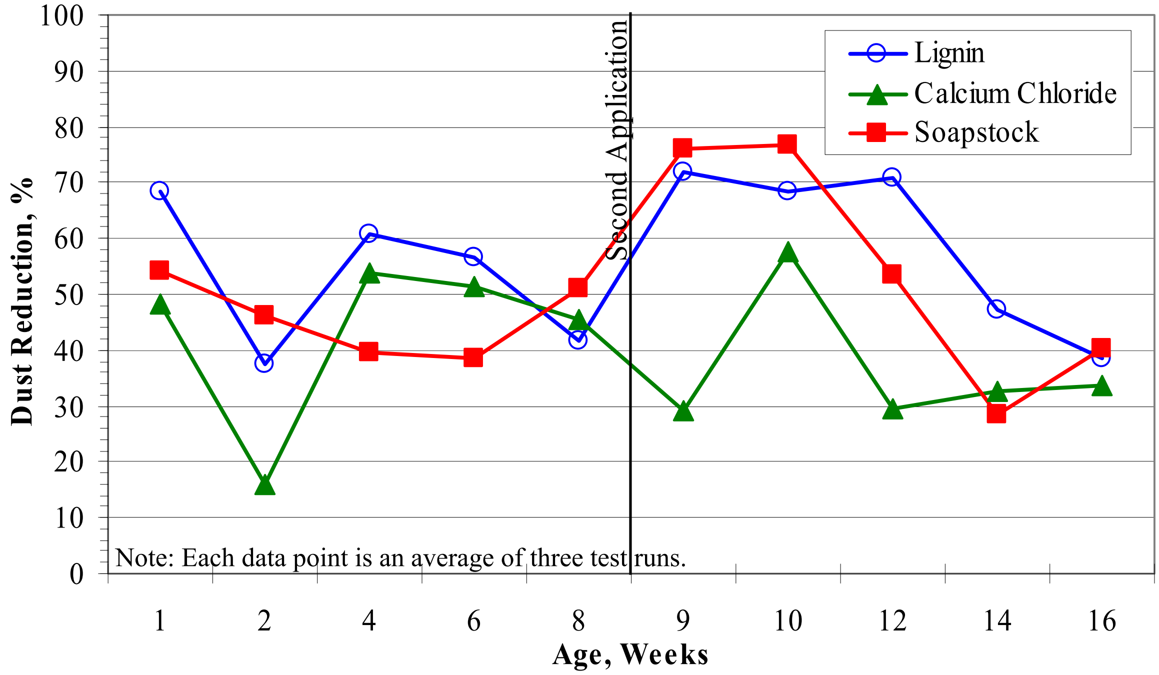

Figure 6.2.2. 260th Street 16 week dust reduction results.

6.2.3 South 530th Avenue

The percent dust reduction for each of the treated test sections on South 530th Avenue are shown in Figure 6.2.3. The lignin sulfonate treated test section performance was good to fair in weeks 1 through 8 and good to excellent in weeks 9 through 16. Dust reductions in weeks 1 through 6 were over 60 %, with the exception of week 2 when all test sections on South 530th Avenue were bladed due to extensive centerline pothole development. In addition to blading, there was 1.2 inches of precipitation the day before the lignin sulfonate 2 week test, which reduced dust production and decreased the dust reduction. Although the lignin treated test section was bladed prior to testing in week 2, the increases in dust reduction in weeks 4 and 6 demonstrate that the lignin has some degree of residual effect. In week 8, the lignin sulfonate treated test section had decreased dust reduction to slightly over 40 % due to relatively dry conditions, followed by a significant increase in week 9 due to the addition of the second application of lignin. Dust reduction decreased in week 10 to slightly over 60 % due to 1.42 inches of precipitation three days prior to testing, before increasing in week 12, decreasing drastically in week 14 due to a relatively dry 2 week period, and increasing to nearly 70 % in week 16.

The calcium chloride treated test section performance was good to poor with initial dust reduction of nearly 65 % in week 1, but due to extensive centerline pothole development all test sections on South 530th Avenue were bladed, which reduced the dust reduction significantly in week 2. Following the blading in week 2, the dust reduction progressively increased from week 2 to week 8, which demonstrates that the calcium chloride has significant residual effect, followed by a drastic decrease in week 9 due to 1.42 inches of precipitation three days prior to testing. The dust reduction increased in week 10 and then decreased significantly to nearly -10 % in week 12, due to a second blading of the calcium chloride treated test section prior to testing, before increasing drastically in week 14, which also demonstrates significant residual effects, and remaining nearly constant into week 16.

The soapstock treated test section performance was fair to poor with dust reduction of slightly over 45 % in week 1 and progressively decreased from week 1 to week 8. The progressive decrease in dust reduction was induced by 0.36 inches of precipitation two days before the 2 week test, blading of all test sections on South 530th Avenue one day before the 4 week test, and 1.2 inches of precipitation two days prior to the 4 week test. These three events as well as the 240 vehicle per day using the roadway caused the soapstock treated test section to degrade and perform unsatisfactorily through week 8. Due to the cumulative effects of the second application of soapstock, the 9 and 10 week tests had increases in dust reduction, followed by a slight decrease in week 12 due to 1.42 inches of precipitation three days prior to testing. Near the end of the testing period, the soapstock treated test section had increased dust reduction in week 14, followed by a drastic decrease in week 16 to nearly -15 % due to a second blading of the soapstock treated test section prior to testing.

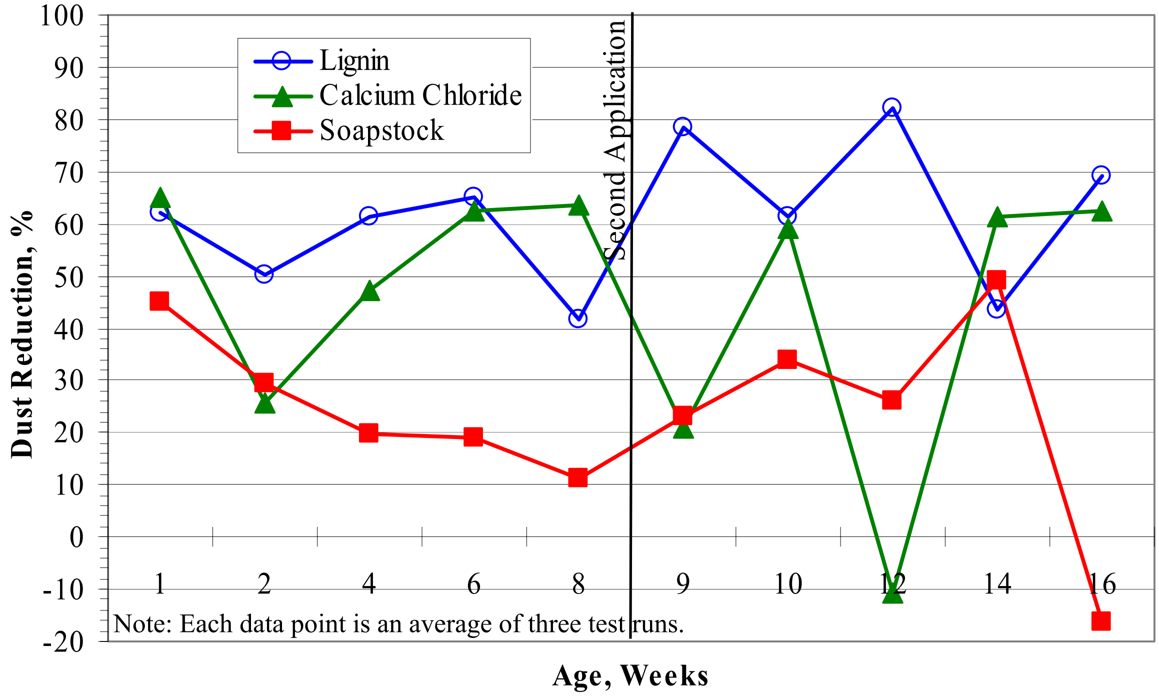

Figure 6.2.3. South 530th Avenue 16 week dust reduction results.

6.2.4 Grant Avenue

The percent dust reduction for each of the treated test sections on Grant Avenue are shown in Figure 6.2.4. The combination of 240 vehicles per day and alluvial sand/gravel aggregate surface caused the dust reduction results of the calcium chloride and soapstock treated test sections on Grant Avenue to be highly erratic, demonstrating undesirable effects of the high AADT and alluvial sand/gravel granular surface combination. The lignin treated test section performance was good to fair with dust reduction of slightly over 35 % in week 1, followed by a decrease in week 2 due to 1.2 inches of precipitation the day before testing. Due to extensive centerline pothole development, all sections on Grant Avenue were bladed causing the 4 week lignin dust reduction to decrease, followed by an increase in weeks 6 and 8, which indicates residual effects, and a decrease in weeks 9 and 10 after the second application of lignin. Decreases in dust reduction in week 10 are due to 1.42 inches of precipitation three days prior to testing. Following the decrease due to precipitation, the dust reduction increased in week 12 and decreased significantly from week 12 to week 16 due to second and third blading of all test sections on Grant Avenue prior to the lignin 16 week test. Although the lignin treated test section performed satisfactorily without negative dust reductions, the dust reductions were not significant, with a maximum value of around 45 % in week 12 after the second application of lignin.

The calcium chloride treated test section performance was fair to poor with an initial dust reduction of slightly over 40 % in week 1, followed by a decrease in week 2 due to 1.2 inches of precipitation one day prior to testing. Due to the blading of all test sections on Grant Avenue, the 4 week calcium chloride dust reduction drastically decreased to -30 %. Proceeding blading, the dust reduction significantly increased in week 6 and increased further in week 8 demonstrating excellent residual effects of the calcium chloride suppressant. The calcium chloride dust reduction decreased in week 9, due to 1.42 inches of precipitation three days prior to testing, and increased in week 10, before remaining nearly constant in week 12. Subsequent second and third bladings after week 12 decreased the dust reduction in weeks 14 and 16 to nearly -55 %.

The soapstock treated test section performance was fair to poor with dust reduction near 25 % in week 1, followed by a slight increase in week 2 and a drastic decrease in week 4 to nearly -15 % due to 1.2 inches of precipitation two days prior to testing. Dust reduction decreased slightly in week 6 due to blading of all test sections on Grant Avenue and decreased to nearly -20 % in week 8. Following the second application there was a significant increase in dust reduction in weeks 9 and 10 due to the cumulative effects of the two applications, followed by a decrease in week 12 due to 1.42 inches of precipitation three days prior to testing and a slow decline in dust reduction from week 12 to week 16.

