SOIL IMPROVEMENT AND INCREASED GROWTH RESPONSE FROM SUBSOIL CULTIVATION

by Kaj Rolf

Abstract. Subsoiling with an excavator, before planting, was used to reduce the negative effects of soil compaction. Two soil types were used and results showed that soil bulk density was reduced and pore volume and airfilled porosity at field capacity had increased. Penetration resistance was lowered for both sites. Three years after planting, plants were higher at the subsoiled sandy soil but not at the clay soil, compared with the controls.

In the different phases of the building process the soil is compressed, either deliberately or unconsciously. Soil damage caused may be permanent and is due primarily to the use of heavy vehicles or machines at unsuitable times, and to the fact that the soil is not afterwards restored to a good growth-promoting condition. It is essential for the good root-development of plants that soil conditions are favourable. Conditions required by different plants vary with the different species (2, 10, 16, 24), but certain soil functions are common to most plant varieties.

When soil is compacted, the large pores in the system are destroyed (23). These pores are essential for the movement of gases and water in the soil and without them, soil conditions will be anaerobic for a major part of the growing season.

A surplus of water in the soil, the result of poor permeability, will in its turn cause oxygen deficiency (anaerobiosis) in the soil, which has consequences such as decreased resistance to road salts (4, 7, 13, 14), dentrification (12), nutrient leakage from roots (20) and changes in plant metabolism (21). It is also known that compaction can lead to damage from chemical and biochemical reactions in the soil. For example, poisonous gases may be formed, the pH value of the soil is lowered, thus liberating substances poisonous to the plant.

The mechanical resistance in the soil encountered by roots increases when the soil is compacted (3, 9, 25). This means that the extent to which roots spread is limited (22) and that the volume of root-permeated soil is smaller. In this way smaller quantities of water and nutrients are available to the plant.

In order to avoid permanent damage to the soil, heavy machines should not be used in wet conditions. When the water content of the soil is normal, axle loads should not exceed 6 tonnes and the inflation pressure in the tyres should not exceed 80-100kPa (5).

Materials and Methods

In 1984 a study was started to evaluate subsoiling with an excavator. The site was used as a storing area during housebuilding and was exposed to heavy traffic. The results from this investigation was very promising (19) and it was decided to do a more controlled experiment.

A controlled experiment at two sites, Alnarp and Landskrona, was constructed. In May, 1987 topsoil was taken away to a depth of about 30 cm and the subsoil was compacted with a wheeldriven excavator which drove over the area, wheel by wheel, 10 times. The excavator had an axle load of 8 tons and an inflation pressure of 500 kPa. After the compaction the top soil was respread and part of the area was subsoiled.

Due to economic reasons we could only have one plot treated at each site. The plots were 5 x 13 meters, where half the area was tree planted and the other half used for soil physical examinations in order to avoid disturbance of the root systems.

In the experiments an excavator is used to break up the compacted soil. The excavator works its way backwards over the area of soil that is to be broken up. The dipper lifts a quantity of soil, shakes it lightly and then drops it back into the hole (see Figure 1). The soil is not turned over as it just falls back into place, but compacted soil layers are broken up and openings in the soil are created.

The method for breaking up soil with excavators has been used successfully in fruit orchards in the United States (8) and trials have also been carried out on cultivated soil in Sweden. Hakansson (11) has reported important effects on drainage conditions even though this is a very complex problem. The effect on drainage conditions in the soil depends on the thoroughness of the breaking up of the soil, on precipitation, evaporation, drainage, etc. Positive results can be expected in compacted/impermeable soils.

The breaking up process described by Hakansson (11) was carried out with the topsoil removed, while these experiments included the topsoil. Whichever method is used, a certain amount of topsoil will fill the cracks created when the soil is lifted up. These cracks are excellent paths for root penetration since the soil is loose and the organic content provides nutrients.

Texture of the soils at the different sites are given in Table 1.

Cores of soil were collected for determination of bulk density, pore volume and pore size distribution. Core samples were collected down to 0.6 m depth. Each core was 72 mm in diameter and 100 mm deep. Six to 10 replicates were taken for every depth. Bulk densities were calculated after oven drying from the mass of dry matter and the total volume of the sample. The soil water release characteristic was determined using standard methods (1, 17).

