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PNEUMATIC METERING OF HARDWOOD TREE SEEDS

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ABSTRACT

A commercial, no-till row planter was extensively modified for use in direct seeding of hardwood tree species in surface mine reclamation. A pneumatic seed metering system was designed, fabricated, and mounted on the planter frame.

The metering device was tested under laboratory conditions which simulated varying terrain slope and field speed with seeds of various hardwood tree species. Metering efficiencies of 97% were achieved for pin oak seeds at 3.2 km/hr (2.0 m/h) and 50% slope. For red oak, 97% efficiency was achieved for 50% slope at 4.0 km/h (2.5 mph). Unsatisfactory metering was noted during tests of larger seeds, namely bur oak and black walnut.

The planter performed satisfactorily in field tests on a regraded sandstone/shale strip mine spoil material with an established vegetative cover. The metering device delivered approximately 95% of expected seed density when operated on a mild slope (≤ 10%) at a relatively slow speed 2.4 km/hr (or 1.5 miles/hr) using red oak seed. Penetration problems encountered in these tests were rectified by installing a 117 cm (46 in.) parabolic ripper tine.

BACKGROUND

Provisions in the Surface Mining Control and Reclamation Act of 1977 have caused renewed activity in reforestation of mined land. Strict enforcement of regulations requiring return to the premining land use and establishment of a "diverse cover of native species" could result in extensive tree planting efforts in the heavily forested regions of the Appalachian coal fields.

Alternatives for reforestation of surface-mined land include planting seeds, bareroot or containerized seedlings, and stemwood or rooted cuttings (Whittwer, 1980). Bareroot seedlings are most commonly used. Steep rough slopes, rocky terrain, and other difficult planting conditions often encountered on surface-mined lands in the Appalachian coal fields make direct-seeding an attractive alternative to planting bareroot seedlings. Potential economic benefits and increased species diversity have also contributed to a renewed interest in direct-seeding.

Richards (1981) determined that survival of direct-seeded hardwood species depended on planting technique, species, cultural treatment, and the presence of herbaceous vegetation. Results indicate that for several species, notably the oaks, which are an important component of the native forest, direct seeding is a reasonable alternative to planting barerooted seedlings.

Successful reforestation of broadcast seeding has been confined largely to black locust (*Robinia pseudoacacia* L.). Some promising results have also been reported for several pines, especially short leaf (*Pinus echinata Mill*), loblolly (*P. taeda L.*), and Virginia (*P. virginiana Mill*) (Brown, 1973; Thor and King, 1964). The inherent ease of broadcast seeding has led researchers and reclamation personnel to try broadcast seeding with other species, usually without success (Davidson, 1980). Spot planting on prepared sites has been more successful (Smith, 1962).

Reforestation trials with direct-seeding were attempted on Midwest surface-mined lands during the 1930s (Schaville, 1941). Results were mixed and led Limstrom (1960) to discourage the use of direct-seeding. He attributed failures to the drying out of germinating seedlings, rodent depredation, erosion and siltation. Until recently, direct seeding of species other than black locust has received little attention.

Desired stocking rates can be obtained by spot-seeding, if a good estimate of survival is available and the proper number of seeds are planted to account for loss. Direct-seeding is a useful method for reforestation, but hand planting seeds is not practical for large-scale plantings. A mechanized planting system is needed to apply direct-seeding techniques to the reclamation of surface-mined land.

Row-planting type tree seeders were developed during the 1960s. Designs, such as the H-C furrow seeder (Croker, 1964) and the Auburn seeder (Richardson, 1965), were developed to prepare a seedbed and plant pine seeds on natural sites. Richards (1981) found that conventional planting machines are ill-equipped to perform reliably under circumstances generally associated with direct seeding onto surface mined areas. Even the so called "no-till" planters, which are designed to operate in untilled soil, do not penetrate the extremely rough and hard surface conditions which can exist in these areas deep enough for adequate coverage of seeds. Furthermore, conventional mechanisms for metering seed depend upon gravity and are adversely affected by moderately sloping terrain. Also, reliable metering of larger tree seeds generally requires modification of the seed metering mechanism.

