CHAPTER IV

EXPERIMENTAL DESIGN AND PROCEDURE

Experimental Procedure

This experiment was designed to determine the effect of material injection on the recompaction of prime farmland subsoil. A total of ten soil bins were prepared. The treatments consisted of:

1) air injection,
2) slag product injection,
3) walnut shell injection,
4) pecan shell injection, and
5) no injection (baseline).

The treatments were replicated twice. In order to assure homogeneity of the soil bins, pertinent factors were held as constant as possible throughout the process of replication. These factors were soil type, applied load for compaction and recompaction, soil moisture content, operating variables of the ripper such as depth-to-width ratio and rake angle, and loosened bulk density of the injection material. The area of study concentrated on the ripped zone. The number of samples extracted and readings taken were determined by the physical limitations of the soil bin (91.4 cm by 121.9 cm by 91.4 cm. (36.0 in. by 48.0 in. by 36.0 in.)) and the volume of the ripped zone.

In this chapter and those that follow, the terms 'bin' or 'soil bin' refer to the physical item. Usually, these two terms are used when describing the processing stages. The term 'trial' refers to a completed bin of soil that is in the stage of analysis. The term 'treatment' usually refers to the combination of two trials, which is the case for the walnut and pecan treatment. This term can be associated with either the bins of soil during processing or the trials during the analysis.

Method of Replication. Each bin of soil underwent three stages:

1) Initially compacted,
2) Ripped and simultaneously injected with material, and
3) Recompacted.

After each stage, samples were taken for bulk density and hydraulic conductivity. In addition, readings were taken for mechanical resistance with a cone penetrometer and bulk density with a nuclear density/moisture gage. The amount of recompaction by natural settling due to gravity was considered negligible (Kouwenhoven, 1986). These measurements of compaction are an indication of the physical condition of the soil.

Initial Compaction. Moisture content and applied pressure were controlled as much as possible during the compaction process of each bin. In order to minimize variance due to the execution of the experiment, it was desired to use the same procedure for each bin.

The soil bin was filled approximately 8 cm (3 in.) at a time and water was added to bring the mass moisture content near optimum for compaction purposes (19.0 %). The soil was then mixed by hand to moisten uniformly all areas. To do this, half of the soil surface was lightly

sprinkled with water. The thin layer of wet soil was then raked to one side (one half) of the bin. The exposed dryer soil was then sprinkled and raked. This was repeated until a layer of soil measuring approximately 8 cm (3 in.) was moistened. Then the other half of the bin was moistened in a similar manner. The direction of raking was parallel to the direction of the ripper path, so that any potential dry area would occur perpendicular to the path of the ripper. This method reduces the area of potentially dryer soil that is affected by ripping.

The soil was compacted in approximately 15-cm (6-in.) lifts with the Giddings soil probe. This was accomplished by applying a vertical load distributed over a flat plate. The operator adjusted the controls on the Giddings soil probe as needed to maintain a constant reading on the digital output device located on the voltage amplifier. In addition, the applied load as a function of time was recorded on the computer monitor display. The soil bin was repositioned with the air pallet for each compaction location as shown in Figure 7.

