Subsoiling in starch potato growing in Sweden
Investigations to determine whether new deep tillage techniques can lead to higher yields of starch potatoes and better water management

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Abstract
Soil compaction due to heavy machinery and intensive cultivation causing yield reduction in potato is an increasing problem worldwide today. In this experiment inter-row subsoiling at the depth of 55 cm has been tested as a strategy to loosen the soil after planting and thereby increase the yield in starch potato production in Sweden. The effects of subsoiling were tested in three different irrigation regimes. The results show that subsoiling can increase the starch potato yield significantly in sandy soils where a compacted plough pan is present. This holds true for all years and all cultivars tested. The effects were greater in dry years and decreased with increasing irrigation intensity. However, the starch content of the tubers was not affected by subsoiling but the total starch yield increased between 0.86 ton/ha and 1.37 ton/ha, depending on year, cultivar and irrigation strategy.

Background
Agricultural practices today include the use of heavy machinery, not only for seedbed preparation but also during growth and harvest of the crop. Heavy machines cause high pressure on the soil which may lead to soil compaction (Pierce & Gaye Burpee 1995; Miller & Martin 1986; Parker et al. 1989). Compacted soils may reduce the root system and limit the area from which the plant can extract water and nutrient (Miller & Martin 1986; Ross 1979; Ibrahim & Miller 1989).

Sandy soils, which often are used in potato production, seem to be especially susceptible to subsoil compaction (Miller & Martin 1990; Westermann & Sojka 1996). The soil compaction may reduce both yield and quality and also physically restrict the development of tubers (Westermann & Sojka 1996; Parker et al. 1988; Pierce & Gaye Burpee 1995; Sojka et al. 1993). Plant roots of most species can penetrate soils with strength up to 2 to 3 MPa, but potato roots are more sensitive. Already at a pressure of 1 MPa the root growth is negatively affected (Stalham et al. 2007). The ideal soil for potato production is therefore deep, well-drained and loose (Pierce & Gaye Burpee 1995).

Potato plants are more sensitive to water stress and soil water fluctuations than most other crops. They require high water availability with minimum variation in the soil moisture in order to produce high yield- and tuber quality (Buxton & Zalewski 1983). The sensitivity to drought is most often explained by the potato plants relatively shallow root system, and low root: shoot ratio, which limit its capacity to extract water.

Subsoiling is a way to loosen up the plough pan by deeper tillage. During the process vertically fixed blades with an angled extension are cutting and lifting the soil in order to break the compaction. In general, subsoiling decrease soil strength and bulk density which allows the roots to penetrate further down in the soil profile. This can lead to a reduced stress caused by inadequate water and nutrient supply (Miller & Martin 1986). However, a restricted root system does not necessarily affect the tuber production negatively. If adequate soil moisture and fertility are maintained at near optimum levels within the root zone no beneficial effects are attributed to subsoiling (Ross 1986; Miller & Martin 1990).

Material and methods
The experimental setup was identical 2008 and 2009 except that two varieties were grown 2009 (Kuras and Seresta) and only one (Kuras) 2008. Due to different experimental setup
2007 the materials and methods from that year are presented under the subheading “Material and methods 2007”.

**Experimental setup**

The experiment consisted of three irrigation strategies, (1) Unirrigated, (2) High soil moisture (10-30 kPa) and (3) Low soil moisture (40-70 kPa). Each irrigation strategy consisted of one subsoiled and one conventional tilled plot. In 2009 the site was twice as big because two potato varieties were grown. Four replicates were included which gives a total of 56 harvest plots 2009 and 28 harvest plots 2008. The experiment was irrigated with an automatic drip irrigation system, monitored with IMetos tensiometers and watermark sensors connected with an online ICA-box. The soil at the experimental site was a sandy loam with a documented plough pan at 25-30 cm which was likely to restrict the root growth and elongation.

![Diagram of experimental setup](image)

**Figur 1.** The experimental setup 2008. Översätt bevattningsprognos på B. Measuring station for irrigation?

**Planting**

The tubers were planted the 8th of May 2008 and 17th of April 2009 with a row space of 75 cm. The size of the seed tubers were 35-42 mm 2008 and 35-55 mm 2009. In 2008 and 2009 the in-row seed spacing was 20 cm and 35 cm, respectively. The experimental field was ploughed in the autumn and tilled three times before planting in spring.

