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A Mechanical System for Soil Reconstruction

John Patrick Fulton
University of Kentucky, jfulton@bae.uky.edu

Larry G. Wells
University of Kentucky, larry.wells@uky.edu

Timothy D. Smith
University of Kentucky

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J. P. Fulton, L. G. Wells, T. D. Smith

ABSTRACT. *One of the most perplexing problems associated with reclaiming surface–mined lands is excessive compaction of soil due to the heavy earthmoving equipment used during the reclamation process. Over the years, some innovative material handling schemes have been devised to limit vehicle traffic during reclamation on reconstructed soil. However, final grading operations can often create root–limiting bulk densities, which affect plant growth and yield. The purpose of this article is to describe a mechanism designed at the University of Kentucky whereby mine soil can be reconstructed without introducing compaction caused by surface traffic in order for the soil to sustain desirable plant life. The soil handling process for this prototype mechanism is also described. The prototype soil forming mechanism is mounted on the front of a conventional bulldozer. Soil and other rooting media are placed atop graded spoil in long, narrow windrows by scrapers or trucks. As the bulldozer pushes its blade into the windrow, material rises up onto the blade and an auger grinds and displaces soil perpendicular to the direction of dozer travel. The agitated soil is then deposited and leveled in an adjacent berm by the auger. Successive parallel passes of the mechanism results in the construction of a non–compacted rooting layer. Preliminary testing of the prototype yielded a soil construction rate of 330 m^3/h (430 yd^3/h), which was 12% of the projected theoretical design capacity [2680 m^3/h (3500 yd^3/h)]. Though the measured capacity is much lower than anticipated, it is believed the actual capacity of the prototype can be increased to 900 m^3/h (1177 yd^3/h) which would be an acceptable soil forming capacity at most mine sites.*

Keywords. *Reclamation, Surface mining, Soil handling system, Reclamation equipment.*

For years, many agricultural communities faced the problem of having coal reserves overlain by productive cropland. Bernard (1979) predicted that coal surface mining may involve as much as 182,100 ha (450,000 acres) in the Corn Belt by the year 2000, with approximately 51,400 ha (127,000 acres) involving prime farmland. Another report published in 1979 estimated 20 million ha (48.5 million acres) of prime farmland was underlain by strippable coal reserve base (Harper, 1979). It has been recently estimated that approximately 10% of this land has been mined (Vories, 1997); leaving over 16 million ha (40 million acres) of potential mineable prime farmland. The Surface Mining Control and Reclamation Act of 1977, Public law 95–87 (SMCRA, 1977) requires separate removal of topsoil and subsoil, the stockpiling of these horizons separately as necessary, and reconstructing soil as excavated. The federal act also states that mined prime farmland must be capable of supporting successful re–vegetation based on pre–mining crop production from approved reference areas or other similar procedures which pertain to reclamation.

Reclaiming surface mined lands often results in excessive compaction of soil caused by heavy excavation equipment used during the soil reconstruction process. The typical reclamation process involves the transporting and placing of soil via trucks or scraper pans and then using bulldozers for final grading. These earthmoving vehicles are extremely heavy and create compaction problems as they continually move across the soil. Controlling traffic patterns helps to an extent, but final grading with small bulldozers can still create a level of compaction, which hinders plant growth, a problem that faces reclaimed farmland areas. Consequently, reduced production capabilities of soil occur due to the poor physical condition of soil after reconstruction.

Jansen et al. (1985) and Dunker et al. (1991a) reported that the physical properties of reconstructed soils are the major factors affecting crop performance. The physical state of reclaimed soil is a direct result of the method and equipment used for soil replacement. Earthmoving equipment applies large surface pressures, which results in an increase in soil density (Dollhopf and Postle, 1988). One of the major limiting factors in trying to reach pre–mining productivity is excessive soil compaction.

The degree and depth of compaction varies with the reclamation practices used to reconstruct mine soils (Vance et al., 1987). Compaction generally produces an undesirable condition which influences plant growth by opposing root development, nutrient and water uptake, and proper aeration. Chancellor (1977) reported that the two plant growth factors most affected by soil compaction are seedling emergence and root development. Consequently, these two factors ultimately affect plant yields and plant stand establishment. Nielson

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The authors are **John P. Fulton**, **ASAE Student Member**, Agricultural Engineer, **Larry G. Wells**, **ASAE Member Engineer**, Professor, and **Timothy D. Smith**, **ASAE Member Engineer**, Agricultural Engineer, Department of Biosystems and Agricultural Engineering, University of Kentucky, Lexington, Kentucky. **Corresponding author:** Larry G. Wells, 128 C.E. Barnhart Building, University of Kentucky, Lexington, KY 40546–0276; phone: 859–257–3000 ext 219; fax: 859–257–5671; email: lwells@ bae.uky.edu.

and Miller (1980) compared corn yields on strip–mined soils and native soils. They reported that yields were reduced 4 to 90% on mined soils, depending upon topsoil application and age. Such a reduction in soil productivity, compared to pre–mining conditions, is important to coal mining operators since this may constitute failure to comply with prime farmland reclamation requirements in accordance with SMCRA (1977) and, as such, would require forfeiture of a substantial cash surety bond required before issuance of the mining permit.

