

**Restoration of Prime Farmland Disturbed by Mineral Sand Mining
in the Upper Coastal Plain of Virginia**

Philip D. Schroeder

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APPROVED:

W. L. Daniels, Chair

M. M. Alley

J. C. Baker

L. W. Zelazny

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W. Lee Daniels, Chairman

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(ABSTRACT)

Economic deposits of heavy mineral sand were identified in the late 1980's under prime farmland along the Upper Coastal Plain of Virginia. Mining in Virginia will commence in 1997 on the Old Hickory Deposit in Dinwiddie/Sussex Counties. Experiments were established on two mine pits representing two likely pit closure scenarios; regrading the surface with unprocessed subsoil (Pit 1) or filling to the surface with processed material (Pit 3). To evaluate topsoil replacement vs. organic amendment, each pit was split into two experiments, and an adjacent undisturbed control was established. One half of each pit was covered with approximately 30 cm of topsoil, and the other half of each pit received 112 Mg ha of yard waste compost. The 1995/1996 experiment was double-cropped with wheat (*Triticum vulgare*) and soybeans (*Glycine max*) in 1995/1996. The control and Topsoil treatment on Pit 1 produced the highest wheat yield, but soybean yield was highest on the Control and the Topsoil and Compost treatments on Pit 3. Wheat yield was positively related to root length, while soybean yield varied with soil bulk density. Soybean rooting was found throughout all horizons in the undisturbed soils, but was limited to the surface 20 to 40 cm in all mine soil treatments. Very wet weather masked treatment effects in both crops, but the physical and chemical properties of the mine soils indicate that the key to reclaiming these areas lies in effective mixing of mined materials, and developing and maintaining soil humus levels.

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Chapter 1

INTRODUCTION

Mineral sand deposits were discovered in Virginia in the late 1980's (Berquist and Goodwin, 1989). These deposits occur along the “Fall Zone” which separates the Coastal Plain and Piedmont provinces. A large portion of the land underlain by these deposits is prime farmland and has traditionally produced high yields of peanut (*Arachis hypogaea* L.), soybean (*Glycine max*), tobacco (*Nicotiana tobacum* L.), and (recently) cotton (*Gossypium hirsutum*). This high productivity necessitates the development of a sound reclamation plan if this major mineral resource is to be exploited.

The largest ore body in Virginia is known as the Old Hickory deposit (Fig. 1) and is the subject of this study. Covering approximately 2,550 ha (6,300 acres), it is located 97 km (60 miles) south of Richmond and 177 km (110 miles) west of the Atlantic Coast. In 1989, (RGC Mineral sands (USA) Inc.) entered into a research agreement with Virginia Tech. This agreement called for the complete mapping and characterization of the soils within the deposit, greenhouse studies of possible reclamation strategies, and field trials on pilot-scale mine tailings. This study will partially fulfill the last part of the research agreement.

The objectives of this study are threefold:

- 1) To characterize and compare the physical and chemical properties of adjacent undisturbed and reclaimed mine soils at the Old Hickory Project. This will serve as baseline research for future comparative studies

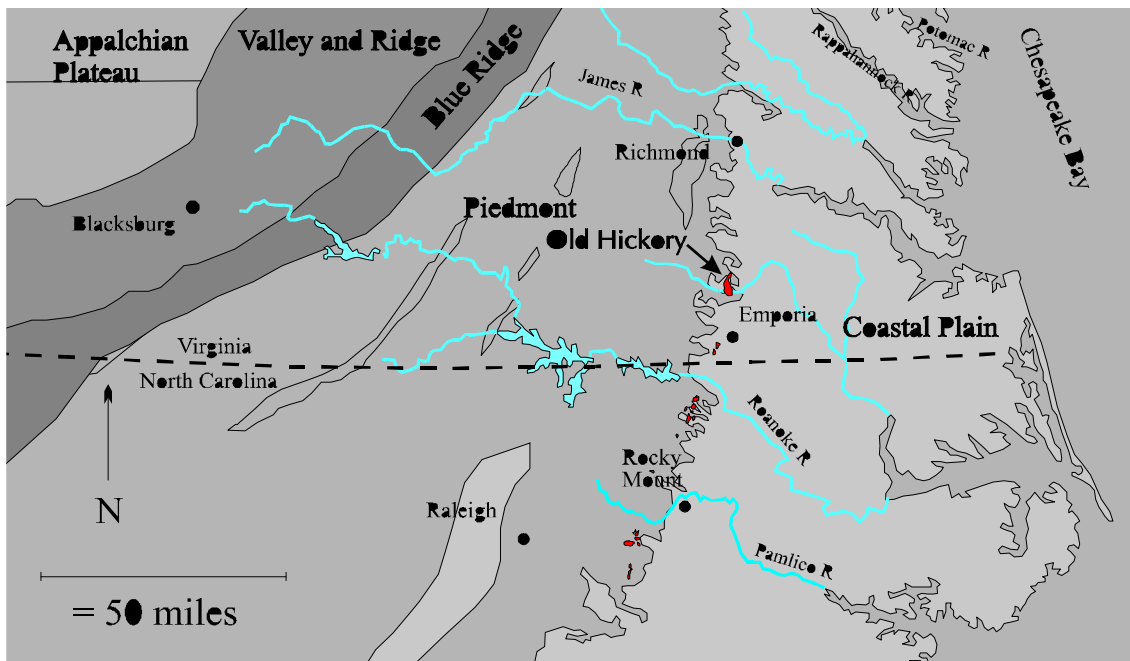


Figure 1. Map of physiographic provinces across Virginia and North Carolina indicating the location of the heavy mineral deposits. (Location from Carpenter and Carpenter, 1991)

(2) To evaluate the agronomic productivity of reconstructed mine soils amended with organic matter (yard waste compost) compared to adjacent undisturbed soils.

(3) To evaluate the agronomic productivity of reconstructed mine soils amended with topsoil compared to adjacent undisturbed soils.

Mineral Sands

The term *mineral sand* is applied to sand that is generally black in color and has a particle density around 4 g cm^{-3} . The economic minerals commonly found in mineral sands include rutile (TiO_2), ilmenite (FeTiO_3), leucxene ($\text{Fe}_2\text{Ti}_3\text{O}_9$), zircon (ZrSiO_4), and other minor high density components. These minerals are a major source of titanium which is most commonly used in the production of white pigments and high strength metal alloys used in various metallurgical applications. Small amounts of titanium minerals are also used in abrasives, foundry sands, and welding rod coatings (Garnar and Stanaway, 1994). Zircon is commonly used in refractories, foundries, and ceramics. When added to ceramics it enhances their thermal characteristics, and is also used in waxes, inks, polishing compounds, and toothpaste (AME Mineral Economics, 1994).

Sand deposits containing heavy minerals are the result of the weathering and erosion of igneous or sedimentary rock. These weathering products are transported and sorted by moving water and concentrated as placer deposits. Placers may be beach deposits, alluvial fans, or river deposits (Lynd and Lefond, 1983). Stanaway (1992) described two types of placers, (1) trap placers, which develop on scour, erosion, and unconformity surfaces, are rarely more than a meter thick, and (2) bed placers which can be tens of meters thick and result when high specific gravity

minerals accumulate in direct response to the fluid and grain flow patterns present at or near the time of their deposit. These placers may be near the present coastline or inland at some relict coastline. Heavy mineral sands (HMS) are also found in offshore deposits (Garnar and Stanaway, 1994).

Economic deposits of HMS are actively mined on every continent except Antarctica. In the USA, HMS deposits have been delineated in Florida, Georgia, North and South Carolina, Virginia, and New Jersey. Australia, which has the most developed HMS industry, has large HMS deposits on both its East and West coasts. Africa has significant deposits on its East coast, both in The Republic of South Africa and in Sierra Leone. The principal producers of HMS in Europe are Norway, Russia, and the Ukraine. There are also limited deposits along the coast of Brazil in South America. In Asia, India is the major producer with lesser deposits in Malaysia (Garnar and Stanaway, 1994).

Mining of mineral sands differs greatly from the methods used to extract most other mineral ores and coal, with the exception of topsoil removal and stockpiling. These sandy deposits, ranging from a few to tens of meters thick, are most commonly excavated by a floating bucket-wheel dredge. The ore is then pumped as a slurry to a “wet mill” where the sand and slimes (silt, clay, and/or humic materials) are separated by density through a series of sumps, cyclones, and spiral concentrators. The concentrated heavy minerals are shipped to a “dry mill” for refining. Tailings, mostly the lower density quartz sand, and the finer slimes are pumped to a dewatering area. Once dewatered, they are regraded and topsoil is usually replaced. In the USA,

this is typically followed by revegetation practices and long term monitoring (Saunders and Clemons, 1991).

In “dry mining” operations, the dredge is replaced by excavators or pan scrapers which carry the ore to a central wet mill for processing and the tailings and slimes are pumped back to the mining pits. This technique will be employed at Old Hickory.

The Old Hickory Deposit

The Old Hickory deposit straddles the “Fall Zone”, which is the boundary between the Coastal Plain and Piedmont physiographic provinces (Berquist and Goodwin, 1989). The Fall Zone contains one or more sediment-buried wave cut scarps that mark the westernmost transgression of the Atlantic during late Miocene time (Howard et al., 1993; Winker and Howard, 1977). The Old Hickory deposit is underlain by one of these scarps which correlates with the Orangeburg scarp to the south (Fig. 2). Carpenter and Carpenter (1991) correlate the deposition of the Old Hickory ore body over the scarp to “a major transgressive-regressive event during the late Pliocene”. They proposed a four-step model comprised of the following events: (1) initial rapid transgression and accumulation of a reworked sand sheet; (2) brief regression or still stand; (3) renewed transgression and deposition of silty shelf sands; and (4) progradation (regression) of shelf, lagoonal, and possibly a deltaic mud blanket. This concept fits the general nature of a shoreline deposit, but the Old Hickory deposit has many irregularities not explained by their transgression-regression theory. The high clay content of the soils, the very high concentration of

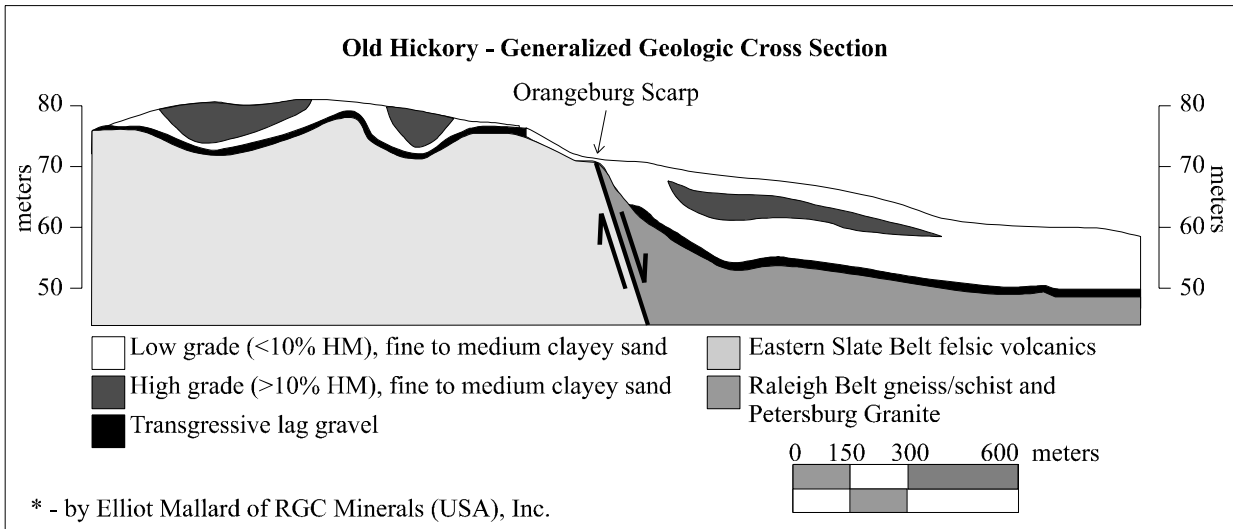


Figure 2. Geologic cross section of the Old Hickory deposit showing the location and concentration of heavy minerals.

mineral in some parts of the ore body (>40%), and the presence of HMS above the scarp, all point to other possibilities. Carpenter and Carpenter (1991) offer two possible origins for the clay. First, they hypothesize that the clay is the weathering product of sand-sized feldspar grains deposited with the HMS, or secondly, that the clay was introduced after HMS deposition. Although the second theory would allow for higher amounts of clay than could be accounted for from feldspar weathering, the authors do not offer any evidence for the process of this clay introduction.

Another possible explanation is offered by Larsen (1993) who hypothesized that HMS accumulation along the Fall Zone is due to changes in stream gradient or slope. As streams cross from the Piedmont to the Coastal Plain, their gradient drops in relation to the decreasing slope of the surface they pass over. Larsen concluded that as stream gradient decreases, sediments are sorted by density and that heavy minerals such as ilmenite would be deposited closer to the Fall Zone.

It has also been postulated that the high concentrations of heavy mineral sands in similar environments in Australia were caused by tsunami (Bryant et al., 1991). This theory may also explain the bisequal nature (discussed later) of soil overlying the scarp at Old Hickory. Tsunami may have sheared off the upper layers of the original soil leaving the lower horizons intact to be buried by mixed sediments when the water receded. Possible tsunami activity in the Atlantic Ocean has been reported by Dawson et al. (1988) who found sand layers far inland along the East Coast of Scotland which may have been deposited by tsunami.

Other possible mechanisms favored by RGC exploration geologists include concentration

of HMS by a cycle of large storms (hurricanes), which could bring HMS in from offshore and concentrate it in beach deposits. In fact, this process is active in Australia today, and earlier HMS mining originally developed to exploit storm deposits immediately following cyclones.

Reclamation of Mineral Sand Mining

Mineral sands have been mined in Australia since the turn of the century (Morley, 1982). Mining was initially confined to rich placer deposits found on the beaches north of Brisbane. Mining these deposits involved little environmental conflict and reclamation was limited to recontouring the remaining sand before the next high tide. As the industry grew, frontal dune deposits became the target of mining operations. Although these areas required reclamation, limited knowledge of dune function focused reclamation on dune stabilization. To this end, dunes were flattened and planted with spiniflex grass (*Spiniflex sericeu*). The first official rehabilitation conditions were placed on mining leases in Queensland in 1951. Over the following decades, changes in Australian societal values and the development of the conservation movement led to the development of reclamation strategies and limited mining in eastern Australia. Mining began in Western Australia in 1956 (Brooks, 1997). With increased restrictions on the East Coast, the western deposits became the focus of mining.

In Australia, mineral sands deposits are located in many different landforms including frontal dunes, high dunes, heathlands, wetlands, and farmland. Brooks (1997) summarized studies of reclamation projects on each of these landforms and concluded that there are several basic principals common to all successful reclamation projects he studied:

- Selection of the post-mining land use prior to the commencement of mining.
- Assessment of the pre-existing environmental conditions, including vegetation, fauna, soils, hydrology, and cultural and natural heritage values.
- Landform reconstruction to re-establish topographic patterns, with particular attention being given to surface drainage.
- Careful management of topsoil because of its organic enrichment and seed load.
- Surface stabilization to enable establishment of native species seedlings, many of which are small and establish slowly.
- Direct seeding of native species as the most efficient means of enhancing regeneration from topsoil, both economically and biologically.
- Enhancement planting of nursery raised stock, with emphasis on species that are difficult to propagate with field techniques.
- Monitoring of the serial development of the vegetation and fauna to ensure the newly created ecosystem is progressing satisfactorily.

These steps are also currently employed, in modified form, by RGC at sites in central Florida (Saunders and Clemons, 1991), and soils at these sites have been found to develop significant subsoil horizonation in 5 to 10 years (Daniels et al., 1992). Daniels et al. also found that rooting was limited to 50 cm or less due to compaction of subsurface tailings and/or the seasonal water table. Bulk densities as high as 1.80 g cm^{-3} were found, and they concluded that wet settling of the

tailings coupled with grading led to compaction.

In Greensville Co. Virginia, near Old Hickory, Stolt et al (1995) concluded that mineral sand mine tailings could be successfully amended with composted yard waste. They compared topsoil replacement to yard waste compost (YWC) amendments on simulated mineral sand mine tailings. They also studied the possibility of using wood ash as a lime substitute. An area 30 x 60 m was excavated and the material was treated in a manner to simulate heavy mineral separation. The material was then returned to the excavation in a slurry form. Treatments included tailings amended with 1, 2, 4, 6, and 12% YWC, unamended controls, and tailings capped with 45 cm of topsoil. Yield of corn (*Zea mays* L.) grown in 1993 varied widely across treatments, with yield on topsoil replacement plots being lower than compost plots. They concluded that this was due to the coarse (loamy sand) texture of the topsoil, as compared to the sandy loam/sandy clay loam texture of the tailings. The increased clay content and the compost application gave the tailings greater water holding capacity. Corn yields exceeded five-year county averages on all compost treatments, with the 12% compost treatment having nearly identical yields to undisturbed natural soil plots. In the same year, peanut yields on all compost-amended tailings plots exceeded yields on unamended controls and topsoil treatments. Two and 4% compost treatments produced yields roughly equivalent to their natural soil counterparts, while tailings amended with 6% compost greatly exceeded those of the natural soils amended with the same amount of compost. Cation exchange capacity (CEC), base saturation (BS), porosity, water holding, and saturated hydraulic conductivity (K_{sat}) increased with compost addition.

In an associated study, Orndorff (1995) evaluated the phosphorus (P)-adsorbing capacity

of mineral sand mine tailings amended with YWC. She reported that P-adsorption potential ranged from moderate to low. Decreases in adsorption corresponded to increases in compost application rate. Untreated tailings adsorbed the most P and undisturbed soil the least.

She hypothesized that the decrease in P-adsorption on compost treated versus untreated plots was related to (1) wood ash application, which increased pH and decreased anion exchange capacity, (2) P-fertilizer applications which satisfied adsorption sites, and (3) organic matter additions, which both physically blocked adsorption sites and competed with P for adsorption sites. Application of 12% YWC reduced P-adsorption of the tailings to levels near that of the natural soils. She concluded that the tailings would be best managed with high compost applications and low annual P-applications.

Sand and Gravel Mine Reclamation

The mining of sand and gravel for construction materials has been practiced for centuries. These areas have often been abandoned with little or no reclamation effort, particularly areas mined before the 1980's. Spoils from sand and gravel mining are generally coarse textured, and mineralogically heterogeneous. They are low in organic matter, have little or no structure, and are deficient in plant nutrients. Without some amelioration, any plants grown on these spoils are susceptible to water, temperature, and nutrient stresses (Hornick, 1982). Hornick (1988) concluded that sewage sludge compost and feedlot manure improved yields in corn and bush beans (*Phaseolus vulgaris l.*) grown on sand and gravel spoils. The improvement in yield was attributed to organic additions through their effect on pH stability, soil physical properties, and

the supply of micro- and macro-nutrients. In studies of aggregate mine rehabilitation to prime farmland in southern Ontario, Mackintosh and Mozuraitis (1982) found that the absence of topsoil or the mixing of topsoil with subsoil, and its inherent dilution of organic matter, was the most common problem limiting reclamation success.

Tin Mine Reclamation

The practice of tin mining produces waste materials similar to those of mineral sand mining. Tin is generally found in placer deposits and is also mined by floating dredge or gravel pump. After mining, sand tailings and slime ponds remain. These materials are often unreclaimed and frequently remain barren after 20 years. In an extensive study of tin tailings in Malaysia, Mitchell (1959) found that there was almost a complete loss of organic matter and N in the tailings. He also noted that in areas where slimes had accumulated, there was a marked increase in the variety and quantity of plant growth. In an earlier study by Birkinshaw (1931), rice (*Oryza sativa* L.) was shown to produce significantly higher yields on tin tailings that were covered with 45 to 60 cm of slimes. Mok and Lim (1985) reported that mixing slimes with sand tailings improved productivity, but that organic amendments were also necessary to achieve sustained yields.

Prime Farmland Reclamation

Prime farmland is cropland that has the most favorable combination of chemical, physical and environmental properties for the production of food, fiber, and oil crops (Grandt, 1988). The

Federal Surface Mining Control and Reclamation Act (SMCRA) of 1977 requires that prime farmland disturbed by coal mining be returned to pre-mining productivity, and there has been extensive research in this area. Much of this research has been focused in the American Midwest where extensive coal deposits underlie prime farmland. Central to this research has been SMCRA's requirement that soil horizons be replaced and original contours recreated.

Jansen and Dancer (1981) observed that corn yields on replaced topsoil depended on the quality of the topsoil and its thickness. They also found that some subsoils can give higher yields than topsoil depending on the chemical and physical properties of the material. Underwood and Sutton (1992) concluded that corn yields on Ohio mine soils increased with increasing thickness of replaced topsoil. Their research also found that increases in clay content led to compaction during replacement. In studies of loamy sand mine spoils in North Dakota, Halvorson et al. (1986) concluded that at least 0.7 m of topsoil was needed to attain maximum yields. In addition to thickness of topsoil, its' physical properties are also important. Potter et al. (1988) report that macroporosity and hydraulic conductivity were significantly lower in reclaimed topsoil as compared to undisturbed topsoil.

Another factor of concern in reclamation is topsoil handling. The best method is to directly haul and place it over recontoured mine spoil instead of stockpiling (Hargis and Redente, 1984). Hossner et al. (1992) reported that mixing of subsoil and topsoil increased productivity in two clayey Texas soils. Another study in Texas found that a more productive soil could be created from selected overburden (DeMent et al., 1992). They reported subsurface materials to be higher in weatherable minerals, higher in pH, and higher in CEC than the native surface soils. Soil formed

in this overburden out-yielded all native soils for coastal bermudagrass (*Cynadon dactylon* [L] Pers.) and wheat (*Triticum aestivum* L.). In contrast, Semalulu and Barnhisel (1992) concluded that acidic subsoils may fix P in quantities large enough to cause significant yield reduction. These findings were supported by Mankolo (1994) in studies of P-uptake by corn on mineral sand mine soils. In Greensville Co. Virginia, she observed that even with P application rates as high as 289 kg ha⁻¹ as triple-superphosphate, corn ear leaves had P contents below the critical 0.25% level. An extensive greenhouse study by Stucky et al. (1986) observed that subsurface soil materials may be suitable for crop production if they have the appropriate balance of pH, fertility, and texture.

Compaction has been found to be the most limiting factor in many mine reclamation studies. Compaction causes an increase in bulk density and associated soil strength. Soils with high bulk density have low porosity, slow saturated hydraulic conductivity (K_{sat}), and high resistance to root penetration. Studies by Taylor (1974) concluded that compaction reduced yields in nearly all soils, and Barnhisel and Gray (1990) concluded that compaction was a major factor limiting yield on mine soils. Schuman et al. (1985) reported compaction to be a major problem in reclaiming bentonite mined land in the Northern Great Plains. Replacement of rooting media by scrapers can cause severe compaction and reductions in corn and soybean yields. Hooks et al. (1992) concluded that end-dumping from trucks and grading with low ground pressure bulldozers was the preferred method of soil replacement.

Deep ripping has been shown to be an effective technique for remediating compaction. Bledsoe et al. (1992) concluded that deep ripping reduced compaction and increased corn yields

on mine soils in Illinois. The same observations were made by Caldwell et al. (1992) in Kansas, and by Powell et al. (1988) and Wells and Barnhisel (1992) in Kentucky.

Although the Old Hickory project will not employ heavy earth moving equipment to replace tailings, compaction may still be a problem. Compaction may result from wet settling as reported by Daniels et al. (1992), bulldozer traffic during regrading and topsoil replacement, or through the use of rubber-tired loaders and haulers during material handling operations.

ORGANIC AMENDMENTS

Additions of organic materials have, since ancient times, been known to improve soil productivity. According to King (1911) the ability of long lived civilizations such as China, Japan, and Korea to maintain their agricultural base is directly linked to the use of organic amendments. Organic matter contributes to CEC, water holding capacity, aggregate stability, and nutrient availability (McConnell et al., 1993). Most soil organic matter is concentrated in the surface horizons and decreases rapidly with depth. The low level of organic matter in subsoils is a major limitation when they must be used as parent material for soil reclamation. Terman et al. (1973) concluded that additions of municipal waste compost improved yields of corn, and tall fescue (*Festuca arundinacea*) due to increased availability of N, P, K, Zn, and Ca. Similar conclusions were reached by Mays et al. (1973) with applications of sewage sludge compost to forage sorghum (*Sorghum bicolor*), corn, and bermudagrass. They observed increases in soil nutrient supply and water holding capacity along with a decrease in bulk density.

Many investigators have studied the ability of organic additions to restore mined land to

productivity. In an extensive review of surface mine reclamation with municipal sewage sludge, Sopper (1993) summarized studies from around the globe as well as his own field studies. He concluded that the application of sewage sludge is an effective and safe method to reclaim surface mined land. In a study of degraded soils in India, Kaura and Verma (1982) reported that organic amendments improved soil structure. They also concluded that aggregate formation was further enhanced when undecomposed organic matter was added instead of compost. Organic amendments have also been used to amend degraded sandy soils in Nigeria. Obi and Ebo (1994) reported that the incorporation of poultry litter improved soil structure, and increased water holding capacity, K_{sat} , and infiltration rate. Similar results were reported by Hortenstine and Rothwell (1972) on organically amended phosphate mine tailings in Florida. Sewage sludge and sludge/garbage compost were employed to amend mine soils and increased yield of corn and grain sorghum. Amended mine soils were less acidic, and had higher levels of available N and P than unamended mine soils. In a long term study of coal mine soils in southwest Virginia, Roberts et al. (1988) found that mine soils amended with sewage sludge developed deeper A horizons than unamended soils. Sludge amended soils also had higher total N, higher extractable P, and less extractable Fe. In a study of prime farmland reclaimed after surface mining, Olsen and Jones (1988) reported that organic amended mine soils produced as good or better corn yields than topsoil replacement.

A number of other investigators have also reported that yard waste compost (YWC) improved soil chemical and physical properties. Studies of sandy soils showed improved water holding capacity and higher crop yields with the addition of YWC (Mays et al., 1973).

Incorporation of YWC into mine soils was shown to decrease compaction, and increase water holding (Clapp et al., 1986), and soil pH (McConnell et al., 1993). Compost additions also improved micronutrient availability and lowered Al toxicity. Terman et al. (1973) reported that YWC can supply relatively high amounts of N, P, and K, while Mankolo (1994) found YWC to be very effective at amending spoils from mineral sand mining. Incidentally, yard waste represents approximately 20 percent of U.S. municipal waste (Parr, 1992).

Physical Factors Affecting Root Growth

Plant roots have three main functions, (1) anchoring the plant in the soil, (2) absorption of water and nutrients, and (3) synthesis of organic compounds needed by the plant (Drew and Goss, 1973). The amount of water and nutrients available to the plant is largely determined by the total volume of soil exploited by its' root system. The volume of soil explored by a plant's root system depends on root genetic properties and soil physical factors. The primary physical factor affecting root growth is soil density and associated strength. Soils with high bulk density and strength will limit root growth by mechanical impedance (Gerard et al., 1982). Roots grow through the soil by penetrating voids or by moving soil particles (when possible) when there are no voids (Taylor, 1974). When a soil is compacted or disturbed, the number and size of pores is reduced. In a study of rooting in mine soils, McSweeney and Jansen (1984) reported that rooting was limited in massive and compacted mine soils, but was prolific in what they termed "fritted" minesoils. This term refers to a structural arrangement of rounded aggregates loosely compressed together. In a recent study of the effects of subsurface compaction on wheat, Oussible et al. (1993) reported

that root density, number of tillers, and N-accumulation were all reduced by compaction.

The most common measure of soil compaction is bulk density. Bulk densities above 1.65 g cm⁻³ to 1.75 g cm⁻³, depending on texture and water content, are commonly reported to limit root growth (Drew and Goss, 1973). Jones (1983) also reported that texture affected the bulk density at which rooting is limited. He concluded that soils with higher clay (or clay + silt) contents exhibited restricted root growth at lower bulk densities than in sandy soils. Although there are many factors which can limit growth, roots can compensate through enhanced growth into areas unaffected by the limiting factor. This compensatory growth results from the independent nature of each axis or lateral in the root system and its ability to react to its own environment (Crossett et al., 1975).

Root Systems of Soybeans

Part of this study will include the mapping of the root systems of soybeans grown on both undisturbed and reclaimed soil, therefore a discussion of the nature and habit of soybean root systems is warranted. Soybeans are usually described as weakly taprooted. The components of the soybean root system include the taproot, secondary or lateral roots, tertiary, and other smaller roots (Kaspar, 1985). Development begins with the emergence of the radicle from the seed. From the radicle, a taproot descends to depths as great as 1.5 m, but is usually limited to a much shallower depth by unfavorable conditions. Four vertical rows of lateral roots extend from the taproot at 90° angles. These laterals will extend 20 to 35 cm before turning downward to a depth of up to 1.8 m. Root hairs can develop from any epidermal cell and are primarily responsible for

water and nutrient uptake (Kaspar, 1985; Mitchell and Russell, 1971). Although some parts of the root system may reach depths of 1.8 m, 90 % of the root mass is found in the upper 15 cm (Mitchell and Russell, 1971).

Methods of Studying Root Systems

The study of plant root systems has evolved into two main fields, root ecology and root physiology. The physiologist is interested in the processes within the root such as cell division or nutrient transport and may use indirect methods to study roots. In contrast, the ecologist wants to know how the root responds to its environment.

Indirect methods of root study include the uptake of radioactive and non-radioactive tracers, staining techniques, and water depletion. These methods attempt to quantify activity within the root system either by the movement of some chemical or by uptake and movement of water. If, however, the researcher wants to observe the interaction of the root system and its environment, a more direct approach is needed. A method must be employed which exposes the entire root system or some part of it.

Bohm et al. (1977) compared five methods for studying soybean root density and development. Those methods included soil water-depletion, framed monolith, core-sampling, mini-rhizotron, and trench profile. They concluded that when the goal of the research is to observe roots in relation to their soil environment, the trench profile method (Bohm, 1976) was the best. This method involves the excavation of a trench across the plant rows so that the soil-root system may be observed directly. If the researcher is interested in root density, the framed

monolith method (Nelson and Allmaras, 1969), where a section of soil and associated roots are removed from the soil, or the core method (Waddington, 1971), in which the entire soil profile is sampled in long continuous cores, are superior. Bohm et al. concluded that both of these methods are more time-consuming than the trench profile method due to root cleaning, but all three methods equally estimate the relative percentage of roots in a given soil layer.

A modification of the core method involves the use of a soil auger to obtain samples for root analysis (Bohm, 1977). Roots obtained in this manner are suitable for length estimate analysis by the line intercept method outlined by Tennant (1975). Using a grid, he estimated the total length of root samples by counting the number of intersections between roots and grid lines. He concluded that this method could estimate root lengths with variation of 5 % or less.

Preliminary Soil and Greenhouse Studies for RGC

Beginning in the summer of 1989, the soils of the entire Old Hickory deposit (app. 2,550 ha) were mapped on a 1:12,000 scale by Hodges et al (1997) of the Virginia Tech Soil Survey. The highly dissected nature of the area gives rise to a variety of soils and parent materials. Hodges et al. identified 25 soil series within the area of the ore body. In a relatively small area, there are adjacent soils that have formed in residual Piedmont materials, unconsolidated Coastal Plain sediments, and colluvial mixes of Piedmont and Coastal Plain materials. The majority of soil series in the deposit have sandy surface horizons underlain by argillic horizons. Soils near the scarp (see Fig. 3) commonly have bisectal character with younger yellowish argillic horizon materials overlying redder B and C horizons. Subsoil clay contents range from 17 to 45 %. The clay

fraction of these soils is dominated by low charge minerals (Vanwormhoudt, 1993), with relatively low CEC's (2-16 cmol/kg) and their pH is in the strongly acid range of 4.5 to 5.5 (Daniels et al., 1992).

Upon completion of soil mapping, five pedons which were typical of soils that would be mined were selected for generation of simulated tailings and slimes. Sampling sites were chosen based on high mineral content, typical soil, and high crop productivity potential. Heavy mineral sands were wet separated from tailings in a spiral separator. These tailings and slimes were then transported to Va Tech and used in greenhouse studies, which focused on the evaluation of different mixtures of tailings and slimes as plant growth media. After several rotations of wheat, soybean, and corn (*Zea mays* L.) it was concluded that a uniform blend of tailings and slimes could be successfully used as a topsoil substitute (Daniels et al., 1995). They also concluded that subsoil variations in texture and water holding capacity may not be a major concern. The field experiment reported in this thesis represents a progression from these greenhouse trials to field conditions.

Chapter 2

MATERIALS AND METHODS

Experimental Design and Installation

In the fall of 1994, RGC began work on a pilot scale mine at a site within the Old Hickory deposit. The initial design of the mine area included three 24 x 60 m pits to be excavated for heavy mineral extraction and one 45 x 45 m area to be preserved as an undisturbed control (Fig. 3). The control area was roped off and no traffic or drainage from the active site was allowed onto this area. Prior to pit excavation, topsoil was removed by pan scrapers and stockpiled for later use. Pit #1 was excavated to a depth of approximately 5 m with a track excavator. The ore from Pit #1 was stockpiled until excavation was complete. Some of the excavated subsoil material was piled around the edge of the pit to form dikes which would allow the pit to be filled above original grade. This was needed to account for expected shrinkage during dewatering.

The stockpiled ore was then fed through a separator, consisting of a shaking screen, a pug mill and a sump where water was used to separate sand from slimes (silt and clay). Heavy mineral sands were separated from the host sands in a series of gravity spirals. In an attempt to improve recombination with the sandy tailings, the slimes were flocculated with an anionic polymer (Nalco™ 9825) in a large stirring tank called a thickener. Tailings and slimes were then recombined and returned to the pit (Fig. 4). This was accomplished by pumping the recombined

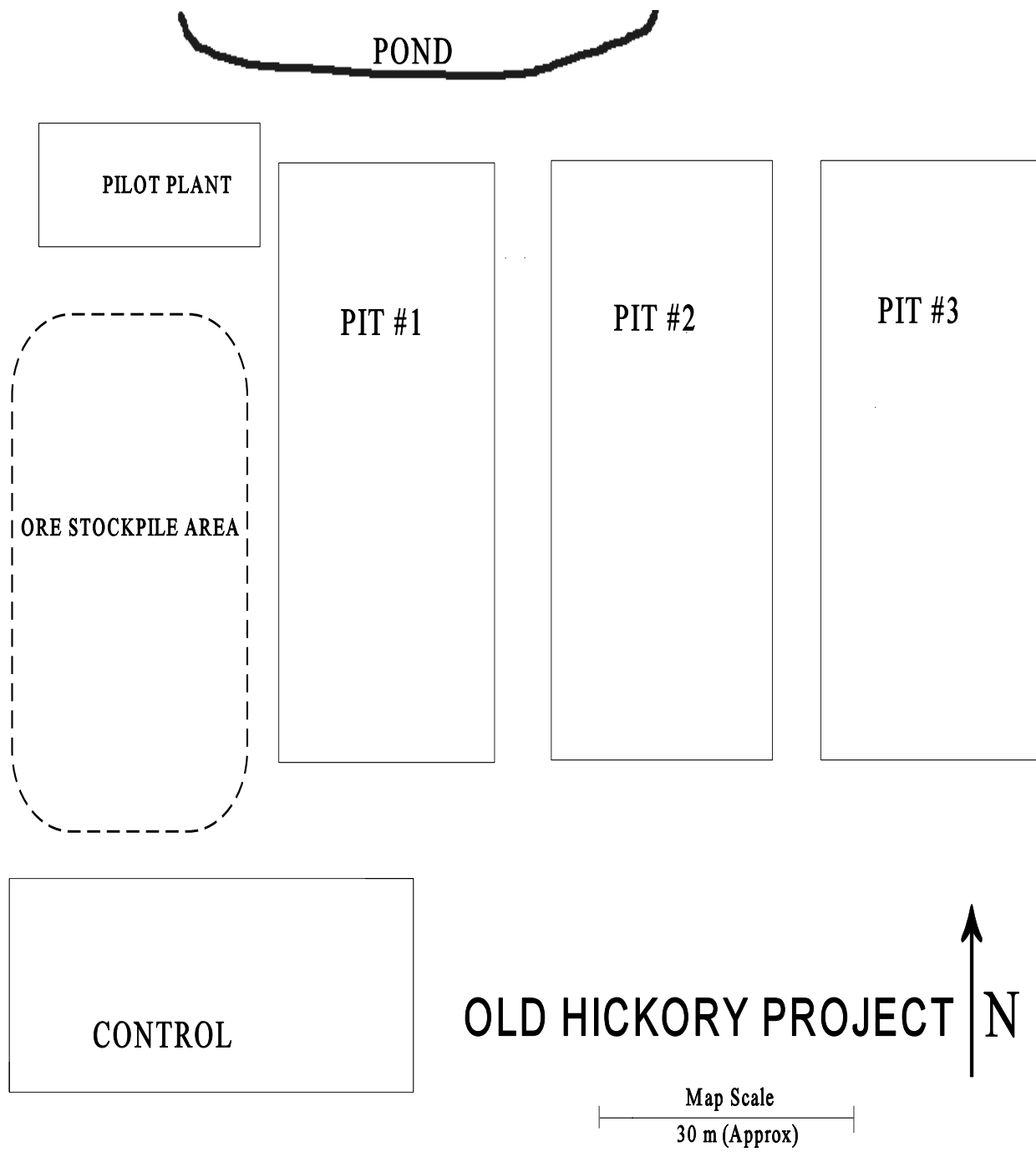


Figure 3. Original pilot mine site map showing location of mine pits, wet mill, ore stockpile, and undisturbed control area.