**Subsoiling**

The subsoiling was carried out after planting and prior emergence to avoid re-compaction during planting. The soil was loosened down to 55 cm in between the potato rows using an Agrisem cultiplow with two shanks.
**Fertilizing strategy**

The fertilizing strategy was the same both years. Two weeks after planting 700 kg of Promagna 11-5-18 (micro) was applied per ha. In the middle of June 250 kg/ha of N27 and 200 kg/ha of KMg was applied in bands. The total amount of fertilizer applied to the field was 212 kg N, 35 kg P, 176 kg K, 12 kg Mg and 36 kg S per ha.

**Plant protection**

All plots were treated in the same way regarding plant protection. Table 1 shows treatments applied 2008. In 2009 the treatments were more or less the same but the dates were different.

**Table 1. Treatments applied to the experimental fields 2008.**

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Product</th>
<th>Dose</th>
<th>Dates applied</th>
</tr>
</thead>
<tbody>
<tr>
<td>Herbicides</td>
<td>Sencor + oil</td>
<td>0,4 + 0,5 l/ha</td>
<td>20/5</td>
</tr>
<tr>
<td></td>
<td>Titus</td>
<td>30 g/ha + 0,3 l/ha</td>
<td>14/6</td>
</tr>
<tr>
<td>Insecticides</td>
<td>Sumi-Alpha</td>
<td>0,5 l/ha</td>
<td>14/6</td>
</tr>
<tr>
<td></td>
<td>Biscaya</td>
<td>0,3 l/ha</td>
<td>14/7</td>
</tr>
<tr>
<td></td>
<td>Sumi-Alpha</td>
<td>0,5 l/ha</td>
<td>3/9</td>
</tr>
<tr>
<td>Fungicides</td>
<td>Shirlan</td>
<td>0,3 l/ha</td>
<td>20/6</td>
</tr>
<tr>
<td></td>
<td>Shirlan</td>
<td>0,4 l/ha</td>
<td>30/6, 22/7, 30/7, 7/8, 15/9</td>
</tr>
<tr>
<td></td>
<td>Epok</td>
<td>0,5 l/ha</td>
<td>7/7, 14/7</td>
</tr>
<tr>
<td></td>
<td>Rannman</td>
<td>0,2 l/ha</td>
<td>15/8, 25/8, 3/9</td>
</tr>
<tr>
<td></td>
<td>Amistar</td>
<td>0,5 l/ha</td>
<td>3/9</td>
</tr>
</tbody>
</table>

**Whether conditions**

There were big differences in the whether conditions between the two years. In 2008 the first part of the growing season was rather dry while the second part was wet. In 2009 almost the opposite conditions occurred, with rather wet conditions during the first part of the growing season and dry during the second. The water deficit in August 2009 was 45 mm while in 2008 there was a surplus of 75 mm for the same period. In total there was a difference of 120 mm water in August between the years.

In 2008 the precipitation was higher and the evapotranspiration lower compared to 2009. This resulted in a larger deficit (32 mm) in 2008 compared to 2009.

**Table 2. Water budget for 2008 and 2009**

<table>
<thead>
<tr>
<th>Date</th>
<th>Evapotranspiration</th>
<th>Percipitation</th>
<th>Drained</th>
<th>Water deficit</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>36,5</td>
<td>6,4</td>
<td>0</td>
<td>30,1</td>
</tr>
<tr>
<td>Jun</td>
<td>63,6</td>
<td>37,4</td>
<td>0</td>
<td>26,2</td>
</tr>
<tr>
<td>Jul</td>
<td>51,1</td>
<td>43,2</td>
<td>0</td>
<td>7,9</td>
</tr>
<tr>
<td>Aug</td>
<td>55,1</td>
<td>149,8</td>
<td>20</td>
<td>+74,7</td>
</tr>
<tr>
<td>Sept</td>
<td>98,7</td>
<td>41,8</td>
<td>0</td>
<td>56,9</td>
</tr>
<tr>
<td>Sum</td>
<td>305</td>
<td>278,6</td>
<td>20</td>
<td>46,4</td>
</tr>
<tr>
<td>2009</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>58,3</td>
<td>39,5</td>
<td>0</td>
<td>18,8</td>
</tr>
<tr>
<td>Jun</td>
<td>58,6</td>
<td>44,5</td>
<td>0</td>
<td>14,1</td>
</tr>
<tr>
<td>Jul</td>
<td>70</td>
<td>90,5</td>
<td>5</td>
<td>+15,5</td>
</tr>
<tr>
<td>Aug</td>
<td>94,9</td>
<td>49,6</td>
<td>0</td>
<td>45,3</td>
</tr>
<tr>
<td>Sept</td>
<td>38,1</td>
<td>22,1</td>
<td>0</td>
<td>16</td>
</tr>
<tr>
<td>Sum</td>
<td>319,9</td>
<td>246,2</td>
<td>5</td>
<td>78,7</td>
</tr>
</tbody>
</table>
Measurements
Yield estimates were conducted twice during the growing season, 20 and 60 days after emergence (d.a.e) in 2008 and 50 and 125 d.a.e in 2009. Petiole samples were collected approximately 25 d.a.e and analyzed for nutrient content. At harvest tubers were collected and analysed for nutrient content. Final tuber yield, size grading and starch content were measured both years. The soil compaction was measured with a penetrometer three times during the growing season; The first one right after planting (before sub-soiling), the second one three weeks after sub-soiling and the third one some days before harvest. The measurement was taken both in the subsoiled plots and in the normal tilled plots.