Deep tillage and other soil loosening procedures have been implemented after reconstruction to improve soil productivity, but none have been fully successful. Research on reconstructed mine land has demonstrated that deep tillage improves yield, especially in corn, and that yield increased with tillage depth (Bledsoe et al., 1992; Dunker et al., 1992a). Dunker et al. (1992a) produced yields at 122–cm (48–in.) tillage depth comparable to an undisturbed plot in three of four years and equaled the adjusted target yield for the county in all four years. However, other research has shown minimal benefit of deep tillage for short periods. Gaultney et al. (1982) found subsoiling was ineffective in reducing the effects of compaction on silt loam soil in Indiana. After an area has been tilled, the tilled soil can return to its compact state. Barnhisel (1988) reported a tendency for bulk density to increase over a period of two years in both ripped and non–ripped areas. Elkins et al. (1983) also noted that subsoiling has short–term benefits but undesirably mixes soil horizons. Subsequent cultivation operations requiring machinery traffic, along with the natural settling of the soil particles, can lead to a reduction on pore space that was created by deep tillage (Larney and Fortune, 1986; Kouwenhoven, 1985). Therefore, some soils may require yearly subsoiling to help reduce soil strength and bulk density and enhance plant growth. Additionally, deep tillage requires large amounts of power and can become economically infeasible if required on an annual basis.

Some innovative material handling schemes have been devised to limit vehicular traffic on reconstructed rooting media or subsoil (B–horizon). Dunker et al. (1991b) proposed a process using large dump trucks to back–fill a mined area. Dump trucks would be loaded by filling the front with topsoil and the rear with subsoil. The mixture would then be back–dumped onto a graded spoil base, allowing most of the topsoil to remain at the top of the soil pile. By replacing the topsoil and subsoil with a single dump, the subsoil material would not be subjected to continual traffic. Using light dozers for final surface grading would minimize surface traffic, but still could create bulk densities that impede plant growth.

Another method utilized a large mining wheel–conveyor–spreader system, developed in Germany, to transport soil onto graded spoil. These large bucket wheel excavators removed and mixed the A and B horizons. A rotating bucket dug soil from an embankment and a belt conveyor then transported the mixed soil horizons to a spreader that placed it onto graded spoil. The use of this type of system still requires minimal grading (Dunker et al., 1992b; McSweeney et al., 1987). Dunker et al. (1992b) showed that this method produced productive soils upon completion of reclamation, but proved to be too costly for use in most surface mining situations, especially small mines found in the Midwest. Soils reconstructed by the wheel–conveyor produced higher yields than those replaced by scrapers (Dunker et al., 1992b) and produced four–year average yields as good as those on natural soils (McSweeney et al., 1987).

As prime farmland continues to be mined, a technique, device, or combination is needed to help mining companies return land to its pre–mining state or an enhanced state so farmers may once again produce crops. The ability of such lands to produce food and fiber needs to be protected to the maximum extent possible for the benefit of society. Therefore, the objectives of this article are 1) to describe a prototype mechanism for reconstructing soil for agricultural lands without introducing surface traffic following surface mining, 2) to describe the soil handling method to be used with this mechanism, and 3) to perform preliminary capacity tests. Since this mechanism provides a new concept for soil reconstruction this article will only present the development and some preliminary testing of the prototype. A subsequent article will present the results of experiments designed to determine soil formation capacity (m^3/h) and the physical condition (bulk density and soil cone index) of soil constructed by the prototype, in comparison to current surface mine reclamation of prime farmland.

Design Solution

The solution concept proposed for reconstructing soil after surface mining without detrimental traffic compaction is illustrated in figure 1 and is called the 'Soil Regenerator.' A powered auger is placed immediately in front of a conventional bulldozer blade. The elevation of the auger relative to the bottom of the blade is adjustable. The auger serves three purposes. First, the auger agitates and breaks up dense soil through its spiraling action. Secondly, it transports soil from in front of the blade and deposits it in a berm adjacent to the windrow. Finally, the action of the auger aids in leaving a level berm.

An auxiliary engine was utilized to power the auger so as not to diminish the power available to the running gear of the bulldozer. A hydrostatic transmission was used to drive the auger system since it safely transferred the required power plus it provided infinite auger speed adjustment.