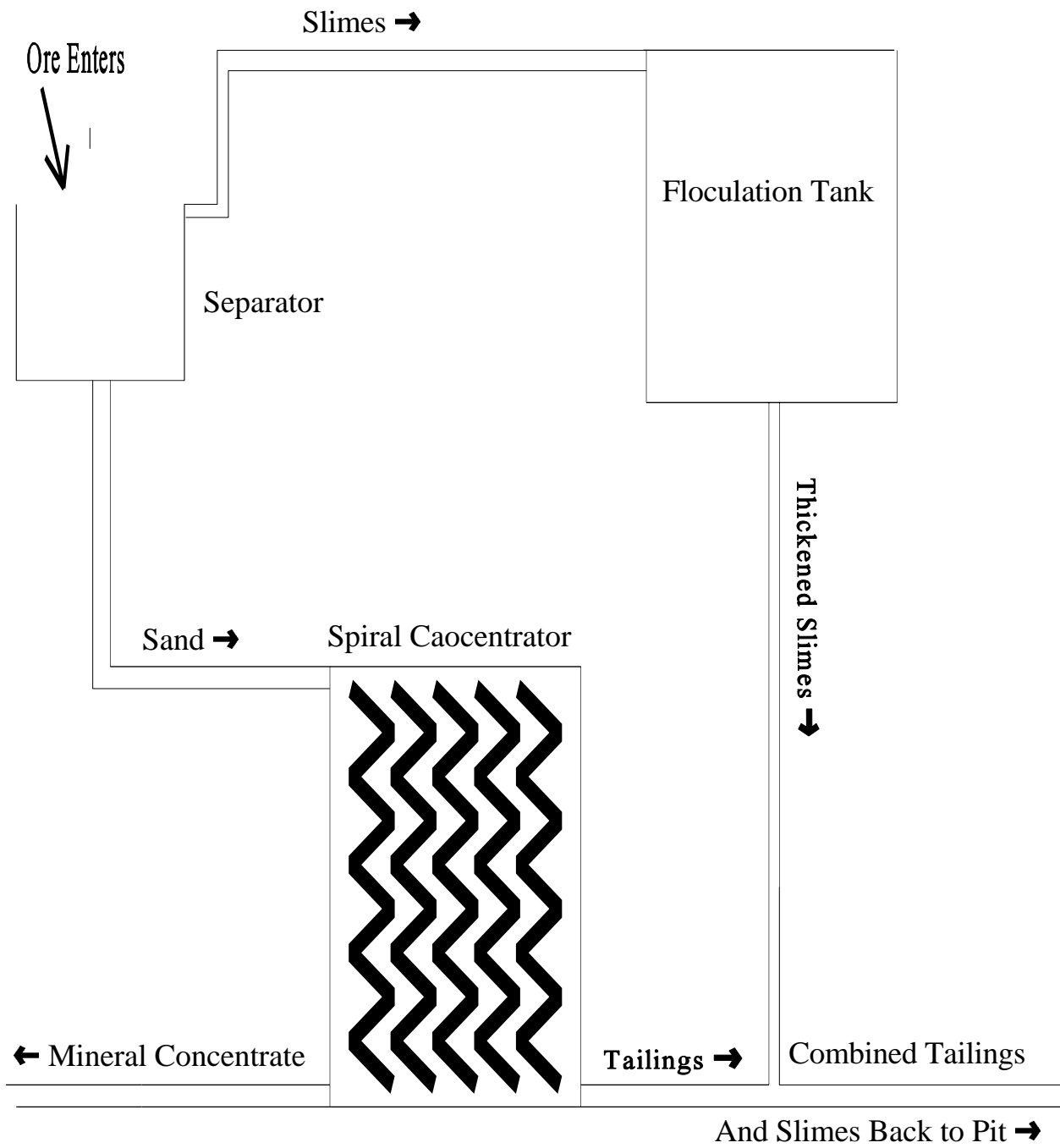


Figure 4. Simplified diagram of wet mill for separating heavy mineral sands from silt and clay.

tailings and slimes, at around 50% solids, through pipes to a dispensing point along the side of a pit. At the end of the pipe a dispersing device was employed to spread the flow over a larger area. Periodically, the discharge point was moved around the pit and between pits in an effort to fill the pits evenly.

As Pit #1 was being filled, Pit #3 was excavated. The same procedure was followed in digging and filling Pit #3, with the exception that Pit #3 was excavated to a depth of 6 m. Pit #2 was excavated last to ensure that if the pit walls proved unstable there would be no chance of RGC ending up with one very large pit instead of three smaller ones.

Upon completion of dewatering, Pit #1 was covered with approximately 1 m of subsoil from the dikes which had surrounded it. The depth of this covering material is variable due to differential settlement or intrusion into pockets of non-bearing slimes. In addition to subsoil, there is an area of topsoil which was pushed onto Pit#1 from the area where the wet mill had operated upon an elevated topsoil fill (Fig. 5). Most of the area affected by this topsoil is beneath the topsoil treatment area but it may have had some affect on that part of the experiment. Additional variability in pit #1 stems from the placement, in the west side of the pit, of reject ore (material which could not be processed (Fig. 6). This material consisted of hard dense clay balls, plinthite, stones, and gravel. Although we originally hoped this pit would be filled to the original surface with remixed tails/slimes, we realize that what took place here may be a common pit closure scenario when full-scale production begins, so we included Pit #1 in our field study. The backfilling of Pit # 2, actually the last one excavated, was never completed because wet milling operations were suspended before it was filled. The pit was brought back up to original grade

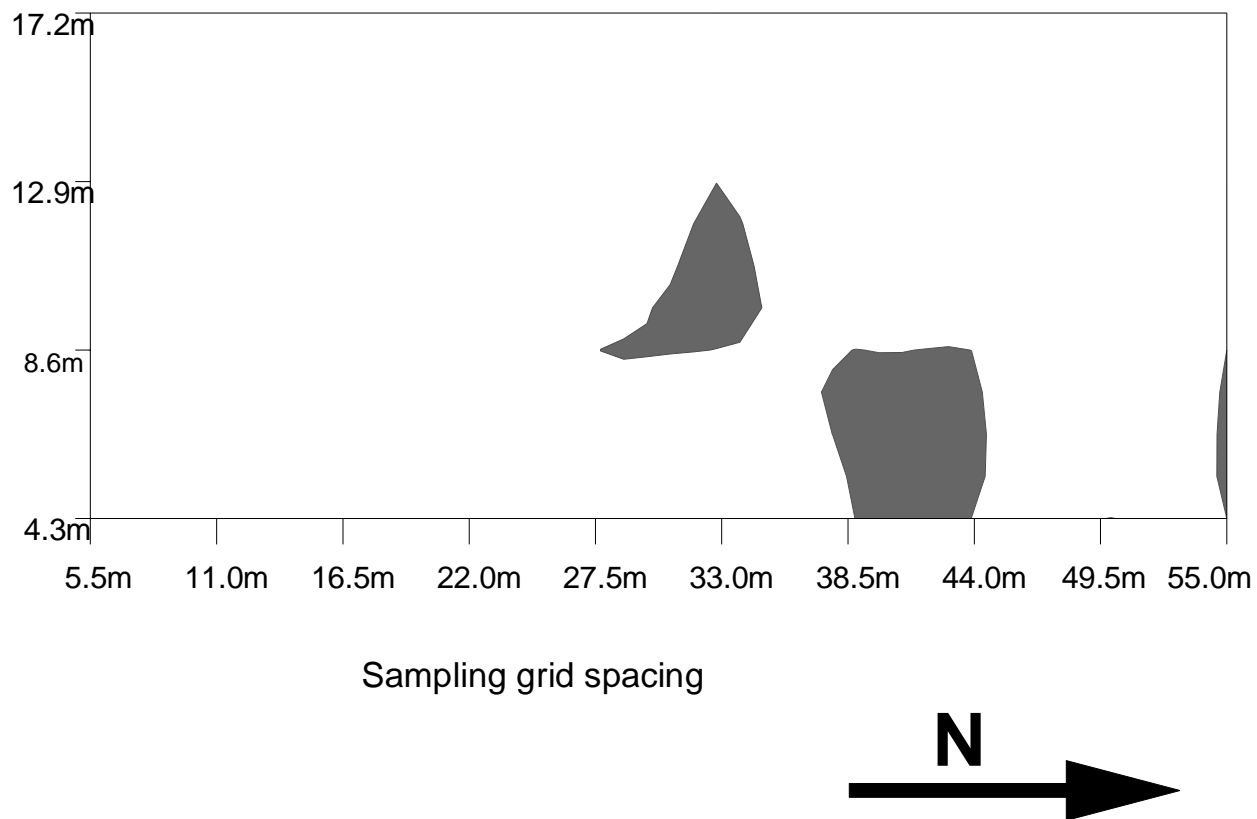


Figure 5. Topsoil material (shaded areas) that was pushed onto Pit 1 during surface grading.

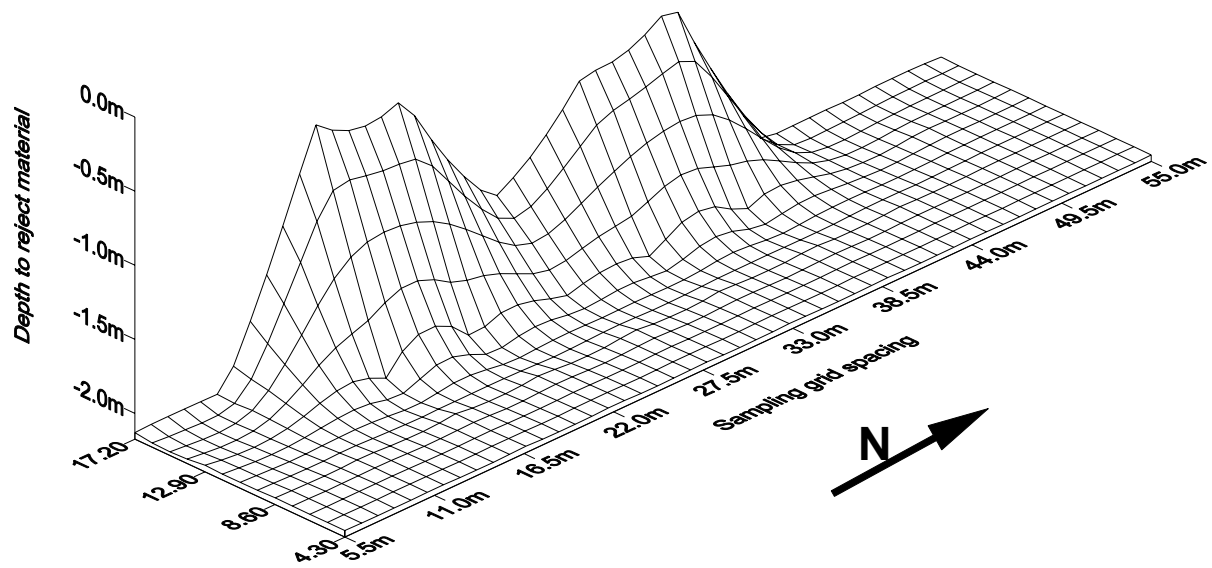


Figure 6. Surface map showing the location of unprocessed materials dumped into Pit 1 during backfilling.

with various dike and mixed surface materials. Because there is limited chance any operational pits will be treated in this manner, Pit #2 was not included in this study.

Due to the problems encountered during the filling of Pits #1 and #2, the filling and surface configuration of Pit #3 became critical. In order to have a surface consisting of remixed tails and slimes, Pit #3 was filled above original elevation in the hope that when dewatering was complete we would have a suitable surface for installation of field plots. After back-filling was completed (early April, 1995) the entire surface of the pit was hydroseeded with a mixture of annual rye (*Secale cereale*) and redtop fescue (*Agrostis alba*) in an effort to speed dewatering and control erosion around the dikes. By early June it was determined that Pit #3 had dewatered enough to begin surface work. On June 5, 1995, a track loader was employed to remove the dikes surrounding the pit. This was accomplished by “back-blading” the material away from the pit. The main goal in removing the dikes in this fashion was to keep unprocessed soil material out of the pit. Once dike removal was complete, an attempt was made to begin “walking” the tails, which involves repeatedly driving a bulldozer back and forth across the pit surface. This proved unworkable when the track loader became stuck and had to be pulled out several times. Over this period it became apparent that there were two major challenges with Pit #3: (1) There was extensive segregation of tailings and slimes; and (2) there was not enough material to bring the surface back up to original grade. These problems were addressed by shortening the pit by about 20 m and by using the excavator to physically remix the materials. Material from the south end of the pit was excavated and used to bring the rest of the pit up to grade. The south end of the pit was then back-filled with subsurface materials from around the site. This enabled us to have a

suitable surface for plot installation that covered an area approximately 30 m by 50 m. This area was sampled for variability in mid-July using the same grid interval as Pit #1 (4.3 m by 5.5 m).

Subsequent to the dewatering and grading of Pits 1 and 3, the entire site (except for the undisturbed control area) received $560 \text{ kg ha}^{-1} \text{ P}_2\text{O}_5$ and $168 \text{ kg ha}^{-1} \text{ K}_2\text{O}$ on September 11. On September 12, the entire site received agricultural lime at a rate of 2.2 Mg ha^{-1} . In an effort to reduce compaction and incorporate the fertilizer, we enlisted the aid of Mr. Mark Spiers who used a large V-ripper to rip all experimental areas to a depth of 25 cm or more. This was followed by a thorough discing to help smooth the surface prior to the installation of experiments.

Originally, we had planned to install a replicated plot experiment involving five loading rates of compost with four replications of each treatment. This would have required twenty plots in each experimental area (4 pit halves plus control) for a total of 100 plots. By the time grading of the pits was completed it became obvious, from the size of the usable pit surfaces, that if we installed this design each plot would have to be very small (less than 3 m by 4 m). Upon consultation with our cropping system expert, Dr. Marcus Alley, we concluded that this design was not feasible based on his recommendation that the plots be no smaller than 4 m by 5 m. In addition to Dr. Alley, we consulted Dr. Erik Smith of the Virginia Tech Statistics Department. After reviewing crop yield variance data from the Ti Sands experiment (Stolt et al., 1995), he advised us that in order to have a sound design and be capable of separating differences in yields as low as 15%, we would need a large number of plots. With this advice in mind, we changed the design.

To achieve our goals of sufficient plot size and statistical power, we settled on a design

that treats the experiment as five separate experimental units within the overall study (Fig.7). One experiment, consisting of 24 plots measuring 3.6 m by 7.2 m was installed on the previously set-aside area of undisturbed soil adjacent to the mined area. The second and third experimental units were set up on Pit #1 which was divided into two experimental areas. Each area was then subdivided into 12 plots measuring 3.6 m by 6 m (Fig. 8). On September 29, the northern half received 30 cm of topsoil (based on the earlier RGC greenhouse studies) which had been scraped off of the pit area prior to excavation. A bulldozer was employed to place the topsoil, and differential settling of the pit surface made depth control difficult and variability in thickness resulted. The southern half received composted yard waste at the rate of 112 Mg/ha on October 12. This rate was based on work by Stolt et al. (1995) at the Ti Sands project. The compost was obtained from the Rt. 623 Landfill west of Richmond, VA (for chemical analysis of compost see App. I). Application of compost was accomplished by weighing out the appropriate amount of compost for each plot and raking it out to achieve even distribution.

The fourth and fifth experiments were installed on Pit #3. This area is also split between a topsoil replacement experimental unit and a compost amendment experimental unit. Due to insufficient retention of topsoil, Pit #3 received two topsoil applications. The first application was from the original stockpile of topsoil and was applied on September 29. This was insufficient to cover the experimental area to a depth of 25 cm. To remedy this, more topsoil was scraped from an undisturbed area south of the control plots and applied to Pit #3 on October 11. Again, each half of the pit was laid out in 3.6 m by 6 m plots. Yard waste compost was applied at the rate of 112 Mg ha⁻¹ by the method described above. On October 26, 1995 all plots received additional

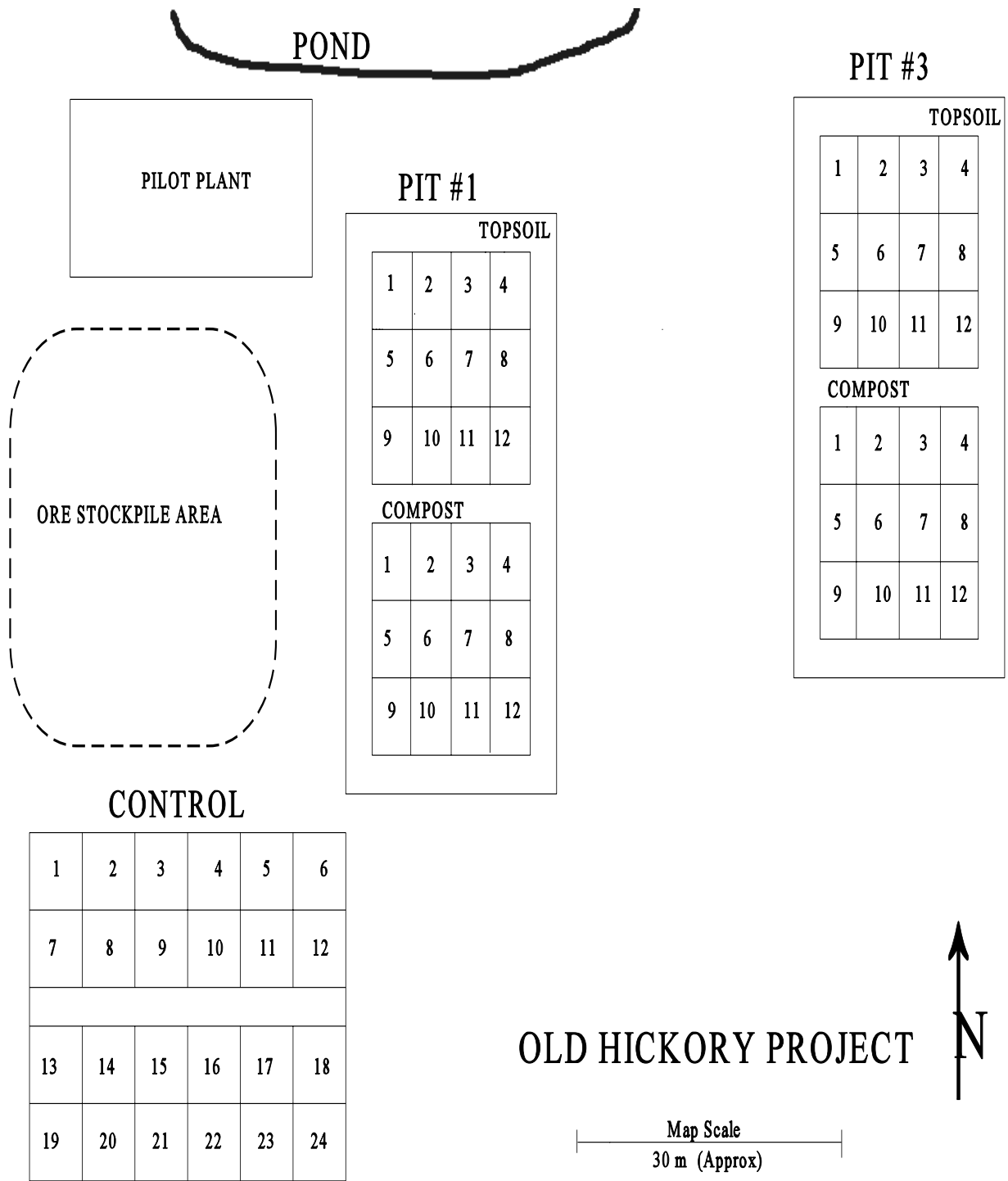


Figure 7. Layout of experimental plots.

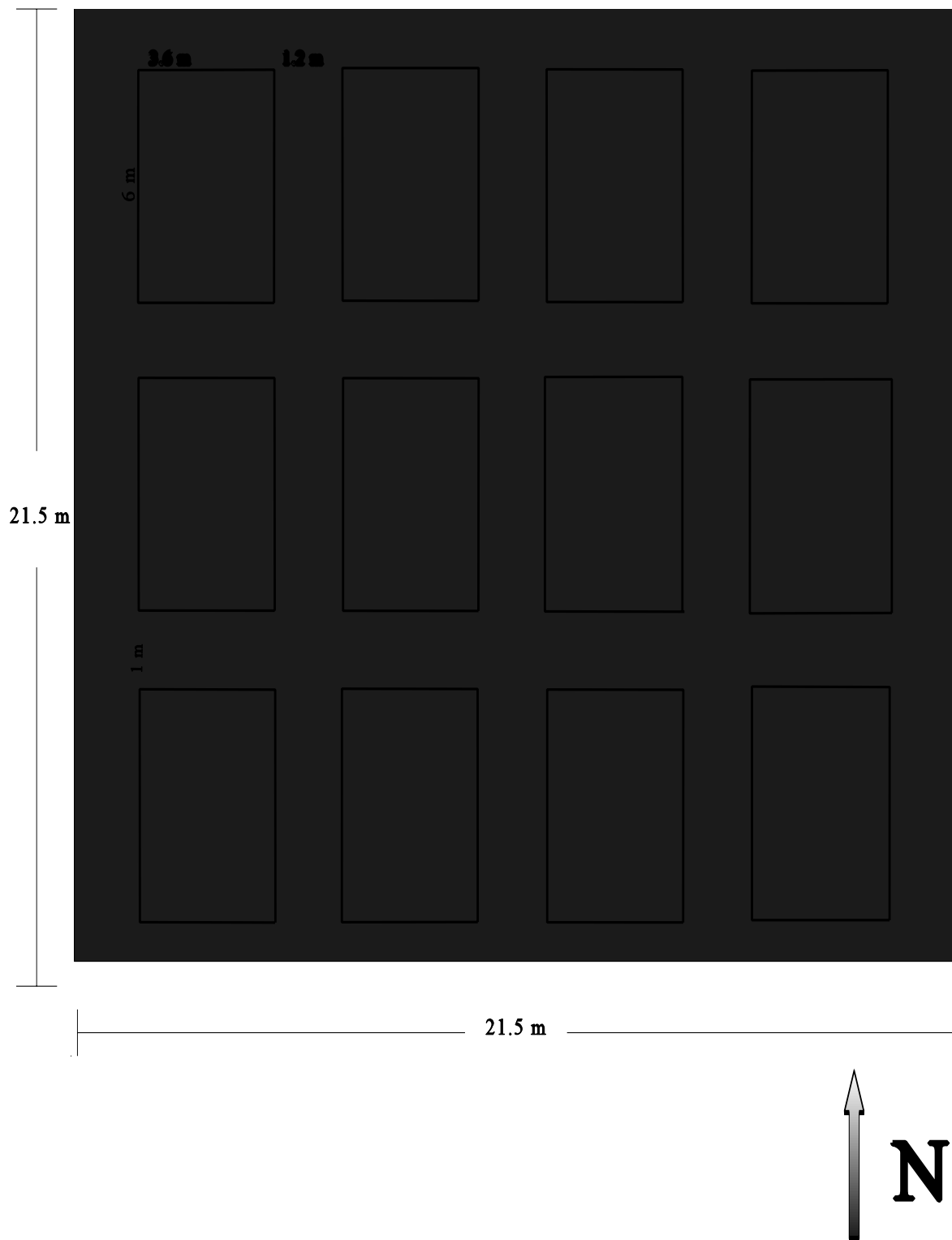


Figure 8. Typical layout of plot on mine pit showing plot, alley and overall dimensions.

fertilizer ($179 \text{ Kg ha}^{-1} \text{ P}_2\text{O}_5$, $179 \text{ Kg ha}^{-1} \text{ K}_2\text{O}$, and $34 \text{ Kg ha}^{-1} \text{ N}$) to ensure adequate and uniform fertility. The fertilizer was weighed out in individual plot applications and hand-applied. The topsoil replacement areas also received 2.2 Mg ha^{-1} agricultural lime to balance pH against the remainder of the experimental areas. With the aid of Mr. Francis Barnes, we chisel-plowed the topsoil treatments to break up any compaction of the topsoil due to bulldozer placement. Mr. Barnes also disced all experimental areas to incorporate fertilizer and compost, and prior to planting used a field cultivator to smooth and firm the seed bed. On October 27, 1995, wheat (*Triticum vulgare* var. Coker 9803) was drilled at a rate of 134 kg ha^{-1} . This was accomplished with a conventional grain drill on a 18 cm row spacing. Several weeks after planting, Mr. Barnes planted the balance of the surrounding Pilot Plant site with Pioneer variety 2580 wheat.

To assess stand establishment, plant population counts were taken on November 11, 1995. This was accomplished by counting the number of plants in four 1 m lengths of row in each plot. On February 2, 1996, $45 \text{ kg ha}^{-1} \text{ N}$ was applied as UAN along with Harmony Extra™ (Thifensulfuron, and Tribenuron) at a rate of 37 ml ha^{-1} for control of broadleaf weeds. Nitrogen was again applied on January 11, 1996 at the rate of 101 kg ha^{-1} to topsoil and control plots, and 34 kg ha^{-1} to compost plots. The application rate was reduced on compost plots because mineralization of N in the compost could lead to lodging if the full rate were applied. On May 3, 1996, Malathion was applied to control cereal leaf beetle, and on May 30, 1996 Manzate™ (Mancozeb) and Bayleton™ (Tridimefor) were applied to insure that fungal disease would not be a problem.

Just prior to harvest, head counts were taken for later yield component calculations.

Wheat was harvested on June 18, 1996. This was accomplished with a Hedge 140 research plot combine. The center 2 m of each plot was harvested and samples were taken to Virginia Tech for yield determination. Following wheat harvest, soil and root samples were taken from six randomly selected plots in each treatment area.

On June 22, 1996, soybeans (var. Hutcheson) were planted with a no-till drill in 43 cm rows. Three days after planting, Squadron™ (Imazaquin, and Pendimethalin) and Roundup™ (Glyphosphate) were applied at rates of 1.75 l ha⁻¹ and 3.5 l ha⁻¹ respectively to control weeds. Plant population counts were taken on July 24, 1996, by counting the number of plants in two 1-m sections of row in each plot. Just prior to harvest, plant heights were measured. This was accomplished by measuring the height of four randomly selected plants in each of the 72 plots. The soybeans were harvested from the Topsoil treatment on Pit 3 on November 17, 1996 and the balance of the treatments were harvested on the November 24, 1996 with the same research combine used to harvest wheat in the spring. The split harvest was due to mechanical difficulties with the combine and bad weather. Samples from each plot were transported to Virginia Tech for yield calculation. After soybean harvest, pits were dug on selected plots for soil description, sampling, and root mapping.

SOIL SAMPLING

Soil sampling began prior to the commencement of pit excavation, with deep auger sampling of the undisturbed soil in the area of each pit. Three borings were taken from each pit location (Fig. 9) to a depth of 300 cm. Samples of all major soil horizons were collected and

descriptions were written. Subsequent to excavation of Pit 1, a detailed description and sampling of the natural soil exposed in the pit face was completed. Both of these sample sets will, along with later samples taken from the control plots, serve as the source for baseline undisturbed soil data.

With the completion of mining operations, Pits 1 and 3 were sampled for variability analysis. These samples were obtained with a 7.5 cm bucket auger to a depth of at least 150 cm on a 4.3 x 5.5 m grid (Fig. 10). Following wheat harvest, composite soil samples from the surface of 6 randomly selected plots in each treatment were taken to a depth of 15 cm with a soil probe. These samples were analyzed for their chemical and physical properties as described later.

Final soil samples were taken just after soybean harvest. This was accomplished by digging pits along the edge of 18 randomly selected plots (Fig. 11). These pits were excavated to a depth of at least 150 cm, except where ground-water intruded. A face in each pit (perpendicular to soybean rows) was described in detail and bulk soil samples were taken from all horizons for laboratory analysis. Three bulk density samples were taken, from each horizon of sufficient thickness, by the core method (Blake and Hartage, 1986).

ROOTING ANALYSES

In addition to sampling the crop yield and soil parameters discussed above, root length and distribution were studied. Following wheat harvest, root samples were obtained from six randomly chosen plots within each treatment. A 7.5 cm bucket auger was employed to collect all the soil and roots to a depth of 46 cm. Roots were separated from soil materials by the flotation

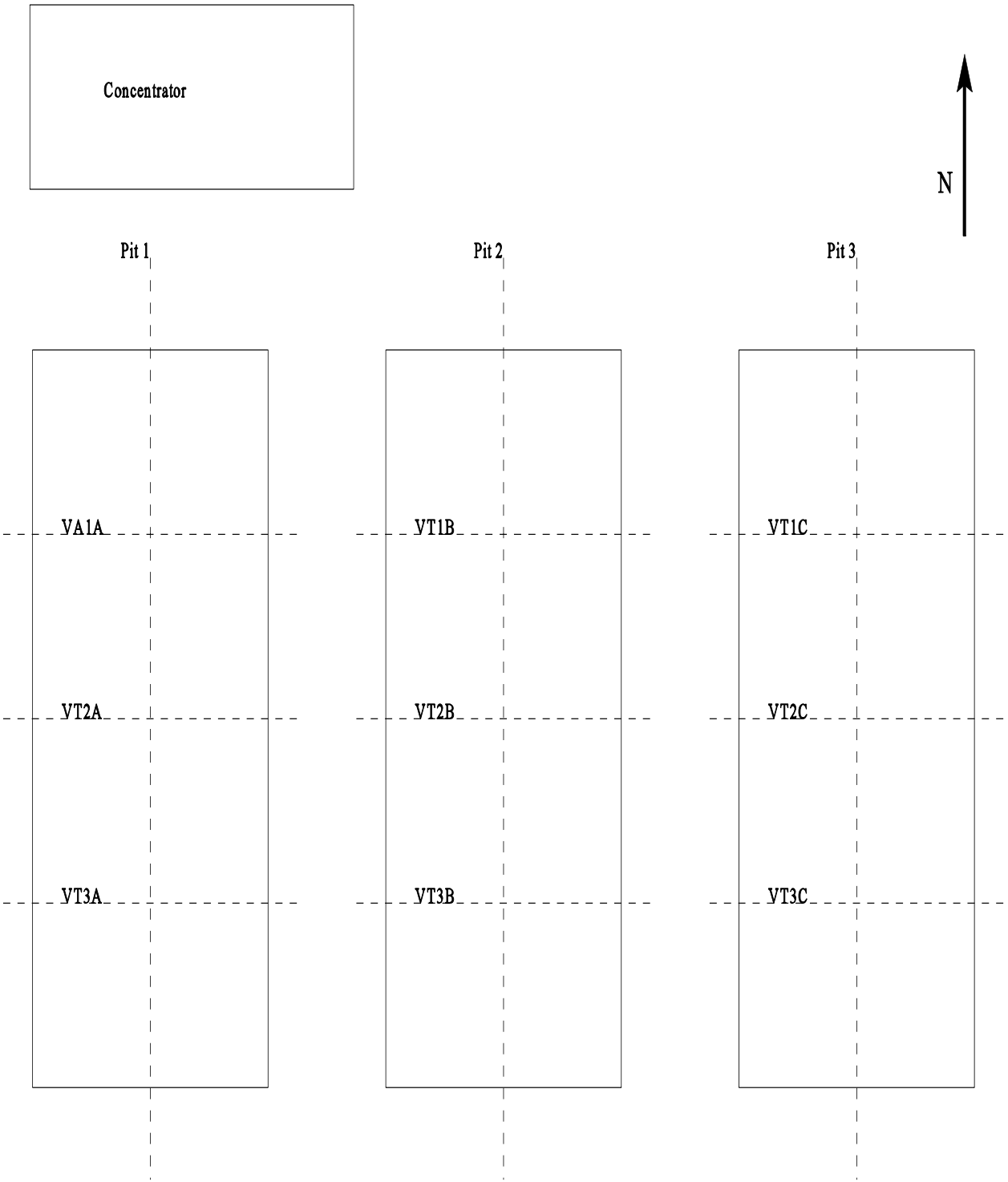


Figure 9. Location of auger sampling site for samples taken in pit areas prior to mining.

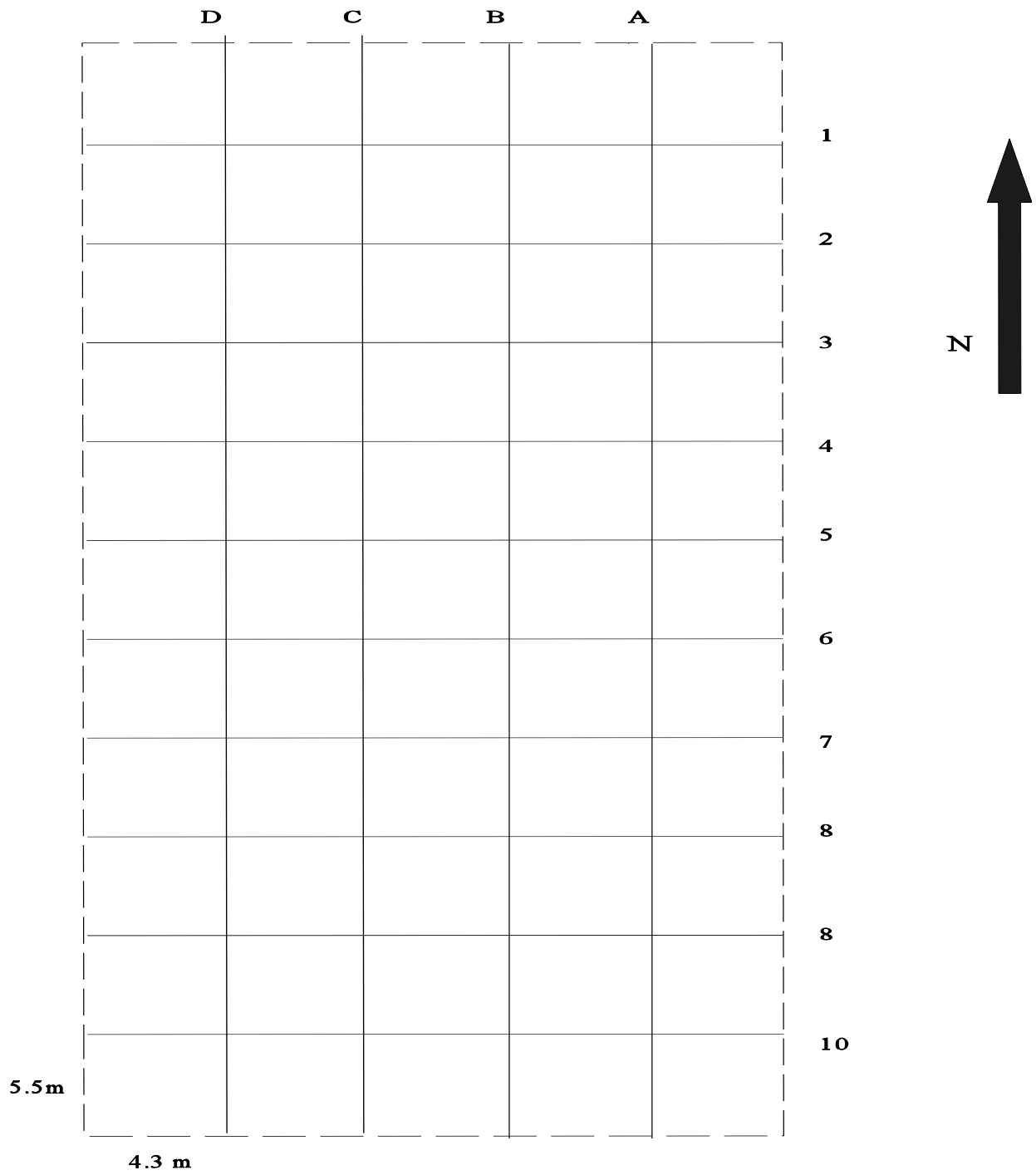


Figure 10. Location of variability samples taken from Pit 1. Auger borings were made at each line intersection.