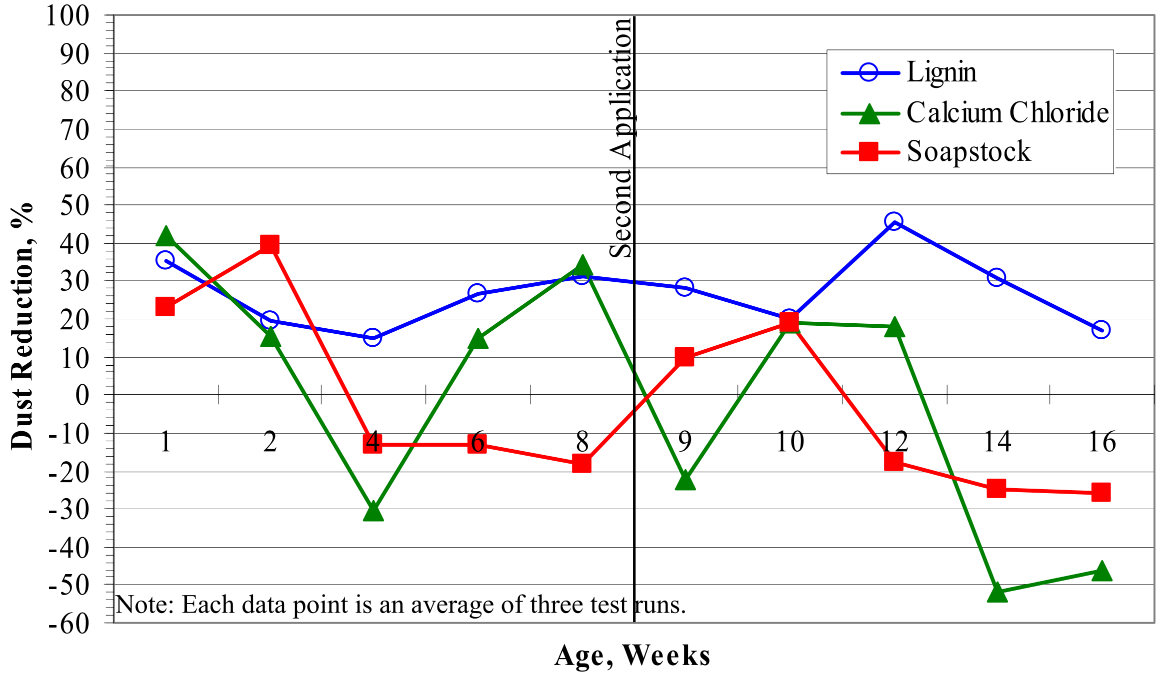

Figure 6.2.4. Grant Avenue 16 week dust reduction results.

6.2.5 Suppressant Performance Based on Aggregate Type and AADT

The performance of the dust suppressants was greatly affected by the granular surface material and the amount of traffic using the roadway. The 16 week average dust reduction and ranking of each dust suppressant for each demonstration site is shown in Table 6.2.1. The 16 week average dust reduction on the lignin, calcium chloride, and soapstock treated test sections for 260th Street were 56 %, 40 %, and 50 %, respectively. As stated in section 6.2.2, the soapstock treated test section on 260th Street was accidentally treated with lignin sulfonate 1 week after the second application of soapstock, which aided in increasing the 16 week average dust reduction. Zumwalt Road had slightly higher 16 week average dust reductions, with 76 % on the lignin treated test section, 51 % on the calcium chloride treated test section, and 51 % on the soapstock treated test section. The 16 week average dust reduction on the lignin, calcium chloride, and soapstock treated test sections for South 530th Avenue were 61 %, 46 %, and 24 %, respectively.

Whereas Grant Avenue had significantly lower 16 week average dust reductions with 27 % on the lignin treated test section, -1 % on the calcium chloride treated test section, and -2 % on the soapstock treated test section.

Table 6.2.1. Demonstration site dust reduction summary and ranking.

Demonstration Site	**260th Street**			**Zumwalt Road**			**South 530th Avenue**			**Grant Avenue**		
Aggregate	Alluvial Sand/Gravel			Crushed Limestone Rock			Crushed Limestone Rock			Alluvial Sand/Gravel		
AADT	60			45			240			240		
Dust Suppressant	Lignin	Calcium Chloride	Soapstock	Lignin	Calcium Chloride	Soapstock	Lignin	Calcium Chloride	Soapstock	Lignin	Calcium Chloride	Soapstock
Average Dust Reduction, %	56	40	50	76	51	51	61	46	24	27	-1	-2
Ranking	1	3	2	1	2	2	1	2	3	1	2	3

With reference to Table 6.2.1, the average 16 week dust reductions on South 530th Avenue and Grant Avenue were comparatively lower than those of 260th Street and Zumwalt Road. These lower averages may be due to the amount of traffic using these two roadways. The large amount of traffic on South 530th Avenue and Grant Avenue decreased the longevity of the suppressants, due to increases in centerline pothole generation and increased fatigue of the aggregate surface. The increase in fatigue, due to the high amount of traffic, caused the surface of the soapstock treated test sections of the two roadways to become brittle and slowly degrade. Due to the increase in centerline pothole generation, all test sections on South 530th Avenue and Grant Avenue were consequently bladed by county forces to protect the safety of the traveling public. This blading decreased the effectiveness of the dust suppressants and allowed more dust production on the treated test sections compared to the untreated test sections, which caused dust reduction results to decrease. Although the blading had an adverse effect on the performance of the suppressants, it gave an excellent indication of their residual performance. Centerline potholes in the soapstock treated test section on Grant Avenue, observed in week 4 before blading, shown in Figure 6.2.5 were nearly two feet in diameter and a few inches deep.

Figure 6.2.5. Centerline potholes in the soapstock on Grant Avenue.

The response of the suppressants to the two types of aggregate can be seen in Table 6.2.1 by comparing the average 16 week dust reductions of either 260th Street to Zumwalt Road or South 530th Avenue to Grant Avenue. Either comparison demonstrates lower average 16 week dust reductions on the alluvial sand/gravel granular surface, especially on Grant Avenue where the combination of high traffic and alluvial sand/gravel granular surfacing material reduced the average 16 week dust reduction to a negative value. This negative percent in dust reduction indicates that the dust produced on the untreated test section was less than that produced on the treated test section.

Due to the lower traffic count on 260th Street and Zumwalt Road, the effectiveness of the three suppressants was excellent compared to those of South 530th Avenue and Grant Avenue, although slightly lower 16 week average dust reduction values were generated on the alluvial sand/gravel granular surfacing material of 260th Street. These two roadways did not have extensive pothole development or surface fatigue like Grant Avenue or South 530th Avenue. Roadway surfaces were relatively level and smooth with normal minor defects such as slight wash boarding and small non-hazardous potholes. Zumwalt Road and 260th Street test sections were not bladed at all throughout the 16 week testing period and were even in good shape weeks after testing concluded.

6.2.6 One Year Follow Up Tests

The performance of the three dust suppressants significantly declined after 52 weeks. The three suppressants on the low AADT roads (i.e. 260th Street and Zumwalt Road) seem to have a small amount of long term residual effect, as shown in Table 6.2.2, with dust reduction ranging from 28.18 % to 6.9 %. The long term residual effect of the suppressants on the high AADT roads (i.e. South 530th Avenue and Grant Avenue) seems to be nonexistent with dust reduction ranging from 14.56 % to -27.40 % as shown in Table 6.2.2.

Table 6.2.2. Percent dust reduction after 52 weeks.

	% Dust reduction after 52 Weeks			
Suppressant	260th Street	Zumwalt Road	South 530th Avenue	Grant Avenue
Soapstock	27.84	6.90	14.56	-27.40
Calcium Chloride	17.87	11.57	-24.02	-25.96
Lignin	28.18	22.01	10.48	*
* New gravel on lignin section, therefore no test.				

6.3 Cost Analysis

Story County has approximately 942 miles of secondary roads including 720 miles of granular, 22 miles of dirt, and 200 miles of paved surfaces. The granular secondary roads are resurfaced with new aggregate every two years and are bladed approximately every two weeks throughout the spring, summer, and fall months. The periodic replacement of the granular surface material on rural low volume roads is one of the largest county fiscal expenditures. Of the $2,610,676 Story County budgeted for the 2004 fiscal year road maintenance, $416,347 was spent on blading and $908,287 on granular surface replacement for a total of $1,324,634. This constitutes slightly over 50 % of the 2004 fiscal year road maintenance budget. An alternative to aggregate resurfacing every two years is the use of annual dust suppressants to bind and stabilize the road surface.

As stated in the introduction, dust poses several threats, but its importance in the stability of an unpaved road is imperative. The dust that we term annoying and unhealthy, acts as a binding agent for coarser aggregate particles and keeps the unpaved road surface compacted. In order to maintain compaction and this binding action, it is important to bind the dust particles together and reduce dust loss through the use of dust suppressants. This binding action aids in road surface stabilization and helps control aggregate throw off which will lead to longer time periods between resurfacing, less resurfacing material, and less blading.

To determine the most economical solution, a cost analysis was completed between periodic aggregate replacement and annual dust suppressant application. A summary of the dust suppressant and granular surface material costs are presented in Tables 6.3.1 and 6.3.2, respectively.

Table 6.3.1. Dust suppressant costs.

Dust Suppressant	**Cost, $/100 ft.**	**Cost, $/mile**
Lignin Sulfonate	65	3432
Calcium Chloride	71.25	3762
Soybean Oil Soapstock	75	3960

Table 6.3.2. Granular surface material costs.

Granular Surface Material	**Cost, $/100 ft.**	**Cost, $/mile**	**Cost, $/mile/year**
Crushed Limestone	82.10	4335	2168
Alluvial Sand/Gravel	35.30	1864	932

The costs quoted in Table 6.3.1 are from the specialty contractors and include the dust suppressant product, transportation, and two applications. The first application is applied in early June and the second application in late August or early September. The costs quoted in Table 6.3.2 are from Story County and include the granular surface material, transportation, and application. The granular surface material is reapplied once every two years or half of the county every year.

Throughout the 16 week testing period it is estimated that the untreated roads or control sections were bladed every two weeks or eight times, while the treated test sections were only bladed two times. The cost of blading was $578 per mile for the untreated roads and $144.50 per mile for the treated test sections. Therefore, the use of dust suppressants reduced the blading cost per mile by 75 %. Results of the cost analysis are presented in Table 6.3.3.