The intended systemized soil handling process for the soil regenerator starts by placing soil or other rooting media atop graded spoil in long, narrow windrows [approximately 46 cm (18 in.) high × 3.7 m (12.0 ft) wide] with scrapers or dump trucks (fig. 2). As the bulldozer pushes into such a berm or windrow, material rises up the blade where an aggressive auger grinds and displaces the material perpendicular to

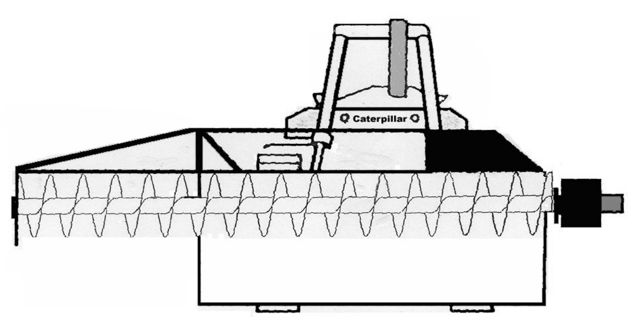

Figure 1. Front view of bulldozer showing the auger mounted in front of the blade.

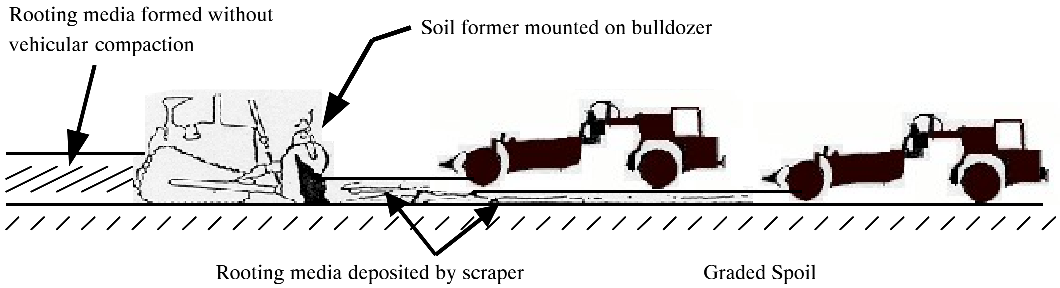

Figure 2. Side view of proposed mechanism loosening and reconstructing soil deposited in a windrow by scrapers.

the direction of bulldozer travel. The disturbed soil is deposited and leveled in an adjacent berm to one side of the bulldozer, which is narrower and deeper [approximately 1.1 m (3.5 ft) deep and 1.2 to 1.8 m (4.0 to 6.0 ft) wide]. Once a berm of subsoil is reconstructed, the same method is implemented to place topsoil on top of the subsoil prior to formation of the next berm. It is expected that in most prime farmland regions, 30 cm (12 in.) of A–horizon will be placed over 91 cm (36 in.) of B horizon. Successive parallel passes of the mechanism results in the construction of a non–compacted rooting layer (fig. 3).

A primary goal of the design was to minimize cost, thus a mechanically driven auger was designed to mount on a bulldozer. Bulldozers are used extensively in surface mining to move earthen material. To function as such, they are built with high power output and in various sizes. Most mines use two to three bulldozers to complete sub– and topsoil reconstruction when a site is labeled as prime farmland. Thus, this final grading operation could be replaced by the proposed system requiring a single bulldozer. A Caterpillar D7 bulldozer was made available for this research and therefore formed the basis of the soil regenerator.

Preliminary Design

A heuristic model of a Caterpillar D7 dozer blade was fabricated to demonstrate and evaluate the proposed concept. The model was mounted on a movable carriage, which operated on a 1.2 m (4.0 ft) wide laboratory soil bin. A model blade was fabricated 25.4 cm (10.0 in.) high and 73.7 cm (29.0 in.) wide to span approximately 60% of the soil bin. This resulted in a geometric scaling factor of approximately 0.2 relative to a full size D7 bulldozer blade. A 10.2 cm (4.0 in.) diameter × 106.7 cm (42.0 in.) long auger was mounted in front of the blade (fig. 1). Mounting was such that different auger heights, relative to the blade, and blade angles could be tested. The auger was driven by a variable speed 3/8–kW (1/2–hp) electric motor at an angular velocity of 120 rpm.

A Maury silt loam soil was first deposited in the soil bin and graded to a level surface to simulate graded spoil at a reclamation site. Then a long narrow windrow or berm of loose soil, 51 cm wide × 20 cm deep (20 × 8 in.), was placed along one side of the bin. The blade was positioned to push into this berm and force soil into the rotating auger. As the blade engaged the soil, the soil built up in front of the blade until the auger started conveying it perpendicular to the movement of the blade, forming another level berm beneath the portion of the auger extending beyond the end of the blade. Forward speed, volume of soil required to form the newly constructed berm, and accuracy of soil placement were recorded during trial runs.