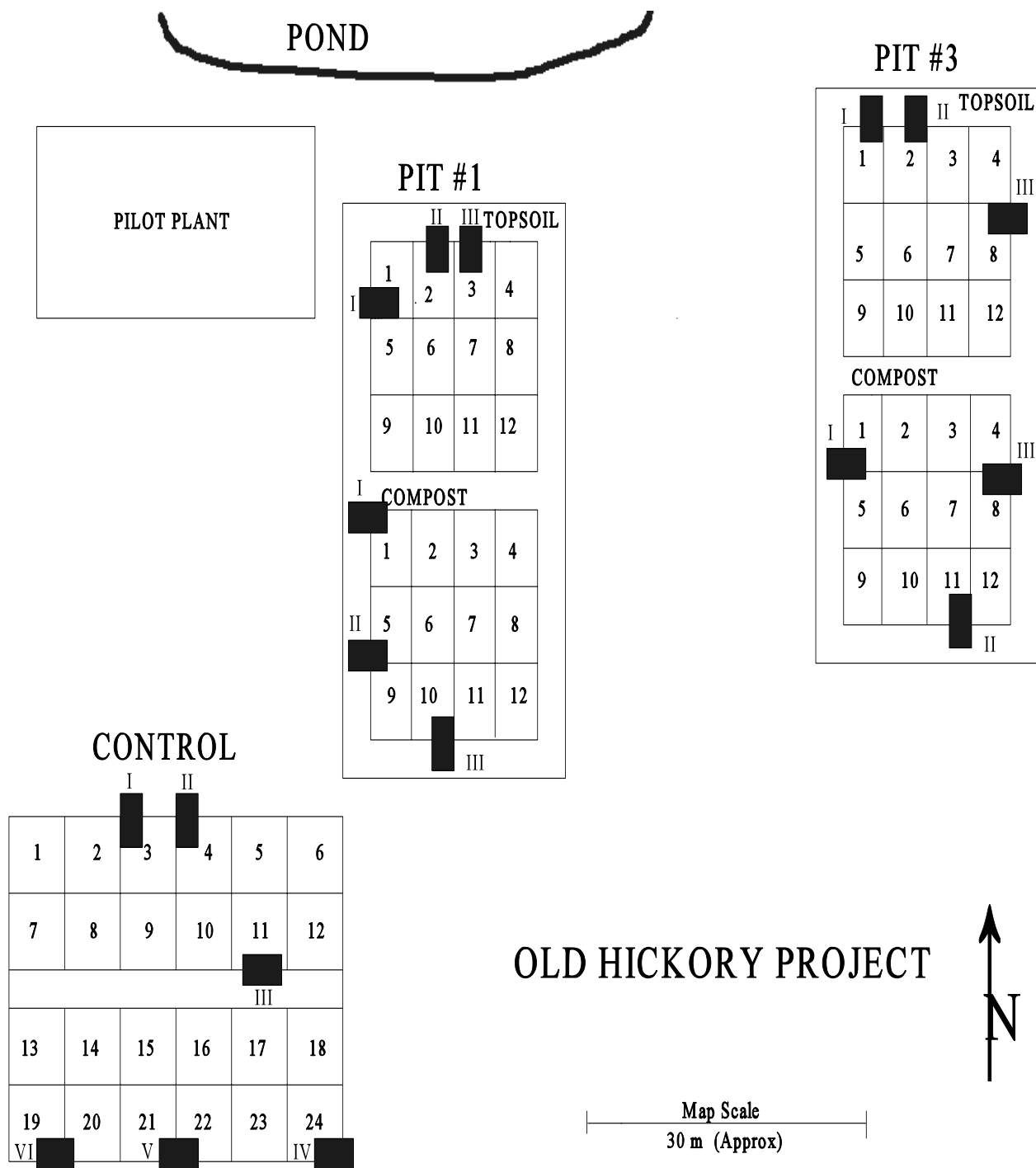


Figure 11. Location of soil pits dug on December 2, 1996 following soybean harvest.

method (Bohm, 1979). After separation, the root samples were stored in alcohol at 10⁰C until length analysis could be preformed. Root length was determined with a Delta T analyzer (DeHart Devices LTD. Cambridge, England).

Following soybean harvest, rooting distributions were mapped by a method similar to that described by Bohm (1976). Pit faces, perpendicular to soybean rows, were made vertical with a spade and smoothed with a small cement trowel. About 5 cm of soil was removed from the pit face to expose roots. A framed 1x1 m plexiglass sheet was mounted on the pit face, and root position was mapped on a polyester film overlay by making a dot on the film for each exposed root. Approximate horizon boundaries were also traced. Root density was estimated by assuming that each dot represents 5 cm of root length and each map represented 0.05 m³. Bohm (1977) concluded that this method would underestimate actual root length and density, but it should prove adequate for comparison among treatments and between natural and disturbed soils in this study.

SOIL PHYSICAL ANALYSIS

In the laboratory, field samples were dried, and ground to pass a 2 mm sieve. Once ground, the samples were analyzed for particle size distribution by the pipette method (Gee and Bauder, 1986). Water retention characteristics were determined on selected surface and subsurface samples (Klute, 1986), and particle densities were determined by the pycnometer method (Blake and Hartage, 1986). Bulk densities were adjusted to compensate for the high particle density of the HM present. This was accomplished by multiplying the bulk density by the

ratio of observed particle density to “normal” soil particle density (i.e. 2.65 g cm^{-3}).

SOIL CHEMICAL ANALYSIS

Chemical analyses included pH in a 1:1 water slurry (McClean, 1982). Total C was determined by combustion on a LecoTM carbon furnace. Extractable Ca, Mg, K, P, B, Zn, Fe, Al, and Cu were determined by a dilute double acid extraction and inductively coupled plasma spectrometer analysis (Donahue, 1994). Exchangeable bases were determined by extraction with pH 7 N NH_4OAc (Thomas, 1982) and atomic absorption spectrophotometer analysis. Exchangeable H and Al were determined by BaCl_2 -TEA and KCl extraction respectively (Thomas, 1982). Effective cation exchange capacity (ECEC) was taken as the sum of bases plus KCl extractable Al. Cation exchange capacity was calculated as the sum of NH_4OAc exchangeable bases and BaCl_2 -TEA exchangeable H. Base saturation was calculated as sum of bases divided by CEC.

CROP YIELD ANALYSIS

Wheat and soybean samples obtained at harvest were transported to Virginia Tech where bulk sample weights, moisture content, average bushel weight, and grain weights were determined. Moisture content and average bushel weights were determined with a Dickey-john (GAC II) Grain computer.

DATA ANALYSIS

The overall experiment was treated as a simple one-way design with six treatments (the 4 pit and 2 control cells) and 12 replications each. A conventional overall F-test was applied to the entire sample set for a given parameter (e.g. wheat yield) at a given time, and then the means were contrasted with the LSD approach if the F-test was significant. To assess whether the data were normally distributed, histograms and box plots were prepared for each data set. For data with non-normal distribution, non-parametric methods such as the Wilcoxon rank-sum test were used. Regression analyses were employed to compare and contrast various interactions such as soil available-P vs carbon content.

Chapter 3

RESULTS AND DISCUSSION

Crop Response to Topsoil Replacement vs Compost Application.

Winter wheat and soybeans were grown from October, 1995 to November, 1996 to evaluate crop response to topsoil replacement and compost application on material mined for HM. With the exception of the first three weeks of July, rainfall was above normal, and 1996 was one of the wettest years on record. Temperatures were below normal for the period as well. The combination of high rainfall and low temperatures definitely affected crop yields and relative treatment response. All results must be considered in relation to these weather conditions.

Wheat Yield

There were strong differences in yield among the treatments ($p = 0.0001$). Undisturbed control plots produced the highest wheat yield of all experimental areas, however, there was no difference in mean yield between the Control and the Topsoil treatment on Pit 1 (Fig. 12). Both the Topsoil treatment on Pit 1 and the undisturbed Control were higher than typical (3000 kg ha^{-1}) wheat yields for this region (App. II). Of the remaining treatments, the Compost treatment on Pit 1 and the Topsoil treatment on Pit 3 produced similar yields, while the Compost treatment on Pit 3 produced lower yield than the Compost treatment on Pit 1.

Shortly after emergence, population counts were taken and, although there were no

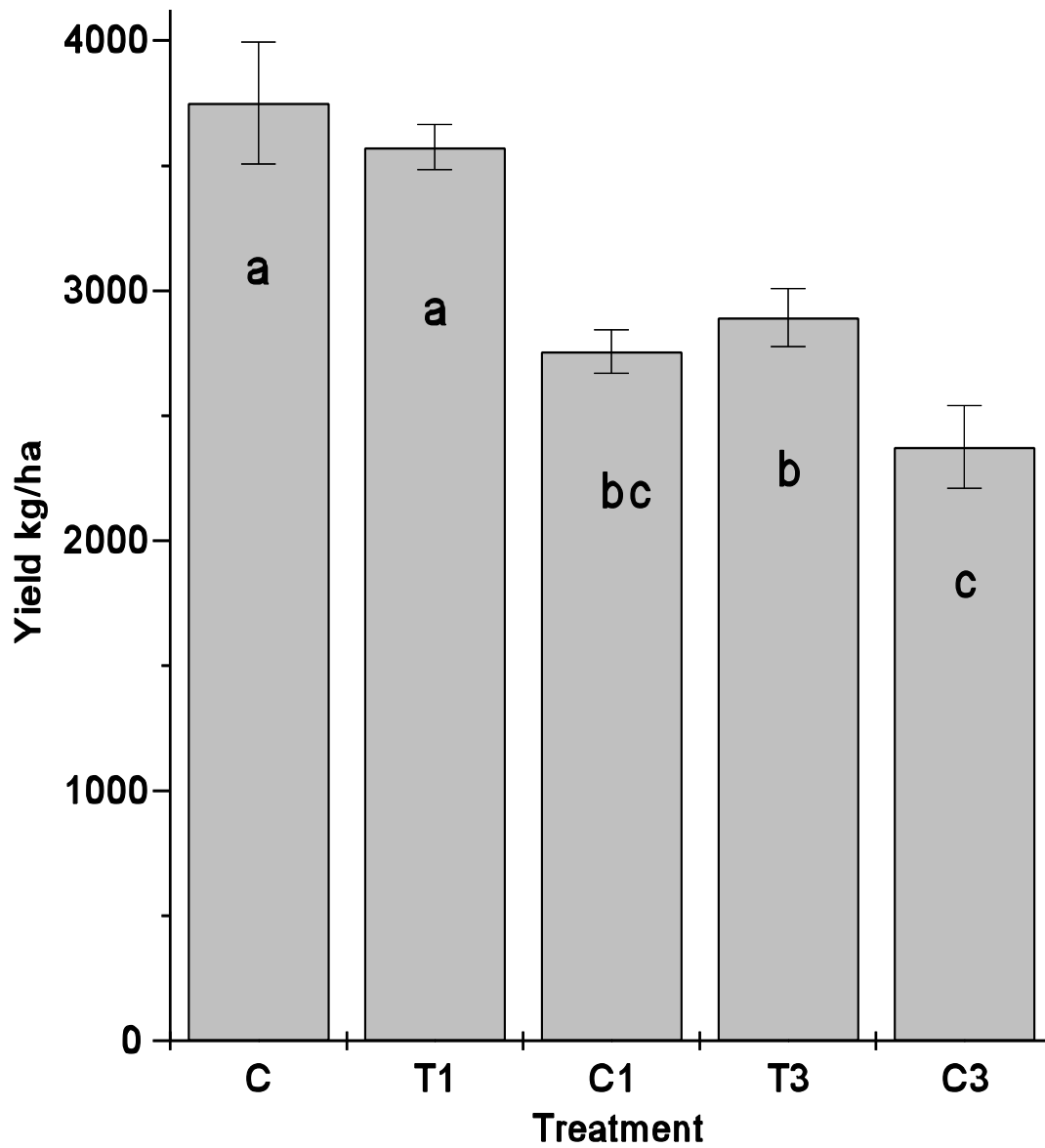


Figure 12. Yield of wheat harvested from experimental plots on June 18, 1996. Means with the same letter are not different ($p = 0.0001$). Error bars indicate Standard error of the mean. C: Control, T1: Pit 1 topsoil, C1: Pit 1 compost, T3: Pit 3 topsoil, C3: Pit 3 compost.

differences by treatment ($p = 0.23$), the treatment that produced the highest yield, the Control, also supported the highest plant population, and the treatment with the lowest population, Pit 3 Compost, had the lowest yield.

The experimental site rests on the summit and shoulder of a low ridge, with Pit 1 on the summit and Pit 3 on the shoulder/sideslope. The control area straddles both the ridge and the shoulder, giving it characteristics of both positions. The location of the treatment areas in relation to the landscape appears to have influenced yield through effects on temperature and moisture factors. Pit 1 is on the summit with the topsoil treatments raised 30 cm above the surrounding grade (due to placement of topsoil on the surface of Pit 1), which would lead to improved soil drainage. Because Pit 3 is on the shoulder/sideslope, it also receives runoff from the slope above and therefore tends to remain wet longer than Pit 1. In fact, when samples were taken after wheat harvest there was free water within 45 cm of the surface in the Compost treatment half of Pit 3. Additionally, the Topsoil treatment on Pit 3 is raised approximately 40 cm above the Compost treatment (again due to placement of topsoil on the surface of the pit) which directed additional water onto the composted half. In a study of the effect of waterlogging on wheat yield in Louisiana, Musgrave (1994) reported that grain yield was reduced by 51 % for wheat (var Coker 9877) grown on waterlogged soil compared to well drained soils. He also reported that yield reductions were due to differences in kernel number and weight. Table 1 shows that the two treatments with the lowest yield also had lower kernel numbers and weights.

Table 1. Average kernels per head and 1000 kernel weight for wheat harvested from experimental plots on June 18, 1996.

Treatment	Kernels per head	1000 Kernel weight (g)
Control	26.7 a†	33.0 a‡
Pit 1 topsoil	26.7 a	33.2 a
Pit 1 compost	23.9 ab	31.5 b
Pit 3 topsoil	25.7 a	30.6 b
Pit 3 compost	20.2 b	30.9 b

† Means followed by the same letter are not different (p = 0.01)

‡ Means followed by the same letter are not different (p = 0.0001)

Another factor that may be evident here is the difference in texture among the treatments (Fig.13). The Topsoil treatments contained less clay in their surface horizons than either of the Compost treatments. Although the compost treated surface on Pit 1 contained more clay than the Compost treatment on Pit 3, the fact that it resides in an area where water would runoff faster may account for the higher yield as compared to Pit 3.

Another yield parameter of interest is grain moisture at harvest. Water content is a measure of plant maturity, the lower the moisture content the more mature the plant. Grain moisture ranged from 12.8 to 15.1 %. These differences were related to time of harvest. Although all plots were harvested on the same day, the plots on Pit 3 were harvested late in the afternoon due to a breakdown of the combine we used. Grain water content was lowest in the Topsoil treatment on Pit 3 followed by Pit 3 Compost, Control, Pit 1 Topsoil, and Pit 1 Compost. These differences were significant at the 0.05 level, but the actual range was not beyond what

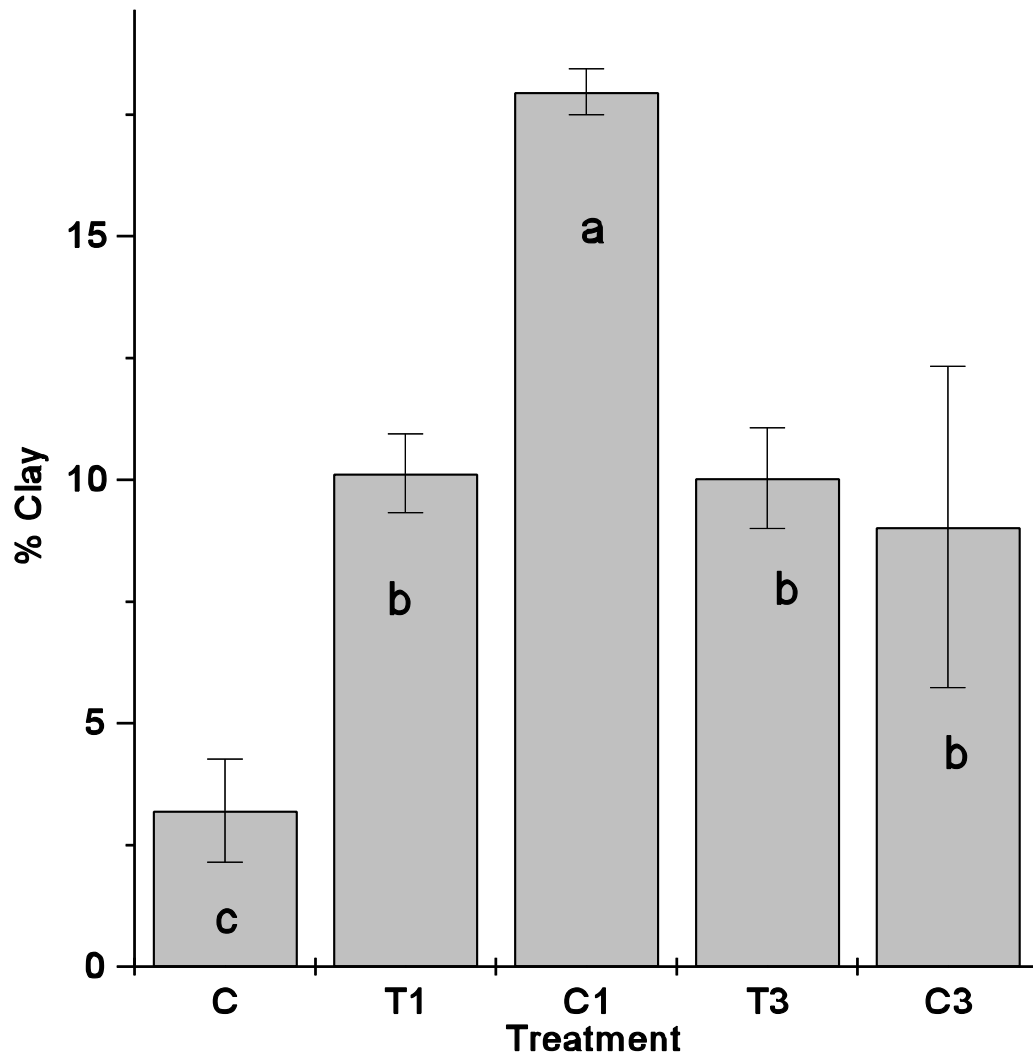


Figure 13. Average clay content of surface horizons for samples take from pits dug following soybean harvest. Means with the same letter are not different ($p = 0.0002$). Error bars indicate standard error of the mean. C: Control, T1: Pit 1 topsoil, C1: Pit 1 compost, T3: Pit 3 topsoil, C3: Pit 3 compost.

could normally be expected in wheat grain. Although the grain moisture does not indicate differences in maturity, differences in maturity were obvious in the field. The plants on Pit 3 matured about 10 days ahead of the other treatments. These differences may be related to stress on the plants. Stressed plants may mature earlier than plants not under stress. In this case, the two treatments with the lowest water content, and hence the most mature, were Pit 3 Topsoil and Pit 3 Compost. One possible source of stress in these treatments would be the presence of ground-water within 30 cm of the surface in the Compost treatment. There was also significant sheet erosion uphill and deposition onto the Compost half of Pit 3 in early January, 1996. This affected the Compost treatment on Pit 3 and to a lesser extent the Topsoil treatment. Erosion was not a problem on Pit 1 because it is situated on a higher area of the landscape which has very little slope. Another stress factor which may have affected the maturity of the wheat on the Pit 3 Topsoil treatment was the presence of significant amounts of annual ryegrass (*Lolium multiflorum* Lam.) and resultant competition for water and nutrients.

Some of the observed treatment effects on wheat yield may be explained by the root length data. Root length from the Control treatment was different from all other treatments ($p = 0.002$). Mean root length was greatest for Control plots, followed by Pit 1 Topsoil, Pit 1 Compost, Pit 3 Topsoil, and Pit 3 Compost respectively (Fig. 14). As would be expected, there was a linear relationship ($P = 0.046$) between wheat root length and yield (Fig. 15). Attempts to correlate root length to bulk density were not successful, however. In fact, there was a positive correlation between root length and bulk density. I believe this to be the result of weather effects masking treatment effects.

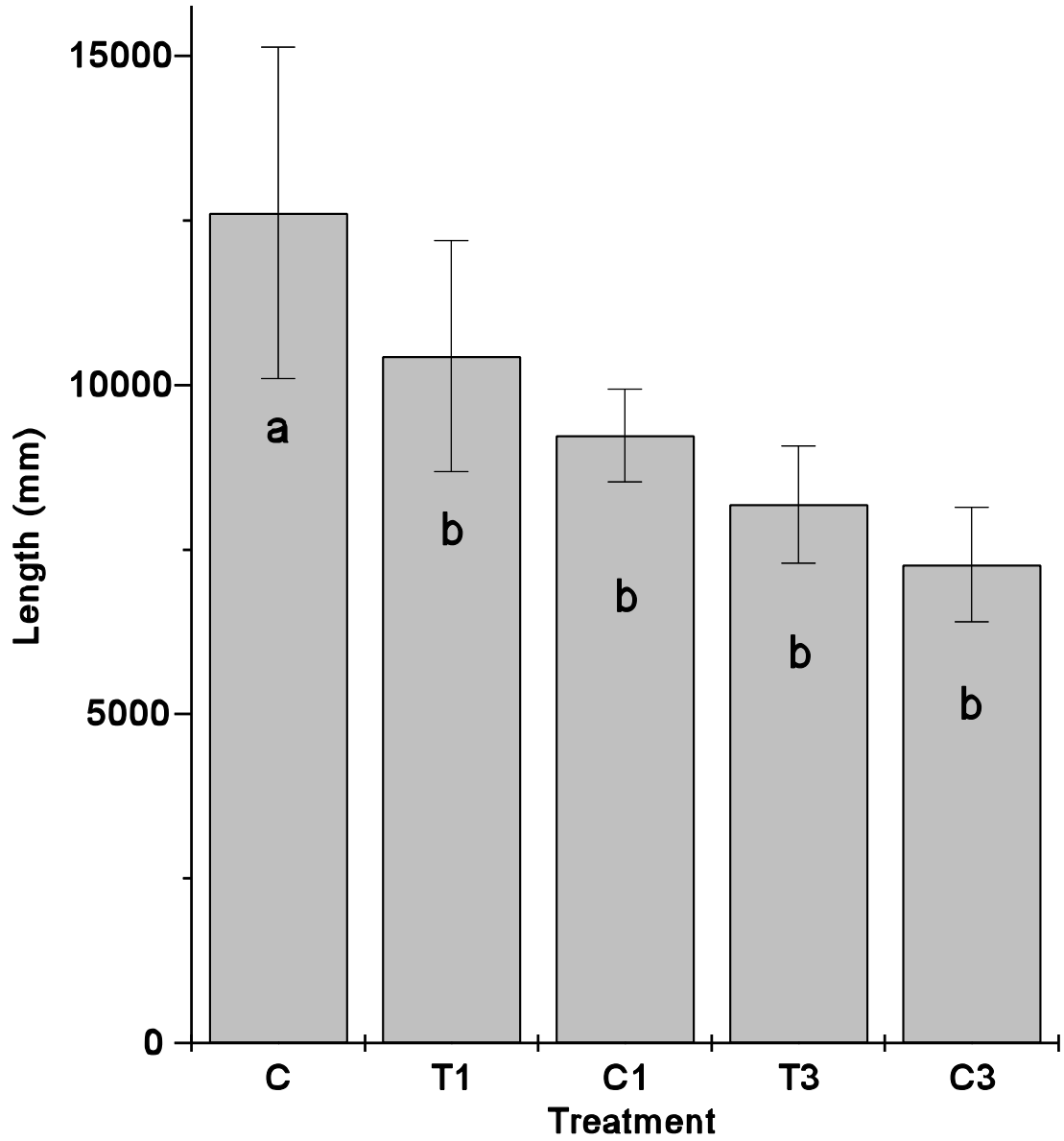


Figure 14. Average length of wheat roots at harvest in June, 1996. Means with the same letter are not different ($p = 0.002$). Error bars indicate standard error of the mean. C: Control, T1: Pit 1 topsoil, C1: Pit 1 compost, T3: Pit 3 topsoil, C3: Pit 3 compost.

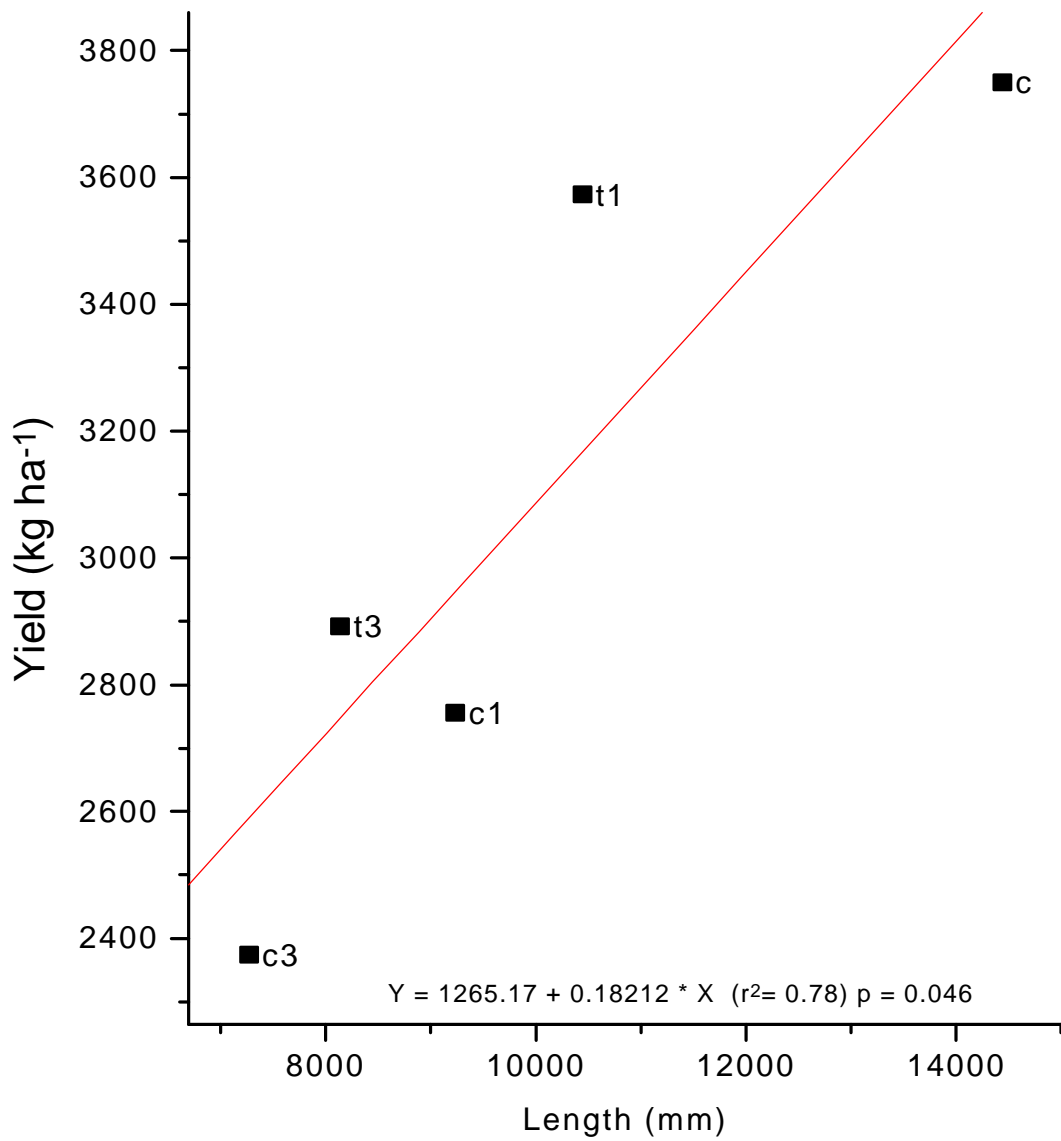


Figure 15. Relationship between wheat yield and average wheat root length from samples taken after wheat harvest in June, 1996. c: Control, t1: Pit 1 topsoil, c1: Pit 1 compost, t3: Pit 3 topsoil, c3: Pit 3 compost.

Analysis of other chemical and physical properties of the treatment soils revealed no other correlations which might explain treatment effects. I believe that the two Topsoil treatments out-yielded their companion Compost treatments due to differences in several factors. First, both of the Topsoil treatments are elevated above their corresponding Compost treatments. This would result in better drainage which was advantageous in the wet weather. Second, the Topsoil treatments were coarser in texture, and therefore better drained. This would result in them warming up faster in the spring, thus giving the wheat an advantage in cold weather. Third, N application was reduced on the Compost treatments because we feared potential N mineralization from the compost would lead to lodging. Although this concern was warranted, I believe the cold weather and wet soil conditions may have limited N mineralization and therefore resulted in sufficient N deficiency to reduce yields, but not enough to cause visible deficiency symptoms. Finally, the added YWC in the compost plots increased water holding. This may have exacerbated the poor drainage and excess water present in this very wet spring. Overall, excess soil water was the main cause of low yield.

Soybean Yield

There were no differences in fall, 1996, soybean yield (Table 2) among the Control, Pit 3 topsoil, and Pit 3 Compost treatments. Yield on Pit 1 Compost was lower than Pit 3 Topsoil, but not lower than the Control. Overall, yield was lowest for the Topsoil treatment on Pit 1. All treatments exceeded typical yields for the region, however, based on a ten year county average of 1716 kg ha⁻¹ (App. II).

As with wheat, plant counts were taken shortly after soybean planting (Table 2) to test for differences in stand establishment. The Compost treatments on Pits 1 and 3 supported the highest populations. These differences may be the result of a four week dry period just after planting. There were no differences in the populations of the Topsoil treatments and the Control, and there was no consistent relationship between plant population and soybean yield.

Measurements were also taken of average seed moisture at the time of harvest to determine differences in maturity. Moisture content (Table 2) was the highest in beans from the Topsoil treatment on Pit 3. Moisture content was not different between the Compost treatment on Pit 3 and the Control, nor was there any difference between moisture contents of either treatment on Pit 1. Differences in moisture content were not outside the expected range and probably do not indicate differences in maturity.

Table 2. Yield, plant population, and seed moisture for soybeans harvested from experimental plots on November 17 and 24, 1996.

Treatment	Yield (kg ha ⁻¹)	Plant Population (Plants per m)	Seed Moisture % (at harvest)
Control	2449 ab†	73.4 b‡	16.2 b§
Pit 1 topsoil	1810 c	71.4 b	14.5 c
Pit 1 compost	2386 b	82.6 ab	15.0 c
Pit 3 topsoil	2684 a	70.4 b	17.6 a
Pit 3 compost	2594 ab	86.4 a	16.1 b

† Means followed by the same letter are not different (P = 0.0001)

‡ Means followed by the same letter are not different (P = 0.05)

§ Means followed by the same letter are not different (P = 0.0001)

Following soybean harvest, maps were made of root distribution for each treatment. Of the five treatments, the undisturbed Control had the greatest estimated root length followed by Pit

1 Compost, Pit 1 Topsoil, and Pit 3 Topsoil. Pit 3 Compost had the lowest estimated root length (Fig. 16). There was no correlation between plot yield and total estimated root length by pit, but the distribution of rooting with respect to depth revealed some interesting patterns. In the undisturbed Control, significant rooting was found in all layers to a depth of at least 150 cm (Fig. 17). In contrast, rooting was limited to the surface 40 cm in all the treatments on disturbed soils except for Pit 3 Topsoil (Figs. 18-21). Roots present at up to 100 cm in the Pit 3 Topsoil pits were probably relics from the grass mixture that was hydro-seeded on the pit surface prior to regrading, because they were mostly found in pockets of concentrated slimes. Rooting in the Compost treatment on Pit 1 showed some areas where roots had ventured into the subsoil by following what appeared to be settling cracks in the regraded subsoil that covers Pit 1. This was also seen in the second pit dug in the Topsoil treatment on Pit 1. Although there was no evidence of roots following cracks in either treatment on Pit 3, the second pit dug into the Compost treatment did display some development of soil structure with associated root exploration.

The fact that there was, generally, very little rooting into the subsoil of any treatment on disturbed soil points to some physical or chemical factors inhibiting root growth. Although there was no correlation between root length and bulk density, there is reason to believe that it was the major factor limiting root length on both treatments on Pit 1. The surface bulk density of both the treatments (Fig. 22) was in the range reported to limit root growth (Drew and Goss, 1973). From this figure it would appear that the root growth should have been limited by bulk density in the control also. The answer to this apparent contradiction lies in the well developed structure in the undisturbed soils (see App. III for complete soil descriptions). Roots will follow the planes

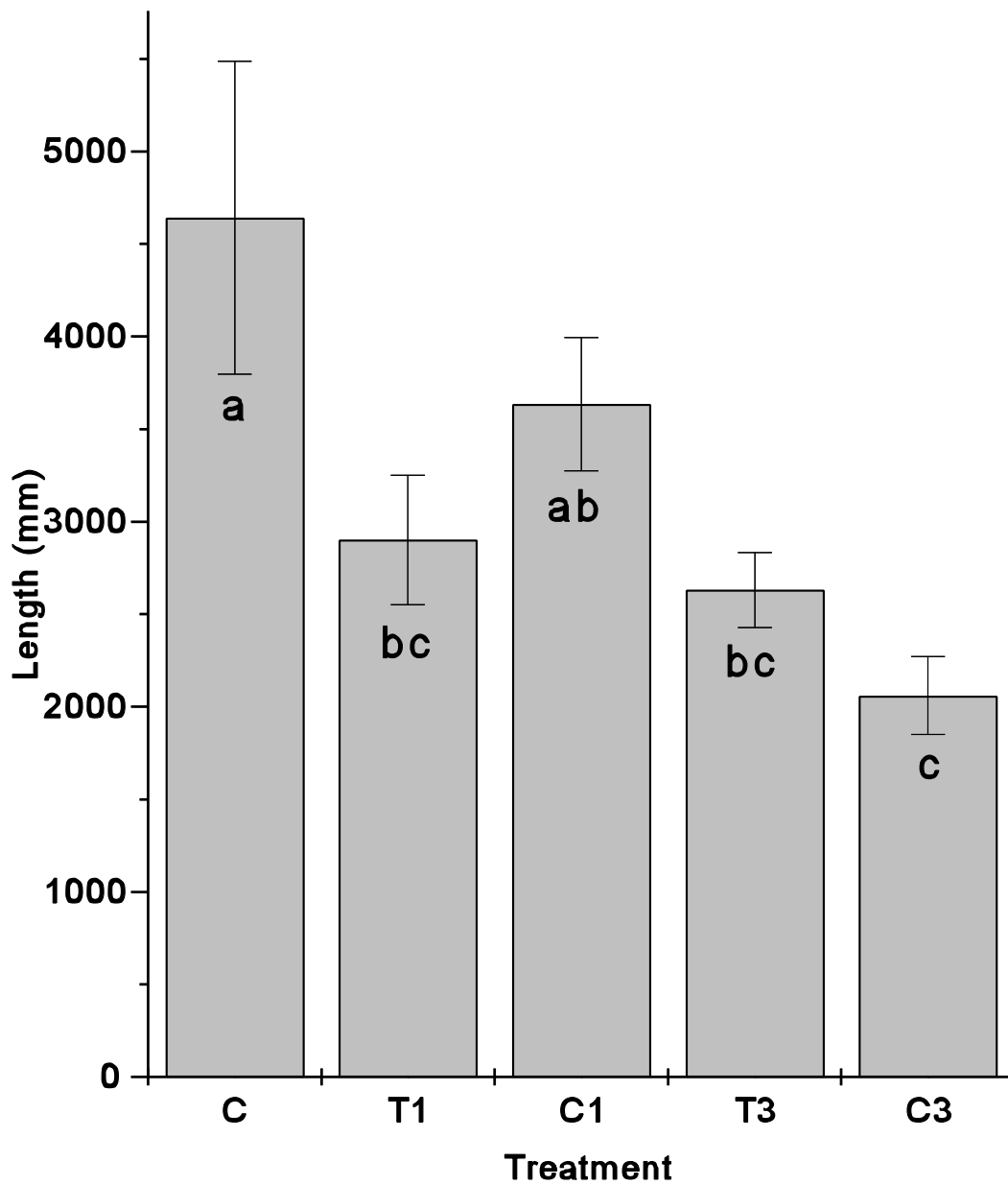


Figure 16. Soybean root length per 0.05 m³ estimated from root mapping done in pits dug after soybean harvest in November, 1996. Means with the same letter are not different ($p = 0.02$). Error bars indicate standard error of the mean. C: Control, T1: Pit 1 topsoil C1: Pit 1 compost, T3: Pit 3 topsoil, C3: Pit 3 compost.

