CHAPTER III

DEVELOPMENT OF THE LABORATORY MODEL

Belknap silt loam subsoil is a prime farmland subsoil as identified by the Soil Conservation Service (1983). This soil type has been affected by surface mining in western Kentucky and was selected for the deep tillage model. The first 30.5 cm (12.0 in.) of topsoil was removed with a backhoe. The depth of subsoil excavation below the surface ranged from approximately 30.5 to 121.9 cm (12.0 to 48 in.). Approximately 3.8 m^3 (5.0 yd^3) of subsoil was deposited into an end-dump truck with a backhoe. Upon arrival at the laboratory, the soil was removed from the truck with hand shovels and transported with wheel barrows. The removal and transportation of the soil from the truck to the laboratory facilitated mixing of the soil profile.

This soil type was probably formed from the weathering of local sandstones, shales, and siltstones of the Upper Pennsylvanian Lisman Formation. The soil was collected on an open pasture area near a perennial tributary of the Green River (Thorofare Branch). The surrounding area is a rural farming community. Generally, the flood plain areas of the Green River are cropped. However, small tracts on the ridgetops are also farmed. The cleared prime farmland is currently being used as pastureland and may be occasionally cropped for hay. These prime farmland soils are not currently being cropped on a yearly basis.

Soil Information

The Belknap series is a deep, poorly draining soil formed in acid alluvium. Belknap is geographically associated with Vicksburg, Collins, and Waverly soils. The soil profile is described as follows (Soil Conservation Service, 1983):

- 0-20.3 cm (0-8.0 in.); silt loam; weak, fine granular structure; very friable; many roots.
- 20.3-30.5 cm (8.0-12.0 in.); silt loam; distinct light, gray mottles; weak, subangular blocky structure; very friable; strongly acid.
- 30.5-50.8 cm (12.0-20.0 in.); light, brownish-gray silt loam; faint, brown mottles; medium to coarse subangular blocky structure; very friable, strongly acid.
- 50.8-91.4 cm (20.0-36.0 in.); gray silt loam; pale-brown and yellowish-brown mottles; coarse, subangular blocky structure; very friable; strongly acid.
- 91.4-121.9 cm (36.0-48.0 in.); gray silt loam; dark- grayish brown mottles; weak, coarse, subangluar blocky structure; very friable; few black concretionary stains; strongly acid.

The color of the soil gradually changed from the initial excavation color of drab mottled grays, yellows and browns to the laboratory color of pale yellows and browns with orange and gray mottling. The excavation colors are an indication of a poorly drained soil. The laboratory colors indicate good aeration and oxidizing conditions. The bulk density of undisturbed Belknap subsoil is reported by the Soil Conservation Service (1991) to range from 1.25 to 1.50 g/cm^3. A range of 1.44 to 1.51 g/cm^3 is reported by Barnhisel (1986).

Proctor Compaction Test. The moisture-density relation of the soil was found (Commonwealth of Kentucky, 1979). A weight of 2.5 kg (5.5 lbs) was dropped from a height of 30.5 cm (12.0 in.) into a mold measuring 10.2 cm (4.0 in.) in diameter and 11.7 cm (4.6 in.) deep. The optimum mass moisture content for compaction purposes, for a standard compactive effort, was found to be

approximately 19.0 % and the maximum dry density was found to be approximately 1.72 g/cm³. See Figure 4 and Table 2. Similar results were reported for the same soil type (Ali, 1991).