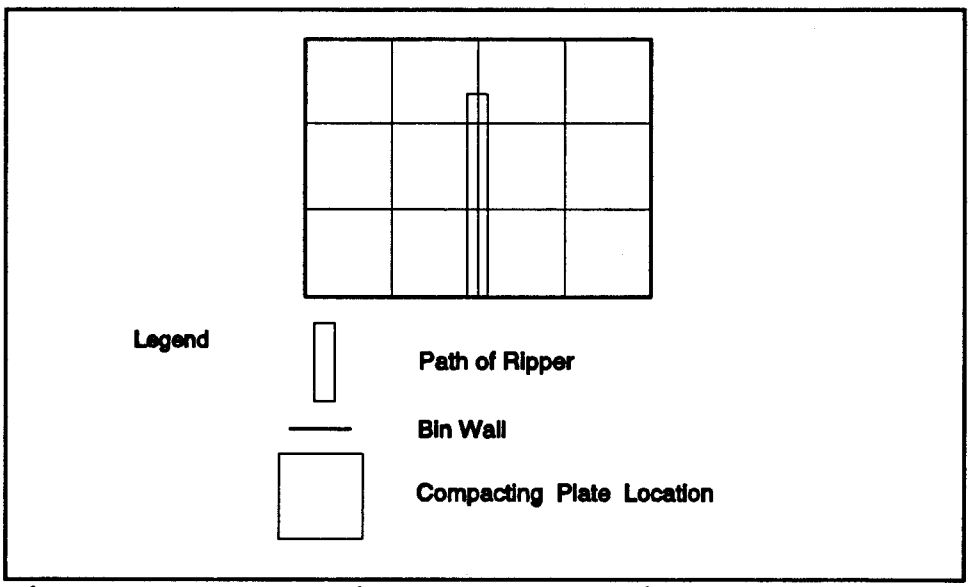

Figure 6 - Compacting Plate Locations

Since the maximum applied pressure available with the Giddings unit was 301.6 kPa (43.8 psi), typical reported ranges of pressures under scraper tires (551 to 860 kPa (80 to 100 psi)) could not be reached (Barnhisel, 1988). Typical dozer pressures, as tabulated by Barnhisel (1988), (31.7 to 152.2 kPa (4.6 to 22.1 psi)) were reachable with the Giddings unit. To obtain a worst case scenario, the upper part of this range was chosen. Therefore, the targeted pressure range under the compacting plate was set at 124-138 kPa (18-22 psi) and maintained for 60 seconds. However, due to the design of the experiment, maintaining consistent pressures among treatments was more important than the level of pressure selected.

Ripping. After initial compaction, the bin was repositioned in order to take samples and readings for the above mentioned parameters. The hose of the sandblaster was then attached to the ripper shank with the hose outlet located at the rear of the ripper foot. A small amount of material was run through the sandblasting hose to assure adequate conveying conditions. The valve at the base of the sandblaster was set at a predetermined level, which allowed for smooth flowing conditions, based on a visual inspection.

To prepare for ripping, the air pallet and the soil bin were moved to the ripper. Ripping was initiated by first applying pressurized air to the sandblaster and allowing the material to be deposited outside of the soil bin. This was done to assure continuous flow through the injection hose. The ripper was then engaged, and pushed through a slot in the soil bin with a hydraulic cylinder. Material was injected into the soil with the sandblaster while being ripped. Due to the expansion of the pressurized air, some of the material was expelled from the soil bin. Most of the expelled material was discharged horizontally in a direction opposite of ripper advance. A small amount of material was discharged vertically from the path of the ripper. Usually, the material stopped exiting the bin when the ripper was about one-third to one-half of the way through the bin.

The hydraulic cylinder reached the end of its travel length at approximately 20.3 cm (8.0 in.) from the wall of the bin. At this point, material injection ceased and the ripper was removed from the bin by hoisting vertically. A wedge of soil that formed in front of the ripper was also removed. This created a cavity near the bin wall.

The weight of the material in the sandblaster was noted prior to ripping and again after ripping to determine the amount of injected material. Also, the material deposited on the floor of the laboratory was collected to give a better estimate of the material injected.

The walnut shells, pecan shells, and slag product cost approximately $264.00, $7.50, and $4.60 per 45 kg (100 lb) bag, respectively.

Recompaction. The soil was then recompacted at a targeted pressure of 75.8 to 89.5 kPa (11.0 to 13.0 psi) and maintained for 30 seconds. This range was determined by a typical pressure range found under a Caterpillar dozer track (78.5 to 88.8 kPa (11.4 to 12.9 psi)). However, the selection of this pressure range was not as critical as maintaining consistency among treatments. The transducer used to document initial compaction and recompaction is discussed later in this thesis.

Excavation. After all samples were taken, the soil in the ripped zone was excavated with a hand spade, examined for injected material and discarded. The gravimetric core holes and cone penetrometer holes were located in the ripped zone using their recorded coordinates. Most of the holes were still evident in the ripped zone when excavating. Those that pierced the injected material were noted for future analysis. The top 61 cm (24 in.) of the model soil were then shoveled out of the bin. The lower 30 cm (12 in.) were left in the compacted state in the bin bottom.

Moisture Content

The optimum moisture content of the soil for compaction purposes was determined by the Proctor compaction test and was found to be 19.0 %. This moisture level was selected for the initial compaction stage to ensure adequate compacting conditions. However, this moisture content is greater than one would select for ripping in actual field conditions, since a plastic flow, instead of the desired shattering effect, is likely to occur (Gill and Vanden Berg, 1968; Stafford, 1979).

