SOIL PHYSICAL EFFECTS OF PNEUMATIC SUBSOIL LOOSENING USING A TERRALIFT SOIL AERATOR

by Kaj Rolf

Abstract. The effects of pneumatic subsoiling using a Terralift soil aerator on a number of soil physical parameters were measured at sites with sandy loam and loam over clay loam, respectively. The subsoil was compacted under controlled conditions prior to aeration. In the sandy loam, aeration led to a decreased bulk density, an increase in porosity (mainly as an increase in macro-porosity) and an increase in saturated hydraulic conductivity and air permeability. Penetration resistance was lowered at this site. After aeration at the loam soil site, measurements indicated that bulk density increased, porosity decreased, there were no changes in saturated hydraulic conductivity and only a small increase in air permeability.

Soil aeration is as important as water and nutrients for growth of most plants. A value for critical oxygen content in the soil is difficult to determine since this not only depends on soil structure and pore sizes but also on the demands of the roots. Factors determining these demands include genetic background, age of root tissue, radius of the root and diffusion coefficients within the root (11). These factors will cause variations in the oxygen demands depending on variations among species.

To meet the oxygen demand of the roots it is important to have a soil pore system that is continuous and free from excess water. The negative effects of too much water and anaerobic soil environments are well documented (8,9,10).

Air has been used as a tool for soil management around trees for at least 60 years (18). In the early sixties Yelenosky (20) reported experiments done with a portable air compressor apparatus. Compressed air under high pressure was forced into the soil through pre-drilled holes. He concluded that the compressed air method was promising as a tool for improving soil aeration in certain areas, especially those where severe soil compaction is not a recurring event.

The Terralift equipment (Figure 1) was introduced in Europe about ten years ago. The unit consists of a gasoline engine and an air compressor. The whole unit is operated by compressed air. A probe is air-hammered into the soil and compressed air is released through the probe with a pressure of up to 20 bars (290 psi). The air is assumed to fracture the soil. At the same time it is possible to inject dry fertilizer, lime or dry materials that stabilize the soil fractures. Experiments were conducted to test the ability of the Terralift equipment to loosen compacted subsoil.

Materials and Methods

In May, 1987, a controlled experiment was

Figure 1. The Terralift equipment at the university experimental fields.

established at two sites in Sweden, Alnarp with a sandy loam and Landskrona with a loam over a clay loam. The topsoil was removed to a depth of about 30 cm (1 ft) and the subsoil was compacted with a wheeled excavator which drove over the area 10 times when the soil was dry. The excavator had two axles and an axle load of 8 Mg (8.8 U.S. tons) and an inflation pressure of 500 kPa. After the compaction the topsoil was returned. The plots were 5 x 13 m. After 45 days one plot was treated with the aerator and the other saved as an untreated control. The injection probe was driven into the soil on 1 meter grid spacings and compressed air was discharged at two depths, 45 and 75 cm (Figure 2).

Cores of soil (7.2 cm (3 in) in diameter and 10 cm (4 in) long with 6-10 replicates from every depth) were collected to 60 cm depth six and 18 months after aeration to determine bulk density, porosity, pore size distribution, saturated hydraulic conductivity and air permeability.

Saturated hydraulic conductivity, K_S, was measured by saturating the soil cores and applying a constant-head. The apparatus used is described by Andersson (1).

The soil water-release characteristics were determined using standard methods (3,15) at water metric tensions of -1.5 kPa using a tension table and at -10 kPa and -60 kPa using a pressure plate apparatus. Total porosity was calculated from the particle and dry bulk densities. Air filled porosity was calculated as the difference between total porosity and the volumetric water content at the different tensions.

The air permeability coefficient, K_a, was measured on the soil cores as described by Andersson (2). The volume of air drawn through the soil sample at a known potential was measured for 2.0 minutes.

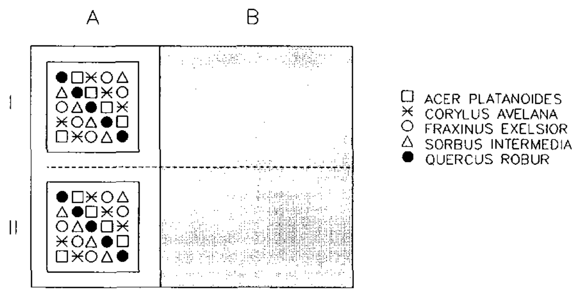

Figure 2. Field plan for Alnarp and Landskrona. I is control plot and II is aerated plot. A is tree planted area and B is area used for soil physical examinations.

Bulk densities were calculated after oven drying at 105°C.