The results were promising. When enough soil built up in front of the blade, the auger deposited soil in a level, uniform berm approximately 15 cm (6 in.) deep. It appeared that the open auger design would convey to about 90% of its total volumetric displacement or fill to approximately 90% of its cross–section; whereas most helicoid augers enclosed by shielding will only transport approximately 45% of their cross–section volume. The open design allowed more material to enter the auger and therefore transport a higher percentage of its volume. Because soil encountered in field testing would be denser (potentially rocks, wet soil, and very dense soil), the assumption was made to use 60% conveyance for designing the full–scale prototype. We reasoned that the auger would not be capable of conveying a higher percentage of material under actual field conditions.

The model demonstrated that the proposed system had potential to reconstruct soil without the introduction of surface traffic. The key to constructing a uniform berm was matching the appropriate volume of soil in the windrow to that of the fill zone or constructed soil berm. The time rate

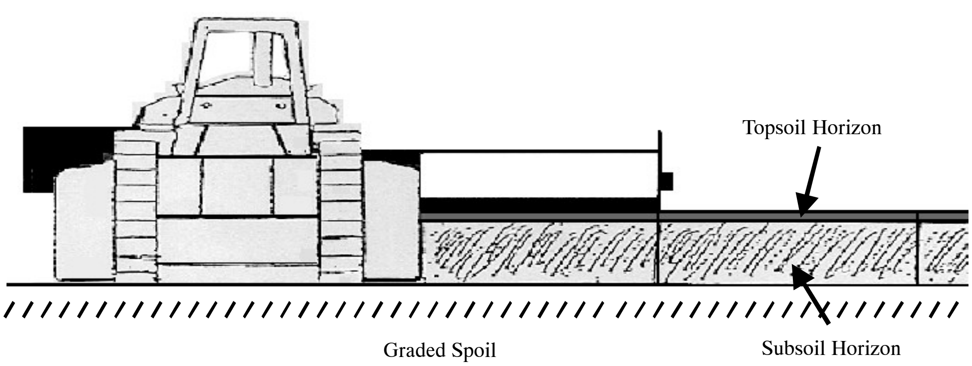

Figure 3. Rear view of soil forming mechanism showing soil placement from successive parallel passes.

of deposition was calculated by taking a cross sectional area of the windrow and recording the forward velocity. It was estimated that the heuristic model required 1/4 kW (1/3 hp) to form soil at a rate of 14.0 m^3/h (18.3 yd^3/h). This information provided the estimate of power per unit volume displacement rate and made it possible to estimate the power requirement of the full–scale prototype.

Performance Criteria

Preliminary calculations indicated that the prototype system would form soil at the rate of approximately 2680 m^3/h (3500 yd^3/h). This projected soil forming capacity was based on processing a soil berm 45 cm high × 365 cm wide (1.5 × 12 ft) at a bulldozer speed of 1.6 km/h (1.0 mph). Working on a cycle time of 3 min, nine 15.3–m^3 (20.0–yd^3) scrapers would be required to deliver material at the production rate of the mechanism. The system could also support three 76.5–m^3 (100.0–yd^3) dump trucks operating on a 5–min cycle time. Thus, several large–capacity earthmoving vehicles would be required to deliver material faster than could be processed by the proposed system, and thus, it appeared that the system would exceed the capacity of most post–mining reconstruction operations.

The calculated results from the heuristic model led to the sizing of components for the full–size prototype system. Based on the 60% conveyance by the auger and 2680–m^3/h (3500–yd^3/h) capacity, a 5.5–m (18.0–ft) long helicoid auger with a 91.4–cm (36.0–in.) outside diameter (OD) and 61.0–cm (24.0–in.) pitch was designed. The 5.5–m (18.0–ft) length was selected by using the cross–sectional area of the projected windrow and assuming an average berm formation depth of 91 cm (36 in.) deep and a bulldozer blade width of 3.7 m (12.0 ft). Therefore, based on these criteria and to achieve the projected capacity, the auger speed must be approximately 180 rpm.

Proportional scaling from the heuristic model results predicted a power requirement of 48 kW (64 hp) to achieve the theoretical required capacity of 2680 m^3/h (3500 yd^3/h) for the full–scale prototype system. However, to compensate for more compact material during infield operations, a hydrostatic auger drive system was designed to produce a maximum output power of 75 kW (100 hp) at 180 rpm.