Soil Analysis Techniques and Sampling Patterns

The soil characteristics measured were soil bulk density (by two methods), mechanical resistance, and hydraulic conductivity. Following is a discussion of the major components of the data analysis equipment, nuclear density/moisture gage, cone penetrometer, and permeameter.

Bulk Density. The two methods used to test for bulk density were the gravimetric method and nuclear gage method. Since the model soil was cohesive and free of rocks, the gravimetric method using core samples was chosen. This method is destructive, but had the advantage of retaining the sample for further analysis with the permeameter. Moreover, this method was limited by the possibility of not sampling the injected material. The location of the injected material in the failure zone was unknown during gravimetric sampling. However, it was fairly certain, after one bin excavation, that the majority of the injected material was located in the path of the ripper. The nuclear gage method had the advantage of taking many density samples perpendicular to the ripping path. This ensured that readings were taken in the area of material injection.

Gravimetric. The method, as described by the American Society for Testing and Materials (ASTM), procedure D2937-83, is not appropriate for sampling friable soils with low plasticity which will not be readily retained in the cylinder (American Society for Testing and Materials, 1988). The soil in the ripped zone was not satisfactorily retained in the drive cylinder, unlike the soil in the initially compacted area. A basket retainer was necessary to increase soil retention in the ripped zone. This precluded the use of a thin-walled cylinder. Furthermore, it was desired to use the same equipment for all gravimetric bulk density sampling. Soil core samples were taken with a split-barrel sampler, sliced, measured, weighed, oven-dried and reweighed to obtain density and moisture readings, gravimetrically. Duplicate samples were taken from each 15.2-cm (6.0-in.) layer down to 45.7 cm (18.0 in.).

The mass moisture content of the soil was measured gravimetrically. The American Society for Testing and Materials (ASTM), procedure D2216-80, recommends an oven temperature of 110 +/- 5 °C (230 +/- 1 °F) (American Society for Testing and Materials, 1988). Maximum available oven temperatures were 45 °C (113 °F). To compensate for this, the drying time was increased until the mass after two successive periods (greater than 1/2 hour) of drying indicated an insignificant change in moisture content (less than .1 %), as recommended by above mentioned procedure. Typical sampling locations for gravimetric bulk density are shown in Figure 8. Also in this figure are locations for hydraulic conductivity, which will be discussed later.

Nuclear Gage. Gamma and neutron radiation were emitted from 10 mCi Cs-137 and 50 mCi Am-241/Be to measure wet bulk density and moisture content, respectively. Both sources were noncollimated. A dual probe strata density/moisture gage, usually referred to as "nuclear gage" or "gage" was used. The manufacturers model number was MCSA-00A with MC-S-36 software (CPN Corporation). The nuclear gage is shown in Figure 9.