Penetration resistance (cone pressure) was measured with an Electronic cone penetrometer constructed at the institute (14). Cone pressure is the instantaneous penetration force divided by the cone base area. Data were collected at every 1 cm level with 30 replicates for each plot. An average was calculated for each level.

T-tests (14) were used to determine statistical significance of all data. The confidence level of significance was set at 95%.

Results

Dry bulk density. When particle density and texture are the same in different plots, dry bulk density may be regarded as an indication of soil compactness. At Alnarp, bulk density was lower in the aerated plot than in the control plot (Table 1). The bulk density down the profile was more uniform in the aerated plot than in the control plot. The second year there was a small, but significant, recompaction in the aerated plot due to natural settlement. At the Landskrona site measurements indicated an increase in bulk density in the aerated plot. Since there is no known reason for aeration treatment to increase bulk density, these data are not presented. There was likely an inadequate number of samples taken.

Changes in soil volume and density are well known in the construction industry. The granular material is disturbed by excavation and the soil increases in volume, which is called the "swell" (4). The swell factor is the percentage increase in soil volume over the original volume. The changes in bulk density given as a swell factor are also shown in Table 1. They clearly indicate the swell at the sandy Alnarp site. At this site all swell values are lower at 18 months than they were at 6 months indicating a settlement of the soil.

Porosity and pore size distribution. Porosity is important for air transport in soil. It is an indicator of the soils potential for diffusion of oxygen from the atmosphere to the roots. The aerated plot had

Table 1. Mean bulk densities in Mg/m^3 (and the swell factor in %) at Alnarp 6 months and 18 months after treatment. n = 6-10.

	6 months		18 months	
Depth cm	Control	Aerated	Control	Aerated
20-30	1.49	1.38*(8.0)	1.51	1.43(5.6)
30-40	1.56	1.41*(10.6)	1.59	1.50*(6.0)
40-50	1.72	1.39*(23.7)	1.79	1.47*(21.8)
50-60	1.80	mv	mv	1.47

* = Statistically significant (P ≤ 0.05).
mv = missing values.

a significantly higher porosity than the control (Table 2) at the Alnarp site. Six months after aeration there was a 25% increase in the profile mean porosity. One year later it was still 17% greater than the control.

Macro-porosity, defined as pores larger than 0.03 mm, significantly increased at the Alnarp site (Table 2). Eighteen months after treatment macro-porosity was lower due to soil settlement. The *macro-pores so important for aeration and drainage* are the weakest and first to collapse when a soil is exposed to a load (19). The percentage of fine pores (<0.005 mm) was significantly smaller in the aerated plots while the percentage of medium sized pores (0.03-0.005 mm) changed very little.

The values in Table 2 for macro-porosity are equivalent to air filled porosity at a -1 meter water column often referred to as 'field capacity'. At Alnarp the air filled porosity in the aerated plot at field capacity was 20%or more.

Saturated hydraulic conductivity. Field saturated hydraulic conductivity is dependent on whether or not compacted layers with a small amount of macro-pores are present. The conductivity values for a soil profile can also be very dependent on the existence of one or two cracks. Due to large sample variation, median and maximum values are presented instead of means (5). The treated plot at the Alnarp site, had a higher saturated hydraulic conductivity than the control (Table 3). This applied to both depths and time after treatment. The maximum values for the aerated plots were usually higher than for the control at both sites indicating the presence of cracks which facilitate drainage.

Table 2. Porosity at Alnarp 6 months and 18 months after treatment. n = 6-10.

	6 months		18 months	
Depth cm	Control	Aerated	Control	Aerated
Total porosity				
20-30	43.1	47.3*	42.0	45.4*
30-40	40.3	46.0*	39.0	42.4*
40-50	34.5	46.6*	31.6	43.6*
50-60	31.3	mv	mv	44.4
Macro-porosity (pores >0.03mm, % by volume)				
20-30	18.4	23.7*	16.2	22.7*
30-40	15.1	24.1*	12.5	19.7*
40-50	6.8	24.8*	5.2	20.0*
50-60	8.3	mv	mv	22.1
Medium pores (pores 0.30-0.005 mm, % by volume)				
20-30	3.74	3.78	4.08	3.52*
30-40	3.54	3.88	4.75	3.95*
40-50	4.20	4.20	3.61	3.95*
50-60	3.84	mv	mv	3.25
Fine pores *(pores <0.005 mm,% by volume)*				
20-30	20.90	19.78*	21.80	19.17*
30-40	21.68	18.08*	21.78	18.74*
40-50	23.55	17.63	22.76	19.71*
50-60	19.08	mv	mv	19.00

* = Statistically significant (P ≤ 0.05).
mv = missing values.

