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HYDROSEEDING, STRAW, AND CHEMICALS FOR EROSION CONTROL[1/]

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CONTENTS

INTRODUCTION

Hydroseeding and the associated materials advertised as controlling erosion or assisting in plant establishment are not substitutes for sound engineering and agriculture, and must be used correctly to be of value. First, the engineer must design the job for proper management of water. Flow must be diverted from adjacent surfaces via structures, and the length of slope must be limited. All structures, temporary or otherwise, must be in place before the first rain. No chemical or fiber can cancel those needs.

In seeding, the plant species must be the correct ones for the area, plantings must be at the proper season, and the fertilizer must be the one needed. Again, fibers and chemicals are no substitute for good agronomic practices.

No product is an improvement over covering the seed to the proper depth with soil, but since seed cannot always be thus covered--particularly on

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1/ No endorsements are implied herein. Adapted from a talk presented to the Washington State University "1976 Soil Erosion and Sedimentation Control Short Course." Olympia, Washington, Feb. 4-5, 1976.

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steep and rocky slopes--fibers and chemicals are an alternative to applying seed to the surface and letting it take its chances. A summary of seeding methods, effectiveness, and cost appears on page 8 of this report.

HYDROSEEDING AND HYDROSEEDERS

Hydroseeding or hydraulic seeding is the application of a slurry of seed and water to soil. The slurry may also contain wood fiber and fertilizer (hydromulching). Hydromulching is an excellent method of applying seed and fertilizers to steep areas where the wood fiber holds the seed and fertilizer in position. On short or gentle slopes the fiber also provides protection against erosion until the vegetation is established. Other advantages include a very even distribution of seed, seeding areas too wet to get on with equipment (if a road is close at hand), and avoidance of planting very small seeds too deep. If a mulch is required with the seeding, hydromulching offers an economic advantage. Also if the only available labor is at union rather than agricultural scale the cost of hydroseeding may be cheaper than conventional seeding.

The following precautions should be followed when hydroseeding. Do not allow the seed to circulate in the machine any longer than necessary since prolonged agitation may damage the seed. Time the addition of seed as closely as possible to the start of seeding, allowing only time for adequate mixing. In machines with centrifugal pumps (this includes most machines), do not seed without a mulch. The mulch (500 lb/1,500 gal water) will cushion the seed, reducing seed damage. If a gear pump is used it may be possible to seed without fiber providing a mulch is not required for other reasons, such as proper mixing or marking area seeded. The study in Appendix I illustrates the problem of seed damage.

FIBERS

A covering of mulch is desirable to hold the seed in place. An excellent product used in hydroseeding is wood fiber applied at 167 to 3,000 lb/acre with the seed and fertilizer in a water slurry; it will stick in place on near-vertical surfaces for extended periods (over one year!). It contains a green dye, which both helps monitor its application and gives it a pleasing appearance. Commercially this is sold as Conwed or Silvafiber.

Fiber's most important function is to hold the seed in place, which requires at least 1,000 lb/acre. It also has a true mulch effect in modifying the environment, particularly holding moisture if 1,500 lb or more is applied/acre. This extra moisture often induces earlier and better germination and has resulted in better seedling survival. Increasing the rate of fiber within the range of 1,000 to 3,000 lb/acre not only increases the number of plants but increases erosion protection.

Three species of trees have been used recently in the manufacture of "hydromulch"--aspen, alder, and hemlock. Hemlock appears to last longer on the slope but is more difficult to apply and apparently has disappeared from the market. The remaining two species seem to give comparable protection while they remain on the slope, and all remain long enough to establish plants.

Waste paper, recently substituted for virgin wood fiber, does not hold seed in place as well and gives less erosion protection. This and similar products contain bits of metal and plastic which plug nozzles. A fiber

made from corrugated paper boxes (PFM) seems better than waste paper but inferior to virgin wood fiber.

Other fibers have been tried. Dairy waste fiber (DWF), washed from milking-parlor floors, shows promise but does not stick to the slope as well as virgin wood fiber. Ground straw, ground newsprint, recycled office waste, rice hulls (whole or ground), seed screenings, and cubed alfalfa were not satisfactory for erosion control. They may be useful as mulches on flat ground, but may blow away if not kept moist.

ORGANIC SEEDING ADDITIVES

Organic seeding additives are generally advertised to hold fiber in place, promote germination, hold moisture, and retard erosion. Most sales literature acknowledges that fiber should be used with the product. Within this group we have tested Bio Binder, Ecology Control M. Binder, Kelgum, Petroset SB, Terratack I (Guar), Terratack III, and Verdyol Super.