Investigations for development of a row-planting type seeder for surface-mined land were begun by the

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University of Kentucky, Department of Forestry, in the fall of 1979 (Richards, 1981). They attempted to modify a commercial planter to plant a range of seed sizes, including very large seeds such as walnuts on steep slopes and on rocky ground. The major difficulty they encountered was unreliable metering of seeds on sloping terrain using a conventional gravity-dependent metering device. Additional difficulty was encountered in preparing a furrow of sufficient depth and/or achieving adequate covering of seeds by soil.

Pneumatic metering was introduced for direct seeding of pine in the 1960s (USDA, 1967). During the 1970s pneumatic metering systems were adopted by several of the major manufacturers of agricultural machinery. Such metering systems perform reliably at moderate to low planting speeds and are essentially unaffected by terrain slope.

The objectives of the study were to:

1. Design and fabricate a prototype unit planting machine for use in direct seeding of hardwood species onto surface mined lands.
2. Evaluate the prototype in both laboratory and field tests with regard to metering accuracy for various terrain slopes, field speeds, and seed types.

PROCEDURES

PROTOTYPE DESIGN AND FABRICATION

A commercial, single-row, no-till unit planter was extensively modified to facilitate direct seeding of hardwood tree species in reclamation of surface-mined areas. The major modifications were as follows:

Seed metering device – A conventional inclined-plate seed metering device was replaced by a pneumatic seed metering system. A centrifugal fan capable of developing a static air vacuum of 30.4 cm (12 in.) H_2O at 5000 rpm was driven by an auxiliary hydraulic motor via a v-belt. A 46 cm (18 in.) diameter circular aluminum plate was constructed with removable seed cells at 72° spacing. This rotating plate was driven by a ground drive wheel via detachable link chain and situated adjacent to a stationary slotted plate, separated by a teflon gasket. The fan intake was connected to a slot machined in the stationary plate to control pick-up and release of seeds by vacuum. Figure 1 shows a schematic of the seed metering assembly.

Ballast weight carrier assembly - The unit planter utilized a double disk furrow opener component which was attached to the frame via a single pinned connection. This arrangement did not result in satisfactory furrow depth in relatively hard untilled surface mine spoils, so a four-bar linkage assembly was installed to add ballast weight and increase penetration of the furrow opener (see fig. 2).

Forward furrow openers - The commercial planter was equipped with a spring shank tine to till in front of the double disk furrow opener. This tine was mounted rigidly on the planter frame and did not perform satisfactorily in hard untilled spoil. A 61 cm (24 in.) diameter coulter with a larger helical steel compressional spring providing downward penetration force was installed, but this too performed unsatisfactorily in hard soil conditions. Finally, a 1.17 m (46 in.) parabolic ripper tine was installed which provided adequate penetration (see fig. 2).

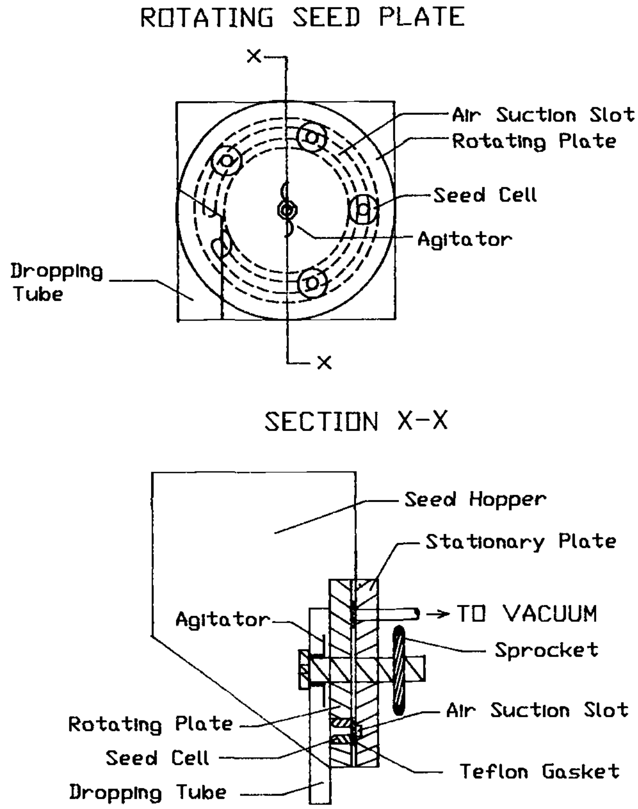

Figure 1–Schematic of the seed metering system.