Soil aeration. Soil air is the oxygen source for root respiration. It also receives the carbon dioxide produced by plants during root respiration and by microbes in the soil. Root respiration and soil microrganisms normally consume 5-24 g of oxygen for each square meter per day (17), which both requires an adequate quantity of macropores and a continuity in the pore system. The air permeability coefficient depends on airfilled porosity, pore radius and, indirectly, on soil texture, *soil structure, bulk density and soil water status.*

Air permeability coefficients (Table 4), K_a (cm/min), followed trends trends similar to that of air-filled porosity, with high values in the 20-30 cm layer, decreasing with the next two depths and

Table 3. Saturated hydraulic conductivity (Ks,cm/h) for the examined depths 6 and 18 months after treatment. n = 6-10.

	6 months		18 months	
Depth cm	Control	Aerated	Control	Aerated
Median values (50 percentile)				
20-30	4.44	19.2	6.80	12.6
30-40	2.32	6.97	0.02	5.75
40-50	0.06	1.05	0.02	1.50
50-60	0.02	mv	mv	0.46
Maximum values (100 percentile)				
20-30	18.3	33.6	21.7	20.5
30-40	6.2	13.4	0.9	52.1
40-50	0.2	1.9	0.02	4.3
50-60	0.8	mv	mv	4.5

increasing at the 50-60 cm layer. Edling (6) uses 400 cm/min as a guide for air permeability for normal arable land. This guide value was not reached 18 mo after treatment, but the values for the 30-40 and 40-50 cm layers were significantly higher in the aerated plots than the controls. This was true for both soil types.

Penetration resistance. A cone penetrometer is a rather simple tool for assessing the soil's mechanical condition. The lower the cone pressure, the looser the soil and the more easily it can be penetrated by roots. In the control plots there was an increase in cone pressure from 30 cm down to 40 cm and a decrease for the deeper horizons (Figures 3 and 4). This peak is due to the compaction created when the experimental plot was constructed. At the Alnarp site (Figures 3 and 4) this peak has disappeared in the aerated plot.

Table 4. Air permeability coefficient (K_a cm/min) at Alnarp for the examined depths 18 months after treatment. n = 6-10.

Depth cm	Control	Aerated
20-30	382	436
30-40	24	323*
40-50	11	168*
50-60	mv	249

* = Statistically significant ($P \leq 0.05$).
mv = missing values.

The curves are clearly separated from 30 cm down. There is a sharp rise in the end of the curves which is explained by a stony layer at the 50 cm depth. Two and a half years after treatment (Figure 4) the compaction persists in the control and the cone pressure is higher than in the previous year (Figure 3). This could be due to a recompaction since the water content at the second measurement was higher than at the first measurement.

Discussion

Compacted soils have poor drainage and poor aeration and are difficult for the roots to penetrate. The intent of using compressed air as a tool for subsoiling is to give plants better soil conditions in which to grow and to increase porosity in compacted horizons. After treatment with a Terralift soil aerator there were differences between the plots but whether or not these differences were due to the treatment is difficult to say because only one plot was treated at each location.

The pore size distribution was markedly changed in the aerated plots. Martinovic (12) stated in an investigation on a prototype to Terralift that the pore space was slightly increased and this increase was primarily in the volume of coarse pores. At the Alnarp site, with a sandy soil, there was an increase in porosity, mainly in macropores. The percentage of fine pores (< 0.005 mm) decreased. The greatest changes were found in the 40-50 cm horizon. This is the depth where the

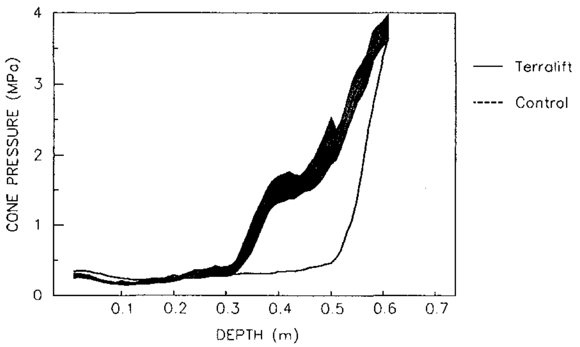

Figure 3. Diagram showing penetration resistance at the Alnarp site 6 months after treatment. Each curve is a mean of 30 individual penetration curves. The control is surrounded by a 95% confidence interval based on the pooled variance of all curves.