It soon became evident that virgin wood fiber generally holds very well by itself. Under extreme wind conditions, increasing the rates of fiber application proved to be as good as adding a chemical. However, because of the high application cost it may be cheaper to add the chemical than to double the fiber rate. Many of the products did not provide additional erosion protection, and one of them gave poorer results than using the fiber alone. One product (Ecology Control M-Binder) at 100 lb/acre has held fiber in place, improved grass stands, and reduced erosion better than fiber alone in some of the more severe tests (sandy soil, steepest slopes, most wind and rain). A new product, Terratack III, shows promise at 40 lb/acre. Both of these products seem compatible with commercial fertilizers. Some others are not.

Some of the other products might prove more effective if the optimum rate could be determined. Manufacturers generally recommend a rate far below the most effective level. Sometimes they don't know what the effective level is, but more often they are reluctant to recommend the effective amount because that would price them out of the market. The customer will purchase a low rate and hope it will work. He will pay $100 for an amount that will not work, but will not pay $200 for the amount that might. He is often satisfied because the plants grow well and he lacks a control area without the chemical to show him that the product was not needed and may actually be of no value. Thus, everyone is happy and the product continues to be sold. No law says it must be effective to be offered for sale.

PLASTIC EMULSIONS

Plastic emulsions are used both with and without plant material. They form a crust which is useful for both erosion and dust control. Among these are polyvinyl acetate homopolymers or vinyl acrylic copolymers generally called PVA (Aerospray 70, Crust 500, Curasol AE, Enviro, MGS, Stickum, Terra Krete and Soil Bond), and a copolymer of methacrylates and acrylates (Soil Seal). A new chemical group under test is styrene butadiene. All retard soil erosion if used in sufficient quantity and correct dilution. They are most effective in intermediate stages of construction or where plant materials are not desired, as when trees or shrubs are to be transplanted. The crust must be protected from vehicles and animals, and is not effective in areas subject to frost-heaving.

The use of plastic emulsions as seeding additives is questionable. They form a crust, an obvious deterrent to establishment of the small-seeded

plants commonly used in erosion control. Tests show that they often delay germination, reduce total germination, and may reduce overall establishment. A salt type of burn is common on grass seedlings growing with emulsion products, particularly if fertilizer is used. These effects will be minimized by using a dilution rate of 5 or 6 parts water to one part plastic emulsion. Such chemicals are used to shed water from the slope, which may be fine for erosion control but can make the environment too dry for plant establishment on steep sites with low water-holding capacity and low total precipitation.

If the plastics are used with seed the slurry should also contain wood fiber. The plastic emulsions will not usually hold the seed or fertilizer in place without fiber. The seed rate should be doubled in an effort to compensate for any undesirable effect of the plastic emulsion. In special situations the plastics may retain moisture and improve germination. However, I have not been able to determine what conditions produce this effect consistently.

The optimum average rate of the plastics as suggested by Ron Mearns and Tom Hoover of the California Department of Transportation is 1,000 lb/acre (about 200 gal/acre) of dry matter for the polyvinyl acetates (750-1100 lb/acre on various soils). This value is expressed as lb/acre because the products vary in solid contents, making gal/acre misleading, and the contents may not be clearly defined on the label. Figures 1 and 2 show the relative effectiveness of 500 and 1,000 lbs and the effect of dilution rate.

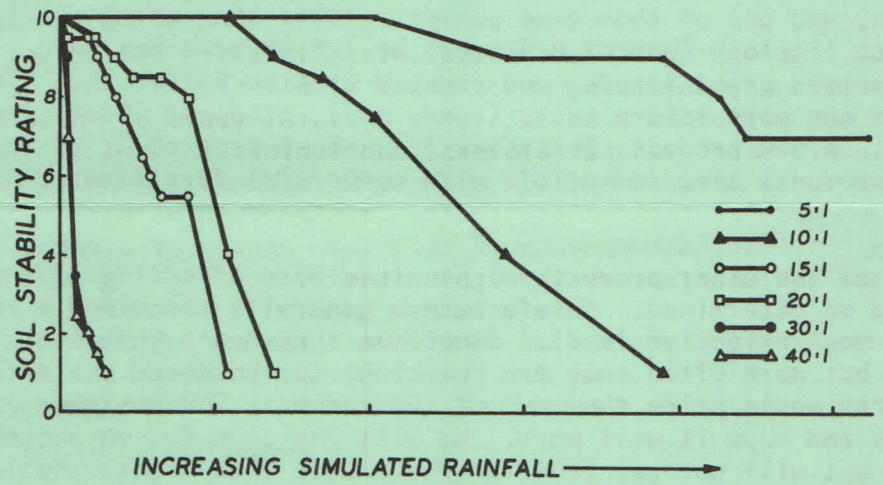


Figure 1. Effect of dilution rate on the effectiveness of 500 lb/acre (100 gal) of PVA.