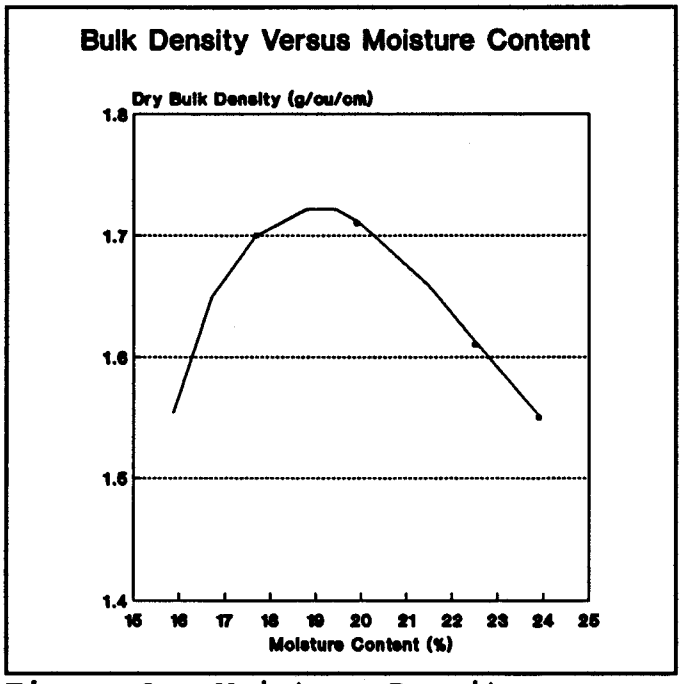

Figure 3 - Moisture Density Relationship

Table 2
Moisture Density Relationship

Density (g/cm³)	1.70	1.71	1.61	1.55
Moisture Content (%)	17.7	19.9	22.5	23.9

Particle Size Analysis. A particle size analysis was conducted by the Agronomy Department at the University of Kentucky. The standard used was developed by the United States Department of Agriculture, Soil Conservation Service (Soil Conservation Service, 1984). The model soil showed a particle size of 63.8 % silt, 23.4 % clay, and 12.8 % sand. Over half of the particles are of the size called "silt." This distribution of particle sizes defines the model soil as a silt loam. When dry it may appear cloddy, but the clumps can be readily broken, and when pulverized it feels soft and floury. When wet the soil readily runs together and puddles. (This description applies only to the silt loam in the undisturbed state.) Published particle size analysis for a Belknap silt loam, or similar soil, have not been located.

Clay Mineralogy. The mineral constituents of the model soil were determined by the Kentucky Geological Survey with the method of X-ray diffraction. The clay sized particles (< .002 mm) were prepared for mineralogical analysis according to the procedures described by Jackson (1964). The phenomenon of X-ray diffraction involves the scattering of X-rays by atoms of a crystalline mineral.

Since no two minerals have exactly the same interatomic distances in three dimensions, the angles at which diffraction occurs is unique for each mineral. The identified minerals were vermiculite, montmorillonite, illite, kaolinite, and quartz.

The kaolinite exhibits less plasticity, cohesion and swelling than most other clay minerals. The vermiculite and montmorillonite are expanding types of clay minerals. Because of this, the clay will exhibit swelling-shrinkage behavior, cracking, crusting, and have a high plasticity and cohesion. When drying, montmorillontic soils tend to form unusually hard clods. Illite exhibits properties of plasticity and cohesion in between that of kaolinite and montmorillonite, and is a nonexpanding type (Hillel, 1980).

Atterberg Limits. The liquid and plastic limits of the soil were determined with the method recommended by the American Society for Testing and Materials (1988), procedure D4318-84. The liquid limit is defined as the moisture content at the boundary between the liquid and plastic states. The plastic limit is defined as the moisture content at the boundary of the plastic and brittle states. The moisture content desired for most effective deep tillage falls within the brittle state. The plasticity index is defined as the difference between the liquid and plastic limits. This index is an indicator of the soil's ability to flow plastically and is a function of the type and amount of clay present (Hillel, 1980). The soil's plastic limit averaged 18.8 %. The soil's liquid limit was determined to be 28.1 %. The plasticity index was 9.3 %. This defines the soil as having low to medium plasticity and low to medium compressibility (Terzaghi and Peck, 1962). Published data for a Belknap silt loam with respect to Atterberg limits were not found.

Particle Density. The particle density of the model soil was determined to be 2.03 g/cm^3 (126.9 lb/ft^3). The American Society for Testing and Materials (ASTM), procedure D854-83, was followed (American Society for Testing and Materials, 1988). Published particle densities for a Belknap silt loam were not found.

System Components

In order to satisfy the research objectives, a physical model was developed in the laboratory. The major pieces of equipment used in this experiment were:

1) soil bin,
2) air pallet,
3) Giddings soil probe,
4) tillage tool: ripper,
5) air and material injection unit: sandblaster,
6) nuclear density/moisture gage,
7) cone penetrometer and data acquisition system, and
8) permeameter.