Table 6.3.3. Cost analysis results.

Product/Material	**Product/Material Cost, $/mile/year**	**# of Bladings/year**	**Blading Cost, $/mile/year**	**Total Cost, $/mile/year**
Calcium Chloride	3762	2	144.50	3906.50
Soybean Oil Soapstock	3960	2	144.50	4104.50
Lignin Sulfonate	3432	2	144.50	3576.50
Crushed Limestone	2168	8	578	2746.00
Alluvial Sand/Gravel	932	8	578	1510.00

With reference to Table 6.3.3, the total cost of alluvial sand/gravel per mile per year is approximately 45 % less than that of crushed limestone. The question then comes about: Why doesn't Story County use only alluvial sand/gravel for aggregate replacement? According to the Story County engineer, the use of alluvial sand/gravel for aggregate replacement is limited for three reasons: 1) alluvial sand/gravel is not as available as crushed limestone, 2) alluvial sand/gravel does not form a crust on its surface that is needed in the spring of the year for stability during thawing, and 3) alluvial sand/gravel has more loose material on the road surface that is lost during winter blading. The total cost of the dust suppressant products range from $3576.50 per mile per year for lignin sulfonate to $4104.50 per mile per year for soybean oil soapstock.

From the results presented in Table 6.3.3, it is evident that the cost of periodic aggregate replacement is more economical than the application of an annual dust suppressant. Although the use of dust suppressants reduces the annual blading cost by 75 %, the cost of the dust suppressant, transportation, and application are relatively high when compared to that of the two aggregate types.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

The results of the dust collection on the four demonstration sites indicate the following:

- All three suppressants performed well on Zumwalt Road and 260th Street, the low traffic roads, with AADT counts of 45 and 60 vehicles per day, respectively. The sixteen week average dust reductions ranged from 40 % to 76 %.
- At south 530th Avenue and Grant Avenue, the sixteen week average dust reductions ranged from -2 % to 61 %. These two demonstration sites represent high traffic roads, with AADT of 240 vehicles per day. The performance of all the suppressants was lower than the low traffic roads.
- In most cases the percent dust reduction increased following the second application of suppressant, likely due to cumulative effects of the suppressants. The calcium chloride test sections did not show improvement after the second application. This is believed to be due to the fact that calcium chloride reduces dust through hygroscopic action rather than binding action. Therefore the addition of a second application of calcium chloride will not necessarily reduce dust production any further than the first application. The opposite is true for the soapstock and lignin suppressants; the more suppressant, the less dust production due to binding action of these suppressants.
- All the treated test sections, with the exception of the Grant Avenue calcium chloride and soapstock sections, produced less dust than the untreated test sections. Lignin sulfonate outperformed soapstock and calcium chloride on all four demonstration sites with 16 week average dust reductions ranging from 27 % to 76 %. The 16 week average dust reduction and performance ranking for each demonstration site is shown in Table 7.0.1.

Table 7.0.1. Demonstration site dust reduction summary and ranking.

Demonstration Site	**260th Street**			**Zumwalt Road**			**South 530th Avenue**			**Grant Avenue**		
Aggregate	Alluvial Sand/Gravel			Crushed Limestone Rock			Crushed Limestone Rock			Alluvial Sand/Gravel		
AADT	60			45			240			240		
Dust Suppressant	Lignin	Calcium Chloride	Soapstock	Lignin	Calcium Chloride	Soapstock	Lignin	Calcium Chloride	Soapstock	Lignin	Calcium Chloride	Soapstock
Average Dust Reduction, %	56	40	50	76	51	51	61	46	24	27	-1	-2
Ranking	1	3	2	1	2	2	1	2	3	1	2	3

- The combination of the high AADT and alluvial sand/gravel granular surface on Grant Avenue did not produce satisfactory results as evidenced by the low percentages of dust reduction. The 16 week average dust reduction results on the Grant Avenue calcium chloride and soapstock treated test sections indicate that there was essentially the same amount of dust produced on these sections as on the untreated test section. The 16 week average dust reduction results on the Grant Avenue lignin sulfonate treated test section indicate slight decreases in dust with a 27 % reduction.
- The Colorado State University Dustometer proved to be an easy to use, reproducible, inexpensive, quantitative moving dust sampler.
- It is generally considered that lignin sulfonate suppressants do not have good residual effects after blading. However, the results on south 530th Avenue and Grant Avenue after blading indicate otherwise, with better performance in dust reduction after blading.
- The calcium chloride treated test sections on South 530th Avenue and Grant Avenue indicate excellent residual effects after blading.
- To minimize the formation of a degradable thin surface crust, other states mix the suppressants into the top two inches of the road surface through a process of scarification, blade mixing, and compaction.
- The cost of biennial aggregate replacement is more economical than the application of an annual dust suppressant.
- The surface of the roadway should be damp when products are applied as well as have a good crown for water drainage to reduce the formation of large centerline potholes (Bolander and Yamada, 1999).
- Higher application rates or more frequent applications are required on roadways with high traffic volumes or low fines content (<10 % passing 75 µm (No. 200) sieve) (Bolander and Yamada, 1999).
- According to Bolander (1997) the optimum percent passing the 75 µm (No. 200) sieve ranges from 8 % to 20 % for lignin suppressant application and 10 % to 20 % for calcium chloride suppressant applications. The gradations performed on the virgin rock and gravel indicate an average of 8.1 % and 6.3 % percent passing the 75 µm (No. 200) sieve, respectively. According to the IDOT (April 2004) the maximum percent passing the 75

μm (No. 200) sieve for class C gravel and class A crushed stone is 15 % and 16 %, respectively. Therefore to increase effectiveness of the lignin and calcium chloride suppressants, the percent passing the 75 μm (No. 200) sieve should be increased closer to the maximum allowed by the IDOT.

- Study of dust reduction obtained by mixing the suppressants into the top two inches of the road surface through a process of scarification, blade mixing, and compaction should be conducted to provide comparisons to the surface spray process currently used.
- Time and budget constraints limited this study to single rates of suppressant application. Study of other rates of suppressant application would give insight into optimal surface application rates for the two granular surface treatments in Story County, alluvial sand/gravel and crushed limestone rock.
- The results of the 52 week test show no long term residual effects on the high AADT roads (i.e. South 530th Avenue and Grant Avenue) and slight long term residual effects on the low AADT roads (i.e. 260th Street and Zumwalt Road).

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APPENDIX A. DAILY WEATHER OBSERVATION DATA

Daily Weather Observations Data Sheet					
Date	Temp., 'F	Wind Speed (Calm, Breezy, Strong)	Wind Direction	Cloud Cover (Clear, Partly Cloudy, Overcast)	Precipitation (in)
5/1/2004	60	B	N	PC,O	0.00
5/2/2004	54	B	N,NW	O	0.03
5/3/2004	61	B	S,SW	C,PC	0.00
5/4/2004	75	B	Variable	O,C	0.00
5/5/2004	80	B	S,SE	C,PC	0.00
5/6/2004	84	B	Variable	PC	0.00
5/7/2004	68	B	E	PC,O	0.00
5/8/2004	86	B	Variable	O	0.40
5/9/2004	81	B	S,SW	O	0.18
5/10/2004	78	B	Variable	O	0.00
5/11/2004	81	B	S,SE	C	0.00
5/12/2004	76	B	S,SW	O	0.00
5/13/2004	61	B	N	O	0.25
5/14/2004	58	B	N,NW	O	0.18
5/15/2004	64	C,B	S,SE	C,PC	0.00
5/16/2004	76	B	S,SE	PC,O	0.00
5/17/2004	80	B	Variable	O	2.25
5/18/2004	70	C,B	N,NE	O	0.00
5/19/2004	75	B	E,SE	O	0.00
5/20/2004	82	C,B	S,SW	PC,O	0.00
5/21/2004	87	B	S,SW	O	0.00
5/22/2004	80	B	Variable	O	3.21
5/23/2004	71	B	Variable	O	0.30
5/24/2004	70	B	Variable	O	1.19
5/25/2004	65	B	N,NW	O	0.00
5/26/2004	71	B	S,SE	PC,O	0.00
5/27/2004	78	B	Variable	PC,O	0.00
5/28/2004	79	B	Variable	PC,O	0.00
5/29/2004	82	B	S,SE	O	0.33
5/30/2004	77	B	Variable	O	0.43
5/31/2004	76	B	W,SW	O	0.37

Daily Weather Observations Data Sheet					
Date	Temp., 'F	Wind Speed (Calm, Breezy, Strong)	Wind Direction	Cloud Cover (Clear, Partly Cloudy, Overcast)	Precipitation (in)
6/1/2004	70	B	Variable	PC,O	0.04
6/2/2004	71	B	W,NW	O	0.00
6/3/2004	75	C	N,NE	C	0.00
6/4/2004	80	C	S,SE	PC,C	0.00
6/5/2004	74	B,C	S,SE	O	0.08
6/6/2004	83	B,C	SW,SE	PC	0.00
6/7/2004	89	B	S	C,PC	0.00
6/8/2004	88	B	S	O,PC	0.00
6/9/2004	80	B	S,SW	O,PC	0.02
6/10/2004	81	B	S,SE	O	0.46
6/11/2004	90	B,S	S,SE	O,PC	0.00
6/12/2004	86	B,S	Variable	O	0.68
6/13/2004	81	B	Variable	O	0.00
6/14/2004	81	B	Variable	O	0.27
6/15/2004	79	B	E,SE	O	0.00
6/16/2004	85	B	S,SE	O	0.22
6/17/2004	77	B	N,NW	O,PC	0.00
6/18/2004	68	B	N,NW	O,PC	0.00
6/19/2004	69	B	N,NE	O,PC	0.00
6/20/2004	69	B	S,SE	O,PC	0.00
6/21/2004	78	B	S,SE	O	0.31
6/22/2004	78	B	Variable	C,PC	0.00
6/23/2004	82	B	SW,W	PC	0.00
6/24/2004	67	B	N,NE	C,O	0.07
6/25/2004	72	B	W,NW	C,PC	0.00
6/26/2004	77	B	W,SW	C,PC	0.00
6/27/2004	74	B	S,SW	O	0.31
6/28/2004	73	B	N,NW	O,PC	0.05
6/29/2004	79	B,C	W,SW	C,PC	0.00
6/30/2004	82	B	S,SW	PC	0.00