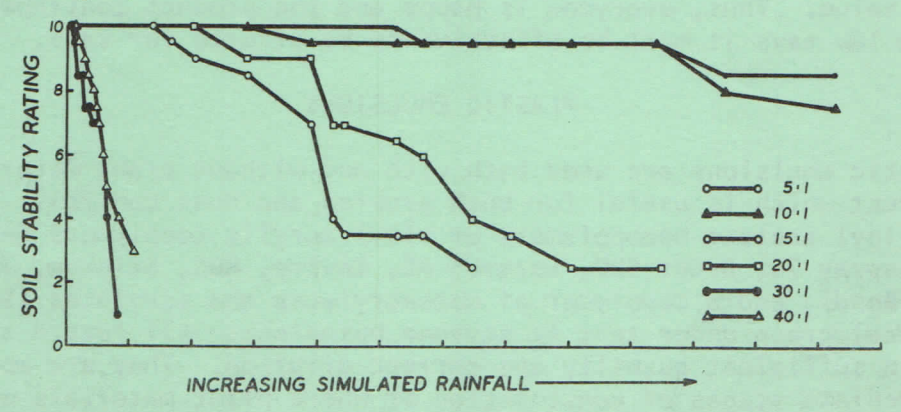


Figure 2. Effect of dilution rate on the effectiveness of 1,000 lb/acre (200 gal) of PVA.

The dilution rate is important with the plastics (Fig. 1 and 2). A dilution rate of five parts water to one part PVA is superior to more dilute mixtures. If seed and fiber are to be included they should be applied first in a separate operation because the low volume of a 5:1 mix will not permit inclusion of sufficient fiber in the hydroseeder. Commercial machines can pump 3 to 6% (by weight) of wood fiber (250 to 500 lb fiber/1000 gal water). Temperature is also important with PVA. Do not freeze in storage, and do not apply at temperatures below 55° F.

STRAW AND TACKIFIERS

Straw is an excellent mulch for stabilizing soil, encouraging seed germination, and speeding plant growth. However, straw may be weedy, and must be incorporated into the soil (disked or punched), or held down with a net or a sprayed chemical tackifier (least expensive method) to prevent blowing. A commonly used chemical tackifier is asphalt emulsion. The tests in Appendix II investigate the merits of products which can be substituted for asphalt and applied with a hydroseeder. The results agree with three earlier tests (unreported) and are presented as a summary of all testing with tackifiers. Terratack II (a seaweed extract), and Ecology Control M-Binder (a plant gum), were the most promising products.

LEGUME INOCULATION IN HYDROSEEDING

Legumes are important in seeding infertile sites because they can supply their own nitrogen, surviving where other plants might not. Legumes that are common on California road cuts after several years of "natural revegetation" are bur clover, vetch, annual clovers, and lupines.

Legumes receive their nitrogen from root-nodule bacteria which remove it from the soil air and convert it to a form usable by plants. Thus, the bacteria are as important as the plant itself.

Many soils either lack root-nodule bacteria or contain ones that do not fix nitrogen. The use of inoculated seed introduces efficient nitrogen-fixing bacteria of the proper strains. Good legume stands require that the inoculum used be especially prepared for the species or variety of legume planted. Since bacteria native to the soil will be highly competitive with bacteria introduced on inoculated seed, the latter will need protection until the seed germinates. By pellet inoculation, high numbers of live bacteria are concentrated on the seed, and the pellet helps protect them until germination.

Each seed pellet contains a legume seed, the inoculant, and an adhesive and a coating material that influences survival of the bacteria. The operator can prepare the pellets in a cement mixer or on a concrete floor, or he can order inoculated seed from a dealer. (Details of pellet inoculation are given in University of California Agriculture Experiment Station Bulletin 842, "Range Legume Inoculation and Nitrogen Fixation by Root-Nodule Bacteria," and Agricultural Extension Service Publication AXT 280, "Pellet Inoculation of Legume Seed.").

There has been some question whether the bacteria is washed off the seed in the hydromulching process. The experiment in Appendix III was designed to measure the effectiveness of inoculation under hydroseeding field conditions.

PRESOAKING SEEDS AND USE OF GROWTH REGULATORS

Enhanced germination from soaking seeds before planting has been investigated by many scientists. The technique is limited in application, however, because of the difficulty of drilling or broadcasting wet seeds and providing a seedbed environment conducive to continued germination or growth of presoaked seeds. Germination of only a few species is enhanced by soaking seeds and redrying them before planting.

Presoaking would seem a natural part of hydroseeding, which is done with wet seeds. The large volume of water and fiber applied in hydroseeding ensures a seedbed environment conducive to germination, provided that temperatures are not limiting. Hydroseeding contractors feel there is a need to increase percentage of germination and speed of germination. The contractor would like to see the seeded species germinate before he turns responsibility for care of the seedings over to maintenance departments. Many supposedly bad seeding jobs were probably the result of poor water management during the germination period after the contractor had left the job site. Experiments were conducted in cooperation with Dr. James A. Young and Dr. R. A. Evans of Agricultural Research Service, USDA, Reno, Nevada.

