STABLE SEED SHEETS -
AN ALTERNATIVE APPROACH TO REVEGETATION

F.D.Bayles & M. A. Dudley
Canada Wire and Cable Limited
Technology Development Department
Noranda Research Centre
Pointe Claire, Quebec

INTRODUCTION

Mining and public works activities inevitably result in the disturbance of large areas of land. This in turn entails a responsibility by the parties involved to reclaim the land to a reasonably aesthetic and productive condition. The major objective is to provide a permanent self-sustaining plant cover which will serve the dual purpose of stabilizing the land surface as well as providing habitat for wildlife. It is obvious that these requirements are as necessary for mining operations as they are for embankment and right of way seeding as undertaken by utilities and public works departments.

Erosion can be caused by one or more of three circumstances: wind, water and rain, and human interference in nature. Under natural conditions, uncompacted soils or graded surfaces which are not adequately consolidated by plant growth are very susceptible to wind and water erosion. When the natural structure of the ground surface is altered during highway construction or the formation of dams for mine tailings settling ponds, it is necessary to rapidly and permanently stabilize the new formations to reduce the continued maintenance requirement and redevelop the natural setting.

Attempts have been made to find and consolidate soils with oils (1), refinery residues (1), cements (2), plastic foams (3), synthetic polymer emulsions (4), and chopped glass(5), but it may be stated that, in general, their efficacy in relation to the work needed to apply them, renders them quite uneconomical (1); as well, the binders seldom maintain or reconstitute the fertility of the soil. One of the more effective approaches to solving the problem has been by hydroseeding (6), or the application of water slurries of seed, fertilizer and mulch, sometimes in admixture with polymeric binders. This technique, however, is relatively expensive, is susceptible to operator skill, and quite often must be repeated if natural or application erosion causes damage before the vegetation has grown sufficiently to consolidate the surface (1,7).

The approach taken in this study was to develop a single system which would simultaneously provide a simple means of uniform seed and fertilizer distribution while at the same time binding the soil to be revegetated prior to the formation of a stabilizing root matrix. To achieve this, the concept of a water-soluble, flexible and inert polymeric sheet containing seed, fertilizer, herbicides and other additives necessary and useful for the speedy development of an erosion controlling ground cover was developed. The stable seed sheet is laid on the ground and provides, for a finite time, a consolidating effect and a microenvironment conducive to germination and growth.

Previous attempts to develop such a product by other workers have met with only limited success when applied for erosion control; one such approach, intended primarily to make consolidated turf for transport elsewhere, locked seed and fertilizer to an inert woven backing, using polymeric adhesives. This mat was then laid on the ground and covered with soil. The well known commercially available seed tapes, more closely akin to stable seed sheets, are deficient in having high raw material cost, no consolidating or stabilizing effect, limitations in seed size and distribution during encapsulation, and the need for burial in order to perform satisfactorily.

It is also felt that the seed sheet system to be described herein could be useful in transporting correctly proportioned and distributed seed/fertilizer mixtures to underdeveloped countries as part of aid programs, and be capable of application with minimal skills; no such product is presently available for aiding needy nations in crop or forage growth.

EXPERIMENTAL DEVELOPMENT

To more clearly understand the stable seed sheet concept, it is preferable to divide the study into three parts: (1) development of the sheet matrix; (2) germination studies; (3) pilot size commercial operations.

1. Development of Sheet Matrix

Initial experiments concentrated on the evaluation of potential candidate water-soluble polymers for use as the continuous phase of the seed sheet. These included carboxymethyl cellulose, hydroxypropyl cellulose, poly(vinyl acetate), poly(ethylene oxide) and poly(vinyl alcohol). These polymers were made up as solutions or dispersions in water at various concentrations, depending on polymer type and molecular weight, cast into sheets of nominal 0.001 inch dry film thickness, air dried and evaluated for film forming ability, flexibility, ease of resolutilization and relative degree of inertness towards the other ingredients, both during processing and after long-term storage. The majority of the films made had poor flexibility, which was overcome by the incorporation of a compatible plasticizer chosen from the family of poly (ethylene glycol)s, which acts to

(a) improve the hygroscopicity of the film, and

(b) overcome the relatively strong, rigidizing secondary valence forces occurring between adjacent molecules.