Daily Weather Observations Data Sheet					
Date	Temp., 'F	Wind Speed (Calm, Breezy, Strong)	Wind Direction	Cloud Cover (Clear, Partly Cloudy, Overcast)	Precipitation (in)
7/1/2004	86	B	E,SE	C,PC	0.01
7/2/2004	82	B	E,SE	O	0.14
7/3/2004	76	B	Variable	O	0.12
7/4/2004	85	B	Variable	O	0.00
7/5/2004	80	B	Variable	O	0.44
7/6/2004	74	B	W,NW	O	0.00
7/7/2004	73	B	W,NW	PC,O	0.00
7/8/2004	75	B	E,SE	O	0.03
7/9/2004	82	B	Variable	O	1.11
7/10/2004	80	B	E,SE	PC,O	0.00
7/11/2004	75	B,S	Variable	O	1.20
7/12/2004	87	B,C	Variable	C,PC	0.00
7/13/2004	89	B	Variable	PC	0.00
7/14/2004	82	B	NW,N	C,PC	0.00
7/15/2004	82	C,B	S,SE	PC,C	0.00
7/16/2004	85	B,C	N,NW	O,PC	0.09
7/17/2004	80	B	N,NE	PC,C	0.00
7/18/2004	79	C,B	Variable	C,PC	0.00
7/19/2004	87	B	S,SW	PC	0.00
7/20/2004	91	C,B	S,SE	PC	0.00
7/21/2004	87	B	Variable	O	0.21
7/22/2004	81	B	N,NW	O	0.08
7/23/2004	77	B	N,NE	O	0.00
7/24/2004	68	B	E,NE	O	0.02
7/25/2004	75	B	NE	PC	0.00
7/26/2004	77	C,B	Variable	PC	0.00
7/27/2004	79	C,B	S,SE	C,PC	0.00
7/28/2004	81	B	S,SE	PC,O	0.00
7/29/2004	80	B	S,SW	O	0.14
7/30/2004	79	B	Variable	O	0.00
7/31/2004	85	B	S,SE	PC	0.00

Daily Weather Observations Data Sheet					
Date	Temp., 'F	Wind Speed (Calm, Breezy, Strong)	Wind Direction	Cloud Cover (Clear, Partly Cloudy, Overcast)	Precipitation (in)
8/1/2004	84	B	Variable	O	0.56
8/2/2004	84	B	Variable	O	0.25
8/3/2004	91	B	Variable	O	2.35
8/4/2004	78	B	N,NE	O	0.02
8/5/2004	76	B	N,NE	C,PC	0.00
8/6/2004	74	B	Variable	C,PC	0.00
8/7/2004	77	B	S,SE	PC	0.00
8/8/2004	81	B	S,SW	O	0.00
8/9/2004	80	B	N,NW	PC	0.00
8/10/2004	70	B	N,NW	O	0.00
8/11/2004	66	B	NW	O	0.00
8/12/2004	69	B	N,NW	O	0.00
8/13/2004	71	B	N,NW	PC	0.00
8/14/2004	74	B	Variable	PC	0.00
8/15/2004	76	B	S,SE	C,PC	0.00
8/16/2004	81	B	S,SW	PC,O	0.03
8/17/2004	81	B	Variable	O	0.06
8/18/2004	79	B	Variable	O	0.48
8/19/2004	69	B	N,W	O	0.00
8/20/2004	74	B	Variable	O,PC	0.00
8/21/2004	75	B	Variable	C,PC	0.00
8/22/2004	84	B	S,SW	PC	0.00
8/23/2004	85	B	S,SE	O	0.59
8/24/2004	79	B	E,SE	O	0.16
8/25/2004	78	B	Variable	O	0.34
8/26/2004	88	B	S,SW	O	0.04
8/27/2004	79	B	N,NE	PC,O	0.00
8/28/2004	76	B	N	O	0.00
8/29/2004	75	B	S,SE	PC	0.00
8/30/2004	82	B	Variable	PC	0.03
8/31/2004	83	C,B	S,SE	PC,O	0.00

Daily Weather Observations Data Sheet					
Date	**Temp., 'F**	**Wind Speed (Calm, Breezy, Strong)**	**Wind Direction**	**Cloud Cover (Clear, Partly Cloudy, Overcast)**	**Precipitation (in)**
9/1/2004	87	B	S	PC	0.00
9/2/2004	83	B	S,SE	C,PC	0.00
9/3/2004	83	B	S,SE	C,PC	0.00
9/4/2004	85	B	S,SE	C,PC	0.00
9/5/2004	84	B	S,SE	O	1.42
9/6/2004	78	B	Variable	O	0.00
9/7/2004	72	B	N,NW	C	0.00
9/8/2004	73	B	E,NE	C,PC	0.00
9/9/2004	77	B	S,SE	C,PC	0.00
9/10/2004	84	B	S,SE	C,PC	0.00
9/11/2004	84	B	S,SW	O,PC	0.00
9/12/2004	84	B	S,SE	C	0.00
9/13/2004	86	B	S,SE	PC	0.00
9/14/2004	86	B	E,SE	O	0.06
9/15/2004	79	B	Variable	O	0.24
9/16/2004	75	B	Variable	C	0.00
9/17/2004	73	B	S,SE	O	0.02
9/18/2004	81	B	E,SE	O	0.00
9/19/2004	85	B	S,SE	C,PC	0.00
9/20/2004	79	B	S,SE	O	0.00
9/21/2004	83	B	S,SE	C,PC	0.00
9/22/2004	82	B	S,SE	C	0.00
9/23/2004	74	B	Variable	O	0.03
9/24/2004	78	B	Variable	C,PC	0.00
9/25/2004	76	B,C	E,NE	PC	0.00
9/26/2004	78	B,C	Variable	C,PC	0.00
9/27/2004	81	B	Variable	O	0.00
9/28/2004	69	B	N,NE	C	0.00
9/29/2004	69	B	S,SE	C,PC	0.00
9/30/2004	77	B	S,SE	O	0.00

Daily Weather Observations Data Sheet					
Date	Temp., 'F	Wind Speed (Calm, Breezy, Strong)	Wind Direction	Cloud Cover (Clear, Partly Cloudy, Overcast)	Precipitation (in)
10/1/2004	67	B	S,SW	O	0.23
10/2/2004	59	B	W,SW	C	0.00
10/3/2004	76	B	Variable	C	0.00
10/4/2004	56	B	N,NW	C	0.00
10/5/2004	67	B	S,SW	C,PC	0.00
10/6/2004	77	B	S,SW	C,O	0.00
10/7/2004	68	B	S,SE	O	0.28
10/8/2004	77	B	Variable	O	0.00
10/9/2004	72	B,C	Variable	C,PC	0.00
10/10/2004	70	B	E	C,O	0.00
10/11/2004	61	B	E,NE	O	0.00
10/12/2004	63	B	E,NE	O	0.00
10/13/2004	57	B	N,NW	O	0.07
10/14/2004	50	B	N,NW	O	0.01
10/15/2004	55	B	W,NW	O	0.00
10/16/2004	50	B	W,NW	PC,C	0.00
10/17/2004	61	B	Variable	O,PC	0.00
10/18/2004	59	B	E,NE	O	0.21
10/19/2004	50	B	E,NE	O	0.04
10/20/2004	51	B	E,NE	O	0.00
10/21/2004	57	B	E,SE	O	0.01
10/22/2004	70	B	S,SE	O	0.01
10/23/2004	67	B	S,W	C,PC	0.00
10/24/2004	72	B	S,SE	C,PC	0.00
10/25/2004	64	B	N,NE	C,PC	0.00
10/26/2004	57	B	E	O	0.58
10/27/2004	57	B	N,NE	O	0.01
10/28/2004	70	B	S,SE	O	0.01
10/29/2004	80	B	S,SW	O	0.15
10/30/2004	57	B	W,SW	O,PC	0.00
10/31/2004	56	B	E	C,O	0.00

APPENDIX B. FIRST EIGHT WEEKS DUST MEASUREMENT DATA

260th Street

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	3.27	1.05	2.95	3.23	2.32
	Run 2	3.28	1.10	2.65	2.62	2.37
	Run 3	3.14	1.17	2.35	2.58	2.15
	Average	3.23	1.11	2.65	2.81	2.28

Lignin Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.01	0.74	1.10	1.24	1.06
	Run 2	1.02	0.72	0.93	1.19	1.31
	Run 3	1.02	0.62	1.10	1.22	1.62
	Average	1.02	0.69	1.04	1.22	1.33
% Dust Reduction		68.52	37.35	60.63	56.58	41.67

260th Street

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	3.27	1.05	2.95	3.23	2.32
	Run 2	3.28	1.10	2.65	2.62	2.37
	Run 3	3.14	1.17	2.35	2.58	2.15
	Average	3.23	1.11	2.65	2.81	2.28

Calcium Chloride Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.51	0.92	1.26	1.37	1.22
	Run 2	1.94	0.97	0.94	1.29	1.27
	Run 3	1.55	0.90	1.46	1.44	1.24
	Average	1.67	0.93	1.22	1.37	1.24
% Dust Reduction		48.40	15.96	53.96	51.36	45.47

260th Street

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	2.30	3.27	2.18	2.39	3.23
	Run 2	2.22	3.28	2.55	2.37	2.62
	Run 3	2.23	3.14	2.39	2.56	2.58
	Average	2.25	3.23	2.37	2.44	2.81

Soapstock Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.08	1.86	1.24	1.43	1.30
	Run 2	1.03	2.14	1.45	1.64	1.53
	Run 3	0.99	1.20	1.62	1.44	1.31
	Average	1.03	1.73	1.44	1.50	1.38
% Dust Reduction		54.07	46.34	39.47	38.39	50.89

Grant Avenue

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.74	0.90	3.22	1.81	1.86
	Run 2	1.10	0.92	3.10	1.52	1.26
	Run 3	1.55	1.01	3.24	1.62	1.38
	Average	1.46	0.94	3.19	1.65	1.50

Lignin Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	0.92	0.68	2.60	1.29	1.02
	Run 2	1.02	0.78	2.89	1.15	1.17
	Run 3	0.91	0.82	2.65	1.19	0.91
	Average	0.95	0.76	2.71	1.21	1.03
% Dust Reduction		35.08	19.43	14.85	26.67	31.11

Grant Avenue

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.74	0.90	3.22	1.81	1.86
	Run 2	1.10	0.92	3.10	1.52	1.26
	Run 3	1.55	1.01	3.24	1.62	1.38
	Average	1.46	0.94	3.19	1.65	1.50

Calcium Chloride Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	0.93	0.82	4.43	1.43	0.92
	Run 2	0.80	0.75	3.85	1.37	1.11
	Run 3	0.83	0.83	4.20	1.41	0.92
	Average	0.85	0.80	4.16	1.40	0.98
% Dust Reduction		41.69	15.19	-30.54	15.15	34.44