The maximum torque needed to turn the auger was calculated using 75kW and 210 rpm; considered the maximum speed required at anytime. The resultant torque was 3390 N·m (2500 ft·lb). It was assumed that this torque remained constant over the entire speed range of the auger, whereas, power changed as speed fluctuated. A maximum thrust force generated by the auger under maximum load was calculated to aid in designing the auger's support structure, bearings and other relevant components using the assumed theoretical constant torque of 3390 N·m (2500 ft·lb). A tangential force of 7430 N (1670 lb.) was calculated for the auger. Transforming this force into a force along the axis of the auger by using the angle of the helix produced a maximum theoretical thrust load of 35.0 kN (7860.0 lb).

The height of the bottom of the auger above the ground was set to be minimally adjustable between 76 and 122 cm (30 and 48 in.). This range corresponds to the projected 91–cm (36–in.) depth of subsoil with another 30 cm (12 in.) of topsoil. As a result, the mechanism should reconstruct soil in accordance with federal and state regulations provided that the spoil has been graded to proper topography.

Prototype

Fabrication of the prototype occurred in the Agricultural Machinery Research Laboratory (AMRL) at the University of Kentucky, Lexington, Kentucky. Figure 4 shows the fabricated soil regenerator. The soil regenerator system was mounted on a Caterpillar D7 bulldozer rated at 150 kW (200 hp) [with 134 kW (180 hp) available for propulsion]. With a maximum power requirement of 75 kW (100 hp) for the auger, an auxiliary engine was needed to drive the auger system. However, enough power was available from the bulldozer engine to operate auxiliary hydraulic actuators for controlling auger height.

The bulldozer was equipped with a semi–universal (SU) 3.3–m (10.9–ft) wide blade, which was modified from its original configuration to provide for lateral soil displacement (fig. 5). The curved right side of the blade was straightened to facilitate soil movement to the right (the side where the auger deposited soil). To help retain soil in front of the blade during operation, its height was increased to 1.7 m (5.5 ft). The final fabricated blade width was 3.4 m (11.0 ft). A left–side helicoid auger with an OD of 91.4 cm (36.0 in.) and a pitch of 61.0 cm (24.0 in.) was fabricated 5.5 m (18.0 ft) in length to extend approximately 2.2 m (7.0 ft) beyond the right end of the modified blade.

A D333C (3306), 6–cylinder Caterpillar engine was used to drive the auger and other hydraulic components. The engine was rated at 163 kW (219 hp) at a speed of 2200 rpm. The engine was mounted at the rear of the bulldozer so not to obscure the operator's visibility. The fuel tank, along with the battery and alternator on the bulldozer provided fuel and power to start the engine.

A hydrostatic system was selected to provide a maximum of 75 kW (100 hp) to the auger. A hydraulic drive provided infinite control over motor speed, reversibility, and dynamic braking. The motor and pump combination was selected such that both performed at optimum efficiency at 2200–pump rpm and 3600–rpm motor speed. A 20:1 gear reducer with spindle drive was selected to provide the desired auger speed and torque to the auger. It was directly coupled to the auger by a spindle and flexible drive coupling. The hydrostatic transmission consisted of a 55.0 cm^3 (3.35 $in.^3$) fixed displacement, axial piston motor and a 100.0–cm^3 (6.10–$in.^3$) variable displacement axial piston pump manufactured by Sauer–Sunstrand. The pump was connected directly to the flywheel of the auxiliary engine by a Funk single pump drive.

Figure 4. Soil regenerator.

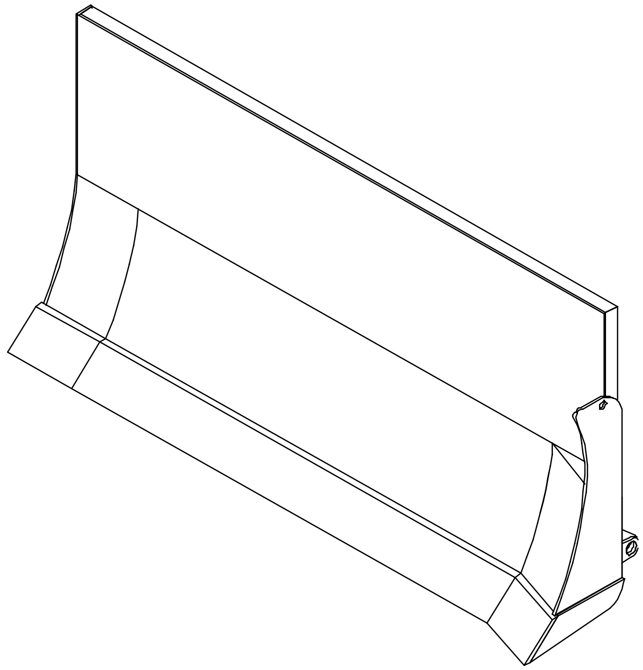

Figure 5. Isometric view of modified blade.