Among other plasticizers having potential utility are ethylene glycol, glycerine and urea. A short series of experiments established that the optimum concentration of plasticizer was between 10 and 25% by weight of total film former, depending on polymer, and plasticizer molecular weight. Table 1 lists a series of early seed sheet compositions, using various polymeric film formers. One can note the general trend to satisfactory films using poly (vinyl alcohol). These initial sheets, where noted, contained a recommended 10:20:20 fertilizer blend which, due to excessive levels of soluble salts, caused whitening and embrittlement.

Considering the performance results and relative costs of the various film forming candidates, it was decided to concentrate on poly (vinyl alcohol) as the prime candidate. Although this polymer is described exhaustively elsewhere (8), a brief resume of its nature is warranted.

Poly(vinyl alcohol) is not produced, as might be expected, by polymerization of vinyl alcohol monomer, but by hydrolysis, under controlled conditions, of solutions or dispersions of poly(vinyl acetate),a common ingredient in adhesives and latex paints. This treatment results in long chain polymers having pendant side chains terminating in hydroxyl groups, interspersed with unattached acetate ester groups. The basic properties of poly(vinyl alcohol) depend on two factors: the degree of hydrolysis (DH), and the degree of polymerization (DP). DH values for poly (vinyl alcohol) may be conveniently subdivided into two main classifications, (a) a partially hydrolyzed type having a DH of from 80-89%, normally soluble in cold and hot water, and (b) a fully hydrolyzed type having a DH of above 98%, soluble only in hot water. In terms of DP, the major sub types are low, medium and high viscosity grades which allow their use in a variety of applications. A further advantage of poly(vinyl alcohol) was that it had already been cited (8) as useful in soil conditioning, where it "improves the physical characteristics of single grained soils by converting them to a crumbed form and imparting water stability. This crumbed structure has excellent air and water permeability, high water retaining capacity, and high water and wind erosion resistance. This results in improved plant growth, with better germination, easy tillage, lower incidence of disease, rapid growth and improved crop quality. Poly (vinyl alcohol) is most effective for use with loam with a high clay content, clayey loam and clay."

For use in the stable seed sheet program, it was recognized that the optimum polymer form of poly(vinyl alcohol) should be partly hydrolyzed and of low or medium molecular weight; studies concentrated on this material.

As previously mentioned, the early sheets were made by air drying the cast solutions. This resulted in drying times well in excess of 8 hours. As this was not economically viable, studies concentrated on attempts to dry the sheets at elevated temperatures. The major obstacle to be overcome was the removal of the large volume of water in the casting solution, a situation caused both by the relative insolubility of poly(vinyl alcohol) in any other solvent which would not detrimentally affect seed viability and the need to use relatively low concentrations of polymer. It was also found, both from literature surveys and experiments, that temperatures in excess of 180^{o}F, or extended exposure times at high temperatures, resulted in loss of seed viability. Thus a third major restriction was introduced by the decision to restrict temperatures to no greater than 150^{o}F.

Further experiments established that significant reductions in drying time could be effected by using convection ovens at 150 F. However, these times were still excessively long. It was realized that this was due to the buildup of saturated atmospheres in the oven which retarded drying. When single pass forced draft ovens were employed, further significant reductions in time were effected. Table II illustrates selected experiments which show the relative effects of oven type on drying time. Although these drying times resulting from forced draft drying were a significant improvement over the other methods, the best, 25 minutes, was still unacceptable long. A further series of experiments then evaluated the concept of starting with a polymer solution preheated to 150^{o}F, and a solids content higher than the average 6% by weight employed in previous series. It can be clearly seen from Table III that this approach provided the key to successfully reducing oven residence times to acceptable levels. Although there were minor problems to be overcome in seed slurry dispersion in these highly viscous, high solids solutions, germination experiments and the successful reduction of residence time indicated that the process was viable and warranted further study on a pilot scale.

2. Germination Studies

From the beginning, the stable seed sheet concept assumed that seed would be encapsulated in a continuous matrix of water-soluble polymer, and that this sheet would be produced by drying from cast, aqueous solutions. The critical factor was whether or not this approach would effect significant changes in seed viability.