Grant Avenue

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.59	1.74	1.49	1.85	1.81
	Run 2	1.28	1.10	1.29	1.67	1.52
	Run 3	1.40	1.55	1.33	1.63	1.62
	Average	1.42	1.46	1.37	1.72	1.65

Soapstock Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.10	0.86	1.27	1.98	2.23
	Run 2	1.08	0.86	1.72	1.76	1.60
	Run 3	1.10	0.95	1.66	2.08	2.03
	Average	1.09	0.89	1.55	1.94	1.95
% Dust Reduction		23.19	39.18	-13.14	-13.01	-18.38

Zumwalt Road

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	3.13	2.16	3.90	3.74	2.74
	Run 2	2.73	1.70	4.69	4.37	2.45
	Run 3	4.04	1.49	4.54	3.88	1.43
	Average	3.30	1.78	4.38	4.00	2.21

Lignin Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	0.48	0.70	0.91	1.30	0.81
	Run 2	0.50	0.59	1.07	1.35	1.02
	Run 3	0.36	0.73	1.03	1.31	0.90
	Average	0.45	0.67	1.00	1.32	0.91
% Dust Reduction		86.46	62.24	77.08	66.97	58.76

Zumwalt Road

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	3.13	2.16	3.90	3.74	2.74
	Run 2	2.73	1.70	4.69	4.37	2.45
	Run 3	4.04	1.49	4.54	3.88	1.43
	Average	3.30	1.78	4.38	4.00	2.21

Calcium Chloride Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.12	0.99	1.61	1.61	0.99
	Run 2	1.12	0.72	1.64	1.64	0.99
	Run 3	1.27	0.75	1.76	1.57	1.05
	Average	1.17	0.82	1.67	1.61	1.01
% Dust Reduction		64.55	54.02	61.84	59.80	54.23

Zumwalt Road

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	Run 1	2.21	3.13	2.56	3.36	3.74
	Run 2	2.25	2.73	2.76	3.14	4.37
	Run 3	2.25	4.04	3.01	3.32	3.88
	Average	2.24	3.30	2.78	3.27	4.00

Soapstock Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	Run 1	1.92	1.64		2.04	2.02
	Run 2	1.52	1.47	2.12	2.42	2.23
	Run 3	1.64	1.35	2.03	1.94	-
	Average	1.69	1.49	2.08	2.13	2.13
% Dust Reduction		24.29	54.95	25.27	34.83	46.83

S. 530th Avenue

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	Run 1	1.88	2.71	2.88	1.86	1.93
	Run 2	2.15	3.10	2.56	2.00	1.91
	Run 3	1.86	2.75	2.48	1.80	1.34
	Average	1.96	2.85	2.64	1.89	1.73

Lignin Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	Run 1	0.85	1.33	1.02	0.66	0.84
	Run 2	0.70	1.54	0.97	0.65	1.11
	Run 3	0.68	1.40	1.08	0.68	1.07
	Average	0.74	1.42	1.02	0.66	1.01
% Dust Reduction		62.14	50.12	61.24	65.02	41.70

S. 530th Avenue

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	Run 1	1.88	2.71	2.88	1.86	1.93
	Run 2	2.15	3.10	2.56	2.00	1.91
	Run 3	1.86	2.75	2.48	1.80	1.34
	Average	1.96	2.85	2.64	1.89	1.73

Calcium Chloride Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	Run 1	0.68	2.33	1.37	0.78	0.79
	Run 2	0.78	1.81	1.37	0.66	0.49
	Run 3	0.60	2.21	1.43	0.68	0.60
	Average	0.69	2.12	1.39	0.71	0.63
% Dust Reduction		65.03	25.82	47.35	62.54	63.71

S. 530th Avenue

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	Run 1	1.77	1.88	2.78	2.57	1.86
	Run 2	2.91	2.15	3.09	2.86	2.00
	Run 3	2.18	1.86	3.10	2.27	1.80
	Average	2.29	1.96	2.99	2.57	1.89

Soapstock Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	Run 1	1.33	1.51	2.58	2.22	1.43
	Run 2	1.35	1.43	2.10	2.00	1.69
	Run 3	1.08	1.21	2.51	2.03	1.91
	Average	1.25	1.38	2.40	2.08	1.68
% Dust Reduction		45.19	29.54	19.84	18.83	11.13

APPENDIX C. SECOND EIGHT WEEKS DUST MEASUREMENT DATA

260th Street

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	2.84	2.41	2.22	2.15	2.09
	Run 2	3.31	2.34	2.12	1.72	2.31
	Run 3	3.10	2.28	2.20	2.10	2.53
	Average	3.08	2.34	2.18	1.99	2.31

Lignin Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	0.93	0.68	0.57	1.06	1.18
	Run 2	0.85	0.81	0.63	1.09	1.53
	Run 3	0.83	0.72	0.70	1.00	1.54
	Average	0.87	0.74	0.63	1.05	1.42
% Dust Reduction		71.78	68.56	70.95	47.24	38.53

260th Street

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	2.41	2.22	2.15	2.09	2.09
	Run 2	2.34	2.12	1.72	2.31	2.31
	Run 3	2.28	2.20	2.10	2.53	2.53
	Average	2.34	2.18	1.99	2.31	2.31

Calcium Chloride Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.87	0.87	1.29	1.59	1.50
	Run 2	1.59	0.90	1.40	1.52	1.53
	Run 3	1.52	1.00	1.51	1.58	1.55
	Average	1.66	0.92	1.40	1.56	1.53
% Dust Reduction		29.16	57.65	29.65	32.47	33.77

260th Street

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	2.32	2.84	2.41	2.22	2.15
	Run 2	2.37	3.31	2.34	2.12	1.72
	Run 3	2.15	3.10	2.28	2.20	2.10
	Average	2.28	3.08	2.34	2.18	1.99

Soapstock Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	0.53	0.70	1.14	2.03	0.95
	Run 2	0.52	0.64	1.09	1.46	1.20
	Run 3	0.58	0.81	1.03	1.19	1.42
	Average	0.54	0.72	1.09	1.56	1.19
% Dust Reduction		76.17	76.76	53.63	28.44	40.20

Grant Avenue

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.84	1.92	1.03	0.99	1.16
	Run 2	1.69	1.13	0.95	1.04	1.43
	Run 3	1.72	1.30	0.89	1.18	1.17
	Average	1.75	1.45	0.96	1.07	1.25

Lignin Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.17	0.80	0.59	0.65	1.08
	Run 2	1.29	1.26	0.42	0.80	1.10
	Run 3	1.31	1.43	0.55	0.78	0.93
	Average	1.26	1.16	0.52	0.74	1.04
% Dust Reduction		28.19	19.77	45.64	30.53	16.80

Grant Avenue

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.92	1.03	0.99	1.16	1.16
	Run 2	1.13	0.95	1.04	1.43	1.43
	Run 3	1.30	0.89	1.18	1.17	1.17
	Average	1.45	0.96	1.07	1.25	1.25

Calcium Chloride Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.67	0.75	0.93	2.00	1.89
	Run 2	1.81	0.90	0.84	1.94	1.81
	Run 3	1.83	0.68	0.87	1.77	1.80
	Average	1.77	0.78	0.88	1.90	1.83
% Dust Reduction		-22.07	18.82	17.76	-52.00	-46.40

Grant Avenue

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.86	1.84	1.92	1.03	0.99
	Run 2	1.26	1.69	1.13	0.95	1.04
	Run 3	1.38	1.72	1.30	0.89	1.18
	Average	1.50	1.75	1.45	0.96	1.07

Soapstock Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.46	1.30	1.62	1.23	1.31
	Run 2	0.98	1.52	1.72	1.20	1.55
	Run 3	1.62	1.44	1.77	1.16	1.18
	Average	1.35	1.42	1.70	1.20	1.35
% Dust Reduction		9.78	18.86	-17.47	-25.09	-25.86

Zumwalt Road

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	3.53	5.34	3.53	3.17	4.12
	Run 2	2.60	4.83	3.23	3.08	4.21
	Run 3	3.32	4.34	3.48	3.17	3.93
	Average	3.15	4.84	3.41	3.14	4.09

Lignin Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	0.45	0.37	0.56	0.47	1.59
	Run 2	0.55	0.36	0.68	0.52	1.36
	Run 3	0.51	0.50	0.53	0.48	1.63
	Average	0.50	0.41	0.59	0.49	1.53
% Dust Reduction		84.02	91.52	82.71	84.39	62.59

Zumwalt Road

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	5.34	3.53	3.17	4.12	4.12
	Run 2	4.83	3.23	3.08	4.21	4.21
	Run 3	4.34	3.48	3.17	3.93	3.93
	Average	4.84	3.41	3.14	4.09	4.09

Calcium Chloride Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.74	1.06	1.81	3.63	3.14
	Run 2	1.81	1.06	1.91	2.98	3.23
	Run 3	1.86	1.12	1.79	3.11	3.19
	Average	1.80	1.08	1.84	3.24	3.19
% Dust Reduction		62.72	68.36	41.51	20.78	22.00

Zumwalt Road

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	2.74	3.53	5.34	3.53	3.17
	Run 2	2.45	2.60	4.83	3.23	3.08
	Run 3	1.43	3.32	4.34	3.48	3.17
	Average	2.21	3.15	4.84	3.41	3.14

Soapstock Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	0.49	0.74	1.52	1.40	1.24
	Run 2	0.44	0.66	2.12	1.48	1.39
	Run 3	0.51	0.74	3.23	1.07	1.42
	Average	0.48	0.71	2.29	1.32	1.35
% Dust Reduction		78.25	77.35	52.65	61.43	57.01

S. 530th Avenue

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	2.09	2.63	4.76	1.32	3.74
	Run 2	2.16	2.17	4.09	1.35	3.21
	Run 3	2.42	2.50	4.32	1.27	3.16
	Average	2.22	2.43	4.39	1.31	3.37

Lignin Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	0.48	0.92	0.87	0.69	1.11
	Run 2	0.49	0.80	0.74	0.79	0.94
	Run 3	0.47	1.10	0.76	0.74	1.07
	Average	0.48	0.94	0.79	0.74	1.04
% Dust Reduction		78.41	61.37	82.00	43.65	69.14

S. 530th Avenue

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	2.63	4.76	1.32	3.74	3.74
	Run 2	2.17	4.09	1.35	3.21	3.21
	Run 3	2.50	4.32	1.27	3.16	3.16
	Average	2.43	4.39	1.31	3.37	3.37