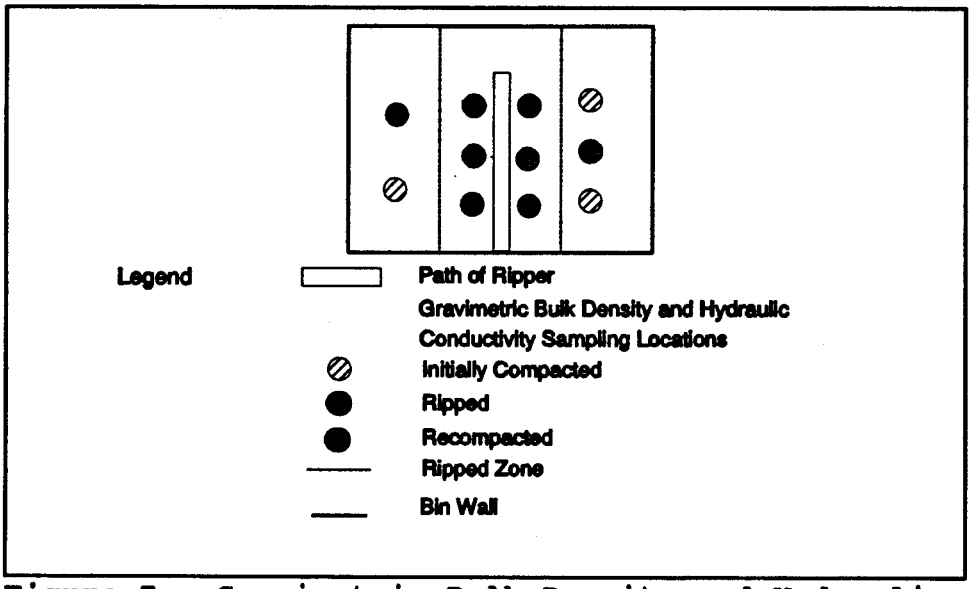

Figure 7 - Gravimetric Bulk Density and Hydraulic Conductivity Sampling Location

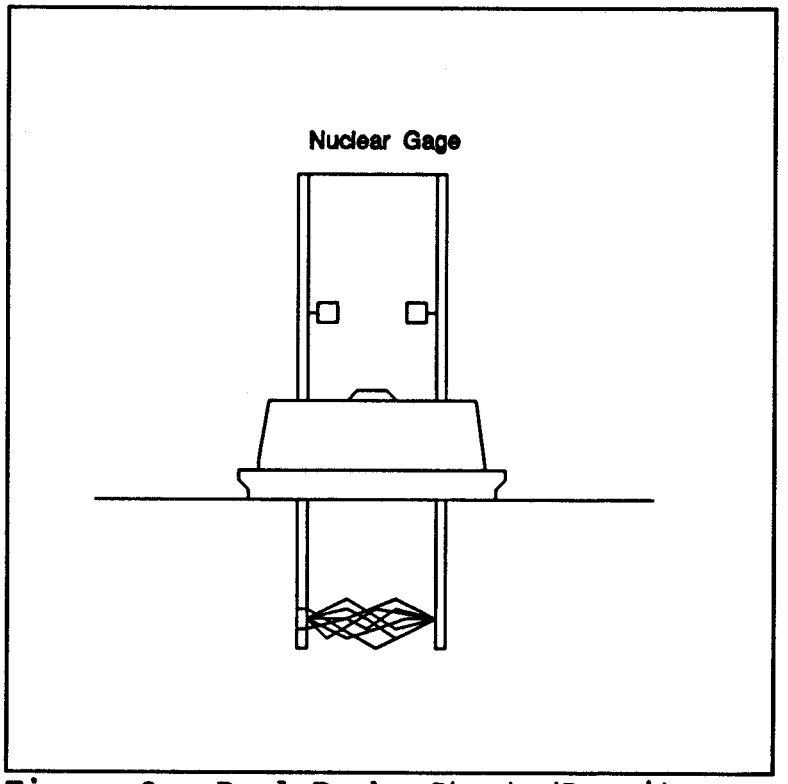

Figure 8 - Dual Probe Strata/Density Moisture Gage

The American Society for Testing and Materials, procedures D2922-81 and D3017-78, were followed, to determine the wet bulk density and moisture content, respectively (American Society for Testing and Materials, 1988). One minute measurements were taken simultaneously with a dual probe gage. The probes were located at least 30.5 cm (12.0 in.) from the walls of the bin, as recommended by the manufacturer. The above referenced American Society for Testing and Materials procedure recommends the probes be located at a distance of at least 22.9 cm (9.0 in.) away from any obstruction. The specification range of densities measured by this instrument was 1.12 to 2.73 g/cm^3.

The gravimetric moisture content was used to calculate the dry bulk density, given the wet bulk density as measured with the gage (CPN Corporation, 1988; Wells and Luo, 1991). The following equation was used:

$$DBD = WBD/(1 + C*MC)$$

where :

DBD = Dry Bulk Density (g/cm^3)
WBD = Wet Bulk Density (g/cm^3)
C = ratio of the mass attenuation coefficient of water to soil = 1.115
MC = Moisture Content (%)

The probes were lowered into the prepared access holes and duplicate readings were taken at 5-cm (2-in.) intervals down to 45.7 cm (18.0 in.).

The nuclear gage locations for the walnut treatment are shown in Figure 10. To increase data collection in the ripped zone, one additional nuclear gage location was selected for the pecan and the baseline treatments as shown in Figure 11.