To study the effects of various approaches to manufacturing seed sheets on seed viability, seed beds were prepared in the greenhouse facilities of the Pulp and Paper Research Institute of Canada in Pointe Claire, Quebec, whose co-operation is gratefully acknowledged. These were portable flats, 4" x 36" x 58", which were lined with randomly pierced polyethylene sheet to retain the soil, and filled to a depth of 4" with a mix of 75% by volume clayey loam and 25% by volume of peat moss. The sheets, appropriately identified, were laid on top of the medium, and watered with controlled aliquots of D.I. water for the first ten days, and every fifth day thereafter. First visual germination was monitored, as was the degree of subsequent germination, vigor and quality of root growth after 30 days. The environment was maintained at an average 12-hour day, artificially augmented,where necessary, with temperatures for day and night, controlled at 75°F/60°F, respectively. In this, and all subsequent studies, except where noted, the seed used was a commercial lawn mix made up of fescues, ryes, bent grasses and clover. The seed loadings were maintained at the commercially recommended broadcast rate.

Table IV shows the results of germination studies of the first series of slurry cast, air dried sheets as described in Table I. In Table IV, the fertilizer, marked with an asterisk, is a commercial 10:20:20 blend, P(VOH) is poly(vinyl alcohol), CMC is carboxymethyl cellulose, and P(VAC) is poly(vinyl acetate). Germination is in days after placement of the sheet, total germination is a subjective assessment of the relative quantity of seed germinated after 15 days as a percentage. Vigor after 15 days is a subjective assessment of the strength of the growth. Root growth is assessed after 30 days by removing the growth from the test flat, shaking free of soil and subjectively rating volume and entanglement of roots, and their length. It can be seen that the trend was to generally good results using poly(vinyl alcohol) as the sheet matrix, although this was a function of molecular weight and the presence of fertilizer. The relative disparity in germination time was explained by noting that the seed was found to have retained a light coating of polymer which, depending on the speed of dissolution, was swelling and imbibing water at different rates, thus controlling onset of germination. In general, sheet disintergration occurred within minutes of laying the sample on the soil. On Day 15, soil integrity was uniformly good, as monitored by subjective compression and disintegration tests.

A further series of experiments evaluated the ability to agglomerate soil by laying selected seed sheets, accompanied by a control, on an artificial bank inclined 30° from the horizontal. The effects of severe watering on seed retention and germination were monitored and are shown in Table V. It may be noted that the control growth seemed better as it was dense and heavily watered at the base of the bank. The experimental plots, however, were uniform and healthy with good soil integrity.

As mentioned in the section describing sheet matrix studies, economic viability of the seed sheet concept required short drying times. A series of experiments, described in Table VI, studied the effects of temperature and oven residence time on seed viability. Germination was determined in petri dishes containing damp glass wool, recording days to germination and percentage visual germination after 15 days. The seeds were placed in a convection oven as is, or prewetted with water. It is quite apparent that a significant deterioration of seed viability occurred between 150°F and 200°F which substantiates similar studies reported in the literature (9, 10). On the basis of these data, the decision was made to use a maximum drying temperature of no greater than 150°F.

Recalling Table II, which described the study to evaluate the comparative efficacy of convection oven drying to forced draft oven drying, a further series of germination experiments were prepared from this series to evaluate the effects on seed viability. Growing conditions in the greenhouse were comparable to the previous series. The overall results are shown in Table VII. Visual germination was rated as a percentage of seed applied, after 10 and 20 days, and vigor of germination after 10 days. Root quality was subjectively evaluated after 30 days. From the data in this table, it may be seen that both the air dried sheets, series 1, 4, and the forced draft dried sheets, series 2, 4, showed good germination which, although somewhat slower than the controls, was comparable after 20 days of growth. The vigor of growth and root quality was equivalent. The convection oven dried series, #3, 6, was, however, uniformly poor in all aspects of growth. It was thus concluded that little effect on growth could be anticipated from the use of high velocity air streams for drying. Further studies were then made to evaluate various other parameters pertinent to pilot studies of continuous sheet production. Although not described in detail, it was found that maintaining a regular watering schedule during the critical first days of germination was vital to vigorous growth. Soaking the seed for extended times in plasticizer or polymer had little effect on germination or vigor. Excessive residence times in the oven, as might be expected if the line stopped, were detrimental, reducing germination by as much as 50%. Presoaking seed in water for 24 hours before casting into sheet, in an effort to encourage germination, had no positive effect. Modifications to the drying ovens to effect increased air velocity were not detrimental, although, as previously mentioned, temperatures in excess of 150°F, even for short residence times, severely retarded germination and growth. The addition of surfactants to effect improved dispersion of the seed during drying had no detrimental effect. Most importantly, as may be recalled from the sheet matrix section, sheet made from solutions of up to 21% by weight of film former showed equal vigor and growth to both broadcast controls and sheet controls made from lower solids content solutions.