Penetration resistance (cone pressure) was measured and data were collected with an Electronic cone penetrometer, constructed at the institute (15). Data were collected for every 10 mm level with 30 replicates for each plot. Cone pressure is the instantaneous penetration force divided by the cone base area.

The impact of treatment on tree growth was studied on five species, *Acer platanoides, Corylus avellana, Fraxinus exelsior, Sorbus intermedia* and *Quercus robur.* Five plants of each species were planted. T-Tests were used to determine statistical significance of all data. The level of significance was set at 95% confidence.

This investigation is a part of a bigger study where pneumatic treatment with a Terralift and the effect of planting directly in a compacted soil surface is also included.

Results and Discussion

Dry bulk density. Subsoiling did lower bulk density values, as we see in Table 2. We get a more uniform bulk density down the profile. If the particle density and texture is the same in the treated and control plots, dry bulk density is often regarded as an indication of soil compaction and we can see that subsoiling reduced the degree of compaction.

Pore volume and macro porosity. Pore volume is very important for the air movement in the soil, because pore volume is an indication of the soils potential for diffusion and diffusion is the most important transport mechanism for oxygen from the atmosphere to the roots. Table 3 shows that subsoiling had a good influence on the pore volume on both sites. There is an increase of up to 42% at the Alnarp site and up to 13% at the Landskrona site.

If we just look at the macro-porosity (Table 4), defined as pores bigger than 0.03 mm, we see that these pores, so important for aeration and drainage, has significantly increased at the Alnarp and Landskrona sites. The figures in Table 4 are also the airfilled porosity at -1.0 meter water column, or expressed in another way, at 1 meter drainage which often is called 'field capacity'.

Airfilled porosity is the best indication for air mass flow in the soil. Richards and Cockroft (18) found, in a study on apple trees, that root growth was inhibited when airfilled porosity was less than 15%. Edling (6) gave a recommendation that the volumetric content of airfilled pores needed to maintain an adequate oxygen level for root respiration should be more than 10%. At Alnarp

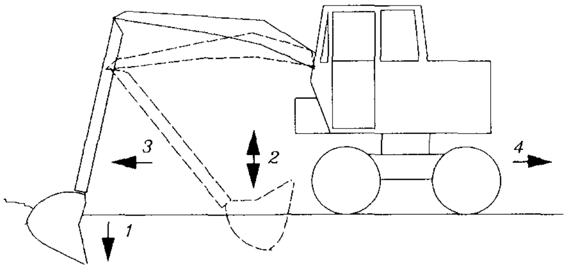

Figure 1. The working principle for the excavator
1. **The dipper digs down to the required depth**
2. **The dipper is lifted up and shaken**
3. **The soil is dropped back into the hole**
4. **The excavator reverses.**

Table 1. Soil textural classes for the two sites

Site	*Depth (m)*	*Soil class*
Alnarp	0.3	Sandy loam
	0.6	Loamy sand
Landskrona	0.3	Loam
	0.6	Clay loam

and Landskrona the subsoiling increased the airfilled porosity over this level of 10%.

The potential for storing water has increased because the pore volume has increased, but the major part of this water is drained away. This is also one of the reasons for subsoiling. You want to get rid of excess water so that part of the pore system can be used for aeration.

Penetration resistance. Using a cone penetrometer is a rather simple way to assess the soil's mechanical condition. The lower the cone pressure is, the looser is the soil and the easier it is for the roots to penetrate the soil. Figures 2 and 3 shows penetrometer resistance graphs from Alnarp and Landskrona. The curves for the control plots show an increase in cone pressure from 0.3 m up to 0.4 m and deeper down there is a decrease. This peak is due to the compaction made when the experiment was constructed. It is easy to see that subsoiling has taken this peak away. The mechanical resistance for the roots to penetrate the soil is lower, so they can penetrate a bigger volume of soil and reach more available water and nutrients.

Table 2. Mean bulk densities, in g cm^{-3}, 1.5 year after treatment. n = 6–10.