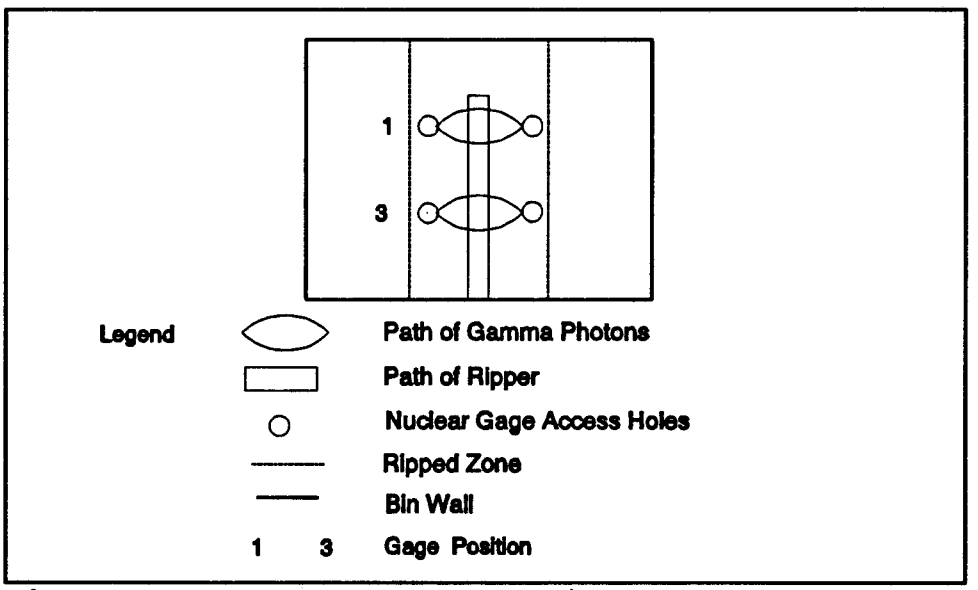

Figure 9 - Nuclear Gage Locations for Walnut Treatment

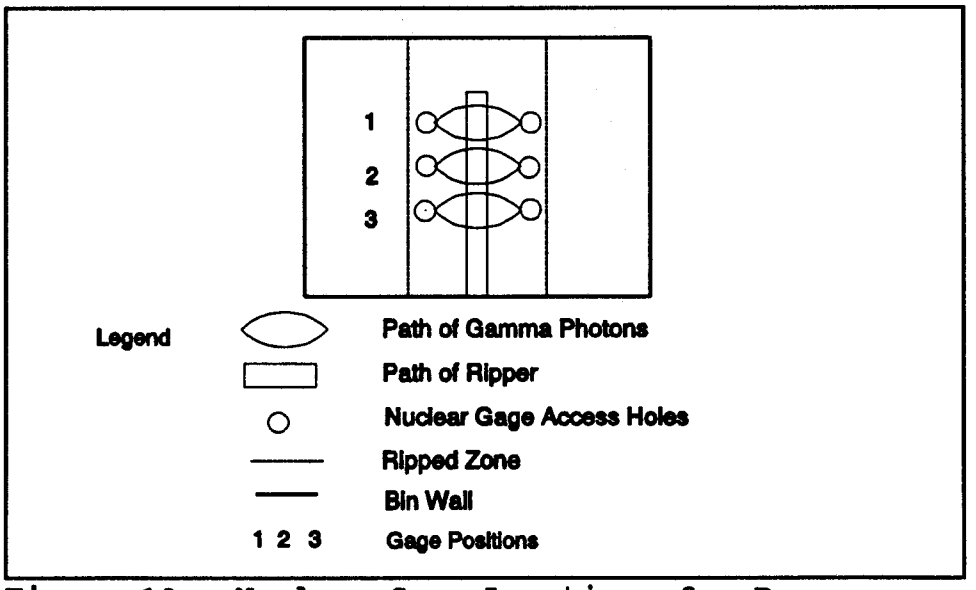

Figure 10 - Nuclear Gage Locations for Pecan and Baseline Treatment

Standard counts were taken at the start of each day's use. Since the radioactive decay influences the number of emitted photons, the decay also affects the determination of soil density. The standard count was taken by placing the nuclear gage on a block of polyethylene and conducting a four-minute count (allowing the detector to measure incoming photons for four minutes). The value of the standard count was stored in the nuclear gage memory as counts/minute and was used for determining soil density.

The precision of this instrument was determined by the square root of the actual accumulated counts divided by the slope of the calibration curve. This value was calculated for each reading.