Calcium Chloride Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.86	2.09	1.53	1.22	1.25
	Run 2	1.93	1.71	1.42	1.33	1.28
	Run 3	1.99	1.60	1.41	1.36	1.25
	Average	1.93	1.80	1.45	1.30	1.26
% Dust Reduction		20.82	59.00	-10.66	61.42	62.61

S. 530th Avenue

Untreated Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.93	2.09	2.63	4.76	1.32
	Run 2	1.91	2.16	2.17	4.09	1.35
	Run 3	1.34	2.42	2.50	4.32	1.27
	Average	1.73	2.22	2.43	4.39	1.31

Soapstock Test Results

	Test	1 Week	2 Weeks	4 Weeks	6 Weeks	8 Weeks
Weight of Dust, g	**Run 1**	1.21	1.59	1.76	1.95	1.50
	Run 2	1.48	1.49	1.65	2.36	1.59
	Run 3	1.29	1.32	1.98	2.38	1.49
	Average	1.33	1.47	1.80	2.23	1.53
% Dust Reduction		23.17	34.03	26.16	49.20	-16.24

APPENDIX D. 52 WEEK DUST MEASUREMENT DATA AND GRAPHS

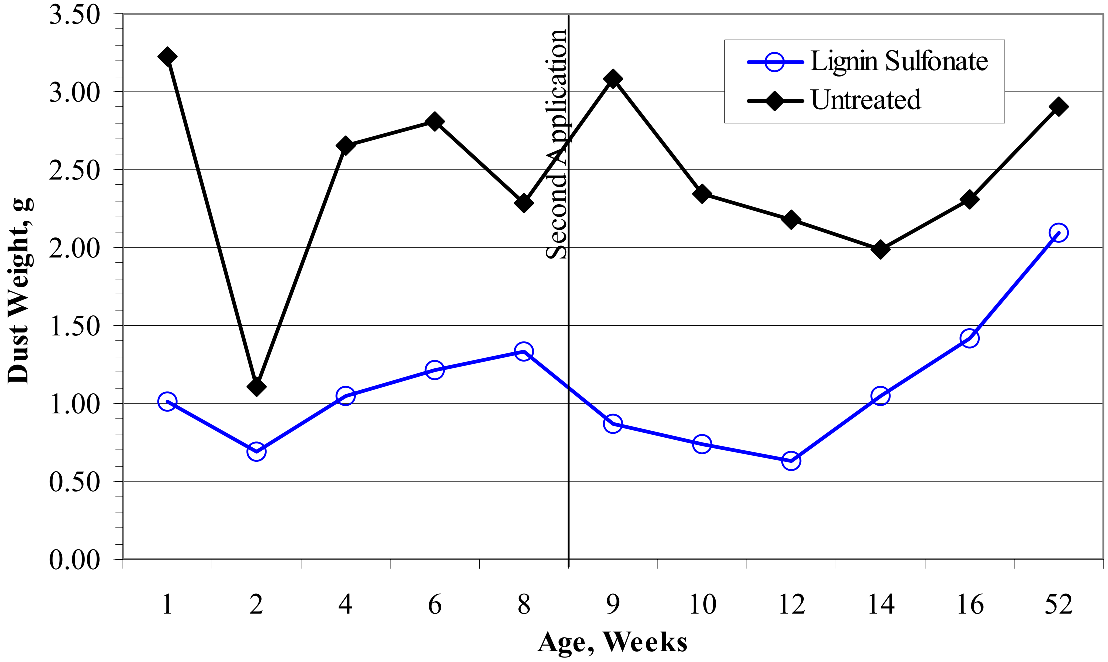
Grant Ave.	Weight of Dust, g			
	Run 1	Run 2	Run 3	Average
Untreated	2.17	2.68	1.39	2.08
Soapstock	2.45	2.32	3.19	2.65
Calcium Chloride	2.35	2.97	2.54	2.62
Lignin	New Gravel on Lignin Section, therefore no test.			

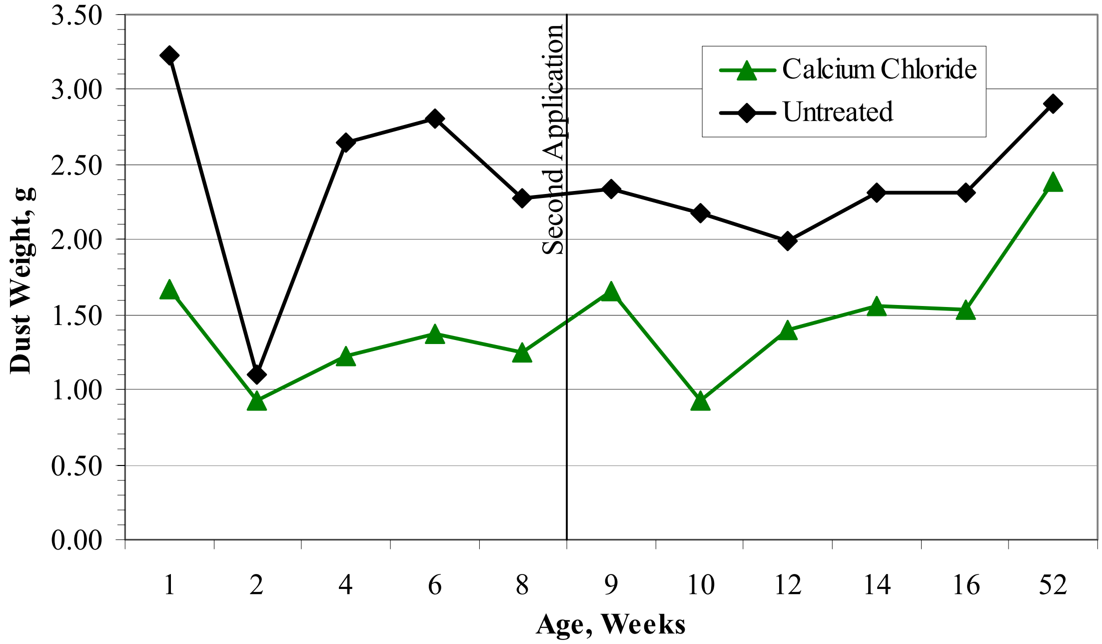
S. 530th Ave.	Weight of Dust, g			
	Run 1	Run 2	Run 3	Average
Untreated	7.29	7.06	6.25	6.87
Soapstock	6.29	5.89	5.42	5.87
Calcium Chloride	8.14	8.62	8.81	8.52
Lignin	6.1	6.49	5.85	6.15

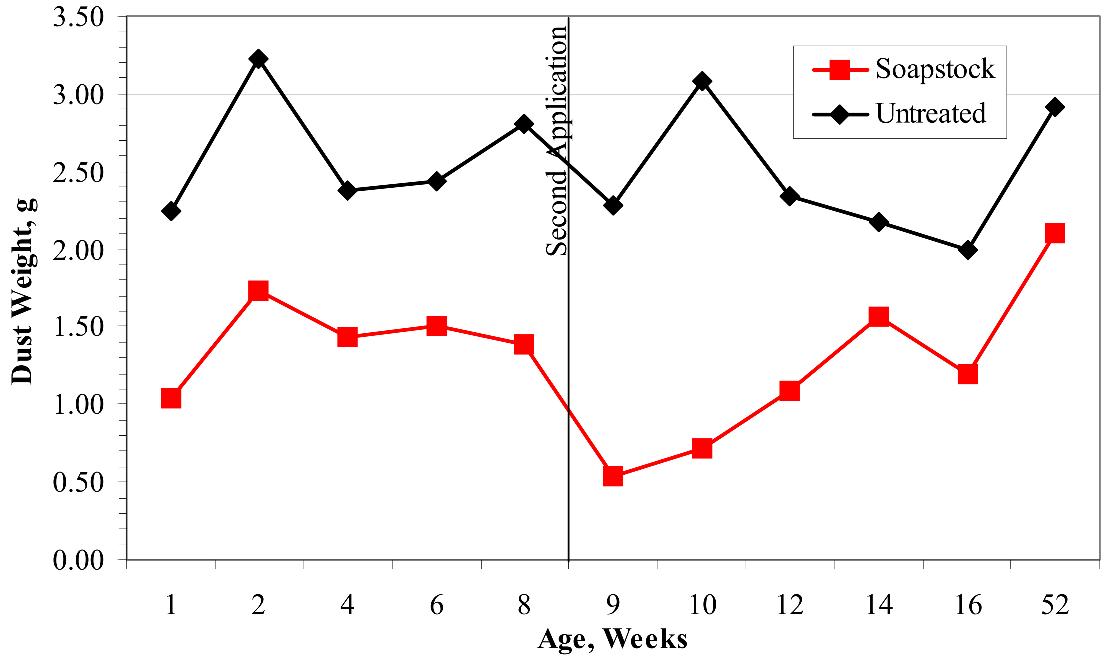
260th St.	Weight of Dust, g			
	Run 1	Run 2	Run 3	Average
Untreated	3.45	2.17	3.1	2.91
Soapstock	2.04	2.09	2.18	2.1
Calcium Chloride	2.38	2.36	2.42	2.39
Lignin	2.05	1.92	2.31	2.09

Zumwalt Rd.	Weight of Dust, g			
	Run 1	Run 2	Run 3	Average
Untreated	4.36	6.25	5.47	5.36
Soapstock	4.59	4.9	5.49	4.99
Calcium Chloride	5.43	3.9	4.89	4.74
Lignin	4.44	4.04	4.06	4.18