The first five components are shown in Figure 5 and will be discussed in this chapter along with the soil analysis equipment.

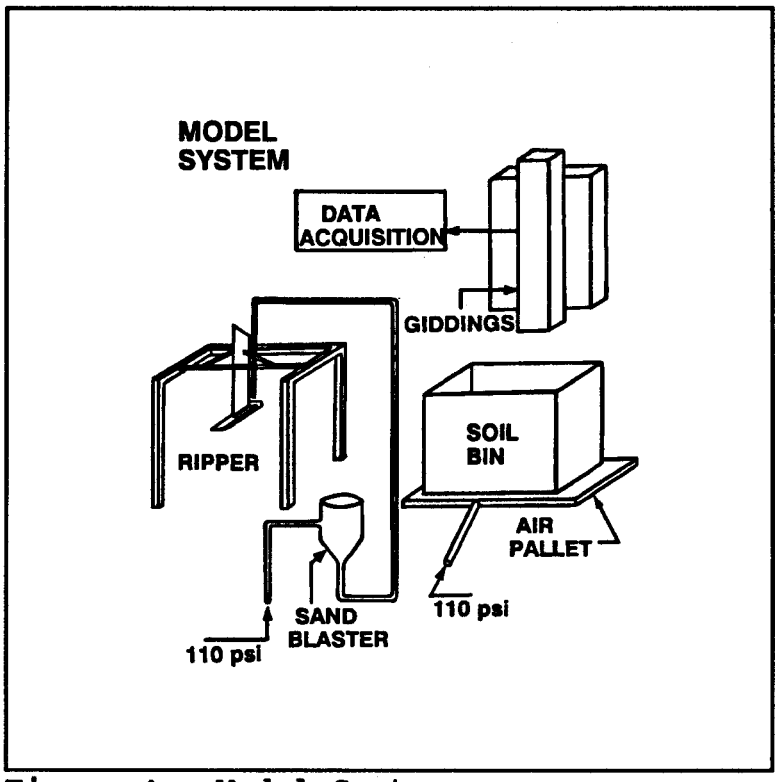

Figure 4 - Model System

Soil Bin and Air Pallet. A soil bin served as the containment unit and measured 91.4 cm by 121.9 cm (36.0 in. by 48.0 in.) in plan view and 91.4 cm (36.0 in.) deep. The bin was made of steel and designed to meet the needs of this project. The front and back panels were removable to facilitate soil removal. A small section was cut out of the front and back panel for ripper insertion and removal. The bin was positioned on top of an air pallet. The base of the pallet had four pads which provided an exit for pressurized air, which was applied in order to float and move the bin of soil. The bin was positioned with the air pallet as needed in order to compact the soil and to take soil samples and readings. When the bin was filled with compacted soil, its weight was 1.8 tonnes (2.0 tons).

Giddings Soil Probe. The Giddings soil probe was used for sampling for bulk density and hydraulic conductivity, driving the cone penetrometer, compacting and recompacting the soil. The maximum applied force was 22 kN (5000 lbs).

A flat plate was machined measuring 30.5 cm by 30.5 cm (12.0 in. by 12.0 in.) and 1.90 cm (0.75 in.) in thickness. The plate was threaded to a 2268 kg (5000 lb) pressure transducer, which was attached with a pin to the shaft of the Giddings. As the shaft was lowered, the soil was compressed under the plate. This resulted in activating the transducer, which sent a voltage to an amplifier and then to a computer to be digitally recorded. The maximum applied pressure available with the Giddings was 301.6 kPa (43.8 psi).

Tillage Tool Design. Due to the limited size of the soil bin, the volume of failure was determined in order to minimize the reaction with the bin walls. It was desired to leave a buffer of undisturbed area between the ripped zone and the bin walls. The important variables to be modeled were the ratio of the operating-depth-to-cutting-width of the ripping tool and angle of the ripper foot off the horizontal (rake angle). These two dimensionless ratios describe the phenomenon of soil failure. The area of surface disturbance was determined with the help of a mathematical model developed by Godwin and Spoor (1977).