EXPERIMENTS

Laboratory tests were conducted to evaluate the seed metering device for a number of seed types (and sizes), simulated terrain slopes, and simulated ground speeds. A special test stand was used to tilt the component to simulate terrain slope up to 50%. Fan speed was adjusted between 0 and 5000 rpm and ground speeds of up to 4.8 km/hr (3.0 mph) were simulated using a hydraulic motor drive unit. Static vacuum corresponding to each fan speed at the seed

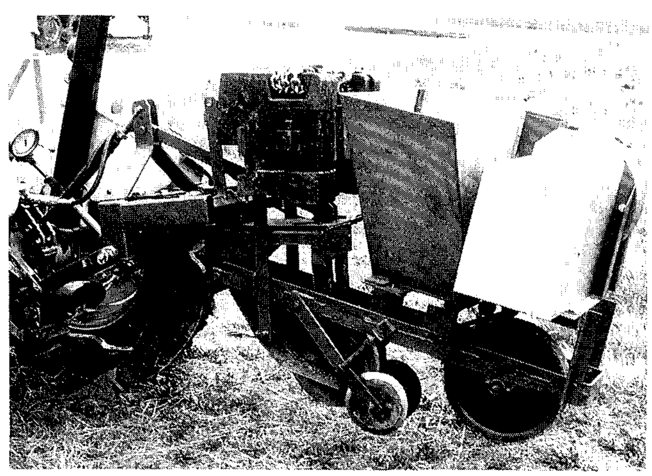

Figure 2–Tractor-mounted, no-till tree seeder.

cell openings was measuring using a Hooke gauge manometer.

A commercial seed monitor was installed to detect seeds which were metered. The seed plate drive assembly was set to obtain a seed spacing of 46 cm (18 in.). Triplicate 30-second trials were run at each slope-seed-fan speed combination with metering efficiency being recorded for each. The seed types tested were pin oak, red oak, bur oak, and black walnut.

The modified planter, equipped with the 61 cm (24 in.) diameter coulter, was tested on a reclaimed surface mine site consisting of sandstone/shale spoil of moderate slope (≤ 10%) with a vegetative cover. The site was located on a mine operated by Falcon Coal Company near Jackson, Kentucky. Red oak seeds were planted at an approximate spacing of 0.5 m and a ground speed of 2.4 km/h (1.5 mph). Metering accuracy was determined by counting seeds removed from the hopper and accurately measuring the length of each row. Approximately 2500 seeds were planted and each row was examined for depth of seed placement and coverage.

RESULTS

LABORATORY METERING TESTS

The results of metering tests for pin oak seeds are summarized in Table 1. The average seed diameter was 1.70 cm (0.66 in.) with a standard deviation of 0.13 cm (0.051 in.). The 0° angle corresponds to the horizontal position (with seed plate vertical). At the slower simulated ground speeds excellent metering accuracies were determined for slower fan speed (lower vacuum). As ground speed increased, higher fan speeds were required to achieve high metering accuracy. At the highest ground speed (4.8 km/hr (3.0 mph)), successful metering occurred only at the highest fan speed of 4500 rpm.

The + 30° angle represents the situation in which the axis of the metering plate was inclined above horizontal (i.e., tilting the seed hopper "upslope") and simulated a terrain slope of 58%. The best metering results were achieved 3.2 km/hr (2.0 mph) and 3000 fan rpm. This resulted because the critical element in the metering operation at this slope was that of seeds dropping from the cells into the delivery tube. Cell cavities were bevelled at 45° included angle so seeds could escape via gravity when vacuum was interrupted at the drop point. Higher fan speeds hindered release due to excessive vacuum whereas higher ground speed hindered release due to insufficient time for seeds to drop out of the tube.