Typical bulk density values for a silt loam soil that has been disturbed by mining activities range from 1.61 to 1.73 g/cm^3 and varies with the method of reconstruction (Barnhisel, 1986). Ranges of 1.63 to 1.75 g/cm^3 were reported by Albrecht and Thompson (1984) for a silt loam subsoil deposited by truck. A range of reported values for a silt loam soil after ripping under desired conditions were from 1.46 to 1.63 g/cm^3 (Barnhisel, 1986). After ripping and recompaction, an increase in bulk density of 1.9% in the ripped zone and 2.6% over the entire profile was reported by Barnhisel, (1986).

To calibrate the nuclear gage, densities of three blocks of material were used to obtain low, medium and high counts. The factory calibration used the following set of known block densities: 1.72 g/cm^3, 2.14 g/cm^3, 2.63 g/cm^3. The block densities were determined by the water displacement method using scales calibrated with the United States Bureau of Standards. In addition, the blocks were X-rayed to verify uniformity. Each block measured 35.6 cm (14.0 in.) by 45.7 cm (18.0 in.) by 61.0 cm (24.0 in.).

The CPN calibration was performed by taking, at each 5.1- cm (2.0-in.) depth, a count on the low, medium and high density blocks. These three measurements, plus the standard count were then fit to an equation of the form:

$$\text{Density} = B * \ln (A/(R-C))$$
$$\text{where } R = \text{Count/ Standard Count}$$

A, B and C Coefficients were determined for each 5.1-cm (2.0-in.) layer down to 20.3 cm (8.0 in.). Below 20.3 cm (8.0 in.) one set of coefficients was determined. This accounts for gamma photons that escape into the atmosphere at the shallow depths due to a noncollimated point source (CPN Corporation, 1988). The nuclear gage then used the coefficients in Table 5 to calculate the experimental soil density.

Table 5
Nuclear Gage Calibration Coefficients

Depth Below Surface (in.)	Coefficients		
	A	B	C
2	8.6416	37.5891	.0257
4	10.43924	36.15039	.02809
6	9.28677	38.71267	.00141
8 to 36	10.72264	36.49432	.02023

Mechanical Resistance. The resistance to penetration was determined with the cone penetrometer, which was driven with the Giddings hydraulic soil probe. A 454 kg (1000 lb) transducer was threaded to the shaft of the Giddings unit. A shaft and cone tip were then threaded to the transducer. The American Society of Agricultural Engineers, standard S313.2, was followed when operating the cone penetrometer (American Society of Agricultural Engineers, 1987). The tip of the penetrometer consists of a 30 degree right circular cone. The cross-sectional area of the base of the cone was 6.35 cm^2 (.98 $in.^2$) (Hooks and Jansen, 1986).

The resistance to penetration was found for a continuous interval of 45.7 cm (18.0 in.) and recorded on two devices. One device, a chart recorder, provided a hard copy in graphic form and the other device provided a digital computerized file. The data acquisition software, LABTECH, read 4 data points per second. At the standard penetration rate of 3.0 cm/sec (1.2 in./sec), one reading was taken every .76 cm (.30 in.). A typical plan view of the reading locations is shown in Figure 12.