Seven varieties of seed most frequently used in revegetation were cast into sheets at the recommended loadings to examine the effects of encapsulation on germination and growth. The results of this study, detailed in Table VIII, indicate that, in general, dicotyledons germinated more quickly but showed poor root formation, whereas monocotyledons had slow germination rates but excellent root growth. Most importantly, however, there was little effect on germination or growth by encapsulation in a seed sheet.

3. Pilot Studies of Continuously-Made Seed Sheets

Experiments were conducted at the pilot facility of the Sandvik Corporation in Fair Lawn, New Jersey, to elucidate the following parameters:

(i) to verify the production feasibility of seed sheet in continuous lengths of controlled thickness;

(ii) allow measurements for the sizing of production equipment and determination of production rates; and

(iii) obtain an accurate estimate of the cost of production equipment and thereby a production cost for the seed sheet.

A schematic diagram of the production facility is shown in Figure 1. Using this equipment, which produced sheet 18" wide, successful manufacturing trials of many hundreds of feet of continuous sheet were concluded. It was found possible to produce sheets of 0.001" thickness with average oven residence times of $\sim$ 2 1/2 minutes and sheet temperatures which did not exceed 150 °F, using polymer solutions of approximately 20% solids by weight. Germination studies in the greenhouse using sheets containing Baron Bluegrass indicated that, for the optimum formulations, first germination occurred in 5 days and percentage germination after 18 days was approximately 50%; control values were 5 days and 60%, respectively. In outdoor growth trials, experimental sheets germinated in 9 days and showed percentage germination after 18 days of up to 75%; control values were 9 days and 85%, respectively. Comparative cost studies indicate that the sheet production, ground preparation and laying of sheets are competitive with other techniques used in mine tailings revegetation.

In conclusion, water-soluble seed-containing polymer sheets have been successfully prepared, which are stable, easily stored and easily applied, both from roll and cut sheet form. With proper formulation they may be used in a variety of climactic areas having a wide range of precipitation conditions to give a controlled speed of resolubilization and provide the required amount of soil cohesion prior to root matrix formation. Furthermore, they allow a uniform distribution and optimum concentration of seed and additives to be applied simply and in a reproducible manner, which suggests potential value in revegetation or food crop production in underdeveloped countries.

This product, and its technique of manufacturing, are covered by patents pending, and Canada Wire and Cable is actively exploring sale or license of the technology.

REFERENCES

1. "Vegetation of mine waste embankments in Canada", D.R.Murray, Circular IC 301, Dept. of Energy, Mines & Resources, Ottawa, Canada.

2. Canadian Patent 915,933, to National Gypsum.

3. British Patent 1,269,107 to Glanztoff AG, Germany.

4. "Curasol"(TM), Farbwerke Hoechst AG, Germany.

5. "Glasgrass"(TM), PPG Industries, U.S.A.

6. Descriptive literature Erocon Ltd., Toronto, Canada.

7. "Experiments in propagating plant cover at tailings basins", S. Dickinson, Mining Congress Journal, October 1972, pp.21-6.

8. "Polyvinyl alcohol, properties and applications", C.A.Finch ed., John Wiley, pub. 1973.

9. "Effect of high temperature on dry seeds", Ben Zeev et al., Plant Physiol. 37, 696-9(1962).

10. "Germination of cultivars of trifol. subterraneum", Young, Agron.J., 62 (5), 638-41 (1970).