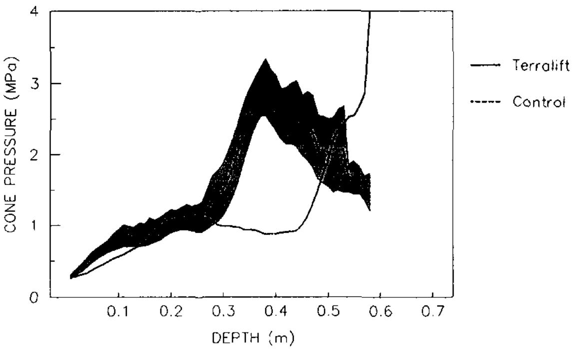

Figure 4. Diagram showing penetration resistance at the Alnarp site 30 months after treatment. Each curve is a mean of 30 individual penetration curves. The control is surrounded by a 95% conficence interval based on the pooled variance of all curves.

first "air-shot" was released, which indicates a more horizontal than vertical effect. Eighteen months after treatment there was a small recompaction or settlement of the soil. Porosity had decreased and so had the amount of macropores. The percentage of finer pores increased which confirms the statement (19) that the first pores to collapse when they are exposed to a load are the coarse pores. At the Landskrona site with the loam soil, the plots had a different pore size distribution. Six months after aeration there was no effect on porosity that could be confirmed by our measurements.

The air permeability coefficient (K_a) is a function of the air content of the soil and shape of the air-filled pores. Subsoiling can create more macropores which can be beneficial but subsoiling may also disturb the existing pore continuity. Both macro-porosity and hydraulic conductivity were higher in the aerated plots indicating both a volume increase and a continuous pore system. The Terralift aerator can create cracks and fissures. Persistence is yet to be established. It may be important in this kind of subsoiling, as in mechanical subsoiling, that treated soil not be exposed to heavy traffic (7,20).

The capacity to absorb water was improved where porosity was increased. The amount of plant-available water at field capacity, however, was not increased since all water from the "extra" pore volume was within macro-pores and this water drains away. However, the better and more uniform porosity down the profile, which resulted at the Alnarp site, gives the roots a possibility of greater vertical expansion and thus access to more water and nutrients.

In my experiment two soils were investigated and there were different effects depending on soil type. The sandy loam was improved while the loam site was not. Similarly, Smiley et al. (18) found no changes in bulk density on clay loams with a clay subsoil. The Terralift soil aerator can be a tool to relieve soil compaction in certain soils. It is, however, not a universal tool for solving soil problems around trees, because the persisting effect depends on the soil type. In a sandy soil, positive soil physical changes may be obtained but in a clay soil, the benefit is questionable.

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Résumé. Le sol était compacté sous des conditions contrôlées. Les effets de l'aération pneumatique du sol, avec un aérateur de sol Terralift, sur un certain nombre de paramètres physiques étaient mesurés sur des sites de loam sableux et de loam sur loam argileux. Pour le loam sableux, l'aération résultait en une densité décroissante, une augmentation de la porosité et une augmentation de la conductivité hydraulique à saturation et de la perméabilité à l'air. La résistance à la pénétration était diminuée. Pour le sol loameux, la densité augmentait et la porosité diminuait, tandis qu'il y avait aucune modification dans la conductivité hydraulique à saturation et que la perméabilité à l'air n'augmentait que lègérement. La seconde année après le traitement, une augmentation de la macroporosité était observée. La résistance à la pénétration était plus élevée la première année, mais elle était identique au sol compacté-contrôle deux ans après.

Zusammenfassung. Erdboden wurde unter kontrollierten Bedingungen verdichtet. Die Auswirkungen der pneumatischen Bodenbelüftung mit dem Terralift Gerät auf eine Anzahl bodenphysikalischer Parameter wurde an Standortenn mit 1) sandigem Lehmboden und 2) sehr lehmigen Lehmboden gemessen. Nach der Behandlung nahm beim sandigen Lehm die Dichte ab, die Porösität, das Leitungsvermögen für Wasser und die Luftdurchlässigkeit zu. Der Eindringwiderstand wurde verringert. Hingegen nahm bei sehr lehmigen Lehmboden nach der Behandlung die Dichte zu, die Porösität ab, das Leitungsvermögen bleib unverändert und es gab nur eine geringe Zunahme der Luftdurchlässigkeit. Im zweiten Jahr nach der Behandlung wurde eine Zunahme bei der Makroporösität beobachtet. Der Eindringwiderstand war höher als im ersten Jahr, jedoch ohne Unterschied zu der verdichteten Kontrolle nach zwei Jahren.