A support structure was designed and fabricated to mount the auger and drive system on the bulldozer. Figure 6 shows the structure, auger, and drive components along with the modified blade. The auger support structure was mounted on the side arms of the bulldozer. The central element of the structure was the main support beam, which is shown with left and right end plates. The main framework of the structure was constructed of steel tubing with steel plating used for mounting the bearing and gear reducer. A stress analysis program was used to determine the appropriate size for the structure components. Due to the large thrust force generated by the auger, a wear plate was added between the structure and blade to transfer this lateral force to the blade. The beam was connected to left and right support arms via quick couplers that allowed the main beam and auger assembly to be detached from the arms for transportation. A removable diagonal–support member reinforced the cantilevered side of the main beam, which extended beyond the right end of the blade. The gear reducer and hydrostatic motor were mounted rigidly to the left end plate. The auger was then connected to the gear reducer via a specially designed flexible coupler, which permitted any misalignment between shafts, yet transmitted the necessary thrust force during soil conveyance.

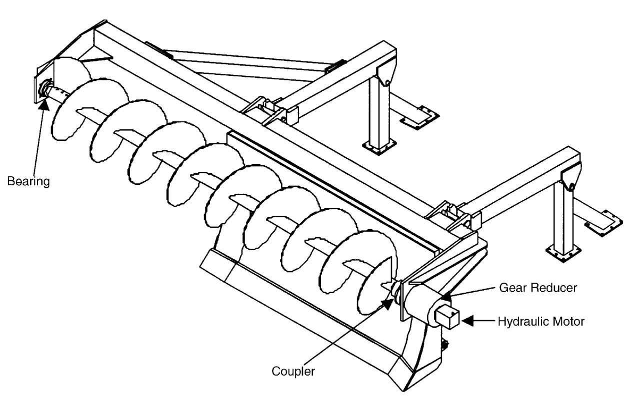

Figure 6. Isometric view of support structure, auger, and drive components.

Two hydraulic cylinders in series were used to adjust the vertical position of the auger. The cylinders insured synchronized movement of the two sides of the structure during extension and retraction. The system consisted of a master cylinder controlling one side and a slave cylinder controlling the other side. The rod end area of the master cylinder equaled the bore area of the slave cylinder. The blade tilt–cylinder hydraulic system on the bulldozer was used to actuate the series cylinders.

Preliminary Testing

Preliminary field testing was conducted between 15 June and 6 July 1998 at the University of Kentucky Animal Research Center (ARC) near Versailles, Kentucky. The goal of the testing was to assess the soil forming capacity of the prototype, to learn how to operate the system, and to verify a soil construction procedure that could be evaluated at a surface mine site. An open, level field was selected as the testing site. Testing consisted of using a Maury silt loam soil, which was readily accessible at the ARC. The moisture content of the soil ranged between 10 to 20%. A scraper owned by the University of Kentucky was used to construct windrows of soil.

Soil handling occurred by placing soil in front of the machine. The scraper pan was used to deposit soil at a nominal width and depth of 3.7 and 0.3 m (12.0 and 1.0 ft), respectively (fig. 7). The soil regenerator was then used to process the entire windrow of soil. Multiple runs were made at approximately 45 m (148 ft) in length. Perimeter restraints of the area did not allow for longer runs.

Different windrow depths were examined up to 80 cm (30 in.) to see how the machine would react. The original intent was to make one pass, but the system was unable to displace the entire 3.7 m (12.0 ft) windrow with one pass and created too many problems. To construct a uniform berm, two passes with the machine were required to displace an entire windrow. The first pass consisted of taking a half blade width [1.8 m (6.0 ft)] and displacing this material on top of the remaining windrow. Several benefits resulted from making this initial pass. The auger loosened soil beneath one tire track left by the scraper, which reduced the overall force

Figure 7. Scraper constructing a windrow of soil.

to push material. Material was also transported closer to its final berm position since the auger extended beyond one end of the blade. Additionally, it was easier to keep the blade horizontal to the ground (base material) during operation, not allowing one corner to cut deeper than the other. The elevation of the auger axis was set relative to the top of the blade, but if one side of the blade started cutting into the base material, then the auger became unlevel.

The second or final pass was then made with the mechanism to construct a berm of soil approximately 91 cm (36 in.) deep and 1.2 m (4.0 ft) wide of loosened soil (fig 8). Placing a new windrow roughly 1.2 m (4.0 ft) away from and parallel to the newly constructed berm repeated the process. Auger speed was adjusted occasionally when more or less material was needed at the fill zone. After deciding upon the two–pass procedure, a test run was executed to collect capacity and power measurements.