The timing of presoaking depends on the phenology of germination of the species being soaked and the temperature of the soaking liquid. If the radicle emerges before hydroseeding, it may be injured when the seeding mixture passes through the pumping system. The hydroseeding mixture is applied with considerable force so as to reach large cut or fill banks from the roadway.

In field-testing with presoaked seeds for hydroseeding, we have had difficulties with fermentation of the soaking liquid and seeds. High-temperature soaking has to be brief and done with aeration.

A natural extension of the methodology is the addition of plant growth regulators to the soaking liquid. Plant growth regulators offer the possibility of breaking dormancy, speeding germination, and increasing the size and vigor of seedlings.

Growth regulators that we have evaluated for use in presoaking for hydroseeding are: gibberellin (as the potassium salt of GA_3); kinetin (6-furfurylaminopurine); ethephon [(2-chloroethyl) phosphonic acid]; hydrogen peroxide (H_2O_2); and potassium nitrate (KNO_3). The inclusion of KNO_3 and H_2O_2, which are not generally considered growth regulators, may be questioned, but we used them in the same manner as we used the other materials.

Many different plant species (25 or more) are commonly hydroseeded, and mixtures of five or more species are often seeded together. These mixtures vary from hard-seeded legumes to light-requiring Kentucky bluegrass (*Poa pratensis*). Obviously, with such diverse species, a variety of soaking times, concentrations, and types of growth regulators may be needed. We are still evaluating possible combinations for several species.

Our most detailed investigations have been with common bermudagrass (*Cynodon dactylon*). The seeds of this species germinate at relatively high temperatures (35 to 40°C), and germination rate is greatly increased by pre-soaking for short periods. GA_3 solutions at very low rates increase seedling size. The addition of KNO_3 plus GA_3 and kinetin possibly increases total germination and seedling size.

ROLE OF FERTILIZATION IN PLANTING OF CRITICAL AREAS

Critical areas are generally of low fertility. In fact, such areas frequently have no soils at all--only subsoils or parent material even lower in available plant nutrients. Fertilizer is therefore usually necessary for satisfactory plant growth.

California's soils are usually deficient in nitrogen (N) and are often deficient in phosphorous (P) and sulfur (S). Wildland soils are seldom so deficient in any other element that plant growth or establishment is thereby limited.

The amount of fertilizer should be limited to what the plants can use under the limitations of available moisture and growing season. Proved satisfactory under natural rainfall in most of California is a total of 80 lb/acre N, 100 lb P_2O_5, and 77 lb S. Irrigated seedings will require reapplications of fertilizer as dictated by deficiency symptoms (generally a yellowing of the plants). Many California soils will never need a reapplication in order to maintain adequate ground cover for erosion control under natural rainfall conditions.

The actual fertilizer formulation used is not critical as long as it adds up to about 80 N, 100 P_2O_5, and 77 S. This rate can be achieved with 500 lb of 16-20-0, 400 lb ammonium sulfate plus 500 lb single superphosphate, 240 lb ammonium nitrate plus 500 lb single superphosphate, or limitless other combinations.

Slow-release fertilizers are not generally needed, and sometimes are not desirable. What is important is that the nutrients be available when the plant needs them--shortly after germination. If a slow-release fertilizer is used it should be used together with a conventional "fast-release" form to satisfy the needs of seedlings. Slow-release fertilizers are expensive (several times the cost of conventional fertilizers) and may lose their slow-release properties due to breakage in the hydroseeding process. They may be desirable in extremely sterile situations where reapplication of conventional fertilizers is not practical, as in road construction of granite areas of the Sierra Nevada, or where "fast-release" fertilizer may harm the environment.

Do not overfertilize. That is expensive, wasteful, and environmentally undesirable. It may produce unwanted amounts of plant material which is unsightly and a potential fire hazard. High fertilizer rates also make the grasses more competitive with the flowers or shrubs in the seed mix.

Seedlings of native shrubs and flowers may do better if not fertilized. Such plants have evolved under low-fertility conditions and cannot compete with other plants under fertilized conditions.

SUMMARY OF METHODS AND COSTS

The following table is an attempt to put the various practices into perspective with cost, initial erosion-control effectiveness, and the effect on plant establishment. Cost figures were derived from conversations with contractors, and by review of recent Caltrans contracts.

Table 1. Summary of methods and costs of common erosion-control practices.