Material and methods 2007
In 2007 the experiment was situated at six different farms in Kristianstad. At each farm one experimental plot was prepared (figure 2). The experimental plot contained two different treatments, subsoiling to a depth of 35 cm and conventional soil tillage. Each treatment had two replications per field. Subsoiling was in this case carried out 1-2 weeks prior to seedbed preparation in the opposite direction to the ridges. In the conventional cultivated plots regular seed bed preparation was made. Total yield and starch content was measured at harvest. Several other measurements were taken but since there was no possibility to make any statistical analyse of the data these measurement are not included in the report.

<table>
<thead>
<tr>
<th>Conventional tillage</th>
<th>AI</th>
<th>AII</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subsoiled</td>
<td>BI</td>
<td>BII</td>
</tr>
</tbody>
</table>

Figure 2. The experimental setup 2007

Results
Final yield
In 2008 subsoiling significantly increased the yield when analysing all three soil moisture treatments together compared with the control (figure 3). The yield increase was approximately six percent or four tonnes per ha. However, when analysing the two different soil management techniques within each soil moisture treatments, 40-70 kPa was the only one showing significant effect of sub-soiling.

A significantly yield increase of subsoiling could also be seen in 2009 for both Kuras (figure 4) and Seresta when analysing all three soil moisture treatments together. The yield increase was 10 % for Kuras and 8 % for Seresta. In contrast to the results in 2008 all soil moisture
treatments, except the 10-30 kPa for Kuras, showed significant higher yields in the subsoiled plots in 2009.

**Figure 3.** Final yield 2008 (Kuras) affected by moisture and subsoiling. Error bars: +/- 1 SE

**Figure 4.** Final yield 2009 (Kuras) affected by moisture and subsoiling. Error bars: +/- 1 SE

**Starch content and starch yield**
The starch content was not affected by the subsoiling and varied between 23.5 % and 25.6 %. Due to the yield increase of the subsoiled plots an increase of total starch yield could be seen; 0.90 ton/ha (Kuras, 2008), 0.86 ton/ha (Seresta, 2009) and 1.37 ton/ha (Kuras, 2009). The increases are statistically significant.

**Penetrometer measurements**
A decrease in soil compaction in the subsoiled plots could be seen in the entire soil profile (figure 5). Subsoiling has at certain depths decreased from 5.5 to 1 MPa compared to normal tillage.

**Figure 5.** Penetration resistance as influenced by subsoiling.
**Nutrient analysis**

The phosphorous content of the petioles 2008 was significantly higher in the subsoiled plots compared to the control, while magnesium was significantly lower. Potassium, iron and manganese content in the leaflets were not affected by subsoiling. The nutrients content of the tubers were also measured at the final harvest 2008. The nutrient content in the tubers was not affected by subsoiling with one exception, sulphur, which had a significantly lower content in the subsoiled plots.

In 2009 the nutrient content in the petioles was not affected by **sub-soiling**. The only exception was the Seresta cultivar which had significantly higher phosphorous content in the subsoiled plots compared with the control.

**Yield estimates**

The plant development was studied during the growing season in all years. No significant differences were found in plant weight between the subsoiled plots and the control in the yield estimates made 2008. Two yield estimates were made in Kuras and Seresta 2009. At the first yield estimate the plant weight was significantly higher in the subsoiled plots compared to the control in Seresta, while no difference could be seen in Kuras. Both cultivars had a significantly higher weight in the subsoiled plots compared to the control at the second yield estimate 2009. In conclusion, it seems like the effects of subsoiling arises during the second part of the growing season since the second and final digging always showed the greatest effects.