A windrow of soil, 3.7 m (12.0 ft) wide × 30 cm (12 in.) deep, was placed in a 30–m (98–ft) long strip by the scraper (fig. 7). This required approximately five loads using the 7.5–m^3 (9.8–yd^3) scraper. Two passes were made over the 30–m (98–ft) length to construct a berm. The auger speed was set at 130 rpm before starting. The hydraulic system pressure and auger speed were recorded using a video camera during operation. The video camera was mounted to monitor the digital displays for pressure and auger speed located in the operator's station on the bulldozer. The depth and width of the final displaced soil was measured at several locations along the constructed berm. The time required to make both passes was determined by analyzing the video film. In return, the rate of berm formation and auger power was calculated over both passes using the recorded information.

Results

Preliminary testing showed that controlling all aspects of the machine was cumbersome at times. The addition of the auger system generated two more tasks for the operator, varying auger speed and height, in addition to basic bulldozer operation. The soil regenerator was operated at a continuous slow pace to properly displace soil, with various adjustments needed during operation to facilitate the formation of a consistent berm. Non–uniformity of the windrows occurred since it was difficult to control the depth of spread by the scraper. This situation produced excessive or inadequate amounts of soil at the blade. The penetration of the blade into the base material also caused problems if one side of the blade started to cut deeper than the other. There was no blade tilt function on the bulldozer, since this system was rerouted for control of the auger height. These problems were addressed by making adjustments to one or more of the following machine control settings: blade height, position of the bulldozer relative to the windrow, ground speed, or auger speed.

Figure 8. Front view of soil regenerator making second pass.

As soil accumulated in front of the blade and slowed the bulldozer, the blade was raised to increase speed. Lowering the blade pushed more soil, which could stall the bulldozer by creating too much pushing force. Increasing engine speed provided more power to the tracks and helped at times, but sometimes caused an undesirable increase in ground speed. Driving too fast did not provide enough time for soil to reach the end of the auger and fill the berm evenly. A berm depression developed when the auger did not convey enough soil. Further, any height adjustment of the blade required an opposite modification in auger height to maintain a constant berm depth.

Changing the bulldozer heading increased or decreased the size of the fill zone to offset non–uniformity in the windrow. If a depression started to develop in the berm, the bulldozer was steered into the berm to reduce the size of the fill zone and keep the surface of the berm level. Conversely, too much soil transported to the fill zone created a mound at the end of the auger. Backing up usually provided the best approach to steer the dozer since it was difficult to turn when pushing a full blade of soil.

Windrows deeper than 30 cm (12 in.) only created problems for the bulldozer since it tried to deviate from its intended path and, at times, the magnitude of the soil being pushed caused the tracks to slip and stop forward progress. Therefore, 30 cm (12 in.) was chosen as the nominal depth to conduct testing. A speed of 130 rpm appeared to be the optimal speed for auger operation. Speeds exceeding 160 rpm only tended to throw material forward instead of transporting it to the fill zone.

Figure 9 presents a plot of the power required to operate the soil regenerator during construction of a soil berm at the Woodford County Animal Research Center. A total time of 5.42 min was required to make two passes. The pressure ranged between 3.5 and 18.3 MPa (508 and 2698 psi) and averaged 9.6 MPa (1392 psi). The pressure depended upon the amount of soil entering and then being conveyed by the auger. With the regenerator operating at full capacity, the system pressure remained at approximately 14 MPa (2000 psi) in constructing a uniform berm while maintaining a steady pace. Auger speed averaged 129 rpm for both passes.

Figure 9 shows the measured power required by the regenerator during the reconstruction of a soil berm [190 cm (74 in.) wide × 50 cm (20 in.) deep × 30 m (100 ft)]. Required power increased steadily during the first pass as soil accumulated in front of the blade and more soil was displaced laterally. The first pass required 1.6 min and approximately one half of the soil deposited by the scraper was displaced. The second pass required 3.8 min because more soil was being displaced to a greater depth while also maintaining a level berm surface, thereby reducing ground speed. Also, during the second pass, too much soil accumulated in front

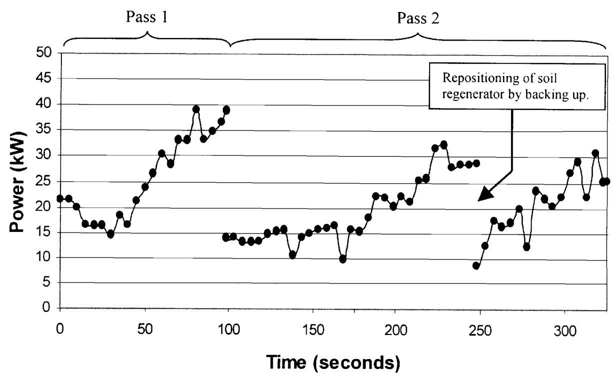

Figure 9. Measured power vs. time for two 30.5–m passes resulting in the deposition of a single berm (0.5 × 1.9 × 30 m).

of the blade, requiring the operator to stop, back up, and steer the bulldozer away from the berm.