The model ripping tool was selected to loosen the soil within the confines of the bin with an operating depth of approximately 30 cm (12 in.). To minimize the reaction with the bin walls, the edge of the surface disturbance extended approximately 30 cm (12 in.) on either side of the ripper. A buffer of undisturbed area, measuring approximately 40 cm (16 in.), was located between the bin wall and the ripped zone on each side of the ripper.

A standard farm implement (Fred Cain subsoiler) was selected. The ripper was mounted on a frame and pushed with a hydraulic cylinder which had a stroke of 91 cm (36 in.) and a maximum applied force of 218 Kn (49,000 lbs). The model ripper had a depth-to-width ratio of approximately 5.5 (i.e., 27.9cm/5.1 cm (11.0 in./2.0 in.)). Typically, the soil surface was approximately 2.5 cm (1.0 in.) below the top of the bin. The angle of inclination of the ripper leg and foot (as a rigid body) was adjustable. The angle between the leg and the foot was $.628\pi$ rad (113 $\circ$) (i.e., when the ripper leg is vertical, the ripper foot makes an angle of $.128\pi$ rad (23 $\circ$) off the horizontal). The ripper foot was machined with an inverted "V" shape at the rear. The material injection hose was located just above this inverted "V" shape to potentially enhance material dispersion into the crescent failure area, as shown in the figure discussed below. The ripper had a velocity of approximately 1.2 cm/s (.48 in./s), which may reasonably develop failure patterns similar to field ripping speeds, as discussed by Stafford (1979).

Air and Material Injection Unit Design. The function of the air and material injection unit was to fill the void space caused by deep tillage with material. If the filling of these cracks and crevices is effective in reducing or preventing recompaction, then initially the design should attempt to fill as many fractures as possible. However, it is unlikely that all of these voids will be filled by the injected material, since a direct path to the void may not be available. The porosity of the soil after deep tilling was found for the baseline trial and was used to determine the amount of injection material needed to fill all available void space created by deep tillage. A commercially available sandblaster, manufactured by Schmidt Mfg., Inc., was capable of delivering 21 kg (47 lb), or 70 % of the maximum design amount, of slag product during each ripping event.

The sandblaster is a tank in which pressurized air enters near the top and, working with gravity, forces material through the funnel-shaped outlet at the base. The material is then pneumatically conveyed through the hose. The base of the sandblaster was funnel-shaped with an angle of $.22\pi$ rad (40$\circ$) off the horizontal. A valve was located at the base of the sandblaster to meter material through the hose. The volume of the blaster was .04 m^3 (1.50 ft^3). The available laboratory air line pressure was 758 kPa (110 psi). The sandblasting hose was downsized with a tapered fitting so that the hose could fit behind the ripper leg. The hose outlet was located at the rear of the ripper immediately above an inverted "V" shape, which was machined on the ripper foot. To prevent an excess of material exiting the path of the ripper, a shield was also machined as a part of the ripper foot. The inside diameters of the sandblasting hose and ripper hose were 3.18 cm (1.25 in.) and 1.3 cm (.5 in.), respectively. Figure 6 shows the system used to inject material pneumatically.

Initially, the material typically used for sandblasting was also used in this experiment (i.e., slag product). Other granular materials that flowed freely and had an angle of repose less than the inclination of the base of the sandblaster were located and subsequently used in this experiment. Standard procedures to determine particle density and bulk density of the injection materials shown in Table 3 were not found.