Site	Depth m	Subsoiled	Control
Alnarp	0.2-0.3	1.40 *	1.51
	0.3-0.4	1.39 *	1.59
	0.4-0.5	1.45 *	1.79
	0.5-0.6	1.51	mv
Landskrona	0.2-0.3	1.38	1.42
	0.3-0.4	1.41 *	1.55
	0.4-0.5	1.49 *	1.65
	0.5-0.6	1.52 *	1.61

* = Statistically significant difference at 95% confidence using t-test.
mv = missing values.

Table 3. Pore volume (% by volume), 1.5 year after treatment. n = 6-10.

Site	Depth m	Subsoiled	Control
Alnarp	0.2-0.3	46.0 *	42.0
	0.3-0.4	46.6 *	39.0
	0.4-0.5	45.0 *	31.6
	0.5-0.6	42.2	mv
Landskrona	0.2-0.3	47.4	45.7
	0.3-0.4	46.3 *	41.5
	0.4-0.5	43.6 *	38.5
	0.5-0.6	42.8	40.9

* = Statistically significant difference at 95% confidence using t-test.
mv = missing values.

Plant growth. The experience from the first study in Staffanstorp was that the first year after planting there is no real difference in growth. This is due to the small root system that is not really restricted in development because it has not yet reached the compacted horizon.

We had the same reaction both in Alnarp and Landskrona. The second year was very dry and for some species the growth was even greater in the compacted control. This is because there was more available water to plants in the control because of a larger amount of smaller pores. In the subsoiled plot the macro pores drain the water away. For a dry region there is a risk for water

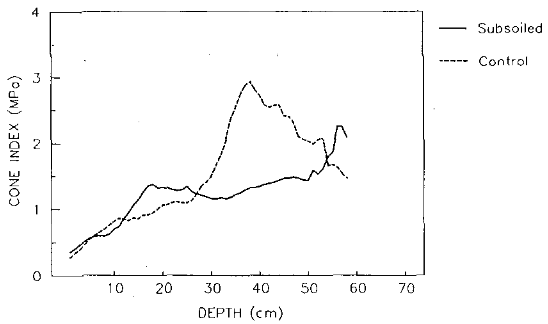

Figure 2. Diagram showing penetration resistance at the Alnarp site, 2.5 years after treatment. Each curve is a mean of 30 individual penetration curves. The control curve is surrounded by a 95% confidence interval based on the pooled variance of all curves.

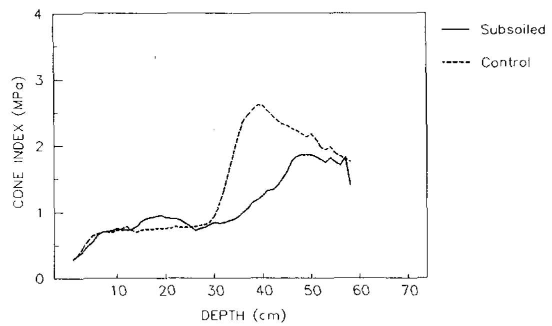

Figure 3. Diagram showing penetration resistance at the Landskrona site, 2.5 years after treatment. Each curve is a mean of 30 individual penetration curves. The control curve is surrounded by a 95% confidence interval based on the pooled variance of all curves.

stress in a subsoiled area. The dry summer also dried out the clay soil at Landskrona so that the soil shrinked and cracked, which created aeration and rooting paths that diminished the differences between the treatments.

Figures 4 and 5 show the total height of the plants. There is significant differences in total height for hazel and oak at Alnarp but no significant differences at Landskrona. The results on dry weight of roots and shoots are under study and probably it is dry weight that will give the best picture of plant growth.

Summary

The compaction that the sites were exposed to had an influence on the macro pore system so that the volumetric content of airfilled pores are lowered. The same has happened with the pore volume. Important soil physical parameters are negatively effected and when the soil has suffered this compaction damage, as is the case on most construction sites, it must be loosened up before planting.

Trials with traditional mechanical subsoilers have given both good and bad results. The efficiency of the loosening up of the soil depends very much on the water content of the soil, which makes it less suitable for use in an urban context, since here loosening-up must be carried out at the right stage in the building process and cannot wait for the moment when the soil conditions are right. Familiarity with soil and its properties is essential if you want to obtain a good result with mechanical subsoiling. Many subcontractors today lack this knowledge.