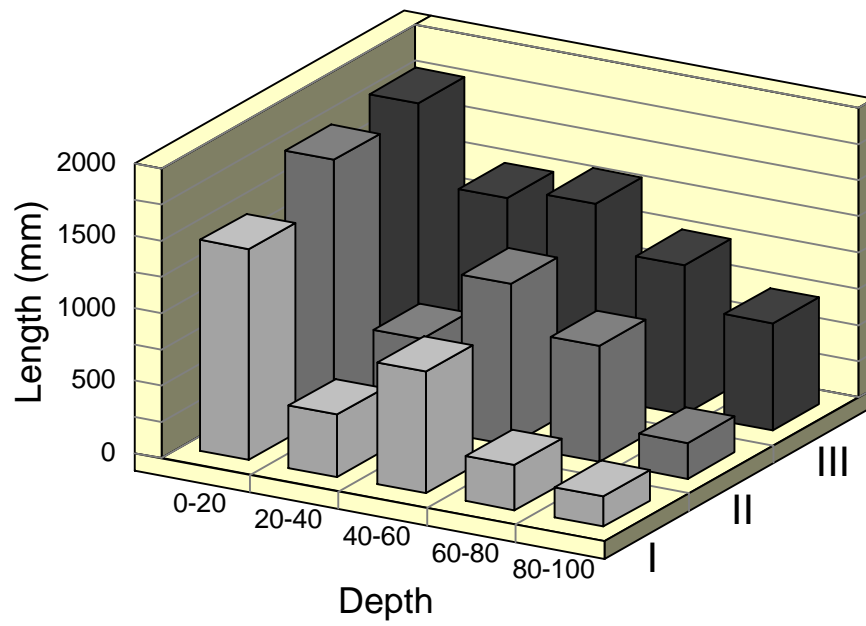


Figure 17. Percentage of total root length in each 20 cm increment in soil pits (I II III) in the undisturbed control. Refer to Figure 11 for the location of these pits.

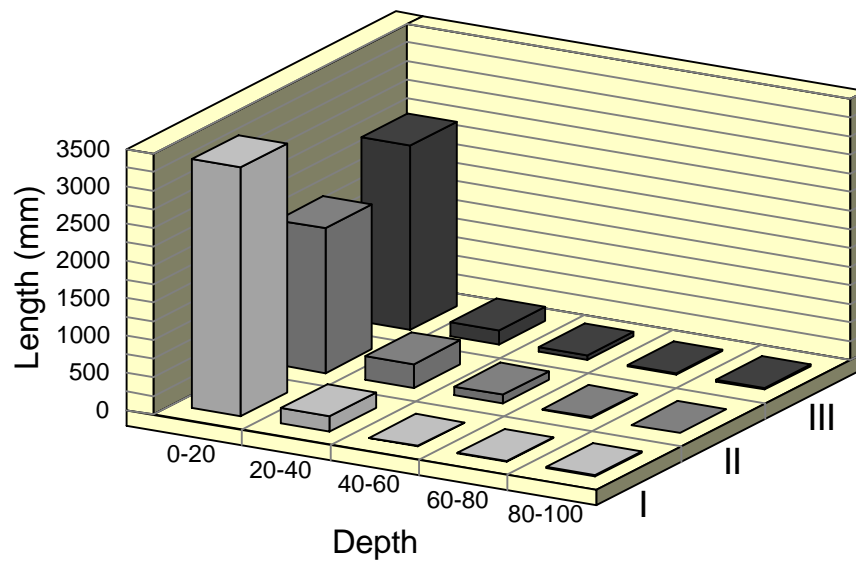


Figure 18. Percentage of root length in each 20 cm increment in soil pits (I II III) in the Topsoil treatment on Pit 1. Refer to Figure 11 for the location of these pits.

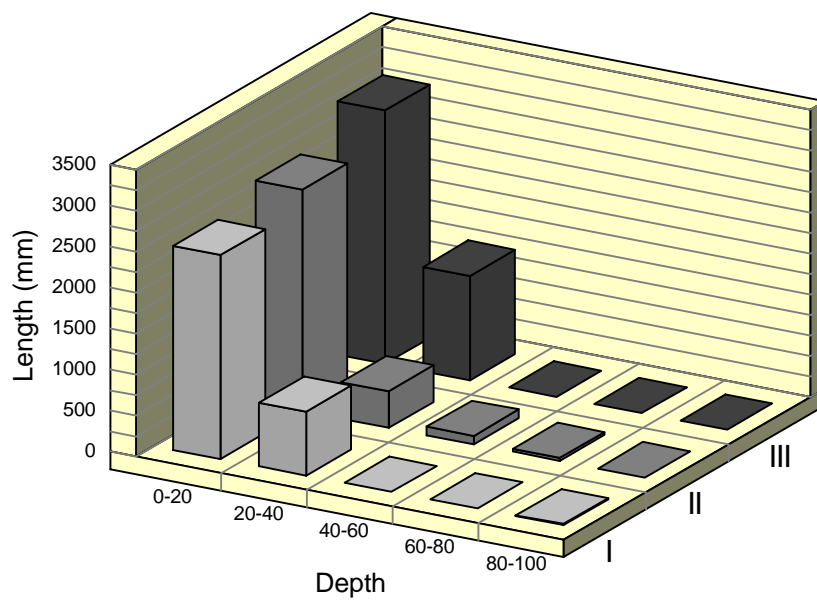


Figure 19. Percentage of root length in each 20 cm increment in soil pits (I II III) in the compost treatment on Pit 1. Refer to Figure 11 for the location of these pits.

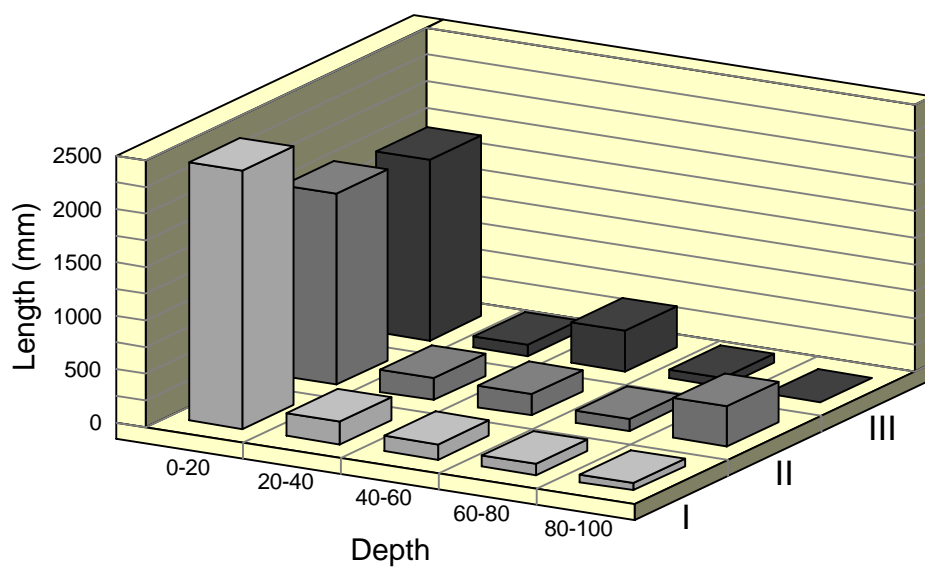


Figure 20. Percentage of root length in each 20 cm increment in soil pits (I II III) in the Topsoil treatment on Pit 3. Refer to Figure 11 for the location of these pits.

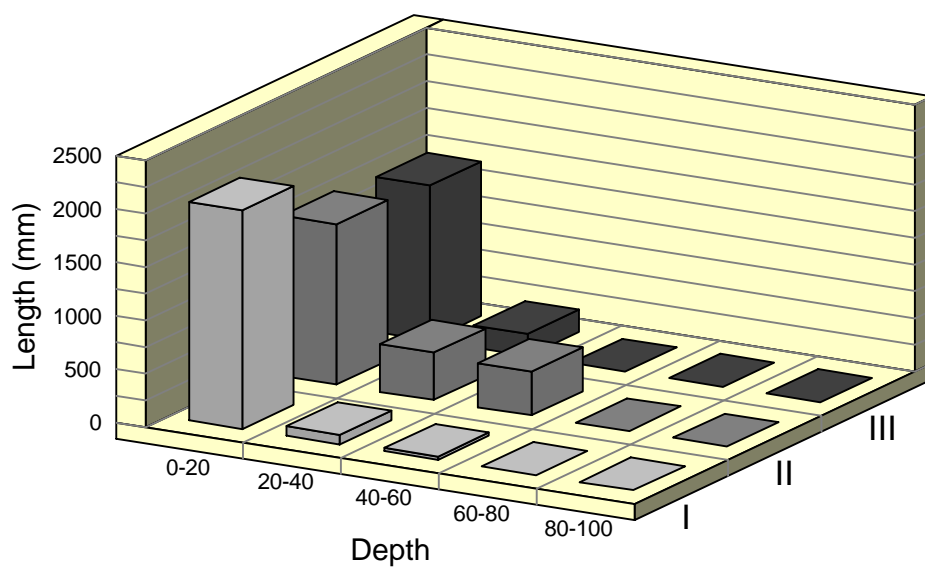


Figure 21. Percentage of root length in each 20 cm increment in soil pits (I II III) in the Compost treatment on Pit 3. Refer to Figure 11 for the location of these pits.

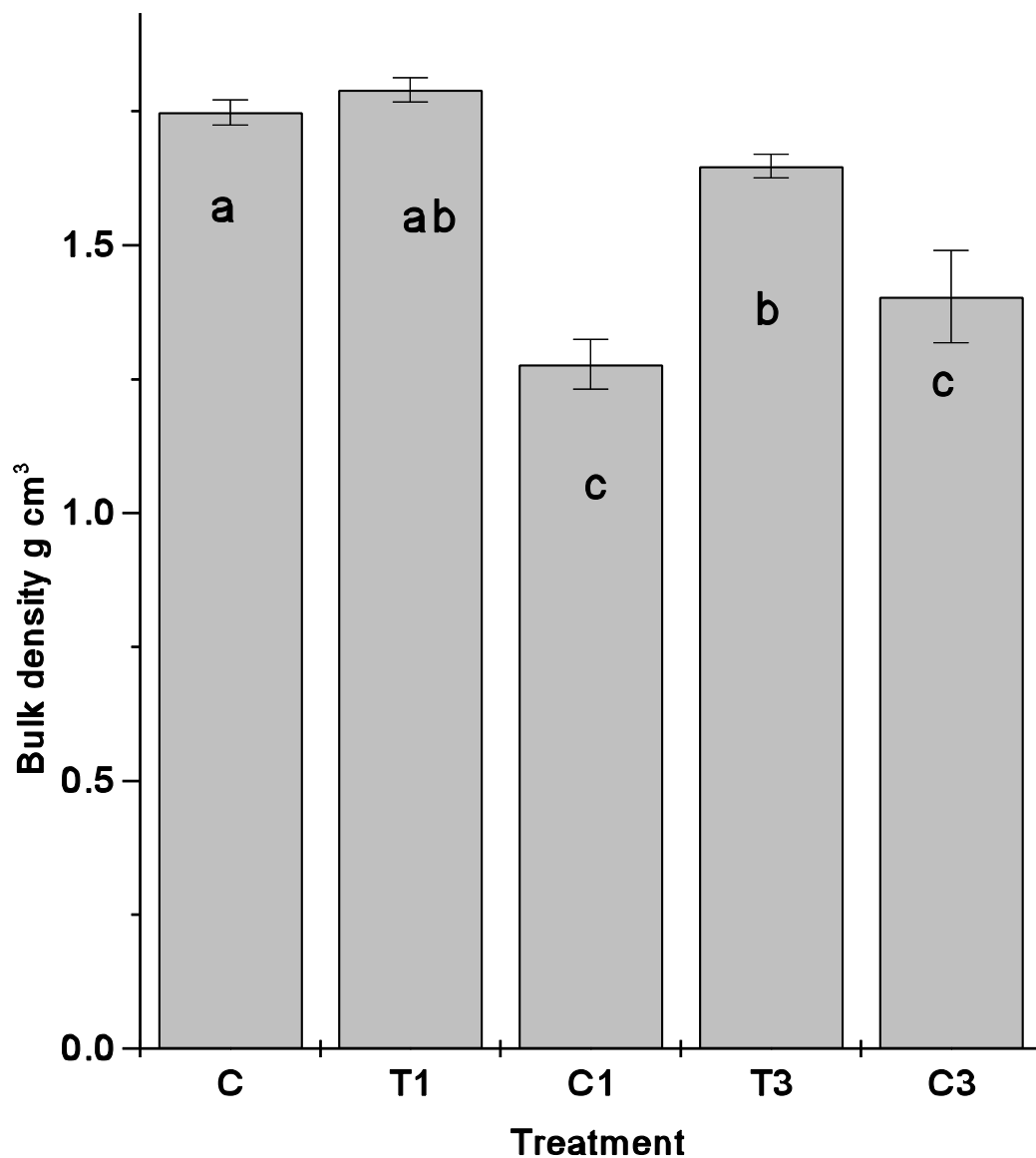


Figure 22. Bulk density of surface horizons adjusted for heavy mineral content by the ratio of actual particle density to normal soil particle density (2.65 g cm^{-3}). Means with the same letter are not different ($p = 0.0001$). Error bars indicate standard error of the mean. C: Control, T1: Pit 1 topsoil, C1: Pit 1 compost, T3: Pit 3 topsoil, C3: Pit 3 compost.

of weakness that define soil structural units even when the overall density is high. In effect, the high bulk density of the control is mitigated by the presence of soil structure which is lacking in the disturbed soils. Similar bulk density levels in highly productive soils were reported by Khosla (1995). According to Dr. N. Presaud (Personal Communication, 1996), the high bulk density of the undisturbed topsoil at Old Hickory could be due to a distribution of sand sizes that allowed for very close packing, but the relatively low strength associated with this packing allowed these soils to be productive .

Another contradiction arises when we look at the bulk density of the Compost treatment on Pit 3. This treatment produced the lowest root length which was almost entirely limited to the surface 20 cm, even though the bulk density was the lowest at that point. This is explained by the presence of a shallow water table near the surface. When pits were dug following soybean harvest, soil pits I and III (See Fig. 11) in the Compost treatment on Pit 3 filled with water to within about 50 cm of the surface. Kaspar (1985) concluded that soybean roots were not able to penetrate into free water, but concentrate in the moist aerated zone just above the free water surface. This saturated zone was found much deeper (80 cm) in Pit II in this treatment and correspondingly, root penetration was deeper.

There were several chemical and physical factors that were related to soybean yield including pH, % carbon, and bulk density. Surface pH was lower (Table 3) in the Topsoil treatment on Pit 1 than any other treatment ($p = 0.02$). This low pH in concert with high bulk density, may have been responsible for the lower soybean yield on Pit 1 Topsoil.

The cause of the low pH on Pit 1 Topsoil is discussed later. The fact that the Topsoil treatment on Pit 1 produced high wheat yield may be due to enhanced acid tolerance in wheat as compared to legumes. Wheat can produce moderate yields at soil pH as low as 5.0 to 5.2 (Westerman, 1987) .

The relationship between yield and % total carbon was nonsignificant ($p = 0.41$). The two Compost treatments logically had the highest carbon content and produced high yields (Table 3). In contrast, the Control had relatively low carbon content, yet also produced high yield. This contradiction is most likely due to the higher ECEC of the subsurface horizons of the Control. Differences in ECEC are discussed in the section on soil physical and chemical properties.

Table 3. Average pH and total carbon for soil samples taken from surface horizons after soybean harvest.

Treatment	pH	Total Carbon
Control	5.59 a [†]	0.53 cd [‡]
Pit 1 Topsoil	5.10 b	0.41 d
Pit 1 Compost	5.47 a	1.41 a
Pit 3 Topsoil	5.73 a	0.82 bc
Pit 3 Compost	5.48 a	1.15 ab

[†] Means followed by the same letter are not different ($p = 0.02$)

[‡] Means followed by the same letter are not different ($p = 0.0003$)

Another factor linearly related to soybean yield was bulk density (Fig. 23). Here again, the r^2 was low (0.23) but the trend was significant ($p = 0.05$). Overall, as bulk density (Bd) decreased, yield increased. If we look at just the control and topsoil treatments (Fig. 24) the relationship becomes stronger ($r^2 = 0.43$, $p = 0.02$), due to much lower surface Bd in the Compost treatments.

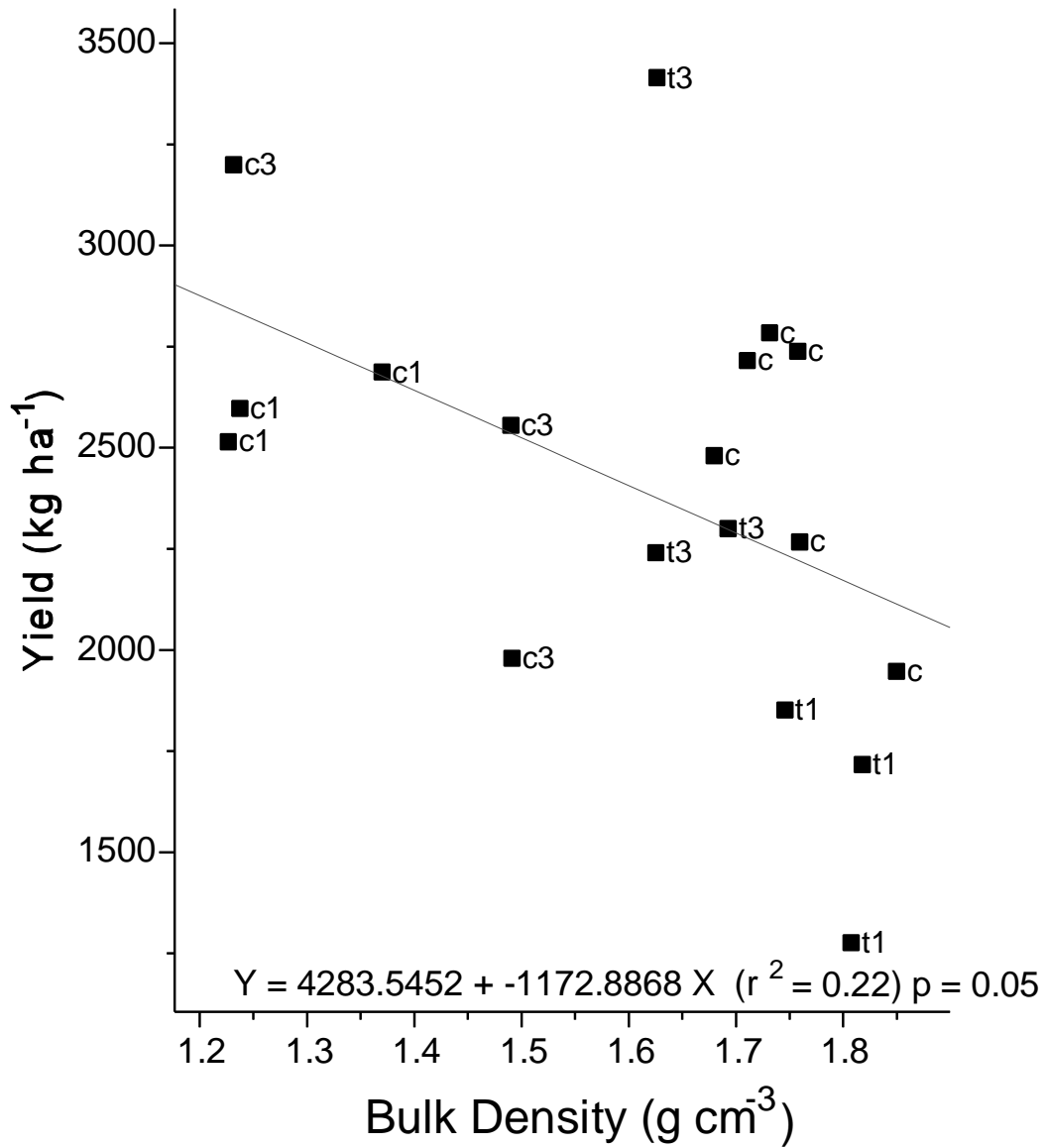


Figure 23. Soybean yield vs Bulk density (adjusted for heavy mineral content) for surface samples taken from soil pits dug after soybean harvest. C: Control, t1: Pit 1 topsoil, c1: Pit 1 compost, t3: Pit 3 topsoil, c3: Pit 3 compost.

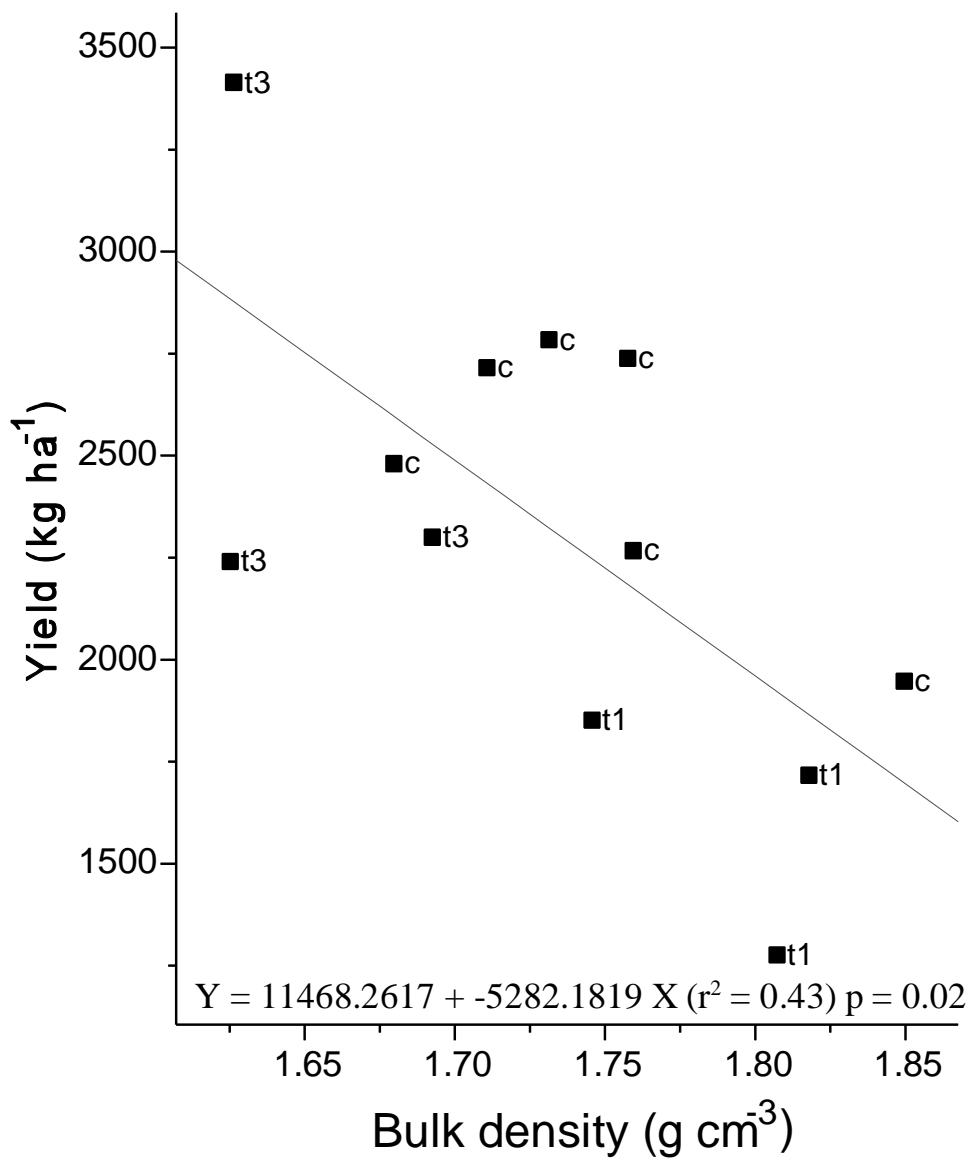


Figure 24. Soybean yield on control and topsoil treatments vs bulk density (adjusted for heavy mineral content) for surface samples taken from pits dug after soybean harvest. C: Control, t1: Pit 1 topsoil, t3: Pit 3 topsoil.

These plots did not produce high yield due to other factors, namely the high water table in Pit 3 and the compacted clay subsurface in Pit 1.

Soil Morphology

The undisturbed soils in the study area are classified as Faceville (clayey, kaolinitic, thermic Typic Kandiudults) and Varina (clayey, kaolinitic, thermic Plinthic Paleudults). These are highly weathered soils that may date to Pliocene time. They feature sandy surfaces underlain by clayey argillic horizons. The Ap horizons of all the profiles sampled had sand to sandy loam textures, dark yellowish brown to yellowish red color, and ranged from 10 to 30 cm thick. They all had weak fine granular structure, and significant rooting and macro-porosity. These surface horizons also exhibited significant concentrations of HM. Subsurface Bt horizons had textures that ranged from sandy clay loam to clay loam, were dark yellowish brown to dark red color, and continued to depths of 300 cm or more. They commonly had weak to moderate subangular blocky structure and were fairly porous. Heavy mineral concentrations were significant, but lower than the surface horizons (for complete profile descriptions see App. III).

The first mine pit refilled (Pit 1) contained a great deal of variability due to mining and regrading. Due to fluctuations in pumping density and the height at which the discharge was set (1 to 1.5 m above the water surface), significant resegregation of the tails and slimes occurred leaving a spatially variable material (Fig. 25). When pit 1 was being back-filled, the mining crew dumped material that could not be processed by the wet mill into it. This material consisted of hard clay balls, gravel, and plinthic masses. Upon the completion of back-filling, Pit 1 was

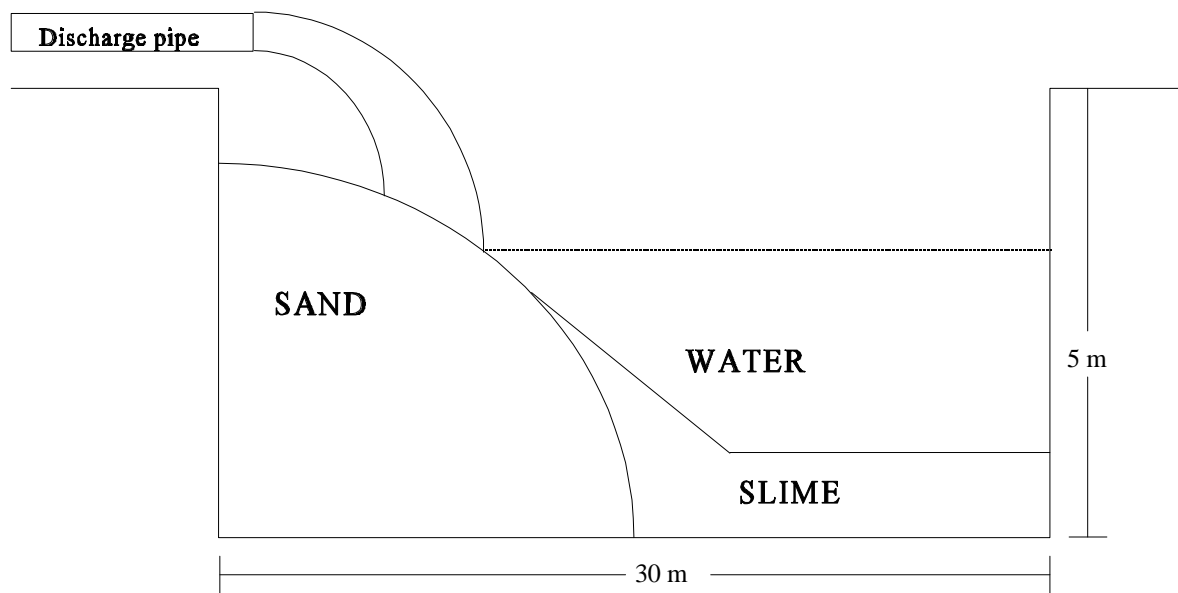


Figure 25. Diagram showing the differential settling of tailings and slimes as they are discharged into a mine pit.

covered with subsoil material from the dikes that surrounded it and the remainder of the unprocessed material from Pit 2. As the bulldozer pushed this subsoil material across Pit 1, areas of concentrated slimes were forced to the surface as the more consolidated subsoil material displaced it. The surface of processed material in Pit 1 is shown in Figure 26. The areas of concentrated slimes correlate with the deeper areas on this figure, and the peaks on this surface relate to points where the tailings were originally discharged into the pit and formed thick fan deposits.

The Ap horizon of the topsoil treatment of Pit 1 was defined by the depth of replaced topsoil and ranged in thickness from 36 to 43 cm (see APP. IV, V, and VI for complete profile descriptions). It was dark brown in color, had a sand to loamy sand texture, few fine pores, and few fine and medium roots. Since this is topsoil that was removed prior to mining, there was considerable HM present. The subsurface C horizons in Pit 1 had textures ranging from clay to sand, with colors ranging from yellow to red. These C horizons ranged in thickness from 40 to 140 cm and were structureless. There were a few roots present in the C horizons just below the contact with the replaced topsoil. Few fine pores were present throughout these horizons. The lower horizons, which are composed of processed material, were typically either sand or mixed silt and clay (slime). The upper horizons were mostly regraded subsoil with small pockets of topsoil mixed in.

The Ap horizon in the Compost treatment on Pit 1 ranged in thickness from 6 to 8 cm and were defined by the depth to which the compost was incorporated. Color ranged from light reddish brown to red, to black in areas of concentrated compost. The texture was sandy loam to

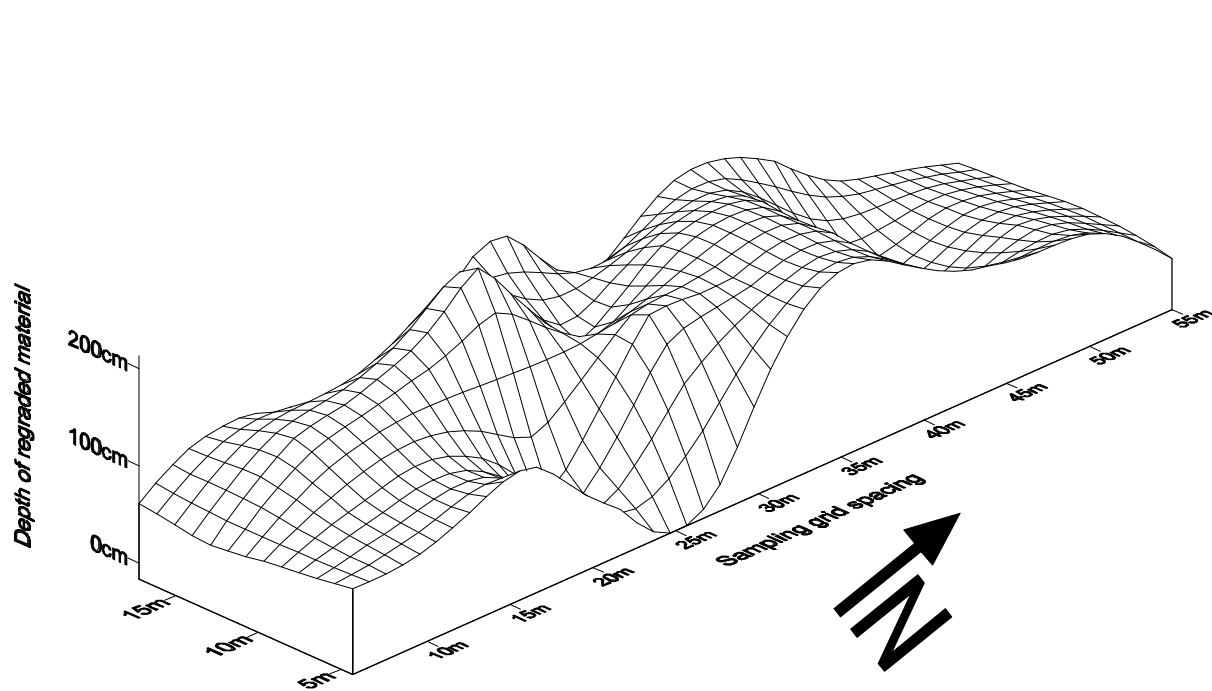


Figure 26. Surface plot of depth to processed material in Pit 1. High points represent areas of concentrated tailings related to fixed pipe discharge points.

sandy clay loam and fine and medium roots were common throughout. The presence of incorporated compost gave rise to common fine and medium pores, although there was no definable soil structure present. The C horizons were very similar to those under the Topsoil treatment on Pit 1.

Like Pit 1, Pit 3 also contains a great deal of variability in spite of RGC's efforts to remix the material. Figure 27 depicts the depth to materials that remain stratified. The variability in depth is related to the re-segregation of tailings and slimes as they were discharged into the pit. The south end of the pit was dominated by slimes and the north end by tailings. The fluid nature of the slimes made them easier to remix, whereas the sandy tailings resisted remixing and remain segregated.

The Ap horizon in the Topsoil treatment on Pit 3 was thicker than the Ap horizon in the Pit 1 topsoil treatment, ranging from 47 to 64 cm. This increased thickness was the result of the uneven nature of the original pit surface and the split application of topsoil. The surface horizon on Pit 3 Topsoil had the same texture and color, and in all other respects was visually identical to the topsoil on Pit 1.

The differences in topsoil thickness on both Pits 1 and 3 from our planned 30 cm thickness were most likely the result of subsidence of the pit surfaces during topsoil application. This subsidence resulted in extra topsoil being added to reach the original design grade for a 30 cm thickness over the original surface.