Treatment	Comments	Pregermination erosion effectiveness*	Effectiveness on plant establishment*	Approx. cost per acre $**
1. Seed and fertilizer broadcast on the surface, no soil coverage or mulch.	Inexpensive and fast. Most effective on rough seedbeds with minimum slope and erodability where seed will cover naturally with soil. Suitable for remote or critical areas where machinery cannot be taken.	1	1-4	250
2. Hydroseeding or hydromulching (seed + fertilizer) with 500 lb wood fiber, 1,500 gal water/3 acres.	Similar effectiveness to broadcasting seed and fertilizer. Not enough fiber to hold seed in place or produce a mulch effect. Seed distribution would be improved by increased volume of water.	1	1-4	250
3. Seed and fertilizer broadcast and covered with soil (raking or dragging a chain, etc.).	Does not require special equipment. Generally a very effective treatment. Labor cost is high on areas not accessible by equipment.	1	3-4	320
4. Hydromulching with 1,500 lb/acre wood fiber (plus seed and fertilizer).	Most common hydromulch mix in California. Advantages include holding seed and fertilizer in place on steep and smooth slopes where there may not be an alternative method. Only a minimal mulch effect. Cost is much higher than 2.	2	3-5	425-520
5. Hydromulching with 1,500 lb woodfiber plus an organic glue: Ecology Control, Terratack III etc. plus seed and fertilizer.	The addition of an organic glue will sometimes improve fiber holding and germination. Does not increase labor or machinery cost.	2 +	3-6	550-650
6. Hydromulching with 2,000-3,000 lb/acre wood fiber plus seed and fertilizer.	Produces a true mulch effect and some erosion protection. Commonly better results than 1,000 lb fiber or fiber plus glue.	2-3	4-7	530-750
7. Seed and fertilizer broadcast and covered with soil as in 3 above, but followed with hydromulch of wood fiber at 2,000-3,000 lb/acre.	Very effective, combines advantages of seed coverage and mulching.	2-3	6-8	680-865
All of the above treatments offer only minimal protection from the impact of raindrops and water flowing over the surface, but are all weed free.				
8. Straw or hay broadcast with straw blower on the surface at 3,000 lb/acre and tacked down (asphalt emulsion, Terratack II, etc.). Seed and fertilizer broadcast with hydroseeder or by hand.	Common elsewhere in U.S. Very effective as energy absorber, mulch; and straw forms small dams to hold some soil. May be weedy depending on straw source. Not for cut slopes steeper than 2:1. Cost would increase significantly if slopes over 50 feet from access, or application is uphill.	5-7	8-10	650
9. Straw broadcast 4,000 lb/acre rolled to incorporate (punched) another 4,000 lb straw broadcast and rolled, seeded and fertilized. Seed and fertilizer broadcast with hydroseeder or by hand.	Common on difficult fill slopes in California. Very effective. Not possible on most cut slopes. Very weedy. Cost would increase significantly if slopes over 50 feet from access.	6-8	8-10	877-1070
10. Roll-out mats (jute, excelsior, etc.). Held in place with wire staples. Seed and fertilize as in 1 or 2.	Some are a good mulch, weed free, adapted to small areas. Can be installed any season, cuts or fills. Unsightly. Difficult to install on rocky soils.	5-7	5-10	2400-2700
11. Polyethylene sheets. (4 mil) Seed and fertilize as in 1 or 2, use clear plastic, black if no seed is used.	Useful for temporary control. Can be installed any season. Unsightly, wind is a problem in installation and maintenance. May be difficult to establish plants.	10	?	2400-2700
12. Seed and fertilizer broadcast, or hydromulched with fiber (treatment 2 or 4), followed by erosion control chemical such as polyvinyl acetate at 6:1 dilution (6 parts water) at 1,000 lb solid/acre (approx. 200 gal. PVA).	Very expensive, but will hold soil and seed in some very difficult conditions. May restrict penetration of water into soil. Will not cure below 55°F. Not effective on soils which crack. Will not support animal or vehicle traffic.	10+	?	1070-1370

* 1 = minimal, 10 = excellent.

** Assumes seed plus fertilizer $150.00, fiber $150/ton, Ecology Control $1.25/lb., PVA $3.00/gal, 1,500 gal hydroseeder with 2 man crew $55.00/hr, labor $13/hr, straw $50/T, straw mulcher with 4 man crew $64/hr (applies 2 T/hr) and markup of 30% for overhead (including equipment depreciation), and profit. Cost figures were derived from conversations with contractors, and by review of recent Caltrans contracts.