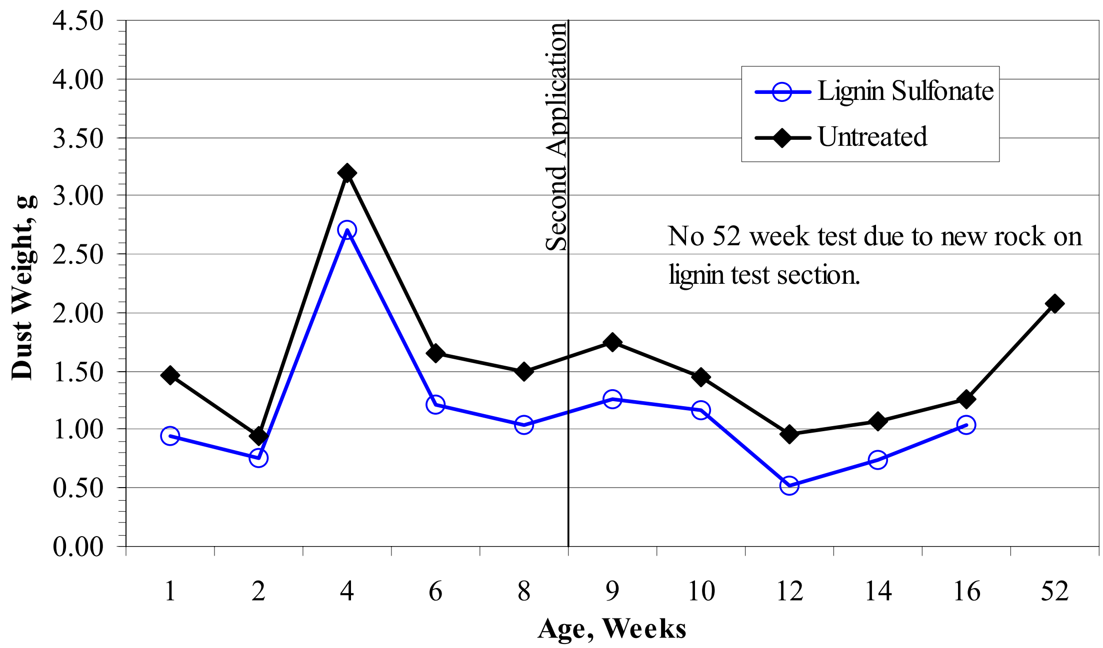
260th Street

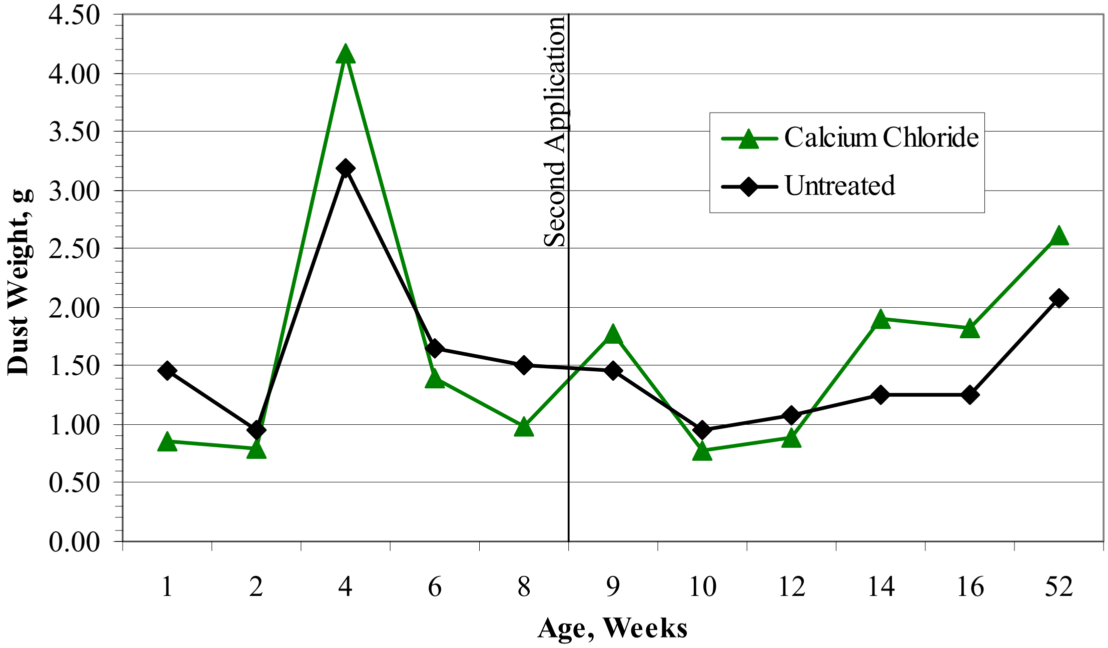






Grant Avenue





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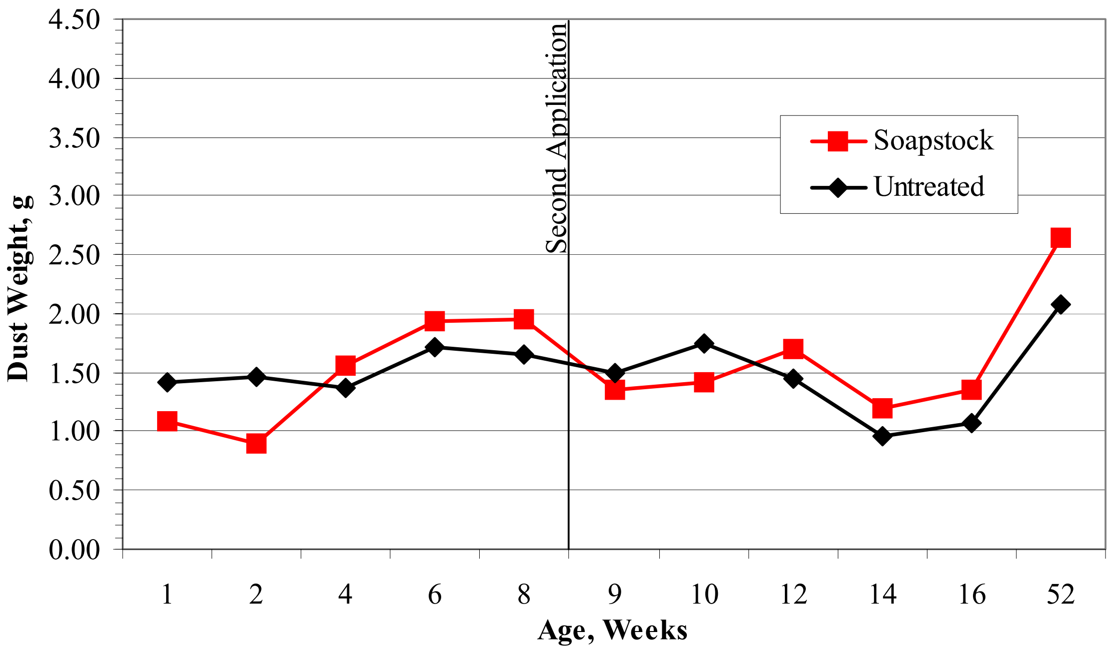
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Second Application
Calcium Chloride
Untreated
1
2
4
6
8
9
10
12
14
16
52
Age, Weeks



Dust Weight, g
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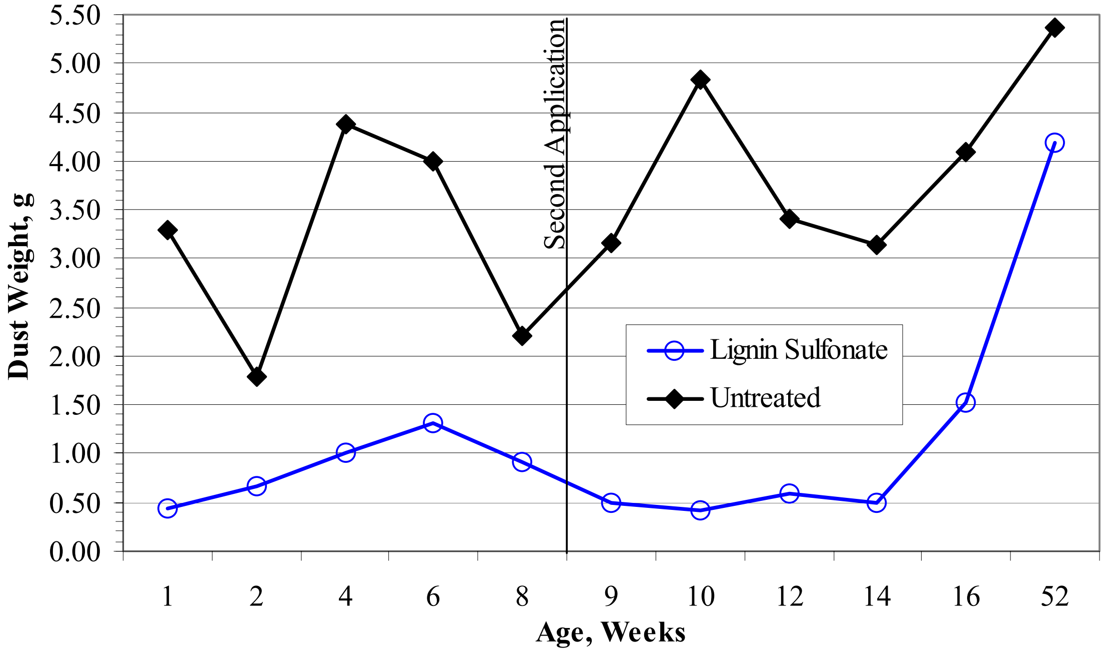
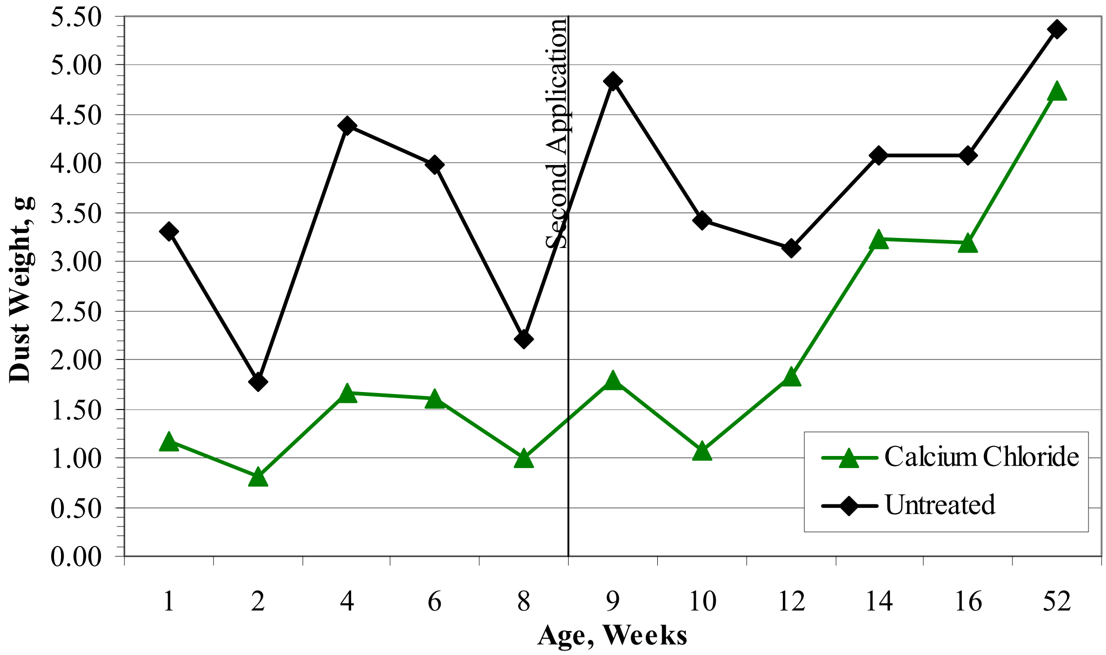
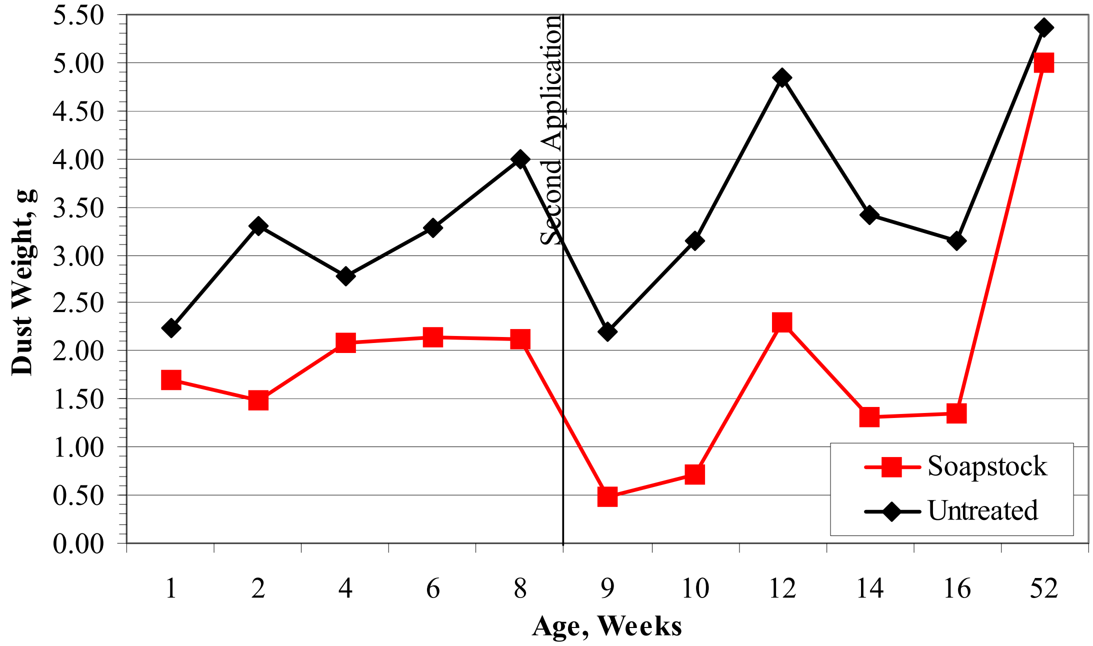
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Second Application
Soapstock
Untreated
1
2
4
6
8
9
10
12
14
16
52
Age, Weeks