When the direction of inclination was reversed (tilt angle = -24°) the performance of the metering device changed markedly. The hopper and metering plate were inclined "downslope" simulating operation on a terrain slope of 45%. In this situation the critical aspect of metering performance was capturing seeds in the cells and retaining them until reaching the drop point. As simulated ground speed increased the required fan speed for acceptable metering increased.

Table 2 presents the results of tests involving red oak seeds. The average seed diameter was 2.11 cm (0.83 in.) and the standard deviation was ± 0.20 cm (0.077 in.). The results were very similar to that of the pin oak seeds. In the horizontal position acceptable metering was achieved for all ground speeds up to 4.8 km/h (3.0 mph), however, required fan speed increased with ground speed.

For the positive 30° inclination, acceptable metering occurred up to 4.0 km/h (2.5 mph) ground speed. Greater

TABLE 1. Results of laboratory tests of the seed metering device using pin oak tree seeds, percent of seeds metered

Inclination angle = 0°

Ground speed (km/h)	Fan speed (rpm) [Static vacuum (cm water)] 2000 [5.89]	2500 [9.67]	3000 [13.94]	3500 [18.72]	4000 [24.14]	4500 [30.18]
Inclination angle = 0°						
1.60	87.8	95.9	94.9	99.0	100.0	**
2.41	64.6	91.3	98.7	98.7	99.5	**
3.20	0.0	69.3	96.7	97.3	100.0	**
4.03	0.0	58.5	74.5	90.4	96.2	99.4
4.82	0.0	0.0	0.0	0.0	92.9	97.3
Inclination angle = + 30°						
1.60	85.8	86.8	85.8	90.9	83.7	**
2.41	96.5	93.5	93.5	93.5	94.3	**
3.20	0.0	96.7	97.8	92.4	91.9	89.2
4.03	0.0	90.8	90.0	91.6	88.3	73.2
4.82	0.0	0.0	0.0	0.0	0.0	0.0
Inclination angle = -24°						
1.60	31.7	56.1	90.9	94.9	95.9	**
2.41	15.9	33.3	84.8	99.3	**	**
3.20	0.0	18.3	26.9	50.5	85.5	97.3
4.03	0.0	7.1	10.0	32.2	86.6	92.6
4.82	0.0	0.0	0.0	0.0	0.0	86.6

**Test not conducted.

TABLE 2. Results of laboratory tests of the seed metering device using red oak tree seeds, percent of seeds metered

Inclination angle = 0°

Ground speed (km/h)	Fan speed (rpm) [Static vacuum (cm water)] 2000 [5.89]	2500 [9.67]	3000 [13.94]	3500 [18.72]	4000 [24.14]	4500 [30.18]
1.60	80.6	93.5	95.7	95.7	97.7	100.0
2.41	0.00	96.1	97.6	100.0	**	**
3.20	0.0	0.0	89.6	96.2	99.0	**
4.03	0.0	0.0	0.0	82.8	99.2	**
4.82	0.0	0.0	0.0	0.0	94.7	99.0
Inclination angle = + 30°						
1.60	0.00	99.0	100.0	100.0	99.0	110.0
2.41	70.0	96.9	98.4	96.9	97.6	100.0
3.20	0.0	0.00	94.6	99.0	96.7	95.2
4.03	0.0	0.00	92.4	94.1	97.1	96.2
4.82	0.0	0.0	0.0	0.0	0.0	0.0
Inclination angle = -24°						
1.60	0.0	64.6	86.1	99.0	97.9	**
2.41	0.0	20.9	69.3	96.1	98.4	**
3.20	0.0	0.0	41.0	71.9	95.2	97.3
4.03	0.0	0.0	0.0	20.02	89.4	92.6
4.82	0.0	0.0	0.0	0.0	0.0	86.6

**Test not conducted.

vacuum at higher fan speed adversely affected seed release and drop from the cells to a lesser extent than occurred for the pin oak seeds. This is probably explained by the additional mass and corresponding centrifugal force assisting seeds in escaping from the cells at the drop point. Similar results to that of the pin oak tests were also obtained at the negative 24° inclination. In this configuration, the best metering was achieved with intermediate fan speeds at slower ground speeds. At ground speeds ≥ 3.2 km/h (2.0 mph), the best metering occurred at the maximum fan speed of 4500 rpm. As with the pin oak seeds, the higher vacuum was necessary to capture and retain seeds in the cells until reaching the drop point.