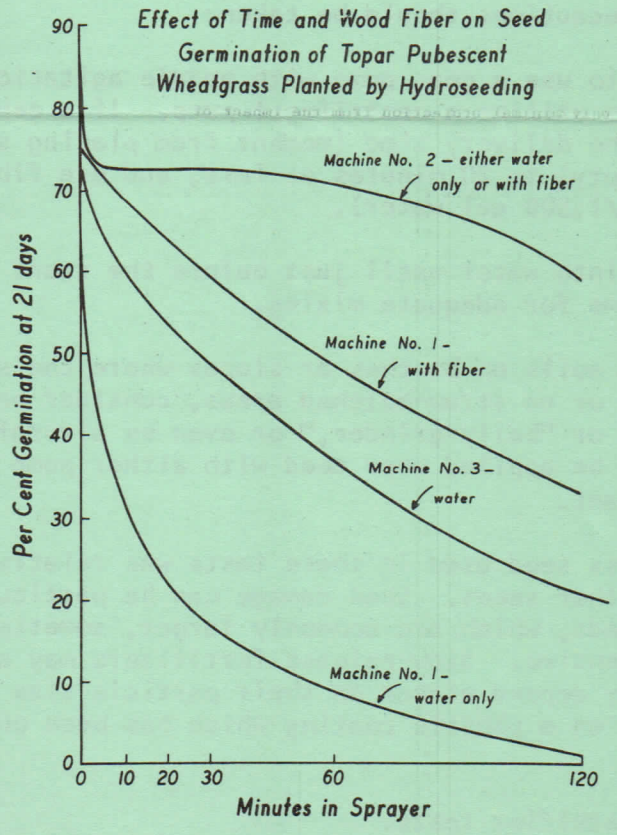
Appendix I. Limiting seed damage in hydroseeders.

Seed of Topar pubescent wheatgrass (Agropyron tricophorum (Link) Richt.) was circulated continuously in three hydroseeders for up to 120 minutes. Samples of the slurry were collected from the nozzle at 1, 10, 20, 30, 60, and 120 minutes. Four seed lots of 50 seeds each were germinated at room temperature on inclined blotters for 21 days. Tests were conducted both with and without wood fiber (Conwed fiber at 50 lb/150 gal water).

Machine No. 1 used a 3 x 3-inch Gorman-Rupp self-priming centrifugal pump (Model 12 D1). The slurry was agitated by bypassing it through this pump back to the main holding tank. This involved constant recycling of the slurry.

Machine No. 2 used a gear pump with rubber-covered gears (Model 2500/IB Bowie) and agitation by paddle only. Thus, the slurry went through the pump only a single time, and much more slowly than in machine No. 1.

Machine No. 3 used a centrifugal pump (Morris) agitated both by a paddle and by recirculating through the pump, but because of the paddle, the seed was not passed through the pump as many times as in machine No. 1.



RESULTS

The above figure illustrates the damage to the seed. Just soaking seed in water and immediately pumping it increased the number of naked caryopses and reduced germination 5% to 15%. This initial loss can apparently be expected from any hydroseeder and is perhaps a small price to pay for the versatility of the seeding technique. Damage beyond that point, however, is of concern.

Seed damage with machine No. 1 was severe, although the wood fiber reduced the damage. Thus, without fibers, germination was reduced to 10% by 60 minutes in the pump, and to 1% by 120 minutes. With fiber, germination was 49% for 60 minutes and 33% for 120 minutes.

Damage in machine No. 2 was not significant through 60 minutes, and germination declined only from 73% to 59% between 60 and 120 minutes. Added wood fiber had no apparent effect.

Damage in machine No. 3 without fiber was similar to the damage in machine No. 1 with fiber. Though not tested, damage with fiber could be expected to be much reduced in machine No. 3. The reduced damage in machine No. 3 can be attributed to the reduction in the number of times the seed passes through the pump.

DISCUSSION AND CONCLUSIONS

The following precautions should be taken:

1. One solution is to use a gear pump with paddle agitation. However, most hydroseeders utilize a centrifugal pump. If a centrifugal pump is used, limit the delivery time (moment from placing seed in water until tank is empty) to 20 minutes or less, and use fiber to protect the seed (500 lb/1,500 gal water).

2. Do not put seed into water until just before the start of seeding, allowing only time for adequate mixing.

3. In seeding loose soils on benches or slopes where the seed would cover naturally, or on straw-mulched areas, consider broadcasting the seed by hand or "belly-grinder," or even by aircraft on larger jobs. Fiber can be applied over seed with either pump if a mulch effect is important.

Although the grass seed used in these tests was relatively large, the principles apply to other seeds. Seed damage can be particularly important with shrub or tree seeds, which are commonly larger, sometimes of irregular shape, and always expensive. Slow-release fertilizers may suffer some similar destruction since they depend either on their particle size for their slow-release properties or on a plastic coating which has been observed to crack when hydroseeded.

Appendix II. Straw tackifier tests.

Barley straw was broadcast at 2,000 lb/acre on the surface of greenhouse flats filled with decomposed granite. The chemicals listed in table 1 were sprayed over the straw. Further details on individual products are in the discussion section. After curing, the flats were inclined on a 2:1 slope and

subjected to winds of up to 84 mph created by a Finn Bantam straw blower. Velocities to 35 mph were measured with an anemometer, and higher velocities were measured with a pitot tube. Table 1 shows the velocity at which 50% of the straw blew away.

The tackifiers tested are of three groups: asphalt emulsion, organic glues (Terratack I and II, Ecology Controls M-Binder), and "plastic" glues (PVA, Soil Seal, and SBR). In general the organic glues attract and hold moisture and improve germination. The plastics, in contrast may inhibit germination.