The Ap horizons in the Compost treatment on Pit 3 were very similar to those on the Compost treatment of Pit 1. The only significant difference in morphology was a sandier

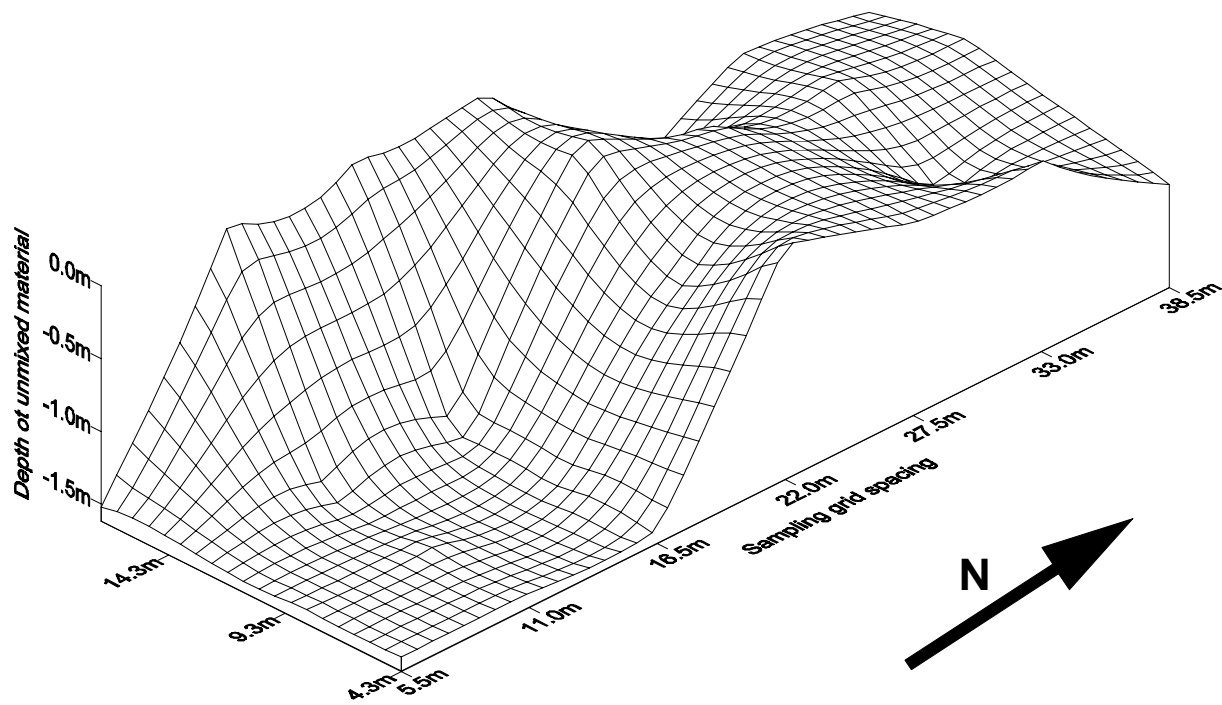


Figure 27. Surface map of Pit 3 showing the depth to material that was not mechanically mixed.

texture in Pit 3. The compost seemed to be dominating the morphology of the surface horizons on the Compost plots to the extent that it was masking the morphological differences that I would expect if these materials had not been amended.

The C horizons in mine Pit 3 were very different from those of Pit 1. Horizon thickness ranged from 4 to 61 cm. Most of the horizons consisted of stratified layers which varied in thickness from a few mm to tens of cm, and in texture from clay to sand. The color of this material ranged from very pale brown to yellowish red. Depending on texture, these horizons were either massive or single-grain, with the exception of some weak structural development in the second pit dug into the Compost treatment of Pit 3. Similar rapid development of structure was reported by Roberts et al (1988). They reported that well developed A horizons and transitional AC horizons were present in three year-old mine soils amended with sewage sludge. They attributed this development to the organic additions and rooting. The presence of pores (packing voids) in these horizons is linked to texture. Areas with sandy texture had some inherent macro-porosity while, in contrast the clayey layers were essentially devoid of macropores.

Soil Physical and Chemical Properties

There were differences in physical and chemical properties among the treatments and between mine soils and undisturbed soils (See App. VII and IX for data). Figure 28 relates the clay content of the surface horizons of the two mined pits prior to compost and topsoil treatment application, and the undisturbed Control. The clay content of the surface horizon of the Control was lower than either mine pit surface, and Pit 1 contained the most surface clay ($p = 0.0001$).

Variance within each of these means is characterized by the standard deviation, standard error, and coefficient of variability. These were all highest for the Control. This variability is due to the highly weathered, and eroded state of the natural soils in this area. The sand fraction of the topsoil on the Control is dominated by quartz and HM which concentrates in the surface due to its higher density. Clay and silt will generally move downhill and accumulate. This is evident by the increase in clay downhill from soil pit I (1.5 %) to soil pit IV (7.8 %) (See Fig. 11).

In contrast to surface clay contents, the Control soils had more clay in subsurface horizons than either Pits 1 or 3 ($p = 0.0001$). Coefficient of variability, standard deviation, and standard error are greatest for Pit 3, and similar to those for Pit 1 (Fig. 29). Compared to the Control, there was much more variability in the disturbed areas. The variability in clay content in the mined pits stemmed from the methods employed to backfill and regrade them. The clay content at 100 cm in Pit 1 is controlled by the presence of the subsoil material that was pushed onto it. This material mixed with the slimes and tailings in the pit, thereby leaving a variable texture. This mixing also explains the lower variability in Pit 1 as compared to Pit 3. The attempt to remix Pit 3 resulted in a fairly uniform surface, but was not successful at remixing materials at 100 cm or more.

As mentioned earlier, there were also differences in the bulk density of the surface horizons among the treatments. Bulk density was highest in the Topsoil treatment on Pit 1 and the undisturbed Control (Fig. 22). There was no difference in bulk density between the two Compost treatments, and the lower bulk density in the Compost treatments was due to the aggregation of

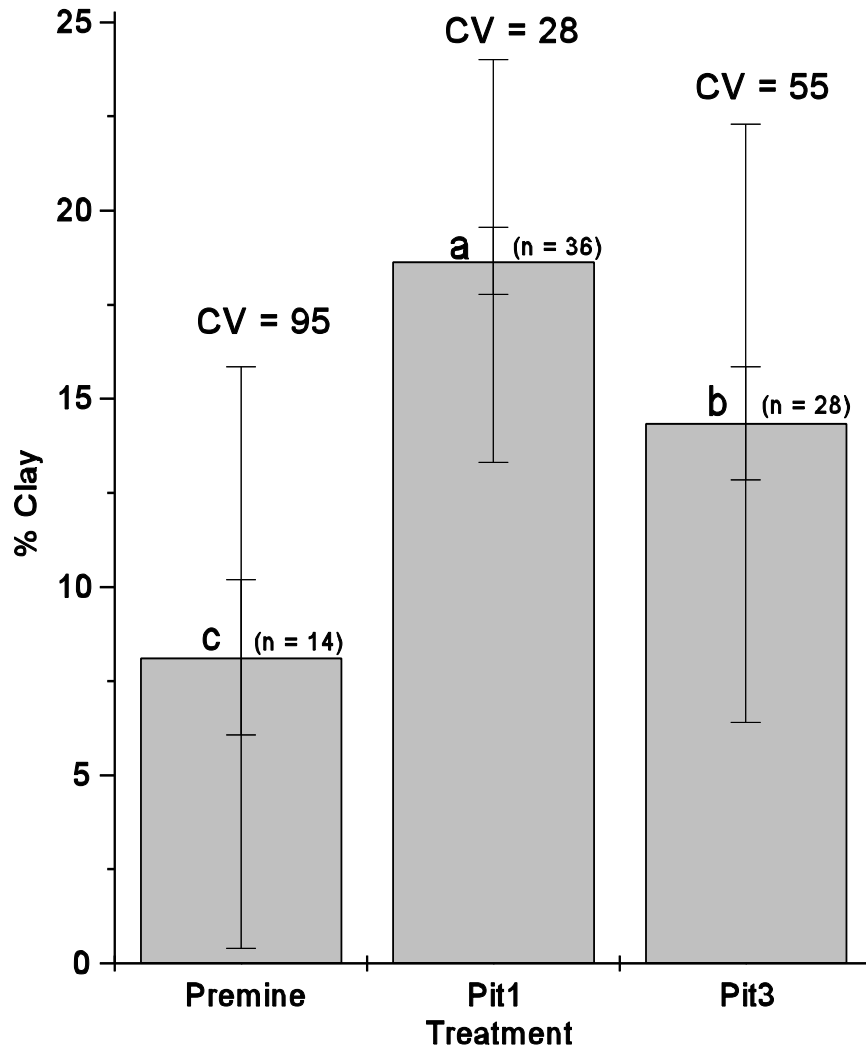


Figure 28. Variability in clay content of surface horizons. Premine clay content based on all samples taken before mining and from undisturbed control plots. Pit 1 and 3 clay content based on samples taken after wheat harvest (June, 1996) and after soybean harvest (November, 1996). CV: coefficient of variability. Error bars indicate standard deviation and standard error. Means with the same letter are not different ($p = 0.0001$).

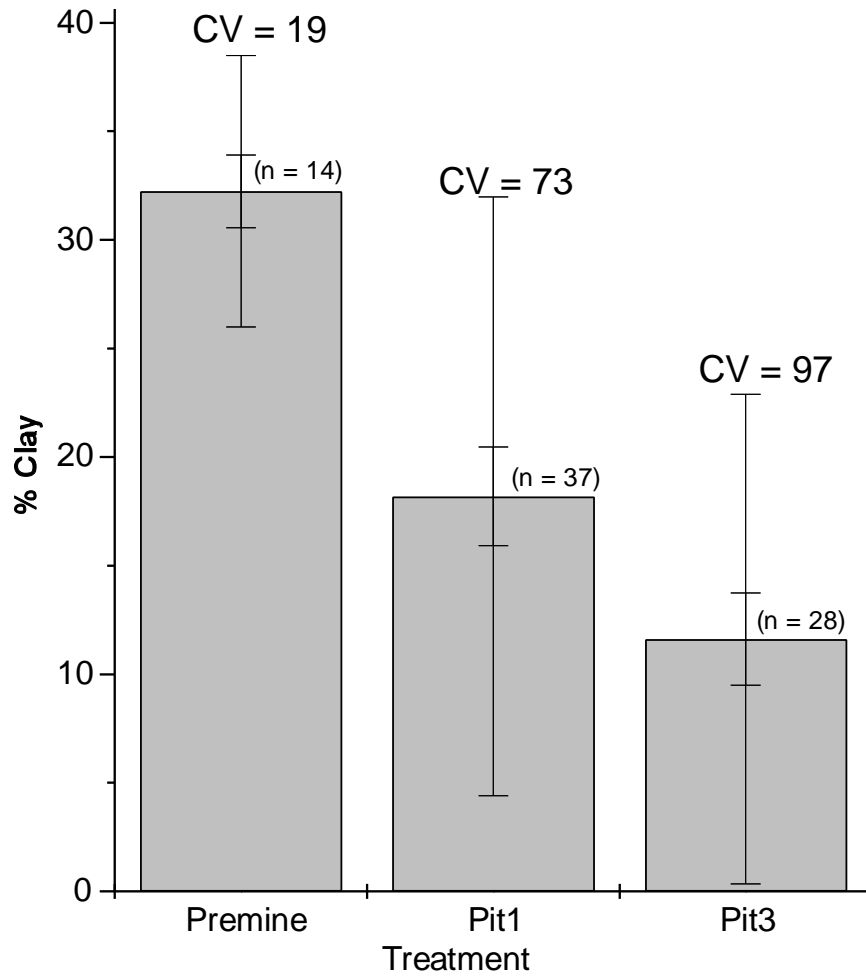


Figure 29. Variability in clay content at 100 cm depth. Premine clay content based on samples taken before mining as well as those from soil pits dug into the undisturbed control after soybean harvest (November, 1996). Pit 1 and 3 clay content based on samples from soil pits dig after soybean harvest (November, 1996). CV: coefficient of variability. Error bars indicate standard deviation and standard error.

the compost. This is supported by the strong linear relationship between surface bulk density and surface carbon content (Fig. 30). This compaction is most likely the result of bulldozer placement and insufficient remedial ripping. As discussed earlier, the high bulk density of the undisturbed Control may have been due to packing arrangement. Packing arrangement could also explain the high bulk density in the topsoil replacement treatments, but this arrangement of particles probably takes a long period of erosion and eluviation to develop.

Subsurface bulk density values did not differ between the undisturbed Control and either of the two mined pits ($p = 0.17$). Bulk density in the mine soils, however, covered a much larger range than in the undisturbed soils due to their stratified nature. Horizons of concentrated slime in the mine soils were observed at densities of $\sim 1.0 \text{ g cm}^{-3}$, while sandy horizon bulk densities range from 1.6 to 1.9 g cm^{-3} .

Due to high variability, water holding capacity of the surface horizons among treatments was not different at the 0.05 level (Table 4), however judging from the data it appears that the compost plots had higher water holding capacity in their surface horizons. There were also differences in subsurface water holding capacity between the two mine pits ($p = 0.06$). Although this p-value is not very low, I believe that it is important to discuss the source of this difference. The same stratification that affected bulk density was also at work here. The slime layers hold large amount of water compared to the sandy layers. The presence of these layers and the difference in particle size could lead to problems with water movement in these soils. Assuming similar gravitational effects, water moves from areas of high matric potential to areas of low potential. Thus when a clay layer overlies a sandy layer there will be no movement of water into

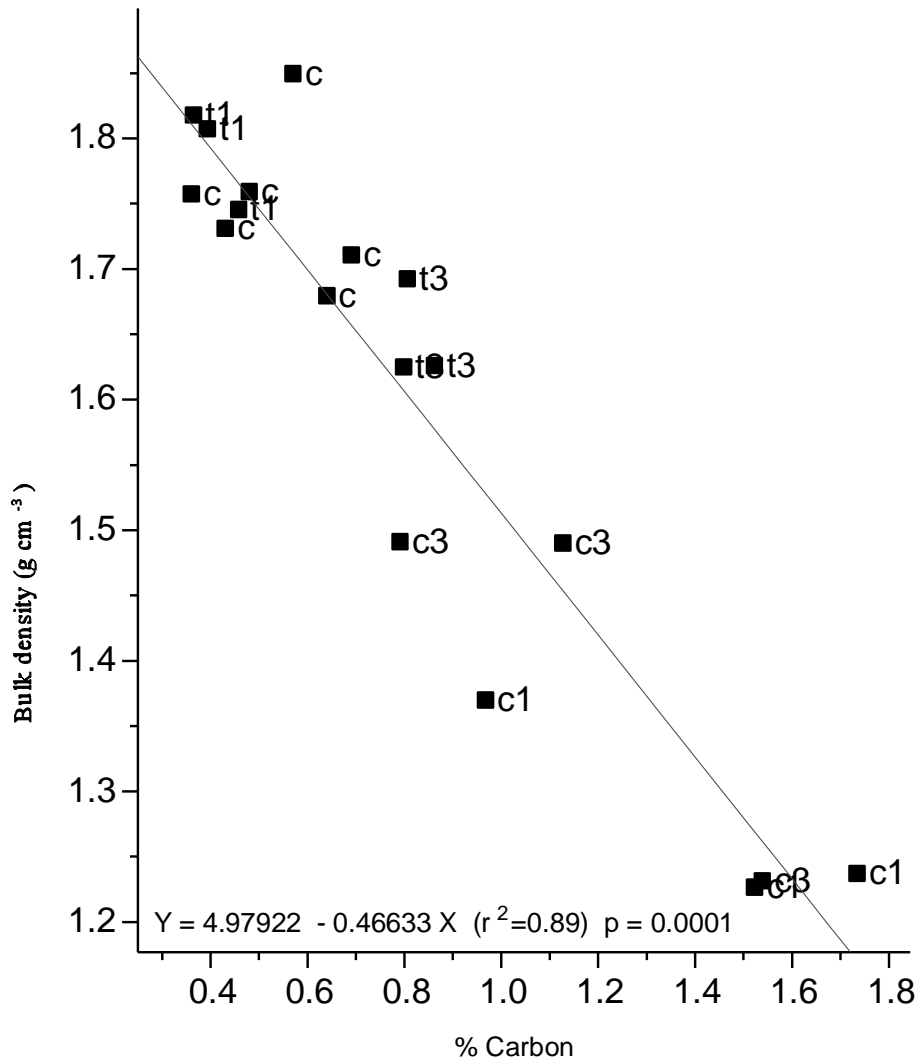


Figure 30. Carbon content vs bulk density (adjusted for heavy mineral content) for samples taken from soil pits dug after soybean harvest (November, 1996). C: Control, t1: Pit 1 topsoil, c1: Pit 1 compost, t3: Pit 3 topsoil, c3: Pit 3 compost.

the sand until the matric potential is overcome by gravitational potential as saturation is reached. When water begins to flow, the rate at which it percolates will be determined by the K_{sat} of the least permeable layer. The slime layers, due to their massive nature and lack of macropores, would limit the flow of water under saturated conditions leading to perched water tables. When drought conditions persist, the sandy layers will become very dry and the slime layers may hold their water at potentials too low for plants to readily absorb.

Table 4. Water holding capacity of surface and subsurface samples taken from pits dug after soybean harvest (November 24, 1996). Subsurface samples were not differentiated by treatment but by whether they were from undisturbed or mined areas.

Treatment	Surface Water Holding %	Subsurface water holding %
Control	2.8 a†	4.1 a‡
Pit 1 Topsoil	2.5 a	2.6 ab
Pit 1 Compost	3.3 a	
Pit 3 Topsoil	2.6 a	1.5 b
Pit 3 Compost	6.2 a	

† Means followed by the same letter are not significant. (P = 0.2)

‡ Means followed by the same letter are not significant. (P = 0.05)

Important differences in chemical properties among the treatments include available P, Ca, % total carbon, pH, and ECEC. Available P was highest among Pit 3 Compost, Pit 1 Compost, and the Control (Table 5). Likewise, there was no difference between the two lower P Topsoil treatments. These groupings are explained by a combination of factors. First, the high P in the Compost treatments would be due to mineralization of organic P from the compost, the P fertilizer applied before treatment application, and the availability factors discussed by Orndorf

(1995). Second, the high P of the Control is likely due to the combination of relatively high humus content, and a history of P fertilization. In contrast, the Topsoil treatments are lower in humus, and did not receive as much P fertilizer as the pit surfaces, and are therefore understandably lower in available P. Available P levels in subsoils were not different between the Control and either of the mined pits.

Table 5. Soil phosphorus, and calcium data. Surface values are for samples taken after wheat harvest (June 18, 1996). Subsurface Ca values are for samples taken from pits dug after soybean harvest (November 24, 1996). Subsurface samples were not differentiated by treatment but by whether they were from undisturbed or mined areas.

Treatment	Surface P (ppm)	Surface Ca (ppm)	Subsoil Ca (ppm)
Control	10.1 a [†]	72.2 c [‡]	313 a [§]
Pit 1 Topsoil	4.2 b	72.7 c	182 b
Pit 1 Compost	7.4 a	137.1 a	
Pit 3 Topsoil	3.1 b	111.5 b	169 b
Pit 3 Compost	11.8 a	111.3 b	

[†] Means followed by the same letter are not different. (P = 0.000)

[‡] Means followed by the same letter are not different. (P = 0.002)

[§] Means followed by the same letter are not different. (P = 0.0002)

Plant available Ca (dilute double acid extractable) was highest in the Compost treatment on Pit 1 (Table 5), but there was no difference in Ca levels between the Compost treatment on Pit 3 and the Topsoil treatment on Pit 3, or between the Control and the Topsoil treatment on Pit 1. The linear relationships between Ca and both % Clay ($r^2 = 0.55$) and % carbon ($r^2 = 0.93$) explain the observed Ca data (Figs. 31 and 32). The Compost treatment on Pit 1 had both the highest clay content and the highest carbon content, while the treatments with the lowest available Ca also had the lowest clay and carbon contents. Subsurface available Ca levels were highest in the Control,

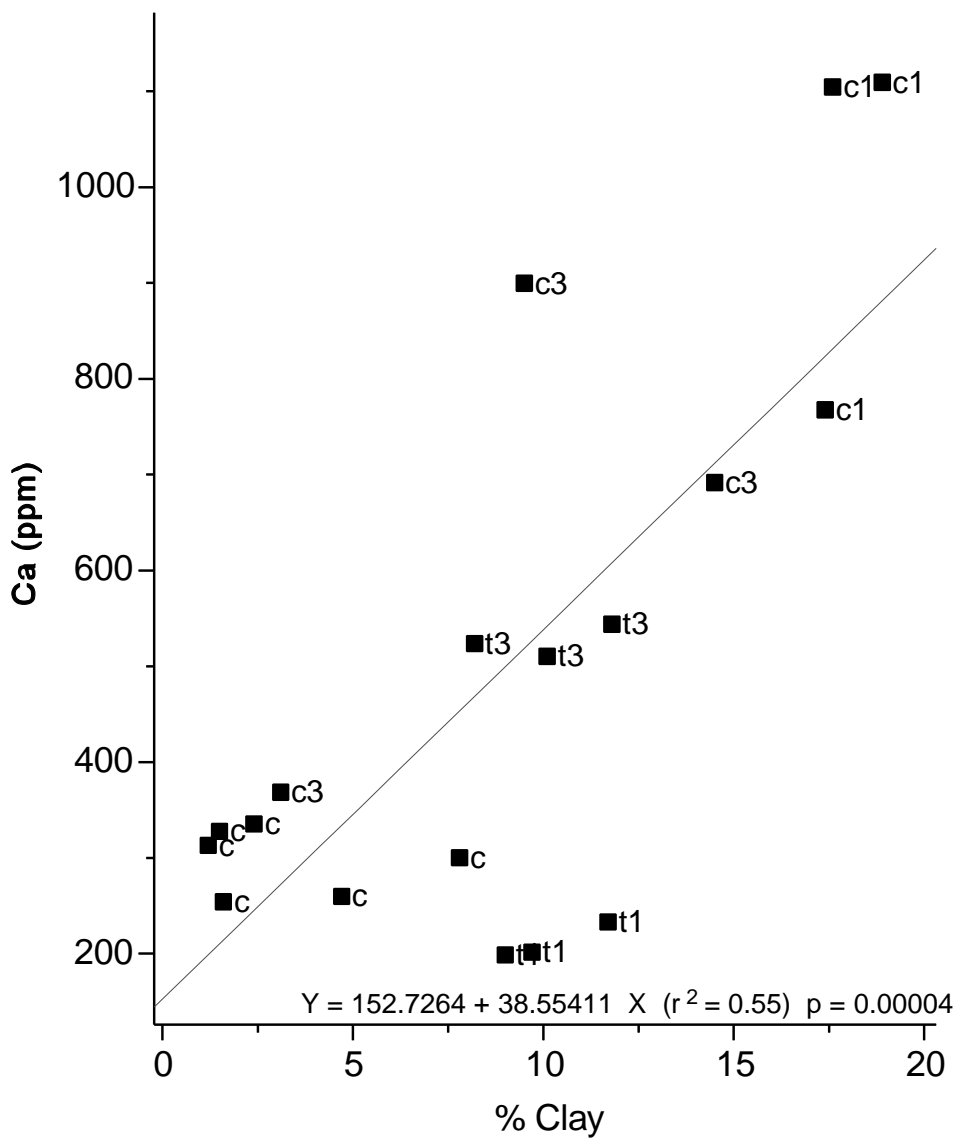


Figure 31. Calcium vs clay content for surface samples taken from soil pits dug after soybean harvest (November, 1996). C: Control, t1: Pit 1 topsoil, c1: Pit 1 compost, t3: Pit 3 topsoil, c3: Pit 3 compost.

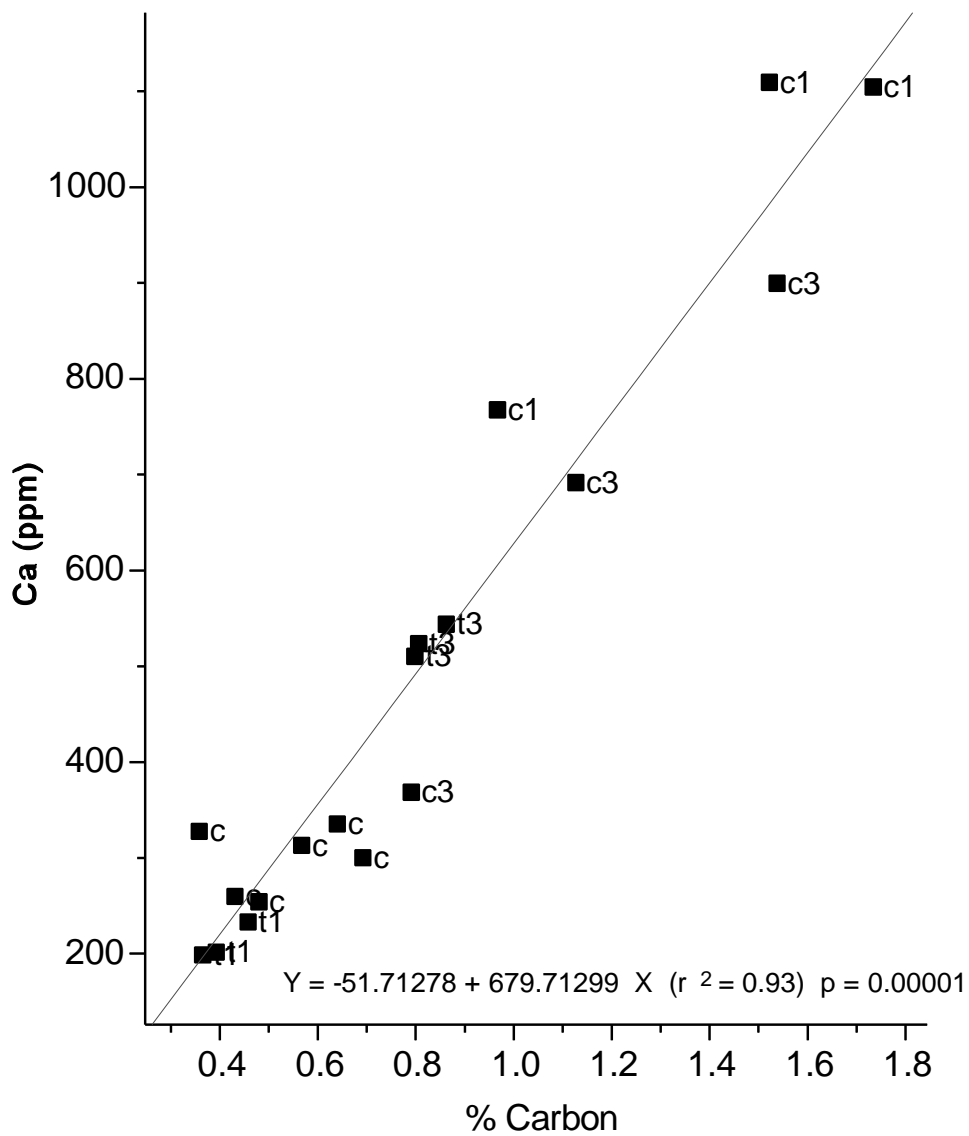


Figure 32. Calcium content vs % carbon for surface samples taken from soil pits dug after soybean harvest (November, 1996) C: Control, t1: Pit 1 topsoil, c1: Pit 1 compost, t3: Pit 3 topsoil, c3: Pit 3 compost.

but there was no difference between Pits 1 and 3 (Table 5). The higher Ca content of the subsurface horizons in the Control area was likely due to its higher clay content and long history of Ca additions in the form of lime and gypsum that are routinely applied for rowcrop production. Lower levels in the mine soil resulted from the dilution effect of mixing soil materials from depths of up to 6 m. The materials from the lower depths of the mine pits would likely have very little plant available Ca. This is supported by the lower levels of Ca in the Btv horizons in the undisturbed Control.

As expected, the carbon content in the surface horizon was greatest for the Compost treatment on Pit 1 and the Compost treatment on Pit 3 (Table 3). The difference in carbon content between the two Topsoil treatments may stem from the fact that the topsoil on pit 1 was stored for about a year while Pit 3 was capped with a layer of fresh directly hauled topsoil. Abdul-Kareem (1984) reported reduction in O.M. of up to 85 % in topsoil of a sandy soil that was stored for eight years. Carbon content of the subsoils showed no difference between disturbed and undisturbed areas.

Acidity of the surface horizons, as measured by pH, was lowest for the Topsoil treatment on Pit 1 (Table 6), and did not differ among the other treatments. These values represent bulk samples of the entire depth of replaced topsoil (30 to 50 cm). The low pH in the topsoil on Pit 1 was likely due decomposition of organic matter and associated production of humic acids and CO₂ acidity during the year it was stockpiled. This should have been ameliorated when lime was applied in October, 1995. To better understand these low pH measurements more samples were obtained from the surface 15 cm of all treatments on February 4, 1997. These samples indicated a

higher pH in the surface (0-15 cm) of the Topsoil treatment on Pit 1. The contradiction between these pH measurements suggests that the applied lime was incorporated into the upper 15 cm of the replaced topsoil, but did not influence deeper soil pH.

Subsurface soil pH was higher in the undisturbed Control than either mine soil (Table 6). The lower pH in the mine soil was due to the mixing of more acidic soil materials from the lower depths of the mining pits. This is supported by the lower pH of the Btv horizons in several of the soil pits dug into the undisturbed control.

Table 6. Surface and Subsurface pH data. Subsoil samples were not differentiated by treatment but by whether they were from undisturbed or mined areas.

Treatment	Surface pH (15 cm) [†]	Surface pH (comp) [‡]	Subsoil pH
Control	5.94	5.59 a§	5.18 a¶
Pit 1 Topsoil	5.78	5.10 b	4.77 b
Pit 1 Compost	5.63	5.48 a	
Pit 3 Topsoil	5.50	5.73 a	
Pit 3 compost	5.35	5.48 a	4.65 b

[†] Sample taken from the upper 15 cm February 4, 1997.

[‡] Composite samples of full topsoil depth taken from soil pits dug after soybean harvest.

§ Means followed by the same letter are not different (p= 0.02)

¶ Means followed by the same letter are not different (p= 0.0001)

Effective CEC of the surface horizons differed among the treatments (Table 7), and there were some interesting trends associated with this data set. The treatment with the largest ECEC value was Pit 1 Compost. This was due to the strong relationship between ECEC and % clay (Fig. 33), and % carbon (Fig. 34). The fact that the relationship between ECEC and clay was not linear reveals the effect of clay content on ECEC is not independent of the effect of carbon

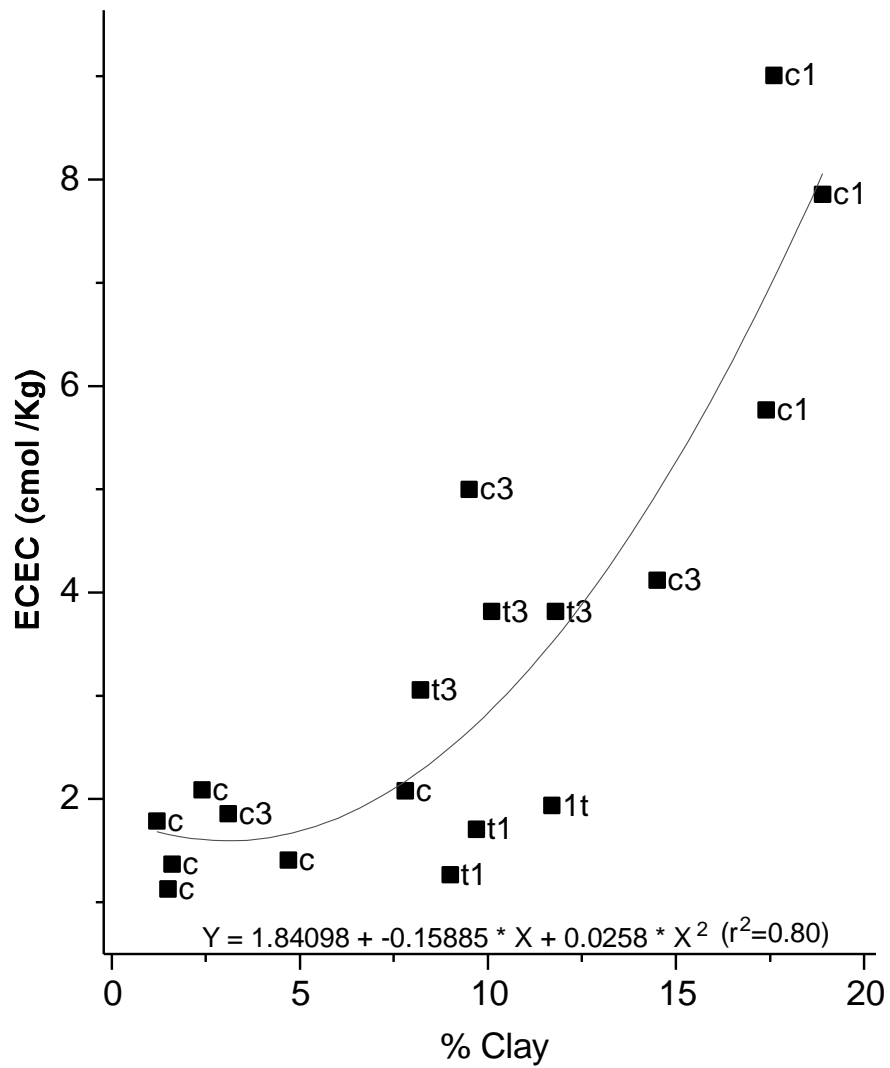


Figure 33. Effective CEC vs % clay in surface horizons for samples taken from soil pits dug after soybean harvest (November, 1996). C: Control, t1: Pit 1 topsoil, c1: Pit 1 compost, t3: Pit 3 topsoil, c3: Pit 3 compost.

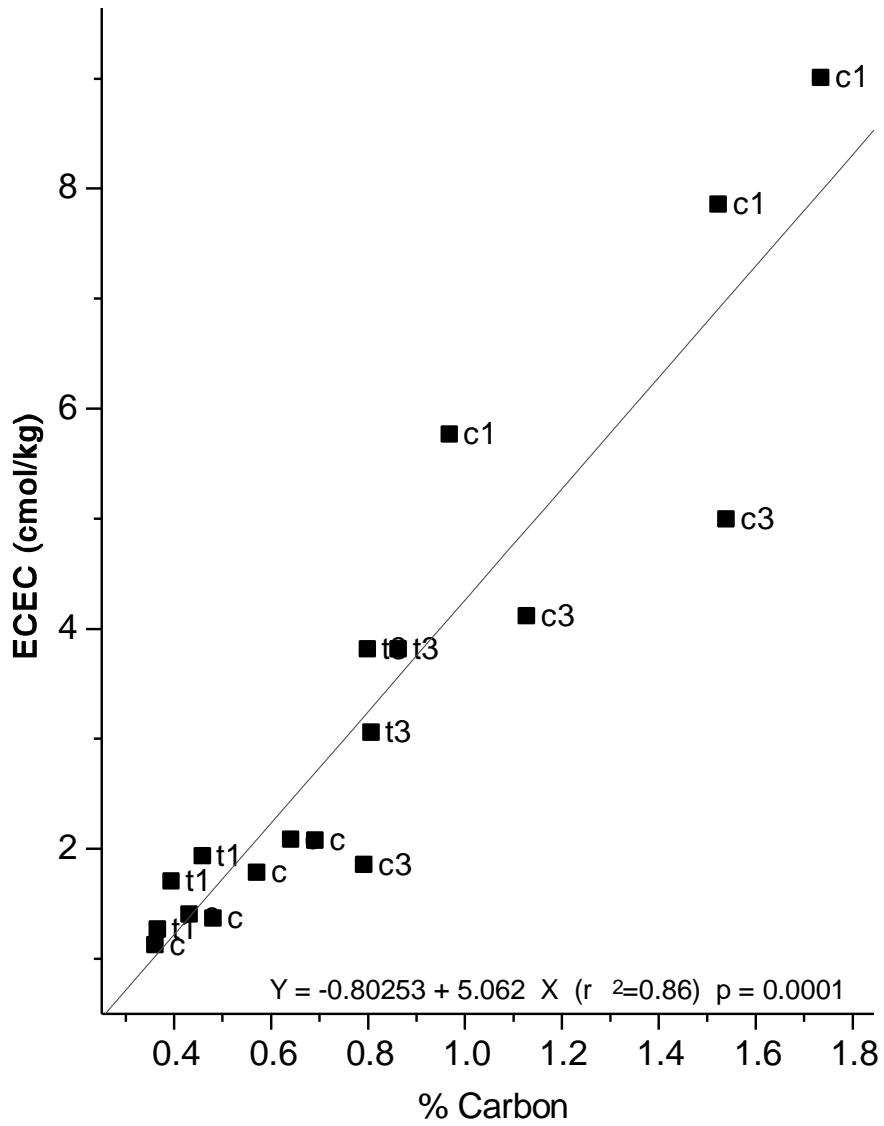


Figure 34. Effective CEC vs % carbon in surface samples taken from soil pits dug after soybean harvest (November, 1996). C: Control, t1: Pit 1 topsoil, c1: Pit 1 compost, t3: Pit 3 topsoil, c3: Pit 3 compost.

content. This interaction can be seen in the position of the Pit 1 Topsoil treatment in relation to that of the Pit 3 Topsoil treatment on figure 36. The two treatments had similar clay content but the Topsoil treatment on Pit 1 had much lower ECEC. The lower ECEC of the Topsoil treatment on Pit 1 is due to its' low carbon content. This would lead to the conclusion that while clay contributes to ECEC, carbon content is more important. This conclusion is supported by the strongly linear relationship ($r^2 = 0.86$) between ECEC and carbon content.