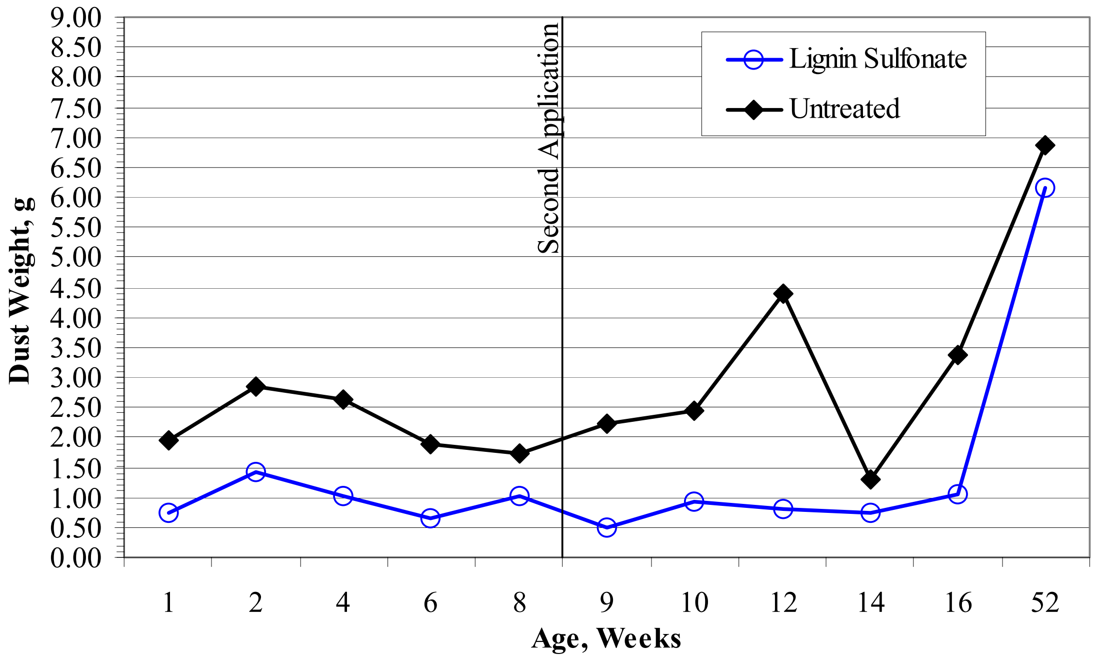
Zumwalt Road

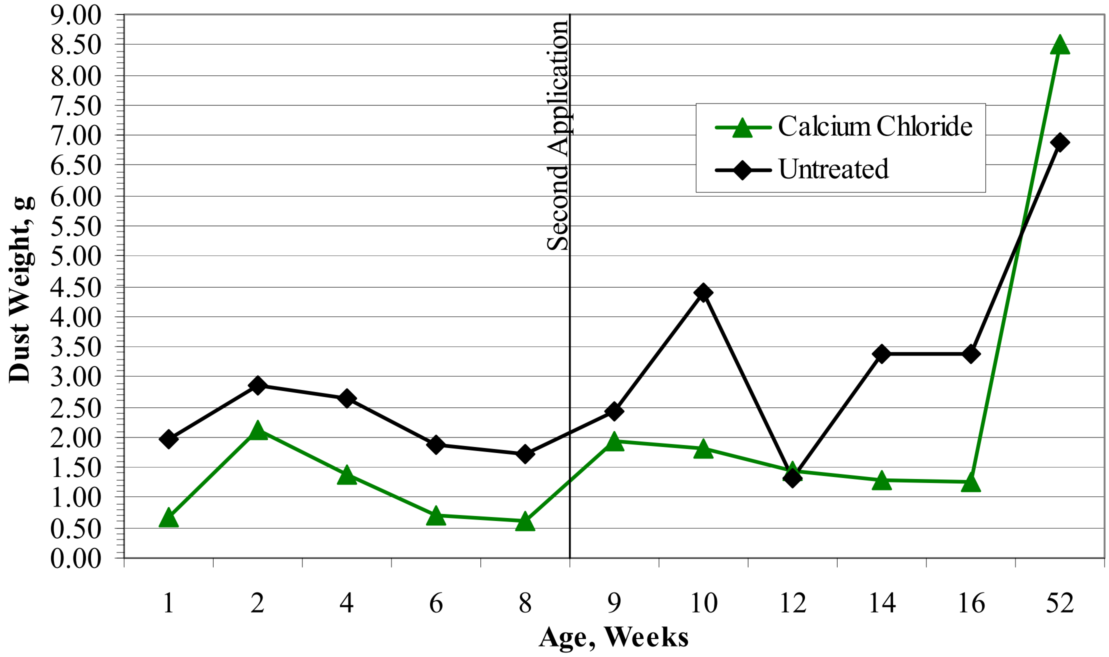






South 530th Avenue





Dust Weight, g
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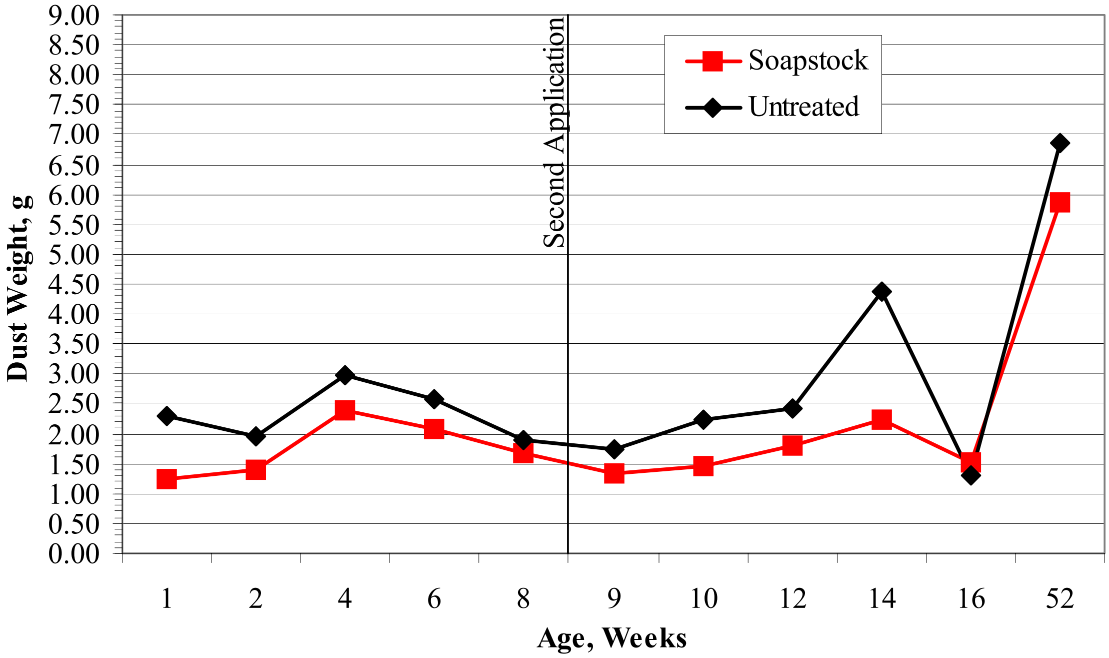
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Second Application
Calcium Chloride
Untreated
1
2
4
6
8
9
10
12
14
16
52
Age, Weeks



Dust Weight, g
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8.50
8.00
7.50
7.00
6.50
6.00
5.50
5.00
4.50
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Second Application
Soapstock
Untreated
1
2
4
6
8
9
10
12
14
16
52
Age, Weeks