RESULTS AND DISCUSSION

Asphalt emulsion is commonly used in the eastern U.S. at rates of 200 to 500 gpa. The Asphalt Institute recommends 484 gpa. Asphalt is seldom used in California because of the hazard of accidentally getting this black sticky substance on nearby surfaces. In this and other tests it was observed to soften, allowing the straw to slip from the flats in hot weather. It may have to be heated, as in this test, to permit spraying. The black color probably helps increase soil temperatures and may encourage growth in cool weather. AE was applied under the product specifications SS-1, and was an excellent tackifier at 400 to 600 gpa. Six hundred gallons was superior to 400 gal. Two hundred gallons was not satisfactory.

Terratack I is a free-flowing powder produced from the ground endosperm of a natural vegetable gum, guar *(Cyamopsis tetragonoloba)*, and contains gelling and hardening agents. It is applied at 40 lb/acre in 600 gpa or more of water (1600 gpa in this study), and 250 lb/acre of wood fiber. When mixed with water and properly cured it forms an insoluble network. It is colorless, unaffected by heat, and can be removed easily from spills or oversprays. The higher rate tested gave results similar to asphalt at 400 gpa.

Terratack II is a free-flowing powder produced from semi-refined seaweed extracts. It is sold as two parts, the alginase and a gelling agent. These are mixed with water (750 gpa) and fiber (150 lb/acre). When properly mixed, it polymerizes, and upon application forms an insoluble network of binding membranes. Proper mixing is essential, and requires vigorous aggitation such as with a centrifugal pump. It will not mix adequately in a gear-pump hydroseeder. This product is also nonstaining and easy to clean up. When used at the low rate tested here it must be applied in stringers or lines rather than uniformly since it is too viscous to give complete coverage at this rate. The resulting network will give satisfactory results under less severe conditions. A higher rate should be used for steeper slopes, heavy traffic, or areas of high wind. The higher rate (1,500 gpa water) gave results comparable to 600 gpa asphalt. Terratack II at the high rate was superior to all of the nonasphalt treatments in the first test.

Performance was improved in the second test at the 45-lb rate. This is probably due to better coverage achieved by using a small nozzle and overall coverage instead of the stringers described above.

Table 1. Effect of tackifier products on wind stability of barley straw broadcast at 2,000 lb/acre.

Product	Chemical Rate/ac	Fiber lb/ac	Water gpa	Wind speed at which 50% of straw was blown away Trial 1	Trial 2	Trial 3	Trial 4	Mean
January 75								
None	--	--	--	8-10	8-10	8-10	8-10	9
SS-1 Asphalt	200 gal	--	--	45	35	40	40	40
SS-1 Asphalt	400 gal	--	--	84+	75	84+	79	80
SS-1 Asphalt	600 gal	--	--	84+	84+	84+	84+	84++
Terratack I	40 lb	250	1600	67	75	63	72	69
	89 lb	250	3200	84	81	84+	80	82
Terratack II	45 lb	150	750	63	81	58	69	68
	90 lb	300	1500	84+	84+	84+	84+	84++
Aerospray 70	50 gal	--	500	20	15	20	13	17
	100 gal	--	1000	30	20	15	25	22
	50 gal	125	500	48	45	35	50	44
	100 gal	250	1000	84+	45	35	50	54
Curasol AH	45 gal	136	500	30	40	40	40	38
	90 gal	135	1000	66	63	64	63	64
	180 gal	135	2000	84+	84+	75	63	76
Soil Seal	100 gal	250	1000	84+	72	63	84	76
March 75								
Terratack II	44 lb	146	728	77	84	84+	84++	82
	88 lb	294	1470	84++	84++	84++	84++	84++
Ecology MB	85 lb	70	329	82	84	84	82	83
	58 lb	146	679	79	84+	84	84++	84
	87 lb	146	679	78	84++	84	84	84
	127 lb	159	742	84++	84++	84++	84++	84++
	142 lb	--	665	40	62	55	64	68
SBR-Dow+MC	54 gal	--	357	59	53	55	57	56
	60 gal	75	395	84+	84	84	79	84
SBR-Amsco	53 gal	75	317	55	51	53	53	53
	106 gal	152	639	84+	84++	84++	84++	84+
SBR-Amsco+MC	59 gal	84	355	57	65	68	84	68

84+ = Very stable at 84 mph.
84++ = Superstable at 84 mph.

Ecology Controls M-Binder is a free-flowing, noncorrosive powder produced from a natural plant gum (*Plantago insularis*). It is used in hydraulic seeding to "hold seed in place, promote germination and control erosion." It has not previously been used for tacking straw. The satisfactory performance of 85 lb/acre in 329 gpa water is significant in that this is the only dry-powder organic-type glue tested which performed satisfactorily at a total volume comparable to that used with asphalt emulsion. Increasing the amount slightly to 127 lb plus 742 gal of water gave the most outstanding organic-glue performance at this volume. The addition of a small amount of fiber is essential to performance--142 lb/acre in 665 gal water without fiber was not satisfactory.