**Tuber size distribution**

The size distribution for Kuras was erratic between the years. In 2008, sub-soiling increased the fraction “>65 mm” significantly compared with the control. However, the following year the fractions “<42 mm” and “42-55 mm” was positively affected by the sub-soiling and not “55-65 mm” and “>65 mm”. Seresta had significantly higher yields in the fractions “55-65 mm” and “>65 mm” in the subsoiled plots compared to the control.

**Results 2007**

The experiment setup 2007, with six different fields and only two replicates on each site, made it hard to draw conclusions about the effect of subsoiling. The mean harvest (ton/ha) of the subsoiled plots were higher in two fields and lower in four, compared with the conventionally tilled plots. There was also large differences in mean harvest (ton/ha) between the fields at the subsoiled plots; 58.5 ton/ha to 24.1 ton/ha.

The starch content varied between fields, but hardly within each field. The highest starch content was 25.5 % and the lowest 19.8 %. Due to the experimental setup it was not possible to make any valid statistical analyse of the data.

The penetrometer measurements showed that there were small effects of the subsoiling, indicating that a recompaction had occurred during seeding. Further more, during the growing season precipitation was intense which might have decreased the need for subsoling.

**Discussion**

The result from this study shows that subsoiling can increase the yield of starch potatoes grown in Sweden, if carried out properly. A positive effect was seen both in 2008 and 2009.
for the cultivar Kuras. An increase in yield was also seen in the cultivar Seresta, which was solely grown in 2009. The results are contradictory to results from Copas et al. (2009), where subsoiling didn’t show any increased in yield. However, in that study the subsoiling was carried out in the autumn or before planting while in this experimental setup it was done after planting before emergence. The differences in timing could be one reason why Copas et al. (2009) didn’t have any effect of subsoiling. The idea is further supported by the penetrometer measurements made in their study, where only small differences in penetration resistant could be seen between normal tillage and subsoiling. In contrast, a decrease in soil resistance in the subsoiled plots could be seen in the entire measured soil profile (figure 5) in our penetration measurements.

Few other studies have achieved the same great response from subsoiling as this study. In a review paper on subsoiling in potato only 28 out of 83 trials showed significant increase in yield (Stalham et al. 2005). Our unique results might be explained by the cultivation depth, the timing, and the machinery used in this trial. It is also important that the subsoiling is carried out before the potatoes are starting to sprout, as subsoiling which disturbs a developed root system should always be avoided (Halderson et al. 1993).

The cost of subsoiling is around 900 SEK/ha. In our study an increase between 0.86 and 1.37 ton starch/ha could be seen. Since the price of 1 ton of starch is around 3000 SEK, it makes the subsoiling economically profitable based on the results from both 2008 and 2009 with both cultivars.

Soil compactions may influence factors such as reduced soil porosity, leading to lower water holding capacity and lower soil O₂ concentrations, as well as reduced diffusion of nutrients. Due to mechanical resistance to root growth and root elongation the area from where the plant can take up water and nutrients could also be limited (Copas et al. 2009). The reason for the increased yield seen in our study is not fully understood. The nutrient content in the tubers and in the leaflets was not higher in the subsoiled plots compared to the control. The only exception was the phosphorous content in the petioles in Kuras 2008 and Seresta 2009. Since the increase of phosphorous was not seen in all nutrient measurements it could not explain the increases solely. Other factors like the water availability may also play an important role. But since the average yield always was higher in all the subsoiled plots compare with normal tillage despite moisture treatments, it can’t solely be responsible for the increases. It is therefore most likely that both water and nutrient are of importance for the responsiveness of potato to subsoiling.

In 2009, the second part of the growing season was rather dry. In this case, the yield effects of subsoiling, declined with increasing irrigation intensity. Similar results were also found in previous studies (Miller & Martin, 1990; Henriksen et al. 2007; Ibrahim & Miller 1989). In 2008, the second part of the growing season was rather wet and there was in general less effect of the irrigation. In this case the positive effect of subsoiling was similar regardless of irrigation strategy which might be explained by increased uptake of nutrient which had leached below normal rooting depth.

Due to the great economic benefits achieved by subsoiling it will be put into common practise already in 2010. Approximately 10% of the contracted area will be subsoiled and followed up. All fields will be measured with a penetrometer together with the final yield. This following study will be managed and funded by the project 101215.
References