Subsoiling with an excavator has a positive effect on the pore system and could be used on most soil types. However a question-mark must be set for soils with a high silt content. These soils have an unstable structure due to the high capillarity and a high water content and will easily be compacted again.

No subsoiling can ever replace nature's ability to heal a soil that is compacted, but subsoiling with an excavator can speed up the recovery. This is because it takes compacted horizons away and opens up aeration paths in the soil. These effects are beneficial for trees.

Table 4. Macro porosity (pores greater than 0.03 mm) (% by volume), 1.5 year after treatment. n = 6-10

Site	*Depth m*	*Subsoiled*	*Control*
Alnarp	0.2-0.3	26.3 *	16.2
	0.3-0.4	28.0 *	12.5
	0.4-0.5	27.1 *	5.2
	0.5-0.6	22.9	mv
Landskrona	0.2-0.3	19.0	14.1
	0.3-0.4	15.6 *	8.2
	0.4-0.5	12.8 *	1.0
	0.5-0.6	10.6 *	3.3

* = Statistically significant difference at 95% confidence using t-test.
mv = missing values.

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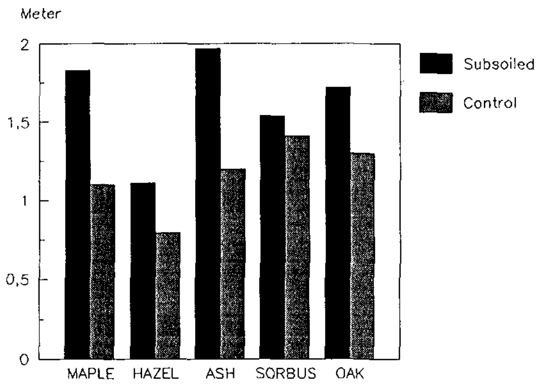

Figure 4. Mean total height of plants at Alnarp 3 years after planting. n = 5.

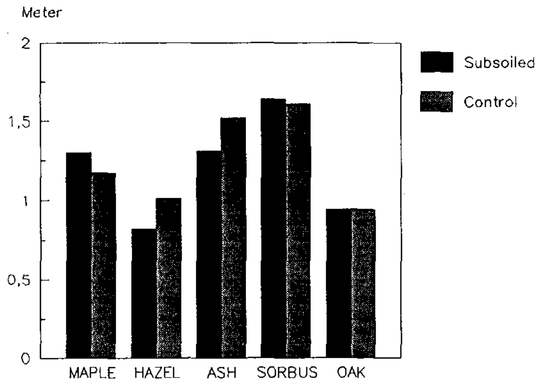

Figure 5. Mean total height of plants at Landskrona 3 years after planting. n = 5.

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Résumé. Le remuement du sol sans le retourner au moyen d'une excavatrice, avant la plantation, était utilisée pour réduire les effets négatifs de la compaction du sol. Deux types de sol étaient employés et les résultats montrèrent que la densité en volume du sol était réduite et que le volume de pores et l'aération de la porosité de la capacité au champ avaient augmenté. La résistance à la pénétration était diminuée pour les deux sites. Trois ans après plantation, les plantes étaient de plus grande taille pour le sol sableux remué mais non pour le sol argileux, les deux comparativement aux sols contrôles.

Zusammenfassung: Die Bodenverarbeitung mit einem Trockenbagger vor der Pflanzung wurde verwendet um die negativen Wirkungen von der Bodendichtigkeit zu mindern. Zwei Bodensorten wurden benutzt und Ergebnisse zeigten, daß Bodendichtigkeitumfang vermindert wurde und Porevolumen und luftgefüllte Porosität bei der Feldkapazität zugenommen haben. Die Penetranzresistenz ist für beide Orte gesunken. Drei Jahre nach der Pflanzung waren, im Vergleich mit der Kontrolle, Pflanzen im sandigen, bearbeiteten Boden höher gewachsen, aber im Tonboden war das nicht der Fall.