The oscillation of power required by the auger shown in figure 9 was caused by variation deposited by the scraper. The average power required during the two passes was approximately 22 kW (20 hp), which was considerably less than the 75 kW (100 hp) available from the auger drive system. The soil used in the test was relatively loose and free of stones. Additional power would likely be required when reconstructing less ideal soil at the surface mine.

The volume of soil constructed by the regenerator during the two passes equaled 29.7 m^3 (38.8 yd^3) at an average speed of 0.3 km/h (0.2 mph). The resulting soil berm, 190 cm (74 in.) wide by 50 cm (20 in.) deep, was constructed at an average capacity of 330 m^3/h (430 yd^3/h). Measured capacity was slightly greater than 12% of the theoretical capacity of 2680 m^3/h (3500 yd^3/h). Slower speed [20% of the projected speed of 1.6 km/h (1.0 mph)] and a smaller fill zone (~66% of projected fill zone) contributed to the lower productivity. The ultimate goal was to make one pass and process a 30– × 370–cm (1.0– × 12.0–ft) windrow of soil. Such a displacement rate was impossible to achieve with the current configuration of the soil regenerator.

Modifications of the regenerator should increase the rate of soil reconstruction compared to that previously described. First, instead of being mounted perpendicular to the bulldozer axis of symmetry or direction of travel, the blade could be remounted at a small angle such that the forward motion of the bulldozer blade would displace soil laterally. Thus, the capacity of the auger would be more fully utilized in displacing and leveling soil beyond the end of the blade. Secondly, a hinged extension could be added to the right side of the blade whereby the effective width of the blade could be adjusted by extending or retracting a hydraulic cylinder. Such a blade extension would allow an operator to more easily control the flow of soil into the soil berm fill zone without leaving cavities or mounds on the surface when the volume of soil being displaced varies. Finally, mechanical stops could be inserted into the cylinders that lift the bulldozer blade to prevent the blade from tilting or being positioned below the bottom of the tracks. This would free the operator to control the height of the auger and the effective width of the blade.

We believe that implementation of these changes could result in displacement of a 30– × 370–cm (1.0– × 12.0–ft) windrow of soil in a single pass and that the average forward speed could increase from 0.3 to 0.8 km/h (0.2 to 0.5 mph. Such improvement would result in a soil reconstruction rate of 900 m^3/h (1177 yd^3/h), which in turn, would require nine 17–m^3 (22–yd^3) scrapers or three 57–m^3 (75–yd^3) dump trucks delivering loads of soil at a time in intervals of 10 min. Such a system could therefore reconstruct soil 1.0 m (3.3 ft) deep at the rate of approximately 1.0 ha/h (2.47 acre/h).

Summary

The development of this mechanism may provide a method to reclaim surface–mined sites. The system was designed to return land to valuable production without introducing compaction caused by surface traffic during reclamation. The mechanism should not increase costs to mining companies or require drastic changes in current reclamation methods since bulldozers are readily available at mining sites. As a result, the mechanism should reconstruct soil in accordance with federal and state laws provided that the spoil has been graded to proper topography as specified by applicable regulations.

Preliminary testing of the prototype system resulted in a soil construction rate of 330 m^3/h (430 yd^3/h). This soil construction rate was 12% of the projected theoretical capacity [2680 m^3/h (3500 yd^3/h)] of the soil regenerator. The lower capacity was caused by the necessity of making two passes to construct a soil berm rather the anticipated one pass, resulting in an average construction speed of 0.3 km/h (0.2 mph). In addition, a smaller berm was constructed reducing the capacity even further. We believe that a 30– × 370–cm (1.0– × 12.0–ft) windrow can be constructed and a speed of 0.8 km/h (0.5 mph) can be attained. Therefore, the resulting processing rate would increase to approximately 900 m^3/h (1177 yd^3/h) that would result in an acceptable soil forming capacity at most mine sites.

An additional function for this mechanism could be to incorporate organic materials and other soil amendments such as solid waste into the soil during the soil forming process. These byproducts could be placed or spread over the windrows of soil prior to reconstruction. The addition of such amendments would enhance the formation of soil structure and increase productivity. Such capability will make it possible for mining companies to return land to original productivity as required by the 1977 Federal Surface Mining Control Act.

Future work will consist of testing the prototype at a surface mine site. The rate of soil reconstruction using the prototype will be compared to that of the mining company's conventional reconstruction operation along with comparing the physical properties of the soil medium constructed by the prototype to that of soil reconstructed by the mining company.

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