A limited number of bur oak seeds (average diameter of 3.20 cm (1.19 in.), standard deviation of 0.24 cm (0.95 in.) were utilized in testing the metering device. Table 3 indicates successful metering occurred in the horizontal position at ground speeds up to 3.2 km/h (2.0 mph). Insufficient vacuum was available to capture and retain the larger heavier seeds in the cells at the highest ground speeds tested.

Satisfactory metering (≥ 80%) of the bur oak seeds could not be achieved in either of the inclined configurations. Failure occurred in part because of improper configuration of the seed cell cavities. The cavities were bevelled as for other seed sizes at an included angle of 45°. At the positive inclination, seeds were captured in the cells at high fan speed but failed to drop due to jamming or wedging into the base of the cavities. At the negative inclination an insufficient number of seeds in the hopper resulted in limited exposure to the rotating seed plate and, thus, no valid determination of performance could be made.

Metering tests were also attempted using black walnut seeds with the exterior seed coats or hulls removed. The seeds were characterized by a nominal diameter of approximately 3.81 cm (1.5 in.) extremely rough irregular surfaces and oblong shape. These seeds were characterized by extreme bridging in the hopper and no cell cavity shape was found that resulted in successful metering. Results indicated that these seeds will require some type of pretreatment which would reduce surface roughness before successful metering could be achieved with this device.

Field Tests

The overall metering efficiency observed during the field trials was approximately 95% and strictly based upon the ratio of seeds actually dropped to the maximum possible for a given trial, i.e., the number of seed cells passing the drop point. The metering accuracy was encouraging for a first trial; however, the seeder was operated on a mild slope (≤ 10%) at a relatively low ground speed (≤ 2.4 km/hr) (1.5 mph). Also, some instances were noted of uneven seed spacing, poor penetration of the furrow opener, and poor coverage of seeds by spoil. It was concluded that the metering performance was encouraging, but that furrow penetration, depth of seed placement, and seed coverage by surface material was unsatisfactory.

The 0.61 m (24 in.) diameter coulter was replaced by a 1.17 m (46 in.) parabolic tine to improve penetration. Tests indicated this arrangement resulted in sufficient penetration of the furrow opening device without the necessity of excessive ballast weights. Depth of seed placement and seed coverage were also noticeably improved.

TABLE 3. Results of laboratory tests of the seed metering device using bur oak tree seeds, percent of seeds metered

Inclination angle = 0°

Ground speed (km/h)	Fan speed (rpm) [Static vacuum (cm water)] 2000 [5.89]	2500 [9.67]	3000 [13.94]	3500 [18.72]	4000 [24.14]	4500 [30.18]
1.60	**	0.0	100.0	100.0	**	**
2.41	**	**	92.9	94.3	97.9	100.0
3.20	**	**	59.0	92.2	93.8	100.0
4.03	**	**	**	**	**	96.0
4.82	**	**	**	**	0.0	0.0

**Test not conducted.

Future Development

Additional development and laboratory testing must be conducted to identify optimum cell cavity configuration for the larger bur oak and black walnut seeds. The latter seed type will be pretreated to reduce surface roughness.

Additional field testing is required to verify that the large ripper tine will result in adequate, controllable penetration of the double-disk furrow opener in all soil conditions. Further work is needed to evaluate the viability of this seeding method in terms of successful establishment of seedlings. Although the results reported herein characterize the performance of the metering system under static conditions in the laboratory, further testing is also needed to determine that these metering accuracies can be duplicated under dynamic conditions at similar slopes and ground speeds.

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