TABLE I

FLEXIBLE SEED SHEET COMPOSITIONS

Code	Ingredients, wt.% Binder	Plasticizer	Seed	Fertilizer	Water	Thickness, in.	Appearance
1A3	3.4	0.9	1.9		93.8	0.001	Flexible, clear sheet
1B3	3.3	0.8	1.8	4.3	89.8	0.0025	Fairly brittle sheet, white
2A2	4.13	0.73	3.0	-	92.15	0.001	Fairly stiff, clear sheet
2A3	5.51	0.98	2.67	-	90.85	0.0015	Fairly stiff but strong sheet
2B3	5.18	0.92	2.51	5.86	85.52	0.0025	Fairly stiff and brittle, white
3A2	2.49	0.35	4.62	-	92.53	0.00075	Flexible clear sheet
3A3	3.67	0.55	4.56	-	91.22	0.001-0.0015	Very flexible, clear sheet
3B3	3.32	0.49	4.12	9.61	82.46	0.00125	White, fairly brittle sheet
4A3	3.29	0.59	3.38	-	92.74	0.002	Film white and quite brittle
4B3	3.05	0.54	3.13	7.31	85.96	0.0015	Film white and brittle
5A3	11.58	-	3.53	-	84.89	0.004	Film clear, slightly tacky, very flexible
5B3	10.69	-	3.26	7.61	78.44	0.004	Film white, stiff, slightly tacky
6A3	2.58	0.30	3.46	-	93.66	0.0008	Film clear and flexible
7A2	4.39	0.49	1.9	-	93.22	0.002	Film clear and flexible
7B2	4.21	0.47	1.82	4.25	89.25	0.002	Film white and quite brittle
9B3	6.73	-	2.68	6.25	84.34	0.0025	Flexible, white sheet

Binders Employed:

Series 1: Slow solubilizing poly(vinyl alcohol) (Grade 1)
2: Slow solubilizing poly(vinyl alcohol) (Grade 2)
3: 1:1 blend of the above binders
4: Carboxymethyl cellulose
5: Poly(vinyl acetate)
6: Fast solubilizing poly(vinyl alcohol) (Grade 1)
7: Fast solubilizing poly(vinyl alcohol) (Grade 2)
9: 1:1 blend of fast solubilizing poly(vinyl alcohol) and poly(vinyl acetate)

TABLE I

TABLE II

EFFECTS OF DRYING MODE ON OVEN RESIDENCE TIME

(6% aq. solutions of film former)

Polymer Type	Plasticizer Employed					
	Low MW Poly(ethylene glycol)			High MW Poly(ethylene glycol)		
	Drying Mode			Drying Mode		
	Time to Dry (minutes)					
	ON*	FDO	CO	ON	FDO	CO
Poly(vinyl alcohol) Type 1	B1 (>120)	B2 (25)	B3 (95)	B4 (>120)	B5 (30)	B6 (110)
Poly(vinyl alcohol) Type 2	D1 (>120)	D2 (30)	D3 (135)	D4 (>120)	D5 (25)	D6 (120)

*ON = Overnight at ambient temperature

FDO = Forced draft oven, 2100 CFM/150°F

CO = Convection oven, 150°F

TABLE III

OVEN RESIDENCE TIME AS FUNCTION OF CASTING SOLUTION SOLIDS CONTENT

Resin	Plasticizer	Ratio	Solids Content, %	Retention Time, min.	Temperature, °F
205	PEG 600	75:25	6.5	16	150
205	PEG 600	75:25	7.22	13	150
205	PEG 600	75:25	8.12	11	150
205	PEG 600	75:25	9.28	8.5	150
205	PEG 600	75:25	10.82	6.5	150
205	PEG 600	75:25	13.00	5	150
205	PEG 600	75:25	16.25	4	150
205	PEG 600	75:25	21.6	3.5	150
205	PEG 600	75:25	28.0	2.25	150