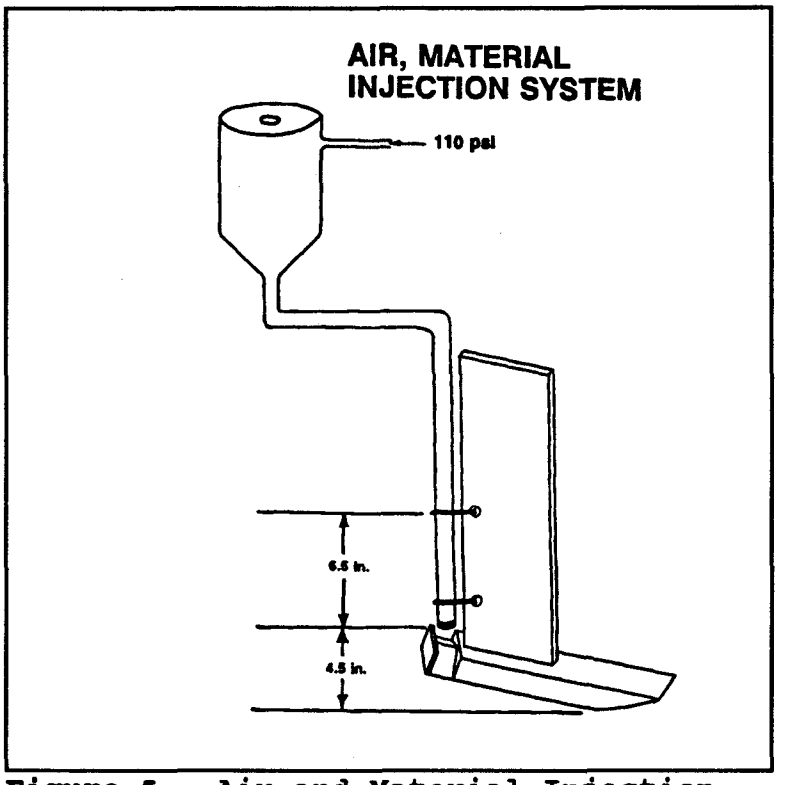

Figure 5 - Air and Material Injection System

Table 3
Injection Material Characteristics

Type of Material	Sieve Size openings passed- retained (cm) (in.)	Particle Density $(g/cm)^3$	Bulk Density (g/cm^3)	Angle of Repose (°)
Slag Product	30-51 12-20	2.42	1.48	34
Walnut Shells	51-76 20-30	1.32	.63	34
Pecan Shells	30-51 12-20	< 1.0	.62	36

Table 3 shows the particle density of the walnut shells to be greater than that of the pecan shells. Yet, the bulk densities, as measured in the loosened state, were nearly the same. Notice that the walnut shells have a slightly wider range of particle sizes as compared to the pecan. Recall that a

wider range of soil particle sizes generally packs more easily (Gupta and Larson, 1979). Thus, the walnut shells may be expected to compact to a higher density.

The amount of injected materials needed to fill all available pore space for the selected materials are shown in Table 4.

Table 4
Injection Material Amount

Material Type	Amount of Material kg (lbs)
Slag Product	30 (65)
Walnut Shells	13 (28)
Pecan Shells	13 (28)

Slag is a byproduct of blast furnaces. To reduce iron ore to iron, the furnace requires coke, iron ore and limestone. Molten iron and slag result from the oxidation of the coke. Productive uses of the slag byproduct include use as an abrasive material in a sandblaster. When a less abrasive material is needed, ground walnut shells or corn cobs are used. Ground pecan shells are used as a decorative material in model train landscapes.

Revisions to the Workplan

A few minor revisions to the workplan were found to be necessary. These revisions did not affect materially the outcome of the project. It was proposed that one of the test bins would be compacted using a rubber tire that was part of a model in the Agricultural Engineering Laboratory. However, due to the delays that the Department of Agricultural Engineering experienced in occupying their new building, this model was inoperative for an extended time and not available when it was needed during the project. This did not affect the laboratory results, since a datalogging system had been installed with a load cell to measure precisely the load that was applied for compaction and recompaction.

In was initially assumed that the air permeability of the soil would be evaluated along with the other parameters. However, it was decided that hydraulic conductivity would be simpler to measure and still indicate the presence of interconnected voids.

Finally, it was not possible to study the effects of freeze and thaw on recompaction. This was primarily due to a lack of equipment. The investigators requested no funds for equipment, selecting rather to procure the equipment independently. However, funding for the temperature-controlled chambers was not available and there was no access to other suitable facilities.

On the positive side, the soil characterization work and the thorough documentation of compactive effort through the use of the load cell and datalogging system exceeded the standard proposed initially. This resulted in very tight control on the compaction and recompaction phases of each test.