Analysis of subsurface ECEC revealed that the undisturbed Control had higher ECEC than either of the two mined pits (Table 7), and that there was no difference between the two mined pits. The reason that the ECEC of the Control was higher relates to the ECEC vs % clay relationship discussed earlier. The fact that no difference existed between the two mined pits probably relates to the variability in texture discussed earlier. The upper subsurface of Pit 1 did have higher clay and hence higher ECEC, but when this was averaged over all the observations, there was no difference with Pit 3.

Table 7. Effective cation exchange capacity data for samples taken from pits dug after soybean harvest(November 24, 1996). Surface indicates A horizons. Subsurface samples were not differentiated by treatment but by whether they were from undisturbed or mined areas.

Treatment	Surface ECEC (cmol kg ⁻¹)	Subsoil ECEC (cmol kg ⁻¹)
Control	1.65 b†	3.99 a‡
Pit 1 Topsoil	1.64 b	1.96 b
Pit 1 Compost	7.55 a	
Pit 3 Topsoil	3.72 a	1.89 b
Pit 3 compost	3.66 ab	

† Means followed by the same letter are not different. (P = 0.01)

‡ Means followed by the same letter are not different. (P = 0.0002)

Chapter 4

SUMMARY AND CONCLUSIONS

Mineral sand mining in prime farmland on Virginia's Upper Coastal Plain will present unique reclamation challenges. This study looked at the possibility of returning this land to agricultural production. The main focus was upon the use of returned topsoil and organic amendments such as yard waste compost applied directly to regraded mine soil materials. To study this possibility, two pilot-scale mine pits were amended with topsoil and compost, and crops of winter wheat and soybeans were grown. The two mining pits represented different pit closure scenarios. All treatments were compared to adjacent undisturbed land.

Wheat yields were highest on the undisturbed Control and the Topsoil Treatment on Pit 1, while the lowest wheat yield was observed on the Compost treatment on Pit 3. The lower yield on Pit 3 Compost was likely due to the presence of saturated zones near the surface of Pit 3. Another factor affecting treatment differences in wheat yield was the infestation of ryegrass in the Topsoil treatment on Pit 3.

Double-crop soybean yields were highest on the Topsoil treatment on Pit 3, the undisturbed Control, and the Compost treatment on Pit 3. In contrast to wheat yield, the Topsoil treatment on Pit 1 generated the lowest soybean yield. This was likely due to a combination of low pH and high bulk density in this treatment. The contradiction that the Compost treatment on Pit 3 produced the lowest wheat yield and the second highest soybean yield was related to the combination of high water table, the high water holding of the compost, and erosion during the

winter reduced wheat yield. In contrast, the high water table and improved nutrient availability due to the compost addition favored the soybean crop.

There were many differences in chemical and physical properties between the mine soils and the undisturbed soil. There were also many differences between the two mining pits along with significant variability within the mine pits. This variability was directly related to the mining and reclamation methods employed. The variability is expressed as differences in texture, ECEC, bulk density, water holding capacity, and associated chemical properties. The effect of this variability on productivity was masked by above-average rainfall; in a more typical year I would expect yields to be lower on all treatments, and relative effects would be more pronounced. The main factor limiting yield in a “typical year” would be water stress. The presence of high bulk density and low water holding in the subsoils of the mined areas would prevent plants from obtaining sufficient water through a combination of mechanical impedance and low moisture content of the soil that roots were able to exploit

Other effects of this variability on productivity stem from the important observed relationships of clay and carbon content to the availability of plant nutrients. As the clay and carbon contents increase, plant nutrients became more available. If these mine soils are to be productive, clay and carbon contents must therefore be controlled. The key to controlling the clay content of these mine soils is in preventing resegregation of the tailings and slimes at the point of discharge. This could be accomplished by increasing the density at which the material is pumped and reducing the discharge height. One possible way to achieve increased pumping density would be to design a mixing and pumping system that could handle very high density material. Such

systems are in regular use in the construction industry to move concrete at very high density. Such a system could be used to pump a dense mix of flocculated slimes and sand to the mine pits. Once at the pit, the discharge would also have to be moved regularly as the thicker material will not spread out as well as it does at lower density. Other advantages of pumping at higher density would be shorter dewatering time and less surface regrading. Another possible solution to the re-segregation problem would be to find some chemical agent that could bind the sand and clay particles together. This would make pumping density and discharge velocity much less important.

Controlling the humus content of the raw mine soils involves addition of a suitable carbon source such as YWC, biosolids, or some other material. The possibility exists that importing this carbon source in the form of YWC may prove too costly. If this is the case, either topsoil will have to be replaced and a significant amount of HM will not be recovered, or some other method of increasing carbon content will need to be employed. One possible method would be to allow natural accumulation of carbon through the production of an herbaceous cover crop. This would likely take many years, but could be an answer to long term reclamation if substantial organic additions prove too costly.

If building and controlling soil humus content proves to be problematic, topsoil replacement may be unavoidable. In this case there are also problems to be addressed. The handling of topsoil is critical to the success of its use on mined land. If the topsoil is stored there may be significant degradation to its chemical and biological properties. The best method is to remove it ahead of the mining operation and replace it directly over recently mined land. The act of placing the topsoil also will present problems. Variability in thickness may result from bulldozer placement of topsoil

due to differences in the bearing capacity of the mined materials. Additionally, bulldozer placement will cause compaction of the topsoil. This may be remedied by deep ripping, but pulling a ripper through the soil at depths of 30 cm or more requires a great deal of force and the freshly laid topsoil may not provide sufficient traction.

From the preceding discussion it is clear that neither of the two reclamation methods studied is clearly better than the other. They both present unique advantages and disadvantages. I believe the Compost treatment may be the best in the long run, especially if the resegregation problem can be solved. The uncertainty about the effect of drought on these mine soils needs to be addressed through further research. However, the fact that both reclamation alternatives (topsoiling and compost additions) equaled the Control for at least one crop, and consistently exceeded the County yield average, should be viewed as a “cautiously optimistic” indicator that these landscapes can be returned to at least moderate levels of row-crop productivity. This success will depend on controlling resegregation of tailings and slimes, remediating compaction in replaced topsoil, and the building and maintaining of soil humus levels.

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APPENDIX I

CHEMICAL PROPERTIES OF YARD WASTE COMPOST

Chemical data from 623 Land Fill compost (A&L Labs, Richmond, VA.).

pH	EC	NH ₄ -N	NO ₃ -N	P	K	S	Ca	Mg	Na	Cd	Ni	Pb	C/N
6.6	0.60	<1	12	38	120	7	66	18	40	<1	27	10	36

EC: mmohs/cm. All other parameters are reported in mg kg⁻¹.

APPENDIX II

Historic Crop production data

			YEAR										
			1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Crop													
Wheat													
	County												
	Dinwiddie	Harvested ac.	4500	2900	3600	3700	5000	4900	4000	4400	4400	5000	5200
	Sussex		5700	3600	4500	3700	5600	5900	5500	7200	6400	6600	6800
	Dinwiddie	Yield (bu/ac)	23	38	36	51	45	42	45	52	48	53	60
	Sussex		27	38	43	55	42	43	51	59	57	61	63
Corn grain													
	Dinwiddie	Harvested ac.	5300	3100	3400	2900	3300	3100	2700	2600	1600	2200	1800
	Sussex		11000	10600	7300	7100	7500	7500	7200	7300	6800	7200	3300
	Dinwiddie	Yield (bu/ac)	85	38	65	84	112	74	76	105	39	79	102
	Sussex		125	33	63	88	99	84	84	118	58	52	114
Soy beans													
	Dinwiddie	Harvested ac.	24300	18200	12800	13400	14200	13000	12800	12300	11200	12200	11700
	Sussex		720000	554400	435000	554900	604800	564900	464400	523900	290700	336000	356200
	Dinwiddie	Yield (bu/ac)	20	21	24	29	33	28	27	31	14	29	25
	Sussex		30	28	25	31	32	31	27	31	17	21	26
Cotton													
	Dinwiddie	Harvested ac.	N/A	N/A	N/A	N/A	N/A	N/A	N/A	625	450	870	2500
	Sussex		N/A	N/A	N/A	N/A	N/A	N/A	615	915	905	1775	8250
	Dinwiddie	Yield (lb/ac)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	553	512	856	502
	Sussex		N/A	N/A	N/A	N/A	N/A	N/A	1194	635	583	834	691
Tobacco													
	Dinwiddie	Harvested ac.	1090	1080	1020	1150	1230	1410	1360	1290	1260	1180	1160
	Sussex		190	180	150	205	200	220	205	195	220	200	200
	Dinwiddie	Yield (lb/ac)	2485	2345	2780	2575	2380	2550	2775	2470	2565	2850	2395
	Sussex		2420	2115	2785	2600	2225	2825	2620	2470	2505	2765	2660

APPENDIX III

Morphological Descriptions of Undisturbed Control Soils

Location: Control plot # 3 (pit I[†]).

Vegetation: Soybeans. Parent material: stratified Upper Coastal Plain fluviomarine sediments.

Physiography: Ridge summit. Relief: 15 m.

Elevation: 65 m. Slope: 2 percent.

Erosion: Moderate. Permeability: Moderate.

Described by Pamela Thomas and Phil Schroeder, 12/4/96.

Ap-- 0 to 19 cm; brown (10 YR 4/3) loamy sand; weak fine granular structure; very friable, non-sticky, non-plastic; common fine and few medium roots; common coarse and few very coarse pores; 20 % HM*; abrupt smooth boundary.

E-- 19 to 27 cm; brown (7.5 YR 5/4) loamy sand; single grain; loose, non-sticky, non-plastic; common fine roots; few coarse and medium pores; 20 % HM. Clear wavy boundary.

Bt1-- 27 to 59 cm; yellowish red (5 YR 5/8) sandy clay loam; weak medium and coarse subangular blocky structure; friable; sticky, slightly plastic; common fine and few medium roots; common coarse, many medium and few fine pores; few faint and many prominent clay films on ped faces, 10 % HM; gradual smooth boundary.

Bt2-- 59 to 89 cm; yellowish red (5 YR 5/8) sandy clay loam; moderate medium and coarse subangular blocky structure; friable; sticky, slightly plastic; common fine roots; common coarse and medium pores; few faint clay films on ped faces, many prominent clay bridges between sand grains; 10 % HM; gradual smooth boundary.

Bt3-- 89 to 150+ cm; red (2.5 YR 4/8) sandy clay loam; weak coarse prismatic parting to moderate medium subangular blocky structure; friable; sticky, slightly plastic; few fine roots; few fine and common medium pores; few faint clay films on ped faces, many prominent clay bridges between sand grains; 10 % HM.

* Heavy mineral content based on visual estimation in situ.

† See figure 11 for the location of these pits.

Location: Control plot # 4 (pit II).

Vegetation: Soybeans. Parent material: stratified Upper Coastal Plain fluviomarine sediments.

Physiography: Ridge summit. Relief: 15 m.

Elevation: 65 m. Slope: 2 percent.

Erosion: Moderate. Permeability: Moderate.

Described by Pamela Thomas and Phil Schroeder, 12/4/96.

- Ap-- 0 to 21 cm; brown (10 YR 4/3) loamy sand; weak fine granular structure; very friable, non-sticky, non-plastic; common medium and fine and few coarse roots; common coarse and few very coarse and coarse pores; 15 % HM; abrupt smooth boundary.
- E-- 21 to 27 cm; brown (7.5 YR 5/4) loamy sand; single grain; loose, non-sticky, non-plastic; few medium common fine roots; few coarse and medium pores; 20 % HM. Clear wavy boundary.
- Bt1-- 27 to 84 cm; reddish yellow (5 YR 6/6) sandy clay loam; moderate medium and coarse subangular blocky structure; friable; sticky, slightly plastic; common fine and few medium roots; common coarse, and few medium; few faint and many prominent clay films on ped faces, 10 % HM; gradual smooth boundary.
- Bt2-- 84 to 150+ cm; red (2.5 YR 4/6) sandy clay loam; weak medium prismatic and moderate medium and coarse subangular blocky structure; friable; sticky, slightly plastic; common fine roots; common coarse and medium pores; few faint clay films on ped faces, many prominent clay bridges between sand grains; 10 % HM.

Location: Control plot # 11 (pit III).

Vegetation: Soybeans. Parent material: stratified Upper Coastal Plain fluviomarine sediments.

Physiography: Ridge summit. Relief: 15 m.

Elevation: 65 m. Slope: 2 percent.

Erosion: Moderate. Permeability: Moderate.

Described by Pamela Thomas and Phil Schroeder, 12/4/96.

- Ap-- 0 to 17 cm; brown (10 YR 4/3) loamy sand; few medium prominent yellowish red (5 YR 4/6) mottles; weak fine granular structure; very friable, non-sticky, non-plastic; few coarse, common fine and medium roots; few medium pores; 15 % HM; abrupt smooth boundary.
- Bt1-- 17 to 82 cm; yellowish red (5 YR 4/6) sandy clay loam; moderate medium and coarse subangular blocky structure; friable; sticky, slightly plastic; common fine and few medium roots; common coarse, many medium pores; few distinct clay films on ped faces, and many prominent clay bridges between sand grains; 10 % HM; diffuse smooth boundary.
- Bt2-- 82 to 150+ cm; red (2.5 YR 4/8) sandy clay loam; weak coarse prismatic parting to moderate medium and coarse subangular blocky structure; friable; sticky, slightly plastic; few fine and common medium roots; few coarse and common medium pores; few faint clay films on ped faces, many prominent clay bridges between sand grains; 10 % HM.

Location: Control plot # 24 (pit IV).

Vegetation: Soybeans. Parent material: stratified Upper Coastal Plain fluviomarine sediments.

Physiography: Ridge summit. Relief: 15 m.

Elevation: 65 m. Slope: 2 percent.

Erosion: Moderate. Permeability: Moderate.

Described by Pamela Thomas and Phil Schroeder, 12/4/96.

- Ap-- 0 to 21 cm; dark yellowish brown (10 YR 4/4) loamy sand; few medium prominent yellowish red (5 YR 4/6) mottles; weak fine granular structure; very friable, non-sticky, non-plastic; few coarse and medium, common fine roots; few medium and fine pores; 15 % HM; 2 % round quartz gravel; abrupt smooth boundary.
- Bt1-- 21 to 62 cm; yellowish red (5 YR 4/6) sandy clay loam; weak medium and coarse subangular blocky and weak coarse prismatic structure; friable; sticky, plastic; common fine roots; few coarse and medium pores; few distinct clay films on ped faces, and many prominent clay bridges between sand grains; 10 % HM; 2 % rounded quartz gravel; gradual smooth boundary.
- Bt2-- 62 to 100 cm; yellowish red (5 YR 4/6) sandy clay loam; weak coarse prismatic parting to moderate medium and coarse subangular blocky structure; friable; sticky, plastic; few fine roots; few medium pores; few faint clay films on ped faces, many prominent clay bridges between sand grains; 10 % HM; 2 % rounded quartz gravel; gradual wavy boundary.
- Btv-- 100 to 150+ cm; yellowish red (5 YR 5/6) sandy clay loam; weak coarse prismatic parting to moderate medium and coarse subangular blocky structure; friable; slightly sticky, slightly plastic; few fine roots; few medium pores; few faint clay films on ped faces, many prominent clay bridges between sand grains; 10 % HM; 5 % rounded quartz gravel; 5 % plinthite.

Location: Control plot # 22 (pit V).

Vegetation: Soybeans. Parent material: stratified Upper Coastal Plain fluviomarine sediments.

Physiography: Ridge summit. Relief: 15 m.

Elevation: 65 m. Slope: 2 percent.

Erosion: Moderate. Permeability: Moderate.

Described by Pamela Thomas and Phil Schroeder, 12/4/96.

Ap-- 0 to 19 cm; dark grayish brown (10 YR 4/2) loamy sand; weak fine granular structure; very friable, non-sticky, non-plastic; few coarse and medium, common fine roots; few coarse and common medium pores; 10 % HM; abrupt smooth boundary.

Bt1-- 19 to 93 cm; yellowish red (5 YR 4/6) sandy clay loam; weak medium and coarse subangular blocky and weak coarse prismatic structure; friable; sticky, slightly plastic; few coarse, common fine and medium roots; few coarse and common medium pores; few distinct clay films on ped faces, and many prominent clay bridges between sand grains; 10 % HM; gradual smooth boundary.

Bt2-- 93 to 162 cm; red (2.5 YR 4/6) sandy clay loam; few common prominent brownish yellow mottles; weak coarse prismatic parting to weak coarse subangular blocky structure; friable; sticky, plastic; few fine roots; few coarse and common medium pores; few faint clay films on ped faces, many prominent clay bridges between sand grains; 10 % HM; gradual wavy boundary.

Btv-- 162 to 187+ cm; red (2.5 YR 5/8) sandy clay loam; weak coarse prismatic parting to weak coarse subangular blocky structure; friable; sticky, slightly plastic; few fine roots; few medium pores; common distinct clay bridges between sand grains; 2 % HM; 5 % rounded quartz gravel; 5 % plinthite.

Location: Old Hickory Test Pit 1, east wall.

Classification: Fine-loamy, siliceous, thermic Typic Kandiudults.

Vegetation: Soybeans.

Parent material: Stratified Upper Coastal Plain fluviomarine sediments.

Physiography: Ridge summit. Relief: 15 m.

Elevation: 65 m., Slope: 2 percent.

Aspect: SE 110 degrees. Erosion: Moderate.

Permeability: Moderate. Drainage: Well drained.

Sampled by: Mike Genthner and Phil Schroeder, 11/4/94.

- Ap-- 0 to 30 cm; dark yellowish brown (10YR 4/4) loamy sand; weak fine granular structure; very friable, non-sticky, non-plastic; common medium and many fine roots; abrupt smooth boundary.
- Bt1-- 30 to 76 cm; yellowish red (5YR 4/6) sandy loam; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; many fine roots; gradual smooth boundary.
- Bt2-- 76 to 168 cm; red (2.5YR 4/6) sandy clay loam; weak coarse subangular blocky structure; firm, slightly sticky, slightly plastic; gradual smooth boundary; common fine roots.
- Bt3-- 168 to 234 cm; red (2.5YR 4/6) sandy clay loam; moderate medium subangular blocky structure; friable, slightly sticky, slightly plastic; gradual smooth boundary; few fine roots.
- Bt4-- 234 to 305 cm; red (2.5YR 4/8) sandy loam; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; gradual boundary.
- C-- 305 to 371 cm; strong brown (7.5YR 4/8) loamy sand; massive; friable, slightly sticky, non-plastic; 2 percent plinthite nodules; few fine vertical white (10YR 8/1) clay depletions; gradual boundary.
- Cv-- 371 to 410+cm; mixed dark red (2.5YR 3/6) and yellowish red (5YR 5/8) sand; massive; friable, non-sticky, non-plastic; 5 percent plinthite nodules; many fine and medium white (10YR 8/1) clay depletions.

Location: Old Hickory Test Pit 1, west wall.

Classification: Fine-loamy, siliceous, thermic Typic Kandiudults.

Vegetation: Soybeans.

Parent material: Stratified Upper Coastal Plain fluviomarine sediments.

Physiography: Ridge summit. Relief: 15 m.

Elevation: 65 m. Slope: 2 percent.

Aspect: SE 110 degrees. Erosion: Moderate.

Permeability: Moderate. Drainage: Well drained.

Sampled by: Mike Genthner and Phil Schroeder, 11/4/94.

- Ap-- 0 to 30 cm; dark yellowish brown (10YR 4/4) loamy sand; weak fine granular structure; very friable, non-sticky, non-plastic; many medium and many fine roots; abrupt smooth boundary.
- Bt1-- 30 to 89 cm; yellowish red (5YR 4/6) sandy clay loam; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; many fine and common medium roots; gradual smooth boundary.
- Bt2-- 89 to 168 cm; red (2.5YR 4/6) sandy clay loam; weak coarse subangular blocky structure; firm, slightly sticky, slightly plastic; gradual smooth boundary; many fine roots.
- Bt3-- 168 to 213 cm; red (2.5YR 4/6) sandy clay loam; weak medium subangular blocky structure; firm, slightly sticky, slightly plastic; gradual smooth boundary; few fine roots.
- Bt4-- 213 to 305 cm; red (2.5YR 4/8) sandy loam; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; few fine roots; gradual boundary.
- CB-- 305 to 350 cm; mixed yellowish red (5YR 4/6) and yellowish brown (10YR 5/6) sandy loam; weak medium subangular blocky structure; friable, slightly sticky, non-plastic; few fine roots; gradual smooth boundary.
- Cv-- 350 to 400+cm; mixed dark red (2.5YR 3/6) and yellowish brown (10YR 5/8) loamy sand; massive; firm, non-sticky, non-plastic; few fine roots.

Descriptions from auger borings in pit areas prior to mining (see Figure 9 for the location of these borings).

VT 1A

Ap-- 0 to 25 cm; dark yellowish brown (10YR 4/4) loamy sand; weak fine granular structure; very friable, nonsticky, nonplastic; abrupt boundary.

Bt1-- 25 to 76 cm; strong brown (7.5YR 4/6) sandy clay loam; weak coarse subangular blocky structure; friable, slightly sticky, plastic; clear boundary.

Bt2-- 76 to 152 cm; red (2.5YR 4/6) sandy clay; weak coarse subangular blocky structure; friable, sticky, plastic; diffuse boundary.

Bt3-- 152 to 198 cm; red (2.5YR 4/6) sandy clay; weak coarse subangular blocky structure; friable, sticky, plastic; gradual boundary.

Bt4-- 198 to 259 cm; red (2.5YR 4/8) sandy loam; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; clear boundary.

BC-- 259 to 305 cm; yellowish red (5YR 5/8) loam; weak medium subangular blocky structure; friable, slightly sticky, nonplastic.

VT 1B

- Ap-- 0 to 20 cm; dark yellowish brown (10YR 4/4) loamy sand; weak fine and medium granular structure; very friable, nonsticky, nonplastic; abrupt boundary.
- Bt1-- 20 to 58 cm; yellowish red (5YR 4/6) sandy clay loam; weak medium and coarse subangular blocky structure; friable, sticky, slightly plastic, clear boundary.
- Bt2-- 58 to 132 cm; red (2.5YR 4/6) sandy clay loam; weak medium and coarse subangular blocky structure; friable, sticky, plastic; gradual boundary.
- Bt3-- 132 to 191 cm; red (2.5YR 4/8) sandy clay loam; weak medium subangular blocky structure; friable, sticky, slightly plastic; gradual boundary.
- BC-- 191 to 229 cm; red (2.5YR 4/8) sandy loam; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; clear boundary.
- C1-- 229 to 274 cm; strong brown (7.5YR 5/8) loamy sand; few medium distinct yellowish red (5YR 5/8) mottles; weak medium subangular blocky structure; friable, slightly sticky, nonplastic; clear boundary.
- C2-- 274 to 305 cm; brownish yellow (10YR 6/8) and white (10 YR 8/1) sand; massive; friable, nonsticky, nonplastic.
-

VT 1C

- Ap-- 0 to 15 cm; reddish brown (5YR 4/4) sandy loam; weak fine, medium, and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; abrupt boundary.
- Bt1-- 15 to 51 cm; red (2.5YR 4/6) sandy clay loam; weak medium and coarse subangular blocky structure; friable, sticky, plastic; clear boundary.
- Bt2-- 51 to 107 cm; dark red (2.5YR 3/6) sandy clay loam; weak medium and coarse subangular blocky structure; friable, sticky, plastic; gradual boundary.
- Bt3-- 107 to 173 cm; red (2.5YR 4/6) sandy loam; weak medium subangular blocky structure; friable, slightly sticky, slightly plastic; gradual boundary.
- BC-- 173 to 231 cm; red (2.5YR 4/8) loamy sand; weak medium subangular blocky structure; friable, slightly sticky, nonplastic; gradual boundary.
- C-- 231 to 305 cm; brownish yellow (10YR 6/8) and white (10YR 8/1) sand; massive; very friable, nonsticky, nonplastic.
-

VT 2A

- Ap-- 0 to 18 cm; dark yellowish brown (10YR 4/4) loamy sand; weak fine granular structure; very friable, nonsticky, nonplastic; abrupt boundary.
- Bt1-- 18 to 81 cm; yellowish red (5 YR 4/6) sandy clay loam; weak medium and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; clear boundary.
- Bt2-- 81 to 137 cm; red (2.5YR 4/6) sandy clay loam; weak medium and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; diffuse boundary.
- Bt3-- 137 to 188 cm; red (2.5YR 4/6) sandy clay loam; weak medium and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; gradual boundary.
- Bt4-- 188 to 239 cm; red (2.5YR 4/6) sandy loam; weak medium and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; gradual boundary.
- BC-- 239 to 305 cm; yellowish red (5YR 5/8) loamy sand; weak medium and coarse subangular blocky structure; friable, slightly sticky, nonplastic.
-

VT 2B

Ap-- 0 to 23 cm; brown (7.5YR 4/4) loamy sand; weak fine and medium granular structure; friable, nonsticky, nonplastic; abrupt boundary.

Bt1-- 23 to 58 cm; red (2.5YR 4/6) sandy clay loam; weak medium and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; gradual boundary.

Bt2-- 58 to 132 cm; red (2.5YR 4/6) sandy clay loam; moderate medium and coarse subangular blocky structure; friable, sticky, slightly plastic; diffuse boundary.

Bt3-- 132 to 188 cm; red (2.5YR 4/6) sandy clay loam; weak medium and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; diffuse boundary.

BC-- 188 to 244 cm; red (2.5YR 4/8) sandy loam; weak medium and coarse subangular blocky structure; friable, slightly sticky, nonplastic; gradual boundary.

C-- 244 to 305 cm; yellowish red (5YR 5/8) loamy sand; weak medium subangular blocky structure; friable, nonsticky, nonplastic.

VT 2C

- Ap-- 0 to 13 cm; reddish brown (5YR 4/4) sandy loam; weak fine and medium subangular blocky structure; friable, slightly sticky, nonplastic; abrupt boundary.
- Bt1-- 13 to 61 cm; reddish brown (2.5YR 4/4) sandy clay loam; weak medium and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; gradual boundary.
- Bt2-- 61 to 107 cm; red (10R 4/6) sandy clay; moderate medium and coarse subangular structure; firm, sticky, plastic; clear boundary.
- Bt3-- 107 to 152 cm; red (10R 4/8) sandy clay loam; weak medium and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; clear boundary.
- Bt4-- 152 to 183 cm; red (2.5YR 4/6) sandy loam; weak medium subangular blocky structure; friable, slightly sticky, nonplastic; gradual boundary.
- BC-- 183 to 244 cm; red (2.5YR 4/6) and yellowish red (5YR 5/8) sandy loam; weak medium subangular blocky structure; friable, nonsticky, nonplastic; gradual boundary.
- C-- 244 to 305 cm; strong brown (7.5 YR 5/8), white (10YR 8/1), and brownish yellow (10YR 6/8) loamy sand; massive; very friable, nonsticky, nonplastic.
-

VT 3A

Ap-- 0 to 18 cm; brown (7.5YR 4/4) loamy sand; weak fine granular structure; very friable, nonsticky, nonplastic; abrupt boundary.

Bt1-- 18 to 69 cm; yellowish red (5YR 5/6) sandy clay loam; weak medium and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; clear boundary.

Bt2-- 69 to 147 cm; red (2.5YR 4/6) sandy clay loam; weak medium and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; gradual boundary.

Bt3-- 147 to 208 cm; red (2.5YR 4/6) sandy clay; moderate medium and coarse subangular blocky structure; firm, sticky, plastic; gradual boundary.

Bt4-- 208 to 282 cm; red (2.5YR 4/6) sandy clay loam; weak medium subangular blocky structure; friable, slightly sticky, nonplastic; gradual boundary.

BC-- 282 to 305 cm; yellowish red (5YR 5/8) sandy loam; weak medium subangular blocky structure; friable, nonsticky, nonplastic.

VT 3B

- Ap-- 0 to 10 cm; brown (7.5YR 4/4) loamy sand; weak fine and medium granular structure; very friable, nonsticky, nonplastic; abrupt boundary.
- Bt1-- 10 to 38 cm; red (2.5YR 4/6) sandy clay loam; weak medium and coarse subangular blocky structure; friable, slightly sticky, slightly plastic; clear boundary.
- Bt2-- 38 to 97 cm; red (2.5YR 4/6) sandy clay loam; moderate medium and coarse subangular blocky structure; friable, sticky, slightly plastic; diffuse boundary.
- Bt3-- 97 to 152 cm; red (2.5YR 4/6) sandy clay loam; moderate medium and coarse subangular blocky structure; friable, sticky, slightly plastic; gradual boundary.
- Bt4-- 152 to 203 cm; red (2.5YR 4/6) sandy loam; weak medium subangular blocky structure; friable, slightly sticky, nonplastic; gradual boundary.
- BC-- 203 to 236 cm; red (2.5YR 4/8) sandy loam; weak medium subangular blocky structure; friable, slightly sticky, nonplastic; gradual boundary.
- CB-- 236 to 274 cm; yellowish red (5YR 4/6) and strong brown (7.5YR 5/8) loamy sand; weak medium subangular blocky structure; friable, nonsticky, nonplastic; gradual boundary.
- C-- 274 to 305 cm; yellowish brown (10YR 5/8) and light gray (10YR 7/1) sand; massive; very friable, nonsticky, nonplastic.

VT 3C

Ap-- 0 to 10 cm; brown (7.5YR 4/4) loamy sand; weak fine granular structure; very friable, nonsticky, nonplastic; abrupt boundary.

Bt1-- 10 to 61 cm; red (2.5YR 4/6) sandy clay loam; moderate medium and coarse subangular blocky structure; friable, sticky, slightly plastic; diffuse boundary.

Bt2-- 61 to 122 cm; red (2.5YR 4/6) sandy clay loam; moderate medium and coarse subangular blocky structure; friable, sticky, slightly plastic; gradual boundary.

Bt3-- 122 to 152 cm; red (2.5YR 4/8) sandy loam; weak medium subangular blocky structure; friable, slightly sticky, nonplastic; clear boundary.

BC-- 152 to 196 cm; red (2.5YR 4/8) sandy loam; weak fine and medium subangular blocky structure; friable, slightly sticky, nonplastic; 5 percent iron stone gravel; gradual boundary.

C1-- 196 to 224 cm; red (2.5YR 4/8), yellowish red (5YR 5/8), and strong brown (7.5YR 5/8) loamy sand; massive; friable, nonsticky, nonplastic; 5 percent iron stone gravel; gradual boundary.

C2-- 224 to 305 cm; yellowish brown (10YR 5/8) and white (10YR 8/1) sand; single grain; loose, nonsticky, nonplastic.

Appendix IV

Morphological Description of Mine Soils

Morphology of mine soils described in soil pits dug after soybean harvest (November, 1996)

Location: Pit 1 topsoil plot # 1 (pit I).

Vegetation: Soybeans. Parent material: stratified mine tailings, slimes, regraded sub-soil, and replaced topsoil.

Physiography: Ridge summit. Relief: 15 m.

Elevation: 65 m. Slope: 2 percent.

Described by Pamela Thomas and Phil Schroeder, 12/6/96.

Ap-- 0 to 36 cm; dark brown (7.5 YR 4/4) loamy sand; massive; very friable, non-sticky,
non-plastic; common fine and few medium roots; few fine pores; 20 % HM; abrupt smooth boundary.

C-- 36 to 120 cm; red (2.5 YR 4/8) sandy clay loam and brown (7.2 YR 4/2) sand; massive;
friable; slightly sticky, slightly plastic; few fine roots; 5 to 50 % HM.

Location: Pit 1 topsoil plot # 2 (pit II).

Vegetation: Soybeans. Parent material: stratified mine tailings, slimes, regraded sub-soil, and replaced topsoil.

Physiography: Ridge summit. Relief: 15 m.

Elevation: 65 m. Slope: 2 percent.

Notes: Water seeping from the Ap-C contact.

Described by Pamela Thomas and Phil Schroeder, 12/6/96.

Ap-- 0 to 43 cm; dark brown (7.5 YR 4/4) loamy sand; massive; very friable, non-sticky,
non-plastic; many fine and few medium roots; few fine pores; 20 % HM; abrupt smooth
boundary.

C-- 43 to 137 cm; red (2.5 YR 4/6) sandy clay loam; massive; friable; sticky, plastic; few fine
roots; 10 % HM 5 % rounded quartz and plinthite.

Location: Pit 1 topsoil plot # 3 (pit III).

Vegetation: Soybeans. Parent material: stratified mine tailings, slimes, regraded soil, and replaced topsoil.

Physiography: Ridge summit. Relief: 15 m.

Elevation: 65 m. Slope: 2 percent.

Described by Pamela Thomas and Phil Schroeder, 12/6/96.

- Ap-- 0 to 41 cm; dark brown (7.5 YR 4/4) loamy sand; massive; very friable, non-sticky, non-plastic; common fine and few medium roots; few fine pores; 20 % HM; abrupt wavy boundary.
- C1-- 41 to 149 cm; red (2.5 YR 4/6) sandy clay loam; massive; friable; slightly sticky, plastic; common fine roots; few fine pores; 5 % HM; 15 % fine gravel; abrupt wavy boundary.
- C2-- 149 to 189 cm; yellowish red (5 YR 5/8) clay; massive; sticky and plastic; 1 % HM; abrupt wavy boundary .
- C3-- 189 to 200 cm; strong brown (7.5 YR 5/8) sand; single grain; loose; non-sticky, non-plastic; 3 % HM.

Location: Pit 1 compost plot # 1 (pit I).

Vegetation: Soybeans. Parent material: stratified mine tailings, slimes, and regraded sub-soil.

Physiography: Ridge summit. Relief: 15 m.

Elevation: 65 m. Slope: 2 percent.

Notes: Free water at 198 cm.

Described by Pamela Thomas and Phil Schroeder, 12/6/96.

- Ap-- 0 to 6 cm; yellowish red (5 YR 4/6) and black (N 2/0) sandy loam; massive; friable, sticky, slightly plastic; many fine and few medium roots; common medium and few fine pores; 5 % HM; abrupt smooth boundary.
- C1-- 6 to 52 cm; yellowish red (5 YR 4/6) sandy clay loam; pockets of strong brown (7.5 YR 5/8) sand; massive; friable; sticky, slightly plastic; common fine and few medium roots; 5 % HM; 20 % cobbles and gravel; diffuse wavy boundary.
- C2-- 52-130 cm; yellowish red (5 YR 5/6), brownish yellow (10 YR 6/8), and yellow (10 YR 7/6) sandy loam/sandy clay loam; massive; friable; sticky, slightly plastic; 2 % HM; 10 % gravel.

Location: Pit 1 compost plot # 5 (pit II).

Vegetation: Soybeans. Parent material: stratified mine tailings, slimes, and regraded sub-soil.

Physiography: Ridge summit. Relief: 15 m.