TABLE IV

GROWTH EXPERIMENTS ON SELECTED INITIAL SEED SHEET FORMULATIONS

Sheet Code	Composition	Germination (days)	Total Germination (%)	Vigor After 15 Days	Root Growth After 30 Days
Control	-	4	∿ 90	Excellent	Heavy
Control	Fertilizer (*)	5	∿ 85	Excellent	Heavy
1A3	P(VOH) slow sol.	5	∿ 80	Very good	Heavy
1B3	P(VOH) slow sol. +*	6	∿ 60	Good	Very heavy
2A2	P(VOH) slow sol.	6	∿ 50	Poor	Poor
2A3	P(VOH) slow sol.	7	∿ 50	Poor	Poor
2B3	P(VOH) slow sol. +*	7	∿ 60	Excellent	Heavy
3A2	Blended 1 & 2	6	∿ 70	Very good	Poor
3A3	Blended 1 & 2	5	∿ 80	Excellent	Heavy
3B3	Blended 1 & 2 +*	6	∿ 50	Poor	Poor
4A3	CMC	5	∿ 60	Very good	Good
4B3	CMC +*	6	∿ 60	Very good	Good
5A3	P(VAC)	8	∿ 10	Very poor	Very poor
5B3	P(VAC) +*	8	∿ 10	Very poor	Good
6A3	P(VOH) fast sol.	5	∿ 85	Excellent	Very good
7A2	P(VOH) fast sol.	6	∿ 90	Excellent	Good
7B2	P(VOH) fast sol. +*	7	∿ 70	Very good	Good
9B3	Blend P(VOH) + P(VAC) +*	9	∿ 30	Poor	Poor

TABLE V

RELATIVE PERFORMANCE OF SEED SHEETS ON 30° INCLINE

Sheet Code	Germination (days)	Visual Appearance (10 days)	Visual Appearance (18 days)	Soil Integrity
Control	5	Heavily washed down germination at bottom	Heavy growth at bottom	Poor, eroded
1	8	No seed displaced; uniform germination	Good uniform growth	Good
2	5	Ditto	Ditto	Good
3	6	Ditto	Ditto	Good

Watering Schedule: 4 times aliquot used on flats, applied from top of test area, once a day for first 10 days, every fifth day thereafter.

TABLE VI

EFFECTS OF THERMAL TREATMENT ON SEED VIABILITY

Treatment		Days to Germination	% Visual Germination
Control		5	∿ 95
Control wet with water, air dried		5	∿ 95
100°F/120 min.	Dry	5	∿ 80
	Prewet	6	∿ 75
150°F/45 min.	Dry	5	∿ 80
	Prewet	6	∿ 80
200°F/15 Min.	Dry	5	∿ 60
	Prewet	5	∿ 70
250°F/15 min.	Dry	6	∿ 20
	Prewet	6	∿ 15
300°F/15 min.	Dry	–	0
	Prewet	–	0
300°F/1 min.	Dry	–	0
	Prewet	–	0

TABLE VII

COMPARATIVE GROWTH TRIALS OF SELECTED SERIES OF SHEETS PREPARED USING VARIOUS OVEN DRYING TECHNIQUES

(Refer to Table II)

Sheet Code	Visual Germination, %		Vigor of Growth 10 days	Root Quality 30 days
	10 days	20 days		
B1	35	85	Excellent	Very good
D1	25	85	Excellent	Good
B2	20	90	Good	Very good
D2	30	85	Excellent	Very good
B3	–	–	None	None
D3	15	40	Poor	Very por
B4	40	90	Excellent	Excellent
D4	40	85	Excellent	Excellent
B5	30	85	Good	Very good
D5	25	85	Good	Very good
B6	–	–	None	None
D6	∿ 2	∿ 2	Poor	Very poor
Controls				
1	60	95	Excellent	Good
2	60	95	Good	Very good

TABLE VIII

EFFECTS OF ENCAPSULATION ON GERMINATION AND GROWTH OF SELECTED SEED

Seed Type		Germination After 22 days, %	Root Matrix Formation (22 days)
Alfalfa		20	Good
	C.	20	Fair
Dogtooth		80	Good
	C.	80	Good
Baron Bluegrass		90	Good
	C.	90	Good
Alaska Clover		80	Good
	C.	70	Good
Sweet Clover		40	Good
	C.	40	Poor
Crown Vetch		3	Poor
	C.	5	Poor
Birds Foot Trefoil		40	Good
	C.	40	Good
Fairway Mix*		60	Good
	C.	60	Good