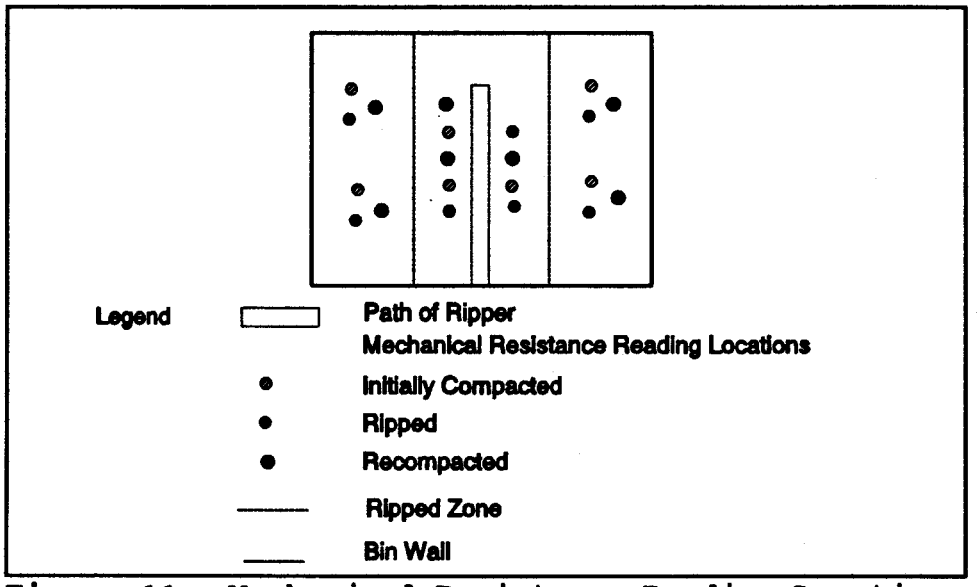

Figure 11 - Mechanical Resistance Reading Locations

Reported values of mechanical resistance as measured with a cone penetrometer for reclaimed mine soils range from .7 MPa to 3 MPa depending upon the soil handling method employed and the factors mentioned in previous chapters (Thompson, Jansen, and Hooks, 1987).

Calibration. Calibration of the transducer used for initial compaction and recompaction will be discussed concurrently with the calibration of the transducer used to document mechanical resistance readings. The two transducers were calibrated against known forces. The voltage output at a series of applied forces was recorded and used to calculate the relationship between force and voltage. The slopes and y-intercepts of these relationships were necessary inputs to the data acquisition package, LABTECH. This procedure was followed before and after data acquisition. The calibration curves used for compaction and recompaction are shown in the Appendix in Figure 19 and Table 13. The calibration curves used for mechanical resistance are shown in the Appendix in Figure 20 and Table 14. The output of the transducers were noticed to drift with time. Prior to each day's use, the transducer was zeroed (i.e., the voltage reading was adjusted to zero to correspond to no applied load).

In addition, the position of the Giddings head was recorded for a series of voltage outputs and used to calculate the relationship between distance and voltage. The slope and y-intercept of this relationship were also necessary input to the data acquisition package, LABTECH. Likewise, this procedure was followed before and after data acquisition. The calibration curves are shown in Figures 21 and 22 and Tables 15 and 16 in the Appendix.

Hydraulic Conductivity. The core samples of adequate size, which were taken for gravimetric bulk density were retained to be further tested for saturated hydraulic conductivity. It was desired to obtain one sample from each 15.2-cm (6.0-in.) interval down to 45.7 cm (18.0 in.). Due to the fragility of the samples taken in the ripped zone and the sample length requirement, this was not always possible. A minimum length of 5.1 cm (2.0 in.) was required to seat adequately the sample between the two platens. Commercially available distilled water was used as the permeating fluid.

Fluid conductivity testing has not been standardized for undisturbed, cored soil samples by the American Society for Testing and Materials (ASTM). These standards are currently being developed. The method and equipment used in this study to determine the saturated hydraulic conductivity closely resembled that of the proposed standard. The common aspects of the two methods are outlined below.

An impermeable, flexible membrane surrounded the sample, which was positioned vertically between two filter papers, porous plates and platens. The plates had a permeability of 3.16×10^{-4} cm/sec (6.23×10^{-4} ft/min), which was greater than the sample conductivity. The diameter of the platens, porous plates and the soil sample were nearly the same. The sample was located inside a cell which was nearly filled with tap water. First, a confining pressure was applied to the cell in order to maintain membrane-to-soil contact. The sample was initially saturated by applying a vacuum to pull distilled water through the sample. The saturation was continued by applying back pressure to force the distilled water through the sample and to reduce the amount of entrapped air. An increase in pressure will cause a reduction in the volume of gas bubbles in the water. For each degree of saturation, there is a corresponding pressure (back pressure) which, if applied to the pore fluid of the sample, will cause complete saturation. After the sample was saturated, the time for the flow of 0.100 cm^3 (6.0×10^{-3} $in.^3$) of distilled water was determined. The saturated hydraulic conductivity was found using Darcy's equation for fluid flow. After the determination of hydraulic conductivity, the sample was diced to examine for injected material. Typical sampling locations for hydraulic conductivity are shown in Figure 8, as previously mentioned. Hydraulic conductivity values reported for organic and inorganic soil (sands, silts, and clays) typically range from 10^{-3} to 10^{-7} cm/sec (Terzaghi and Peck, 1962).