Elevation: 65 m. Slope: 2 percent.

Notes: Free water at 168 cm. Roots in C1 growing in cracks.

Described by Pamela Thomas and Phil Schroeder, 12/6/96.

- Ap-- 0 to 8 cm; red (2.5 YR 4/6) and black (N 2/0) sandy loam; massive; friable, slightly sticky, slightly plastic; common fine and few medium roots; few coarse, common medium and fine pores; 3 % HM; 1 % rounded quartz gravel; abrupt smooth boundary.
- C1-- 8 to 75 cm; red (2.5 YR 4/6) sandy clay loam; massive; friable; sticky, plastic; common fine roots in the upper 20 cm; few fine and medium pores; 3 % HM; 1% gravel; clear smooth boundary.
- C2-- 75-168 cm; stratified yellowish red (5 YR 5/8), and reddish yellow (7.5 YR 7/6) sand; single grain; loose; non-sticky, non- plastic; 1 % HM.

Location: Pit 1 compost plot # 10 (pit III).

Vegetation: Soybeans. Parent material: stratified mine tailings, slimes, and regraded sub-soil.

Physiography: Ridge summit. Relief: 15 m.

Elevation: 65 m. Slope: 2 percent.

Notes: Bt horizon at 152 cm represents bottom of mine pit.

Described by Pamela Thomas and Phil Schroeder, 12/5/96.

- Ap-- 0 to 8 cm; red (2.5 YR 4/6) and black (N 2/0) sandy clay loam; moderate medium granular structure; friable, slightly sticky, slightly plastic; many fine and few medium roots; common fine pores; 5 % HM; abrupt smooth boundary.
- C1-- 8 to 26 cm; red (2.5 YR 4/6) sandy clay loam; massive; friable; sticky, plastic; common fine roots; few fine pores; 10 % HM; clear smooth boundary.
- C2-- 26 to 139 cm; yellowish red (5 YR 5/8) sand; single grain; loose; non-sticky, non-plastic; common fine roots in the upper 10 cm; few fine pores; 2 % HM; 1 % gravel; abrupt wavy boundary.
- C3-- 139 to 152 cm; yellowish red (5 YR 5/6) clay; massive; sticky, plastic; 1% HM; abrupt smooth boundary.
- 2Bt-- 152-- cm; red (2.5 YR 4/6) clay loam; moderate medium subangular blocky structure; friable; sticky, plastic, few fine pores; many distinct clay bridges. 10 % HM.

Location: Pit 3 topsoil plot # 1 (pit I).

Vegetation: Soybeans. Parent material: stratified mine tailings, slimes, and replaced topsoil.

Physiography: sideslope. Relief: 15 m.

Elevation: 65 m. Slope: 5 percent.

Described by Pamela Thomas and Phil Schroeder, 12/5/96.

Ap1-- 0 to 16 cm; dark yellowish brown (10 YR 4/4) sand; massive; very friable, non-sticky, non-plastic; common fine and few medium and coarse roots; few coarse and many medium and fine pores; 30 % HM; clear smooth boundary.

Ap2-- 16 to 53 cm; dark yellowish brown (10 YR 4/4) sand; massive; very friable, non-sticky, non-plastic; few fine, medium and coarse roots; few coarse and medium pores; 30 % HM; abrupt smooth boundary.

C1-- 53 to 111 cm; red (2.5 YR 4/8) sand; many strong brown (7.5 YR 8/5) sand pockets; massive; very friable; non-sticky, non-plastic; few fine, medium, and coarse roots; few coarse and medium pores; 2 % HM; clear irregular boundary.

C2-- 111 to 164 cm; yellowish red (5 YR 5/6) clay; many strong brown (7.5 YR 8/5) sand pockets; massive; sticky and plastic; few fine roots; 1 % HM; abrupt wavy boundary .

C3-- 164 to 190 cm; stratified reddish yellow (7.5 YR 7/6) and very pale brown (10 YR 8/4) sand; single grain; loose; non-sticky, non-plastic; 1 % HM.

Location: Pit 3 topsoil plot # 2 (pit II).

Vegetation: Soybeans. Parent material: stratified mine tailings, slimes, and replaced topsoil.

Physiography: sideslope. Relief: 15 m.

Elevation: 65 m. Slope: 5 percent.

Described by Pamela Thomas and Phil Schroeder, 12/5/96.

Ap1-- 0 to 21 cm; dark yellowish brown (10 YR 4/4) sand; moderate fine granular structure;

very friable, non-sticky, non-plastic; common fine roots; few medium and common fine pores; 20 % HM; clear smooth boundary.

Ap2-- 21 to 64 cm; dark yellowish brown (10 YR 4/3) sand; massive; very friable, non-sticky,

non-plastic; few fine roots; few fine and medium pores; 20 %HM; abrupt smooth boundary.

C1-- 64 to 137 cm; reddish yellow (5 YR 6/8) sand; many reddish yellow (7.5 YR 6/6) sand pockets;

massive; very friable; non-sticky, non-plastic; few fine roots; few fine pores; 2 % HM; clear irregular boundary.

C2-- 137 to 150 cm; yellowish red (5 YR 5/8) clay; massive; sticky and plastic; 1 % HM; abrupt wavy boundary .

C3-- 150 to 160 cm; very pale brown (10 YR 8/4) sand and many 1 to 3 cm yellowish red (5 YR 5/8) clay strata;

single grain; loose; non-sticky, non-plastic; 3 % HM.

Location: Pit 3 topsoil plot # 8 (pit III).

Vegetation: Soybeans. Parent material: stratified mine tailings, slimes, and replaced topsoil.

Physiography: sideslope. Relief: 15 m.

Elevation: 65 m. Slope: 5 percent.

Notes: free water at 150 cm. Described by Pamela Thomas and Phil Schroeder, 12/5/96.

- Ap1-- 0 to 31 cm; dark yellowish brown (10 YR 4/4) loamy sand; moderate fine granular structure in the upper 15 cm; very friable, non-sticky, non-plastic; common fine roots in the upper 15 cm, few fine roots in the lower 15 cm; few very coarse, common coarse and medium pores; 100 % HM; abrupt wavy boundary.
- C1-- 31 to 47 cm; red (2.5 YR 5/8) loamy sand; reddish yellow (7.5 YR 6/8) strata in the lower 5 cm; massive; friable; non-sticky, non-plastic; few fine, and medium roots; few fine and medium pores; 10 % HM, 50 % HM in bottom 1 cm; 5 % clay balls 1 cm in diam; abrupt wavy boundary.
- C2-- 47 to 63 cm; red (2.5 YR 5/8) clay; massive; sticky and plastic; few fine roots; few fine pores; abrupt wavy boundary.
- C3-- 63 to 89 cm; yellowish red (5 YR 5/8) coarse loamy sand; massive; friable; slightly sticky; few fine roots; few fine pores; non-plastic; 1 % HM; abrupt wavy boundary.
- C4-- 89 to 105 cm; red (2.5 YR 4/8) clay; massive; sticky, plastic, abrupt wavy boundary.
- C5-- 105 to 134 cm; reddish yellow (5 YR 6/8) sand; single grain; non-sticky, non-plastic; 1 % HM; abrupt wavy boundary.
- C6-- 134 to 150 cm; yellowish red (5 YR 5/8) clay; massive; sticky, plastic.

Location: Pit 3 compost plot # 1 (pit I).

Vegetation: Soybeans. Parent material: stratified mine tailings, slimes.

Physiography: sideslope. Relief: 15 m.

Elevation: 65 m. Slope: 5 percent.

Notes: Free water at 61 cm.

Described by Pamela Thomas and Phil Schroeder, 12/6/96.

Ap-- 0 to 6 cm; red (2.5 YR 4/6) and black (N 2/0) sandy loam; weak fine granular over massive structure; friable, slightly sticky, non-plastic; common fine roots; common coarse and medium pores; 3 % HM; abrupt smooth boundary.

C-- 6 to 67 cm; red (2.5 YR 4/6) loamy sand; massive; very friable; slightly sticky, non-plastic; few fine roots; few coarse and medium pores. 3 % HM.

Location: Pit 3 compost plot # 11 (pit II).

Vegetation: Soybeans. Parent material: stratified mine tailings, slimes.

Physiography: sideslope. Relief: 15 m.

Elevation: 65 m. Slope: 5 percent.

Notes: Free water at 80 cm.

Described by Pamela Thomas and Phil Schroeder, 12/6/96.

- Ap-- 0 to 9 cm; red (2.5 YR 4/8) and black (N 2/0) loamy sand; weak fine granular and weak fine subangular blocky structure; very friable, non-sticky, non-plastic; common fine roots; few medium pores; 5 % HM; 2 % rounded quartz gravel; abrupt smooth boundary.
- Bw-- 9-26 cm; red (2.5 YR 4/8) loamy sand; weak medium subangular blocky structure; friable; slightly sticky, non-plastic; few fine roots; few medium pores; 5 % HM; clear irregular boundary.
- C1-- 26 to 60 cm; red (2.5 YR 4/8) sandy loam; common prominent light brown (7.5 YR 6/4) strata 5 cm thick; massive; friable; slightly sticky, non-plastic; few fine roots; few medium pores. 5 % HM; abrupt smooth boundary.
- C2-- 60 to 64 cm; yellowish red (5 YR 5/8) sand; common prominent light brown (7.5 YR 6/4) strata 5 cm thick; single grain; loose; non-sticky, non-plastic; 40 % HM; abrupt smooth boundary.
- C3-- 64-125 cm; yellowish red (5 YR 5/8) and light brown (7.5 YR 6/4) stratified sand; single grain; loose; non-sticky, non-plastic; 3 % HM.

Location: Pit 3 compost plot # 8 (pit III).

Vegetation: Soybeans. Parent material: stratified mine tailings, slimes.

Physiography: sideslope. Relief: 15 m.

Elevation: 65 m. Slope: 5 percent.

Notes: Free water at 40 cm.

Described by Pamela Thomas and Phil Schroeder, 12/6/96.

Ap-- 0 to 7 cm; yellowish red (5 YR 5/6) and black (N 2/0) sand; single grain; loose, non-sticky, non-plastic; few medium and fine roots; few coarse pores; 5 % HM; clear wavy boundary.

C-- 7 to 60 cm; reddish yellow (5 YR 6/8) and reddish yellow (7.5 YR 7/6) stratified sand; single grain; loose; non-sticky, non-plastic; few fine roots in upper 5 cm; 5 % HM.

Appendix V

Profile Descriptions for Auger Borings from Pit 1 Prior to Application of Treatments

Refer to Figure 10 for the location of these sampling points

1A

0-36 cm; dark yellowish brown (10YR 3/4) sandy loam; regraded top soil.

36-41 cm; yellowish red (5YR 4/6) sand; tailings.

41-48 cm; yellowish red (5YR 5/8) sandy loam; tailings with some slimes.

48-152 cm; yellowish red (5YR 5/6) sandy loam; tailings.

1B

0-46 cm; dark yellowish brown (10YR 3/4) sandy loam; regraded top soil.

46-56 cm; yellowish red (5YR 5/8) sandy clay loam; mix of tailings and slimes.

56-152 cm; yellowish red (5YR 5/8) and reddish yellow (7.5YR 6/6) sand; tailings.

1C

0-41 cm; dark red (2.5YR 3/6) sandy clay loam; regraded sub-soil.

41-79 cm; yellowish red (5YR 4/6) loamy Sand; tailings..

79-152 cm; yellowish red (5YR 4/6) loamy sand; tailings.

1D

0-36 cm; yellowish red (5YR 4/6) sandy clay loam; regraded sub-soil.

36-71 cm; red (2.5YR 4/6) sand; tailings.

71-81 cm; red (2.5YR 4/6) sand; tailings.

81-152 cm; yellowish red (5YR 4/6) sand; tailings.

2A

0-46 cm; dark yellowish brown (10YR 4/6) loamy sand; regraded topsoil.

46-99 cm; strong brown (7.5YR 5/6) sandy clay loam; regraded sub-soil.

99-152 cm; yellowish red (5YR 5/8) sand; tailings.

2B

0-76 cm; yellowish red (5YR 5/8) sandy clay loam; regraded sub-soil.

76-152 cm; yellowish red (5YR 5/8) and red (2.5YR 4/8) loamy sand, tailings with many thin slime layers.

2C

0-61 cm; yellowish red (5YR 4/6) sandy clay loam; regraded sub-soil.

61-152 cm; yellowish red (5YR 5/8) and red (2.5YR 4/8) loamy sand, tailings with some slime layers.

2D

0-30 cm; yellowish red (5YR 4/6) sandy clay loam; regraded sub-soil.

30-61 cm; yellowish red (5YR 5/8) sandy loam; regraded sub-soil.

61-66 cm; strong brown (7.5YR 5/6) clay, slime layer.

66-152 cm; yellowish red (5YR 5/8) and red (2.5YR 4/8) loamy sand, tailings with many thin slime layers.

3A

0-30 cm; dark yellowish brown (10YR 3/4) sandy loam; regraded topsoil.

30-112 cm; yellowish red (5YR 4/6) sandy clay loam; regraded sub-soil.

112-152 cm; yellowish red (5YR 5/8) sand.

3B

0-46 cm; dark yellowish brown (10YR 3/4) sandy loam; regraded topsoil.

46-123 cm; yellowish red (5YR 5/8) clay; slimes.

123-152 cm; yellowish red (5YR 4/6) sand.

3C

0-46 cm; red (2.5YR 4/6) sandy clay loam; regraded sub-soil.

46-112 cm; red (2.5YR 4/6) clay/sandy clay. Mix of regraded sub-soil and slimes.

112-6-152 cm; strong brown (7.5YR 5/8) sand.

3D

0-61 cm; yellowish red (5YR 4/6) sandy clay loam; regraded sub-soil.

61-122 cm; reddish brown (5YR 4/4) sandy loam; regraded sub-soil.

122-152 cm; yellowish red (5YR 4/6) sandy loam, mix of sand and slimes.

4A

0-30 cm; dark yellowish brown (10YR 4/4) sandy loam; regraded topsoil.

30-152 cm; reddish yellow (10YR 6/8) sandy clay loam; regraded sub-soil.

4B

0-30 cm; yellowish red (5YR 5/6) sandy loam; regraded top soil.

30-152 cm; yellowish red (5YR 4/6) sandy clay loam; mix of slimes and regraded sub-soil.

4C

0-91 cm; yellowish red (5YR 5/6) sandy clay loam; regraded sub-soil.

91-152 cm; reddish brown (5YR 4/4) sandy clay loam; regraded sub-soil.

4D

0-30 cm; yellowish red (5YR 4/6) sandy clay loam; regraded sub-soil.

30-91 cm; yellowish red (5YR 4/6), brownish yellow (10YR 6/8), and gray (2.5Y 6/0) sandy loam. Regraded sub-soil.

91-152 cm; brownish yellow (10YR 6/8), and yellowish red (5YR 4/6) sandy clay loam; unprocessed (reject) sub-soil material

5A

0-46 cm; dark yellowish brown (10YR 4/4) and strong brown (7.5YR 5/6) sandy loam; regraded sub-soil with some topsoil mixed in.

46-152 cm; dark yellowish brown (10YR 4/3), and yellowish red (5YR 5/8) sandy loam; mix of slimes and regraded sub-soil.

5B

0-91 cm; brown (10YR 4/3) sandy loam; regraded topsoil.

91-152 cm; yellowish red (5YR 4/6) sandy loam; regraded sub-soil.

5C

0-30 cm; dark yellowish brown (10YR 4/4) and strong brown (7.5YR 5/6) sandy loam; mix of regraded top and sub-soil.

30-152 cm; yellowish red (5YR 4/6) sandy loam; regraded sub-soil.

5D

0-91 cm; reddish brown (5YR 4/4) sandy clay loam; regraded sub-soil.

91-112 cm; very dark gray (5YR 3/1) and yellowish red (5YR 4/6) sandy loam; remixed tails and slimes.

112-152 cm; yellowish red (5YR 4/6) sandy loam; mixed unprocessed subsoil and slimes.

6A

0-10 cm; yellowish red (5YR 4/6) sandy clay loam; regraded sub-soil.

10-152 cm; yellowish red (5YR 5/8) clay; slimes.

6B

0-36 cm; dark yellowish brown (10YR 3/4) sandy loam; regraded top soil.

36-152 cm; yellowish brown (10YR 5/8) and strong brown (7.5YR 5/6) sandy loam; regraded sub-soil.

152-213 cm; yellowish red (5YR 4/6) sandy clay loam; remixed tails and slimes.

6C

0-91 cm; yellowish red (5YR 4/6) sandy clay loam; regraded sub-soil; water content too high to get deeper samples.

6D

0-91 cm; brown (10YR 4/3) and yellowish red (5YR 5/6) sandy loam; mixed regraded top and sub-soil.

91-168 cm; brown (10YR 4/3) loamy sand; regraded topsoil.

168-213 cm; yellowish red (5YR 4/6) and brownish yellow (10YR 5/8) sandy loam; unprocessed (reject) sub-soil.

7A

0-30 cm; yellowish red (5YR 4/6) sandy clay loam; regraded sub-soil.

30-213 cm; yellowish red (5YR 5/8) clay; slimes.

7B

0-15 cm; yellowish red (5YR 5/8) clay loam; regraded sub-soil.

15-213 cm; yellowish red (5YR 5/6) clay; slimes.

7C

0-91 cm; reddish brown (5YR 4/4) sandy clay loam; regraded sub-soil.

91-213 cm; yellowish red (5YR 5/8) sandy clay loam. Regraded sub-soil.

7D

0-30 cm; yellowish red (5YR 5/8) sandy clay loam. Regraded sub-soil.

30-71 cm; strong brown (7.5YR 5/6) sandy clay loam; regraded sub-soil.

71-91 cm; brownish yellow (10YR 6/8) and yellowish red (5YR 4/6) sandy loam; unprocessed (reject) sub-soil.

91-213 cm; yellowish red (5YR 4/6), brownish yellow (10YR 6/8), and gray (2.5Y 6/0) sandy loam unprocessed (reject) sub-soil.

8A

0-112 cm; yellowish red (5YR 5/6) sandy clay loam. Regraded sub-soil.

112-213 cm; yellowish red (5YR 5/8) sandy loam; remixed tails and slimes.

8B

0-91 cm; yellowish red (5YR 4/6) and dark yellowish brown (10YR 3/4) sandy clay loam; mixed regraded top and sub-soil.

91-122 cm; yellowish red (5YR 5/8) sandy clay loam; remixed tails and slimes.

122-213 cm; strong brown (7.5YR 5/6) loamy sand; mostly tailings.

8C

0-152 cm; yellowish red (5YR 4/6) sandy clay loam; regraded sub-soil.

152-213 cm; yellowish red (5YR 5/8) loamy sand; mostly tailings.

8D

0-61 cm; yellowish red (5YR 4/6) sandy clay loam; regraded sub-soil.

61-213 cm; brownish yellow (10YR 6/8) and yellowish red (5YR 4/6) sandy loam; unprocessed (reject) sub-soil.

9A

0-81 cm; dark yellowish brown (10YR 3/4) and yellowish red (5YR 4/6) sandy clay loam; mixed regraded top and sub-soil.

81-112 cm; yellowish red (5YR 5/8) sandy clay loam; remixed tails and slimes.

112-147 cm; strong brown (7.5YR 5/8) loamy sand; tailings.

147-152 cm; yellowish red (5YR 5/8) sand clay loam; remixed tails and slimes.

152-213 cm; yellowish red (5YR 5/6) sand; tailings.

9B

0-91 cm; yellowish red (5YR 4/6) and dark yellowish brown (10YR 3/4) sandy loam; mixed regraded top and sub-soil.

91-213 cm; reddish yellow (7.5YR 6/6) sand; tailings.

9C

0-122 cm; yellowish red (5YR 4/6) and dark yellowish brown (10YR 3/4) sandy loam; mixed regraded top and sub-soil.

122-213 cm; reddish yellow (7.5YR 6/8) sand; tailings.

9D

0-102 cm; yellowish red (5YR 4/6) and dark yellowish brown (10YR 3/4) sandy loam; mixed regraded top and sub-soil.

102-213 cm; light brown (7.5YR 6/4) sand; tailings.

10A

0-71 cm; yellowish red (5YR 4/6) sandy clay loam; regraded sub-soil.

71-91 cm; yellowish red (5YR 5/8) sand; tailings.

91-152 cm; yellowish red (5YR 5/6) sand; tailings.

152-213 cm; strong brown (7.5YR 5/8) sand; tailings.

10B

0-61 cm; yellowish red (5YR 4/6) sandy loam; regraded sub-soil.

61-91 cm; reddish yellow (7.5YR 6/6) sand; tailings.

91-147 cm; strong brown (7.5YR 5/8) and yellowish red (5YR 4/6) sand; tailings with many thin layers of slimes.

147-183 cm; red (2.5YR 4/8) loamy sand; remixed tails and slimes.

183-213 cm; strong brown (7.5YR 5/6) sand; tailings.

10C

0-51 cm; yellowish red (5YR 4/6) sandy loam; regraded sub-soil.

51-91 cm; reddish yellow (7.5YR 6/8) sand (coarse); tailings.

91-213 cm; reddish yellow (7.5YR 6/8) sand; tailings.

10D

0-61 cm; yellowish red (5YR 4/6) and dark yellowish brown (10YR 3/4) sandy loam; mixed regraded top and sub-soil.

61-91 cm; reddish yellow (7.5YR 7/6) sand; tailings.

91-147 cm; reddish yellow (7.5YR 6/8) sand; tailings.

147-213 cm; strong brown (7.5YR 5/8) sand, tailings.

APPENDIX VI

Profile Descriptions for Auger Borings from Pit 3 Samples Taken Prior to Application of Treatments

1A

0-20 cm; yellowish red (5YR 5/8) sandy clay loam; remixed tailings and slimes.

20-76 cm; yellowish red (5YR 5/8) clay; slimes with decaying plant material.

76-122 cm; yellow (10YR 7/6) sand; tailings.

122-152 cm; yellowish red (5YR 5/8) sand; tailings.

1B

0-30 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes.

30-61 cm; yellowish red (5YR 5/8) clay; remixed tailings and slimes.

61-137 cm; yellow (10YR 7/6) sand; tailings.

137-152 cm; yellowish red (5YR 5/8) sand; tailings.

1C

0-76 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes.

76-60 cm; very pale brown (10YR 8/4) sand; tailings.

1D

0-25 cm; yellow (10YR 7/6) sandy loam; remixed tailings and slimes.

25-91 cm; yellowish red (5YR 5/8) sandy clay loam; remixed tailings and slimes.

91-152 cm; yellowish red (5YR 5/8) sand; tailings.

2A

0-61 cm; yellowish red (5YR 5/8) sandy clay loam; remixed tailings and slimes.

61-91 cm; yellow (10YR 7/6) sand; tailings.

91-97 cm; yellowish red (5YR 5/8) clay; slimes.

97-152 cm; yellowish red (5YR 5/8) sand; tailings.

2B

0-46 cm; yellowish red (5YR 5/8) sandy clay loam; remixed tailings and slimes.

46-152 cm; yellow (10YR 7/6) sand; tailings.

2C

0-30 cm; yellowish red (5YR 5/8) loamy sand; remixed tailings and slimes.

30-91 cm; yellowish red (5YR 5/8) clay; remixed tailings and slimes.

91-152 cm; yellow (10YR 7/6) sand; tailings.

2D

0-30 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes.

30-152 cm; yellowish red (5YR 5/8) sand; tailings.

3A

0-30 cm; sandy loam; remixed tailings and slimes.

30-122 cm; yellowish red (5YR 5/8) sandy clay loam; remixed tailings and slimes.

122-152 cm; reddish yellow (7.5YR 6/6) sand; tailings.

3B

0-152 cm; yellowish red (5YR 5/8) sandy clay loam; remixed tailings and slimes.

3C

0-30 cm; yellowish red (5YR 5/8) loamy sand; remixed tailings and slimes.

30-152 cm; yellowish red (5YR 5/8) sand; tailings.

3D

0-30 cm; yellowish red (5YR 5/8) loamy sand; remixed tailings and slimes.

30-152 cm; yellowish red (5YR 5/8) sand; tailings.

4A

0-30 cm; red (2.5YR 4/8) sandy clay loam; remixed tailings and slimes.

30-36 cm; brown (10YR 5/3) sand; tailings.

36-152 cm; yellowish red (5YR 5/8) sand; tailings.

4B

0-91 cm; yellowish red (5YR 5/8) sand; tailings.

91-152 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes.

4C

0-76 cm; yellowish red (5YR 5/8) sand; tailings.

76-152 cm; yellowish red (5YR 5/8) sand; tailings.

4D

0-56 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes.

56-152 cm; yellowish red (5YR 5/8) sand; tailings.

5A

0-76 cm; yellowish red (5YR 5/8) sand; tailings.

76-152 cm; yellowish red (5YR 5/8) sand; tailings.

5B

0-20 cm; strong brown (7.5YR 5/8) sandy loam; remixed tailings and slimes.

20-76 cm; yellowish red (5YR 5/8) sandy clay loam; remixed tailings and slimes with decaying plant matter.

76-152 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes.

5C

0-76 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes with decaying plant matter.

76-152 cm; yellowish red (5YR 5/8) sand; remixed tailings and slimes with decaying plant matter.

5D

0-30 cm; yellowish red (5YR 5/8) sandy clay loam; remixed tailings and slimes.

30-122 cm; yellowish red (5YR 5/8) loamy sand; remixed tailings and slimes.

122-152 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes with decaying plant matter.

6A

0-36 cm; pink (7.5YR 7/4) sand; tailings.

36-152 cm; yellowish red (5YR 5/8) sand; tailings.

6B

0-30 cm; very pale brown (10YR 8/4) sand; tailings.

30-91 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes.

91-152 cm; yellowish red (5YR 5/8) sandy clay loam; remixed tailings and slimes.

6C

0-76 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes..

76-152 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes.

6D

0-91 cm; yellowish red (5YR 5/8) sandy loam; tailings.

91-117 cm; yellowish red (5YR 5/8) loamy sand; remixed tailings and slimes with decaying plant matter.

117-152 cm; yellowish red (5YR 5/8) clay; slimes with decaying plant matter.

7A

0-36 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes.

36-61 cm; reddish yellow (7.5YR 6/8) loamy sand; tailings.

61-152 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes.

7B

0-76 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes..

76-152 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes.

7C

0-76 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes..

76-152 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes.

7D

0-76 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes..

76-152 cm; yellowish red (5YR 5/8) sandy loam; remixed tailings and slimes.

APPENDIX VII

Chemical and Physical Data for Soil Samples Taken from Pit Areas Prior to Mining

Plant available nutrients and pH for samples from premine auger borings refer to Fig. 9 for sampling location.

Sample	Horizon	Depth (in)	Ca	Mg	P	K	Mn	Zn	Fe	Al	Cu	B	pH
			ppm in soil										
VT1A	Ap	0-10	44.06	6.18	3.70	12.29	2.30	0.19	4.23	21.51	0.05	0.02	5.10
VT1A	Bt1	10-30	107.10	21.09	0.11	18.70	.293	0.09	2.11	21.23	0.05	0.03	6.20
VT1A	Bt2	30-60	116.50	20.19	0.01	4.63	.003	0.06	1.87	20.24	0.04	0.02	6.20
VT1A	Bt3	60-78	104.20	8.89	LDL*	2.48	LDL	0.07	1.64	15.38	0.03	0.01	4.80
VT1A	Bt4	78-102	27.18	3.98	LDL	2.17	LDL	0.07	2.50	36.45	0.03	0.02	4.40
VT1A	BC	102-120	21.01	5.17	LDL	2.38	LDL	0.08	2.14	31.62	0.02	0.02	4.30
VT1B	Ap	0-8	74.63	9.41	0.85	22.87	1.93	0.11	3.19	22.08	0.05	0.03	5.20
VT1B	Bt1	8-23	121.30	31.74	LDL	9.64	.041	0.07	2.35	23.99	0.06	0.04	6.30
VT1B	Bt2	23-52	88.94	17.08	LDL	3.16	.013	0.07	1.83	17.98	0.04	0.01	5.20
VT1B	Bt3	52-75	42.63	18.61	LDL	3.39	.016	0.11	1.89	25.88	0.04	0.02	4.50
VT1B	BC	75-90	15.20	7.29	LDL	4.04	LDL	0.09	2.26	32.48	0.03	0.01	4.30
VT1B	C1	90-108	13.45	6.56	LDL	2.84	LDL	0.09	2.32	27.12	0.01	0.01	4.30
VT1B	C2	108-120	11.52	5.06	0.05	1.96	LDL	0.12	2.40	17.43	0.02	0.00	4.40
VT1C	Ap	0-6	103.70	13.94	0.42	26.81	1.26	0.13	2.06	21.90	0.06	0.04	5.30
VT1C	Bt1	6-20	109.60	31.76	LDL	10.47	LDL	0.11	1.98	22.11	0.04	0.03	6.40
VT1C	Bt2	20-42	73.10	20.83	LDL	6.50	LDL	0.12	1.81	16.65	0.03	0.01	4.90
VT1C	Bt3	42-68	33.00	9.88	LDL	2.92	LDL	0.13	2.25	26.71	0.02	0.02	4.40
VT1C	BC	68-91	20.10	7.54	LDL	3.03	.409	0.12	2.25	28.14	0.03	0.01	4.40
VT1C	C	91-120	9.08	3.21	0.14	1.20	LDL	0.12	2.37	8.34	0.01	0.00	4.50

* LDL: lower than detection limit.

Sample	Horizon	Depth	Ca	Mg	P	K	Mn	Zn	Fe	Al	Cu	B	pH
		(in)	ppm in soil										
VT3A	Bt1	7-27	107.50	25.36	LDL*	22.49	0.11	0.08	1.97	22.29	0.04	0.03	6.20
VT3A	Bt2	27-58	80.78	18.13	LDL	9.22	0.00	0.07	1.63	16.45	0.03	0.01	5.40
VT3A	Bt3	58-82	78.52	12.16	LDL	2.70	0.00	0.06	1.63	15.59	0.03	0.01	4.70
VT3A	Bt4	82-111	32.20	8.74	LDL	2.79	0.01	0.06	2.21	31.23	0.03	0.02	4.40
VT3A	BC	111-120	21.07	9.80	LDL	3.12	0.02	0.07	1.94	27.80	0.03	0.02	4.40
VT3B	Ap	0-4	66.98	10.05	0.73	23.97	1.78	0.12	2.51	21.72	0.04	0.02	5.10
VT3B	Bt1	4-15	127.20	26.35	LDL	9.05	0.13	0.09	2.10	22.97	0.05	0.03	6.30
VT3B	Bt2	15-38	87.76	24.16	LDL	3.67	LDL	0.08	1.86	18.91	0.04	0.01	5.30
VT3B	Bt3	38-60	81.05	12.06	LDL	2.52	LDL	0.08	1.65	14.99	0.03	0.01	4.80
VT3B	Bt4	60-80	33.95	8.31	LDL	2.06	LDL	0.04	2.11	27.45	0.03	0.03	4.30
VT3B	BC	80-93	15.91	7.45	LDL	2.11	LDL	0.05	2.20	32.81	0.03	0.02	4.40
VT3B	CB	93-108	9.17	8.36	LDL	1.74	LDL	0.04	2.06	26.46	0.02	0.03	4.30
VT3B	C	108-120	7.20	5.47	0.11	1.00	LDL	0.05	1.88	15.77	0.02	0.01	4.30
VT3C	Ap	0-4	83.39	13.58	0.41	20.87	0.99	0.11	2.07	20.40	0.05	0.04	5.30
VT3C	Bt1	4-24	79.31	23.80	LDL	5.75	LDL	0.05	1.85	19.46	0.03	0.02	5.10
VT3C	Bt2	24-48	73.59	17.78	LDL	2.82	LDL	0.05	1.77	19.26	0.03	0.02	4.80
VT3C	Bt3	48-60	25.40	6.41	LDL	2.41	LDL	0.06	2.50	35.15	0.03	0.02	4.40
VT3C	BC	60-77	14.93	4.64	LDL	2.10	LDL	0.08	2.36	31.77	0.03	0.02	4.40
VT3C	C1	77-88	13.04	5.03	0.03	1.94	LDL	0.06	2.10	26.83	0.02	0.02	4.40
VT3C	C2	88-120	7.49	2.40	0.10	0.51	LDL	0.06	1.66	9.24	0.01	0.01	4.40

Particle size data for samples taken from auger borings of pit areas prior to mining

Series	VT1A	VT1A	VT1A	VT1A	VT1A	VT1B	VT1B	VT1B	VT1B	VT1B	VT1B	VT1B	VT1C
Horizon	Bt1	Bt2	Bt3	Bt4	BC	Ap	Bt1	Bt2	Bt3	BC	C1	C2	Ap
%VCS	0.5	0.6	0.5	1.3	1.6	0.5	0.5	0.6	0.9	0.8	2.0	0.8	0.4
%CS	5.3	5.1	6.0	6.6	5.9	4.4	4.0	5.7	4.9	5.0	7.5	4.9	4.3
%MS	17.0	16.4	15.6	17.3	17.1	15.3	15.4	15.6	16.6	17.8	19.4	19.7	15.8
%FS	32.9	33.5	28.7	35.1	40.1	44.0	32.3	33.2	34.5	38.5	41.5	52.7	38.6
%VFS	6.2	5.8	10.6	5.5	6.6	7.7	6.1	5.9	6.3	5.9	6.8	7.9	6.6
Total % Sand	61.9	61.4	61.4	65.8	71.3	71.9	58.3	61.0	63.2	68.0	77.2	86.0	65.7
%CSI	2.5	4.9	5.3	6.7	0.1	4.8	5.9	5.3	1.4	4.5	3.9	3.6	0.1
%MSI	5.7	5.2	3.2	4.8	0.0	6.6	5.1	1.3	4.9	2.4	2.2	1.2	8.3
%FSI	6.8	1.8	1.5	0.8	1.1	3.3	4.5	1.8	1.4	1.7	0.0	0.6	1.9
Total % Silt	15.0	11.9	10.0	12.3	1.2	14.7	15.5	8.4	7.7	8.6	6.1	5.4	10.3
Total % Clay	23.1	26.7	28.6	21.9	27.5	13.4	26.2	30.6	29.1	23.4	16.7	8.6	24.0
Textural Class	SCL	SCL	SCL	SCL	SCL	SL	SCL	SCL	SCL	SCL	SL	LS	SCL

Series	VT1C	VT1C	VT1C	VT1C	VT1C	VT2A	VT2A	VT2A	VT2A	VT2A	VT2A	VT2B	VT2B
Horizon	Bt1	Bt2	Bt3	BC	C	Ap	Bt1	Bt2	Bt3	Bt4	BC	Ap	Bt1
%VCS	0.6	0.5	0.6	1.4	1.0	0.3	0.7	0.5	1.0	1.3	1.6	1.1	0.8
%CS	4.0	4.7	722.4	5.8	4.3	6.2	5.9	4.8	5.6	5.5	5.3	4.9	4.8
%MS	14.3	15.6	-700.1	19.6	27.0	19.4	17.0	14.7	15.0	15.8	16.6	17.6	15.4
%FS	32.7	31.9	38.7	41.5	53.3	43.9	33.0	35.1	31.3	32.7	40.5	40.0	32.4
%VFS	5.6	5.6	0.0	6.8	7.7	10.4	5.5	6.4	5.6	5.7	6.8	7.6	5.6
Total % Sand	57.2	58.3	61.6	75.1	93.3	80.2	62.1	61.5	58.5	61.0	70.8	71.2	59.0
%CSI	2.9	3.0	9.7	3.9	6.1	6.9	5.5	3.9	3.6	3.5	4.1	5.7	2.8
%MSI	3.0	2.9	2.2	1.9	0.0	7.2	6.1	4.6	3.0	1.1	2.1	5.9	4.6
%FSI	1.8	0.9	0.1	0.8	0.6	1.2	4.3	2.4	1.3	2.0	0.9	3.2	2.4
Total % Silt	7.7	6.8	12.0	6.6	6.7	15.3	15.9	10.9	7.9	6.6	7.1	14.8	9.8
Total % Clay	35.1	34.9	26.4	18.3	0.0	4.5	22.0	27.6	33.6	32.4	22.1	14.0	31.2
Textural Class	SCL	SCL	SCL	SL	S	LS	SCL	SCL	SCL	SCL	SCL	SL	SCL