Line identifying seed type is experimental sheet.
C = Control

* 40% blue grass
30% creeping red fescue
20% ryegrass
10% colonial bent grass

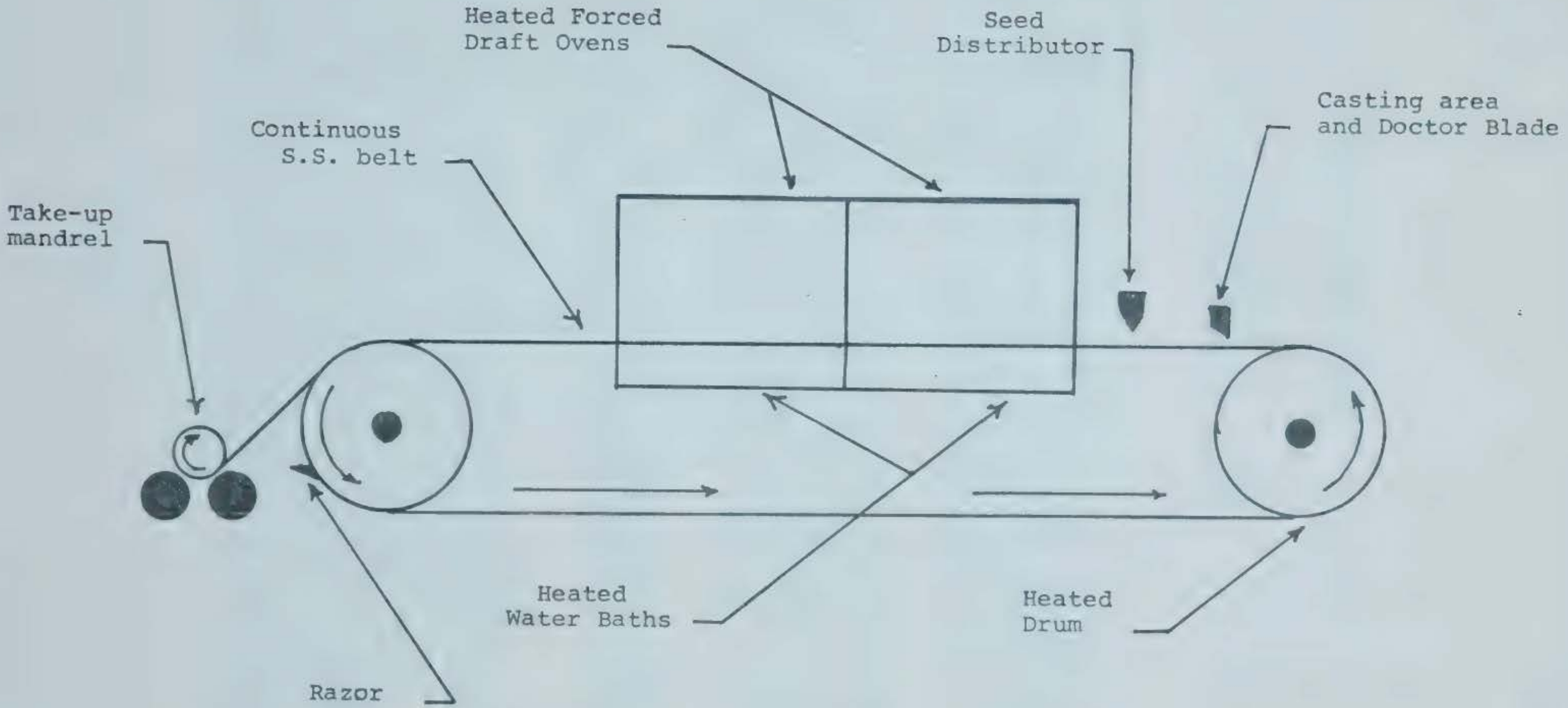
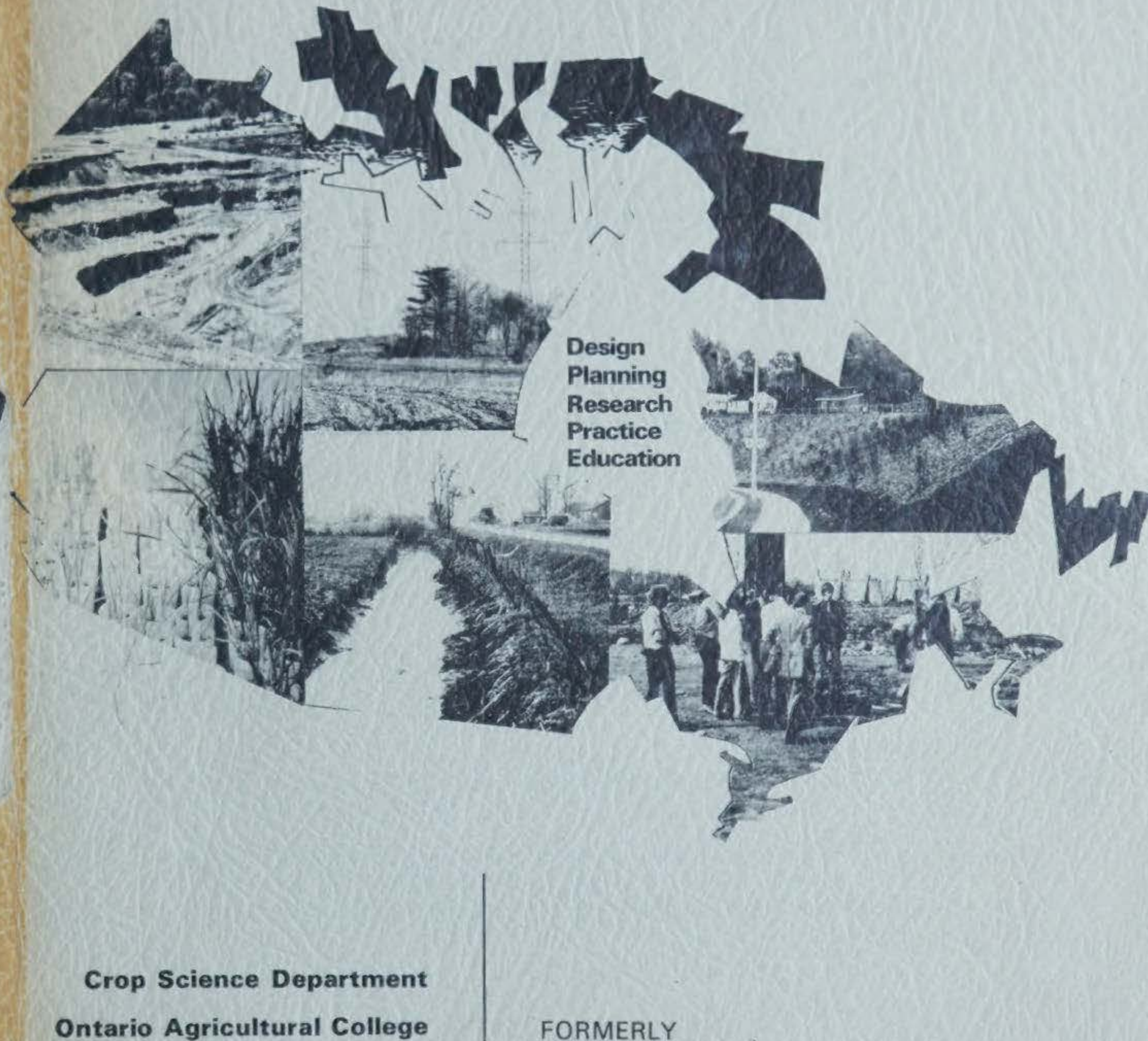


Figure 1. Schematic of the pilot line

FIGURE 1

Proceedings of the Inaugural Meeting
Canadian Land Reclamation Association

DECEMBER 1975



Crop Science Department
Ontario Agricultural College
University Of Guelph
uelph, Ontario, Canada
March 1976

FORMERLY
PROCEEDINGS OF
THE ONTARIO COVER CROP COMMITTEE

PROCEEDINGS OF THE INAUGURAL MEETING
OF THE
CANADIAN LAND RECLAMATION ASSOCIATION

Table of Contents

(continued)

Table of Contents (continued)