Aerospray 70 and Curasol AH are white liquid glues (polyvinylacetates). They may be corrosive to equipment if not carefully flushed off. They have considerable binding effect on soil and are excellent for erosion control if used at high enough amounts and at the proper dilution rates. As successful straw tackifiers they must be used with wood fiber, as can be noted from data under Aerospray in table 1. The low rate of 50 gpa with fiber was superior to 100 gpa without fiber. None of the rates tested gave results equal to 400 gpa of asphalt. Under excessively high rainfall, however, these products might prove superior if used at higher rates than tested here. Aerospray was applied as 10 parts water to 1 part product, and Curasol as 11 parts water to 1 of product.

Soil Seal, a liquid plastic (copolymer of methacrylates and acrylates) is not normally advertised as a straw tackifier. However, it was tested as 10 parts water and 1 part concentrate and proved to be equal to a much higher volume of Curasol.

Styrene butadiene copolymer emulsion (SBR) was tested as both XFS 4163-L Mulch Binder from Dow Chemical and Experimental AB-1881 from Amsco Division Union Oil Company. Methocel (methylcellulose) was added at 2 lb/acre to both Dow treatments and one Amsco treatment. It appears to improve pumping characteristics and performance as a tackifier. Fiber at 75 lb/acre improved the performance of the Dow product.

Appendix III. Successful legume inoculation in hydroseeding.

This experiment was conducted in cooperation with Dr. M. B. Jones at the Hopland Field Station of the University of California, on the north coast of California. The site chosen had previously been determined to be a problem inoculation area. Seeds of both the 'Mt. Barker' and 'Woogenellup' cultivars of subclover (*Trifolium subterraneum* L.) were pellet-inoculated with the appropriate *Rhizobium* bacteria at 4 times the supplier's recommended rate, with the UC formula used in pelleting. The pellets were allowed to cure overnight. These were then circulated through a hydroseeder for up to 120 minutes. This machine has a self-priming centrifugal pump (Gorman-Rupp Model 13 DI, size 3 x 3 in.) and is agitated by bypassing the slurry through this pump back to the main holding tank. Thus, the slurry was constantly being recycled through the pump. The slurry contained 150 gallons water, 50 lb "Conwed" wood fiber, 35 lb of treble superphosphate fortified with elemental sulfur (0-35-0-20), and 2 lb of clover seed. Samples of the slurry were sprayed on a prepared seedbed after 1, 10, 20, 30, 60, and 120 minutes in the hydroseeder. Application rates per acre were 875 lb of wood fiber, 612 lb of 0-35-0-20, and 35 lb of seed. These were compared with the same batch of pellet-inoculated seeds broadcast dry at 20 lb/acre and with uninoculated seed also broadcast dry at 20 lb/acre. The latter two treatments were fertilized with 0-35-0-20 at 500 lb/acre. Each treatment was replicated 4 times. Planting date was October 1, 1971. The first effective rain was in mid-November.

RESULTS

On March 2, 1972, the treatments were evaluated as to healthy plants--evidenced by vigorous growth, size, and dark-green color. Plants inoculated ineffectively or not at all were very small and sickly yellow by comparison and ultimately died. Stands were rated on a 1-to-10 basis, from no plants inoculated to all plants effectively inoculated.

Effect of hydroseeder on subclover inoculation (10 is excellent inoculation, 1 is none).

Treatment	Mt. Barker	Woogenellup[3/]
1 minute	10a	9a
10 minutes	9a	9a
20 minutes	8a	8a
30 minutes	8a	8a
60 minutes	4b	8a
120 minutes	1c	2b
Dry pellet	8a	8a
No inoculation	1c	1b

[3/] Values followed by the same letter are not significantly different at the 0.01 level.

Mt. Barker remained effectively inoculated through 30 minutes, and Woogenellup through 60 minutes. It is unknown whether the decline beyond those times was due to a washing of the bacteria from the seed or to seed damage by the centrifugal pump. Other studies with this machine indicate excessive damage to seed of pubescent wheatgrass (*Agropyron tricophorum* (Link) Richt.). Very few plants resulted from the 120-minute treatment (either inoculated or uninoculated), indicating that seed damage may have been a factor. A gear-type pump would probably result in less seed damage, and would be less likely to wash the inoculum from the seed.

CONCLUSIONS

Pellet-inoculated subclover seed will remain effectively inoculated in a hydromulching slurry if delivery time is limited to 30 minutes or less with a centrifugal pump, and probably longer with a rubber-covered gear pump.

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THIRD CLASS

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