Series	VT2B	VT2B	VT2B	VT2B	VT2C	VT2C	VT2C	VT2C	VT2C	VT2C	VT2C	VT2C	VT3A	VT3A
Horizon	Bt2	Bt3	BC	C	Ap	Bt1	Bt2	Bt3	Bt4	BC	C	Ap	Bt1	
%VCS	0.5	0.9	0.7	1.1	0.7	1.0	0.5	0.3	1.6	1.0	0.7	1.1	0.9	
%CS	4.2	4.4	4.6	6.4	3.5	5.0	3.7	4.1	5.0	4.7	3.4	6.4	5.5	
%MS	13.7	14.7	16.9	20.4	16.2	16.2	13.1	15.0	17.9	19.2	22.4	19.7	16.0	
%FS	35.3	36.4	41.1	44.4	41.3	31.2	31.9	36.3	46.5	46.6	52.6	45.3	29.5	
%VFS	6.1	6.3	6.7	6.7	6.8	5.2	5.3	5.9	6.7	6.4	9.3	7.9	5.6	
Total % Sand	59.8	62.7	70.0	79.0	68.5	58.6	54.5	61.6	77.7	77.9	88.4	80.4	57.5	
%CSI	4.5	3.4	2.8	4.9	3.4	7.5	5.5	4.3	5.7	4.3	5.0	4.5	6.9	
%MSI	2.0	2.4	3.5	1.1	6.7	2.6	1.4	2.0	1.7	2.3	1.3	7.3	0.0	
%FSI	1.5	1.2	1.1	0.2	1.4	0.8	0.7	0.0	0.6	0.0	0.0	1.4	4.7	
Total % Silt	8.0	7.0	7.4	6.2	11.5	10.9	7.6	6.3	8.0	6.6	6.3	13.2	11.6	
Total % Clay	32.2	30.3	22.6	14.8	20.0	30.5	37.9	32.1	14.3	15.5	5.3	6.4	30.9	
Textural Class	SCL	SCL	SCL	SL	SCL/SL	SCL	C/SC	SCL	SL	SL	LS	LS	SCL	

Series	VT3A	VT3A	VT3A	VT3A	VT3B	VT3B	VT3B	VT3B	VT3B	VT3B	VT3B	VT3B	VT3B	VT3C
Horizon	Bt2	Bt3	Bt4	BC	Ap	Bt1	Bt2	Bt3	Bt4	BC	CB	C	Ap	
%VCS	1.2	0.9	1.0	1.6	0.6	0.8	0.5	1.1	0.6	1.2	1.6	1.1	0.7	
%CS	6.1	5.9	6.4	6.5	4.3	6.1	5.3	5.3	4.8	6.1	5.2	5.0	4.4	
%MS	17.6	15.4	16.2	16.6	16.8	16.4	15.5	15.3	15.5	17.3	18.2	20.7	14.3	
%FS	33.4	32.0	34.0	40.3	44.3	29.4	34.0	34.1	37.9	39.9	46.4	53.1	43.1	
%VFS	5.8	6.1	5.8	6.7	8.1	5.3	6.0	5.9	6.6	6.8	7.3	8.1	7.1	
Total % Sand	64.1	60.3	63.4	71.7	74.1	58.0	61.3	61.7	65.4	71.3	78.7	88.0	69.6	
%CSI	2.8	3.4	5.4	2.1	4.8	3.9	3.8	0.5	3.6	2.6	2.5	3.4	0.0	
%MSI	4.9	1.8	0.0	3.2	3.7	4.0	0.9	4.0	2.7	2.3	0.7	0.0	5.5	
%FSI	2.6	3.0	0.6	0.6	2.5	1.5	2.6	1.4	0.6	1.2	0.2	0.0	2.1	
Total % Silt	10.3	8.2	6.0	5.9	11.0	9.4	7.3	5.9	6.9	6.1	3.4	3.4	7.6	
Total % Clay	25.6	31.5	30.6	22.4	14.9	32.6	31.4	32.4	27.7	22.6	17.9	8.6	22.8	
Textural Class	SCL	SCL	SCL	SCL	SL	SCL	SCL	SCL	SCL	SCL	SL	LS	SCL	

Series	VT3	VT3C	VT3C	VT 3C	VT 3C	VT 3C
Horizon	Bt1	Bt2	Bt3	BC	C1	C2
%VCS	0.8	0.6	1.2	2.7	2.1	0.6
%CS	5.0	4.7	5.1	6.8	7.1	4.4
%MS	14.2	13.9	18.4	17.9	21.0	26.1
%FS	30.1	32.3	37.9	40.8	42.4	51.6
%VFS	5.0	5.3	6.4	6.4	6.2	8.2
Total % Sand	55.1	56.8	69.0	74.6	78.8	90.9
%CSI	0.0	0.3	0.3	2.8	2.8	4.0
%MSI	4.2	2.8	3.7	2.3	2.4	0.0
%FSI	1.0	1.4	1.2	0.1	0.0	0.0
Total % Silt	5.2	4.5	5.2	5.2	5.2	4.0
Total % Clay	39.7	38.7	25.8	20.2	16.0	5.1
Textural Class	C/SC	C/SC	SCL	SCL/SL	SL	S

Exchangeable cations and CEC data for samples taken from the walls of Pit 1

Sampling Location	Horizon	Depth (in)	pH	Ca	Mg	K	H	Al	Bases	ECEC	CEC	BS
				Exchangeable								
East Wall	Ap	0-12	5.60	0.57	0.05	0.18	5.40	0.60	0.80	1.40	6.20	12.90
	Bt1	12-30	6.10	2.96	0.69	0.30	3.40	0.20	3.95	4.15	7.35	53.74
	Bt2	30-66	5.20	2.48	0.32	0.05	5.60	0.90	2.85	3.75	8.45	33.73
	Bt3	66-92	4.80	0.36	0.25	0.04	8.00	2.00	0.65	2.65	8.65	7.51
	Bt4	92-120	4.80	0.06	0.39	0.05	6.40	1.90	0.50	2.40	6.90	7.25
	C	120-146	5.60	0.02	0.12	0.02	4.80	1.10	0.16	1.26	4.96	3.23
	Cv	146-162	4.90	0.04	0.06	0.02	4.00	0.80	0.12	0.92	4.12	2.91
West Wall	Ap	0-12	5.20	0.49	0.07	0.18	2.80	1.60	0.74	2.34	3.54	20.90
	Bt1	12-35	5.90	2.88	0.64	0.37	3.80	0.20	3.89	4.09	7.69	50.59
	Bt2	35-66	5.10	1.70	0.31	0.22	6.40	0.90	2.23	3.13	8.63	25.84
	Bt3	66-84	5.10	2.27	0.21	0.33	8.00	0.90	2.81	3.71	10.81	25.99
	Bt4	84-120	4.70	0.43	0.20	0.09	5.80	1.60	0.72	2.32	6.52	11.04
	CB	120-138	4.50	0.31	0.20	0.03	5.60	1.80	0.54	2.34	6.14	8.79
	Cv	138-159	4.70	0.07	0.20	0.02	3.00	0.80	0.29	1.09	3.29	8.81

Particle size data for samples taken from the walls of Pit 1

location	E. WALL	E. WALL	E. WALL	E. WALL	E. WALL	E. WALL	E. WALL
Horizon	Ap	Bt 1	Bt 2	Bt 3	Bt4	C	Cv
Depth	0-12	12-30	30-66	66-92	92-120	120-146	146-162
%VCS	0.8	0.3	0.9	1.2	0.9	1.6	1.0
%CS	8.0	5.5	7.3	5.9	6.8	5.8	4.6
%MS	20.4	18.0	18.1	15.6	16.9	22.0	21.4
%FS	42.7	31.3	29.3	30.5	35.3	45.6	54.5
%VFS	7.2	5.3	8.5	4.8	5.5	6.1	7.2
Total % Sand	79.1	60.4	64.1	58.0	65.4	81.1	88.7
%CSI	4.2	2.6	1.6	2.1	2.8	1.8	3.7
%MSI	8.1	0.1	3.1	0.9	3.2	0.0	1.6
%FSI	1.6	8.1	1.9	2.4	0.0	4.1	0.1
Total % Silt	13.9	10.8	6.6	5.4	6.0	5.9	5.4
Total % Clay	7.0	28.8	29.3	36.6	28.6	13.0	5.9
Textural Class	LS	SCL	SCL	C/SC	SCL	SL	LS/S

location	W. WALL	W. WALL	W. WALL	W. WALL	W. WALL	W. WALL	W. WALL
Horizon	Ap	Bt1	Bt2	Bt3	Bt4	CB	Cv
Depth	0-12	12-35	35-66	66-84	84-120	120-138	138-159
%VCS	0.6	0.9	1.0	1.0	1.0	2.2	2.0
%CS	7.4	6.6	5.4	5.6	6.1	7.7	5.5
%MS	21.7	16.0	15.6	16.5	17.2	17.9	19.6
%FS	46.0	28.8	37.2	34.0	35.5	38.7	44.1
%VFS	5.8	5.7	6.3	5.4	5.9	5.8	6.8
Total % Sand	81.5	58.0	65.5	62.5	65.7	72.3	78.0
%CSI	5.1	3.4	3.2	2.0	2.8	2.2	7.6
%MSI	7.9	5.7	4.7	3.8	1.8	1.5	2.0
%FSI	2.6	3.7	2.5	0.3	2.6	1.2	1.2
Total % Silt	15.6	12.8	10.4	6.1	7.2	4.9	10.8
Total % Clay	2.9	29.2	24.1	31.4	27.1	22.8	11.2
Textural Class	LS	SCL	SCL	SCL	SCL	SCL	SL

APPENDIX VIII

Chemical Data for Soil Samples Taken After Wheat Harvest

Plant available nutrients for surface soil samples taken after wheat harvest (June, 1996)

SAMPLE ID	Ca	Mg	P	K	Mn	Zn	Fe	Al	Cu	B	pH	TOT C
	ppm in soil											
CONT2	71.32	10.45	19.89	12.85	2.17	0.28	3.72	33.54	0.03	0.02	6.0	0.39
CONT4	89.20	11.89	20.49	14.22	1.84	0.26	3.92	31.32	0.01	0.02	6.3	0.42
CONT5	68.90	10.25	9.66	13.24	1.43	0.20	3.23	23.47	0.01	0.03	6.3	0.43
CONT6	67.83	10.87	6.43	14.94	1.42	9.30	3.05	23.18	0.01	0.03	6.5	0.49
CONT7	61.23	10.36	12.74	13.09	1.57	0.36	3.02	29.95	0.02	0.02	6.1	0.40
CONT10	73.72	12.02	6.45	17.53	1.68	0.25	2.87	24.25	0.01	0.03	6.3	0.55
CONT13	62.86	11.84	9.16	12.63	1.62	0.21	3.51	27.03	0.02	0.02	6.2	0.50
CONT14	86.16	13.97	7.37	16.89	1.87	0.19	2.92	22.97	0.01	0.04	6.5	0.57
CONT16	78.73	13.46	5.59	21.90	1.71	0.17	3.62	23.04	0.01	0.04	6.3	0.58
CONT17	62.45	10.98	3.58	18.74	1.33	0.14	2.90	21.51	0.01	0.03	6.1	0.55
PT1TS1	82.81	23.49	4.46	19.24	1.51	0.13	4.22	25.54	0.03	0.03	6.4	0.41
PT1TS3	72.54	18.25	4.11	22.94	1.44	0.13	4.80	26.72	0.04	0.03	6.2	0.43
PT1TS4	69.89	17.20	4.85	23.41	1.44	0.14	5.31	26.42	0.04	0.02	6.2	0.42
PT1TS7	70.03	17.88	3.93	19.45	1.31	0.13	4.46	24.74	0.03	0.02	6.2	0.40
PT1TS10	68.79	19.37	3.57	16.15	1.32	0.13	3.96	23.87	0.01	0.03	6.5	0.37
PT1TS12	72.48	19.84	4.76	21.92	1.41	0.13	4.67	24.81	0.02	0.03	6.4	0.40
PT1CP1	134.10	24.67	5.41	23.32	2.42	0.32	4.98	27.55	0.01	0.08	5.9	0.66
PT1CP6	142.80	24.36	7.88	30.22	2.36	0.35	6.04	29.32	0.01	0.09	6.0	0.81
PT1CP7	128.20	22.46	6.44	27.19	2.21	0.31	4.85	28.30	0.01	0.07	5.9	0.67
PT1CP9	137.40	24.41	9.37	29.72	2.15	0.31	4.85	31.16	0.01	0.09	6.1	0.74
PT1CP10	144.20	25.74	9.04	32.51	2.25	0.33	5.01	31.96	0.01	0.10	6.0	0.78
PT1CP12	136.20	25.68	6.75	28.13	2.01	0.28	4.63	29.93	LDL*	0.09	6.0	0.69
PT3TS1	101.20	25.34	2.62	25.52	1.73	0.15	5.20	21.77	LDL	0.04	6.9	0.61
PT3TS2	101.80	28.62	1.53	23.95	1.34	0.12	3.50	20.85	LDL	0.04	6.8	0.82
PT3TS3	120.30	33.20	4.37	26.27	1.79	0.14	4.05	25.61	LDL	0.05	6.9	0.80
PT3TS5	109.60	27.22	3.01	22.86	3.60	0.18	3.51	25.12	0.01	0.05	6.9	0.61
PT3TS9	120.50	30.58	3.23	29.98	1.70	0.15	3.73	25.07	0.01	0.05	6.8	0.68
PT3TS12	115.90	30.54	4.32	25.49	1.86	0.15	5.05	25.42	0.02	0.05	6.8	0.72
PT3CP2	108.80	18.80	9.93	23.93	1.41	0.29	5.57	20.47	0.03	0.07	6.0	0.50
PT3CP3	123.60	19.53	13.65	22.50	1.83	0.38	8.13	21.60	0.04	0.07	6.2	0.58
PT3CP5	107.40	18.52	11.05	20.76	1.37	0.30	5.53	23.21	0.03	0.05	5.8	0.59
PT3CP8	82.55	12.31	12.61	14.49	1.10	0.29	5.35	15.07	0.03	0.04	6.2	0.40
PT3CP10	123.40	21.02	12.40	26.17	1.57	0.30	6.05	22.78	0.05	0.07	6.2	0.49
PT3CP12	122.30	19.69	11.49	23.18	1.46	0.34	6.00	23.89	0.12	0.08	5.8	0.58

* LDL: Lower than detection limit. CONT: Control, PT1TS: Pit 1 topsoil, PT1CP: Pit 1 compost
PT3TS: Pit 3 topsoil, PT3CP: Pit 3 compost.

APPENDIX IX

Physical and Chemical Properties of Soil Samples Taken After Soybean Harvest

Chemical and physical data for soil samples taken from soil pits dug after soybean harvest (November, 1996)

Pit #	Horizon	Depth (cm)	% Sand	% Silt	% Clay	% carbon	Bulk den.	Adj Bd	pH	BASES	ECEC	CEC	BS	Ca	Mg	K	H	Al	Exchangeable	
Control I	Ap	0-19	84.9	13.5	1.6	0.48	1.93	1.76	5.90	1.27	1.37	4.07	31.22	1.00	0.26	0.01	2.80	0.10		
Control I	E	19-27	73.8	17.3	8.9	0.191		ns	5.08	0.74	1.24	2.74	27.01	0.40	0.13	0.21	2.00	0.50		
Control I	Bt1	27-59	60.6	15.3	24.1	0.287	1.80	1.59	4.80	2.36	2.86	3.36	70.24	1.60	0.38	0.38	1.00	0.50		
Control I	Bt2	59-89	55.9	9.0	35.1	0.21	1.84	1.62	4.72	4.04	4.44	10.64	37.97	2.50	1.22	0.32	6.60	0.04		
Control I	Bt3	89-150	63.0	7.9	29.1	0.138	1.84	1.62	4.86	2.72	3.22	5.92	45.95	1.80	0.63	0.29	3.20	0.50		
Control II	Ap	0-21	84.8	13.7	1.5	0.358	1.93	1.76	5.58	1.03	1.13	2.43	42.39	0.80	0.14	0.09	1.40	0.10		
Control II	Bt1	27-84	59.8	12.9	27.3	0.252	1.73	1.53	5.54	3.21	3.36	6.01	53.41	2.10	0.70	0.41	2.80	0.15		
Control II	Bt2	84-150	63.8	9.8	26.4	0.116	1.86	1.64	5.14	2.73	3.23	7.93	34.43	1.70	0.88	0.15	5.20	0.50		
Control III	Ap	0-17	80.9	14.4	4.7	0.431	1.90	1.73	5.74	1.31	1.41	2.51	52.19	0.90	0.28	0.13	1.20	0.10		
Control III	Bt1	17-82	54.3	10.5	35.2	0.263	1.68	1.48	5.88	4.58	4.68	9.58	47.81	3.00	1.35	0.23	5.00	0.01		
Control III	Bt2	82-150	61.1	8.8	30.1	0.0114	1.75	1.54	5.85	2.52	3.22	9.32	27.04	2.00	0.47	0.05	6.80	0.70		
Control IV	Ap	0-21	78.2	14.0	7.8	0.692	1.88	1.71	5.65	1.93	2.08	8.53	22.63	1.20	0.49	0.24	6.60	0.15		
Control IV	Bt1	21-62	56.0	8.8	35.2	0.173	1.68	1.48	5.78	6.29	6.44	12.69	49.57	4.20	1.84	0.25	6.40	0.15		
Control IV	Bt2	62-100	54.4	7.7	37.9	0.129	1.63	1.44	5.41	4.40	4.85	11.20	39.29	3.30	1.03	0.07	6.80	0.45		
Control IV	Btv	100-150	55.3	8.5	36.2	0.118	1.57	1.39	4.51	0.69	3.69	7.29	9.47	0.30	0.32	0.07	6.60	3.00		
Control V	Ap	0-19	83.1	14.5	2.4	0.64	1.84	1.68	5.30	2.04	2.09	2.04	100.00	1.40	0.49	0.15	0.00	0.05		
Control V	Bt1	19-93	57.3	9.8	32.9	0.173	1.62	1.43	5.54	4.56	4.61	6.16	74.03	2.90	1.54	0.12	1.60	0.05		
Control V	Bt2	93-162	53.2	5.6	41.2	0.131	1.56	1.41	4.85	4.62	6.02	7.02	65.81	4.00	0.53	0.09	2.40	0.14		
Control V	Btv	162-187	60.5	4.9	34.6	0.124	1.62	1.43	4.63	0.48	3.28	8.68	5.53	0.20	0.23	0.05	8.20	2.80		
Control VI	Ap	0-21	83.5	15.3	1.2	0.567	2.03	1.85	5.37	1.74	1.79	1.94	89.69	1.20	0.41	0.13	0.20	0.05		
Control VI	Bt1	21-69	55.2	10.4	34.4	0.259	1.57	1.38	5.48	4.29	4.39	7.69	55.79	2.40	1.42	0.47	3.40	0.10		
Control VI	Bt2	69-99	61.6	7.5	30.9	0.127	1.70	1.50	5.20	2.85	3.10	6.45	44.19	1.60	0.98	0.27	3.60	0.25		
Control VI	Bt3	99-124	52.3	3.4	44.3	0.152	1.60	1.41	5.37	3.82	4.37	7.82	48.85	3.00	0.51	0.31	4.00	0.55		
Control VI	Bt4	124-150	51.4	8.3	40.3	0.15	1.56	1.38	4.73	3.46	4.76	10.06	34.39	2.90	0.49	0.07	6.60	1.30		

Pit #	Horizon	Depth (cm)	% Sand	% Silt	% Clay	% carbon	Bulk den.	Adj Bd	pH	BASES	ECEC	CEC	BS	Ca	Mg	K	H	Al
1TS I	Ap	0-36	80.1	10.9	9.0	0.365	1.99	1.82	4.99	0.97	1.27	5.17	18.76	0.60	0.18	0.19	4.20	0.30
1TS I	C	36-120	75.1	10.7	14.2	0.217	2.06	1.82	4.74	1.15	1.75	2.55	45.10	0.70	0.31	0.14	1.40	0.60
1TS II	Ap	0-43	80.0	10.3	9.7	0.393	1.98	1.81	5.34	1.46	1.71	5.06	28.85	0.90	0.29	0.27	3.60	0.25
1TS II	C	43-137	66.7	8.2	25.1	0.187	1.23	1.62	4.91	1.86	2.46	9.66	19.25	1.20	0.53	0.13	7.80	0.60
1TS III	Ap	0-41	80.3	8.0	11.7	0.458	1.92	1.75	4.96	1.64	1.94	4.24	38.68	1.00	0.31	0.33	2.60	0.3
1TS III	C1	41-149	66.3	9.3	24.4	0.205	1.80	1.59	5.31	1.64	2.34	5.44	30.15	1.00	0.50	0.14	3.80	0.70
1TS III	C2	149-189	19.2	14.3	66.5	0.266	0.92	0.92	4.64	3.07	5.27	13.07	23.49	1.90	0.92	0.25	10.00	2.20
1TS III	C3	189-200	92.7	3.6	3.7	0.061	1.55	1.55	4.80	0.09	0.39	1.49	6.04	0.00	0.07	0.02	1.40	0.30
1CP I	Ap	0-6	72.2	10.4	17.4	0.967	1.55	1.37	5.25	5.72	5.77	9.12	62.72	4.30	1.25	0.17	3.40	0.05
1CP I	C1	6-52	70.10	9.6	20.3	0.179	1.79	1.58	4.70	1.66	2.46	4.46	37.22	1.00	0.52	0.14	2.80	0.80
1CP I	C2	52-130	73.70	9.1	17.2	0.107	1.84	1.63	4.54	0.55	1.95	1.75	31.43	0.20	0.27	0.08	1.20	1.40
1CP II	Ap	0-8	70.50	10.6	18.9	1.522	1.39	1.23	5.53	7.76	7.86	9.16	84.72	5.90	1.60	0.26	1.40	0.10
1CP II	C1	8-75	71.10	10.5	18.4	0.197	1.92	1.69	4.85	1.61	2.21	6.01	26.79	1	0.42	0.19	4.40	0.60
1CP II	C2	75-100	97.10	2.6	0.3	0.05	1.64	1.64	4.80	0.14	0.29	0.14	100.00	0.10	0.02	0.02	0.00	0.15
1CP III	Ap	0-8	71.30	11.1	17.6	1.734	1.40	1.24	5.65	8.86	9.01	14.06	63.02	6.70	1.75	0.41	5.20	0.15
1CP III	C1	8-26	72.80	6.7	20.5	0.194	1.88	1.66	4.66	1.68	2.13	4.28	39.25	1.00	0.46	0.22	2.60	0.45
1CP III	C2	25-139	94.5	3.8	1.7	0.055	1.73	1.73	4.50	0.16	0.36	0.56	28.57	0.10	0.04	0.02	0.40	0.20
3TS I	Ap1	0-16	76.9	14.9	8.2	0.806	1.86	1.69	5.85	3.01	3.06	8.61	34.96	1.80	0.94	0.27	5.60	0.05
3TS I	Ap2	16-53	82.8	8.5	8.7	0.372	ns		5.33	0.94	1.34	6.74	13.95	0.50	0.19	0.25	5.80	0.40
3TS I	C1	53-111	80.2	6.4	13.4	0.13	1.75	1.75	4.68	1.04	1.49	4.04	25.74	0.50	0.38	0.16	3.00	0.45
3TS I	C2	111-164	35.8	16.3	47.9	0.29	1.11	1.11	4.44	3.07	3.97	11.07	27.73	1.70	1.09	0.28	8.00	0.90
3TS I	C3	164-190	98.5	1.4	0.1	0.051	ns	ns	4.73	0.14	0.29	0.34	41.18	0.10	0.02	0.02	0.20	0.15

Pit #	Horizon	Depth (cm)	% Sand	% Silt	% Clay	% carbon	Bulk den.	Adj Bd	pH	BASES	ECEC	CEC	BS	Exchangeable				
														Ca	Mg	K	H	Al
3TS II	Ap1	0-21	74.6	13.6	11.8	0.862	1.78	1.63	5.66	3.72	3.82	7.12	52.25	2.30	1.16	0.26	3.40	0.10
3TS II	Ap2	21-64	83.0	9.6	7.4	0.381	ns		4.95	0.85	1.28	1.05	80.95	0.50	0.14	0.21	0.20	0.43
3TS II	C1	64-137	83.6	4.0	12.4	0.093	1.82	1.82	4.87	0.63	0.93	3.23	19.50	0.30	0.23	0.10	2.60	0.30
3TS II	C2	137-150	34.7	16.2	49.1	0.274	1.17	1.17	4.50	3.26	4.46	13.26	24.59	1.80	1.15	0.31	10.00	1.20
3TS II	C3	150-160	98.4	1.5	0.1	0.032	ns		4.86	0.15	0.20	0.15	100.00	0.10	0.02	0.03	0.00	0.05
3TS III	Ap	0-31	75.5	14.4	10.1	0.798	1.78	1.63	5.68	4.22	4.27	7.42	56.87	2.60	1.33	0.29	3.20	0.05
3TS III	C1	31-47	86.8	3.6	9.6	0.105	ns		5.12	0.83	1.08	7.63	10.88	0.40	0.24	0.19	0.80	0.25
3TS III	C2	47-63	19.5	20.3	60.2	0.378	1.28	1.28	4.36	4.10	5.70	16.70	24.55	2.40	1.40	0.30	12.60	1.60
3TS III	C3	63-89	82.8	6.3	10.9	0.091	ns		4.33	0.32	1.05	0.92	34.78	0.10	0.17	0.05	0.60	0.73
3TS III	C4	89-105	49.3	12.9	37.8	0.237	ns		4.36	2.10	3.45	7.30	28.77	1.20	0.71	0.19	5.20	1.35
3TS III	C5	105-134	91.4	2.9	5.7	0.051	1.79	1.79	4.53	0.13	0.53	0.13	100.00	0.00	0.10	0.03	0.00	0.40
3TS III	C6	134-150	33.4	19.4	47.2	0.255	ns		4.44	2.80	4.70	13.20	21.21	1.60	0.95	0.25	10.40	1.90
3CP I	Ap	0-6	78.0	7.5	15.5	1.127	1.49	1.49		4.09	4.12	5.89	69.44	3.10	0.84	0.15	1.80	0.03
3CP I	C1	6-67	82.4	5.9	11.7	0.106	1.73	1.73	4.58	0.68	1.08	5.08	13.39	0.30	0.26	0.12	4.40	0.40
3CP II	Ap	0-9	82.3	8.2	9.5	1.538	1.23	1.23	5.61	4.97	5.00	5.77	86.14	3.70	1.04	0.23	0.80	0.03
3CP II	Bw	9-26	80.7	6.4	12.9	0.127	1.88	1.88	4.72	0.89	1.39	0.89	100.00	0.40	0.32	0.17	0.00	0.50
3CP II	C1	26-60	81.0	6.2	12.8	0.114	1.81	1.81	4.59	0.70	1.05	4.10	17.07	0.30	0.31	0.09	3.40	0.35
3CP II	C3	64-125	92.0	3.4	4.6	0.04	1.92	1.92	4.50	0.31	0.61	0.71	43.66	0.20	0.08	0.03	0.40	0.30
3CP III	Ap	0-7	93.3	3.6	3.1	0.791	1.49	1.49	5.58	1.71	1.86	4.31	39.68	1.30	0.34	0.07	2.60	0.15
3CP III	C1	7-60	96.6	3.3	0.1	0.045	1.74	1.74	5.48	0.10	0.13	0.30	33.33	0.00	0.07	0.03	0.20	0.03

Plant available nutrients for soil samples taken from soil pits dug after soybean harvest (November, 1996). Refer to Figure 11 for the location of these pits.

Pit #	Ca	Mg	P	K	Mn	Zn	Fe	Al	Cu	B
ppm in soil										
Control I	254.40	37.80	33.52	30.22	4.33	0.80	19.05	94.24	0.29	0.09
Control I	154.44	24.60	7.39	62.28	2.01	0.52	6.91	86.40	0.24	0.07
Control I	284.96	42.76	0.60	83.36	2.12	0.36	5.72	78.64	0.27	0.10
Control I	334.28	87.12	0.13	0.03	0.03	0.22	6.09	79.20	0.13	0.09
Control I	297.16	60.68	LDL	57.56	LDL	0.20	5.58	73.20	0.12	0.09
Control II	327.96	30.74	91.00	30.30	3.67	0.83	17.26	115.76	0.16	0.06
Control II	336.16	61.48	1.61	77.12	0.42	0.37	5.71	74.44	0.21	0.13
Control II	271.76	75.36	0.00	29.25	0.00	0.20	5.25	70.60	0.12	0.05
Control III	259.76	40.24	11.10	35.86	3.49	0.56	10.08	75.84	0.25	0.10
Control III	420.00	106.80	0.40	36.47	0.10	0.23	6.23	78.44	0.13	0.13
Control III	326.88	48.20	0.14	10.17	LDL	0.14	5.29	73.04	0.08	0.06
Control IV	300.52	63.40	3.44	66.20	2.89	0.45	10.23	81.64	0.11	0.13
Control IV	441.20	117.80	LDL	29.90	LDL	0.15	6.18	71.92	0.13	0.08
Control IV	400.80	76.76	0.14	11.66	LDL	0.17	5.11	76.68	0.11	0.05
Control IV	105.88	34.36	LDL	13.12	LDL	0.17	7.08	193.12	0.07	0.12
Control V	335.64	63.28	6.96	41.04	4.26	0.67	9.65	73.48	0.13	0.13
Control V	391.44	116.48	0.07	18.40	2.23	0.25	5.37	69.20	0.08	0.09
Control V	404.40	38.83	0.16	9.32	LDL	0.19	4.97	82.64	0.09	0.06
Control V	86.52	27.26	LDL	8.40	LDL	0.19	6.74	187.28	0.12	0.12
Control VI	313.20	54.48	20.34	34.01	4.21	0.72	18.02	85.76	0.13	0.10
Control VI	349.68	114.92	0.51	91.92	0.12	0.20	5.83	72.92	0.13	0.12
Control VI	277.00	85.12	0.39	51.84	LDL	0.18	5.06	71.44	0.08	0.07
Control VI	393.92	46.60	LDL	52.12	LDL	0.15	4.48	69.48	0.06	0.05
Control VI	362.76	42.28	0.02	11.74	LDL	0.17	4.53	72.56	0.07	0.07
1TS I	199.08	30.65	4.92	60.16	6.43	0.44	29.02	80.96	0.24	0.09
1TS I	199.68	42.52	7.35	41.48	6.43	0.36	22.20	88.56	0.14	0.07
1TS II	201.96	34.43	6.65	64.60	5.00	0.53	32.92	85.56	0.38	0.09
1TS II	244.96	58.60	0.41	35.30	1.67	0.22	7.90	83.20	0.08	0.09
1TS III	233.36	40.20	5.07	81.60	3.48	0.41	21.84	84.32	0.30	0.13
1TS III	224.16	54.72	0.12	36.87	2.40	0.22	9.30	78.84	0.19	0.11
1TS III	278.64	71.52	LDL	37.74	2.47	0.22	10.84	164.60	0.19	0.17
1TS III	67.64	16.00	LDL	7.38	0.16	0.17	5.30	36.64	0.10	0.04

Pit #	Ca	Mg	P	K	Mn	Zn	Fe	Al	Cu	B
ppm in soil										
1CP I	767.60	116.04	26.57	37.66	11.18	0.34	22.15	95.52	0.27	0.22
1CP I	226.92	56.52	0.50	34.85	1.37	0.24	7.54	78.36	0.20	0.10
1CP I	118.76	39.57	LDL	25.04	0.97	0.25	7.37	85.00	0.19	0.05
1CP II	1109.20	152.80	44.76	57.56	15.58	2.59	23.58	116.16	0.36	0.33
1CP II	275.72	56.44	1.19	46.00	3.05	0.32	7.79	76.08	0.35	0.09
1CP II	44.56	9.39	0.24	6.31	0.06	0.26	6.16	18.80	0.08	0.04
1CP III	1104.40	148.16	61.16	86.28	13.17	2.78	22.35	117.32	0.28	0.32
1CP III	266.28	56.48	1.59	56.40	0.97	0.28	6.21	66.84	0.17	0.18
1CP III	58.48	12.99	0.00	11.96	0.09	0.13	4.24	25.52	0.05	0.06
3TS I	523.60	123.24	32.56	72.68	5.32	0.45	15.37	97.84	0.19	0.17
3TS I	190.40	32.30	4.58	64.80	6.80	0.43	26.07	86.72	0.28	0.10
3TS I	160.48	43.36	0.92	38.19	1.60	0.23	8.35	48.72	0.17	0.05
3TS I	312.52	93.04	LDL	52.72	5.15	0.35	57.12	107.24	0.40	0.15
3TS I	36.81	9.74	0.08	4.78	0.06	0.39	6.34	15.92	0.83	0.05
3TS II	544.00	133.88	9.03	58.00	5.12	0.51	8.85	86.92	0.22	0.16
3TS II	184.52	26.48	4.15	54.20	10.88	0.36	16.14	93.80	0.28	0.09
3TS II	159.76	38.06	1.41	35.84	4.62	0.21	0.77	44.32	0.16	0.10
3TS II	317.52	94.44	LDL	56.12	3.41	0.32	36.78	106.08	0.34	0.13
3TS II	32.15	8.07	0.58	3.79	LDL	0.10	12.84	25.13	0.08	0.02
3TS III	510.40	123.96	7.29	61.36	4.37	0.51	8.79	84.24	0.22	0.16
3TS III	187.56	42.16	4.64	54.24	0.68	0.23	11.30	48.16	0.18	0.06
3TS III	380.48	107.40	LDL	46.92	4.58	0.28	25.58	134.12	0.29	0.13
3TS III	105.36	29.45	0.03	12.87	0.55	0.19	6.32	67.16	0.20	0.04
3TS III	247.20	62.72	LDL	30.89	2.40	0.29	12.04	98.52	0.20	0.13
3TS III	76.84	18.92	0.08	8.12	0.34	0.31	4.79	39.42	0.15	0.04
3TS III	281.24	72.60	LDL	39.43	3.55	0.34	17.02	122.96	0.20	0.12
3CP I	691.60	87.76	34.16	42.44	9.37	1.68	22.64	83.16	0.27	0.11
3CP I	152.24	37.05	1.45	36.62	0.50	0.20	7.12	46.12	0.17	0.06
3CP II	899.60	110.16	45.84	70.04	11.80	2.62	27.42	88.92	0.27	0.20
3CP II	165.56	41.80	2.17	47.48	0.66	1.03	8.68	51.52	0.18	0.13
3CP II	148.40	43.40	0.97	28.91	0.77	0.26	10.78	53.04	0.15	0.09
3CP II	64.52	17.03	0.06	12.12	0.27	0.28	4.80	37.03	0.26	0.04
3CP III	368.44	44.16	34.63	19.67	6.38	1.27	22.73	49.12	0.21	0.05
3CP III	88.64	19.25	17.30	11.26	0.10	0.17	6.56	30.12	0.09	0.04

Vita

The author, Philip D. Schroeder, was born in Philadelphia Pennsylvania in 1963 to a Naval officer, Clyde Schroeder, and his wife, Louise Eichorn Schroder. Being a military brat, the author moved several times before the family settled in Virginia Beach in 1971. After graduating from Kempsville High School in 1981, he worked various jobs as an engineering technician, a Transmission shop manager, and a salesman. In the fall of 1990, the author decided to go back to school in hopes of finding some direction in his life. The decision to enroll at Virginia Tech was motivated by family tradition; both of his brothers are alumni. In 1994, the author received his Bachelor of Science degree in Crop and Soil Environmental Sciences, Suma Cum Laude. In the fall of 1994, the author continued his education by enrolling as a graduate student in the Crop and Soil Environmental Sciences department in pursuit of a Master of Science degree, under the direction of Dr. W. Lee Daniels.