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Potato yield and soil physical properties as affected by subsoiling

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Effekten av djupbearbetning på potatisskörd och jordstruktur

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Abstract

Agriculture practices today include the use of heavy machinery which leads to soil compaction. High soil strengths are known to restrict the root development and prevent root growth. Sandy soils, which often are used in potato production, seem to be especially susceptible to subsoil compaction. Subsoiling is a way to loosen up the plough pan by deeper tillage. General it decreases soil strength and bulk density, the effect is that the roots can penetrate further down in the soil which may reduce stress caused by inadequate water and nutrient supply. The persistence of subsoiling is dependent on several factors such as soil moisture at the time of subsoiling, the choice of subsoiling equipment and traffic practices following the subsoiling. The best way to prevent recompaction is to apply controlled wheel traffic. The conclusion from my literature study is that under near optimum irrigation levels subsoiling are of no benefit to the yield but during more drought conditions the additional rooting volume significantly increase potato yields, but have no effect on the quality. Therefore subsoiling can be of importance in areas were irrigation is not used.

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Sammanfattning

Idag används mycket tunga maskiner i lantbruket, vilket orsakar skador på jordens struktur och därmed ger sammanpackade jordar. Packskadorna uppstår ofta precis under normalt plöjningsdjup och bildar då en så kallad plogsula. Rötterna har svårt att tränga igenom plogsula och resultatet kan bli ett grundare rotsystem som gör att växten stressas av vatten- och näringsbrist. Djupbearbetning kan lösa upp plogsulan och underlätta rotpenetreringen, därigenom kan stress undvikas. Hur länge effekten av djupbearbetning kvarstår beror på flera faktorer, så som markfukt vid bearbetningen, val av utrustning samt körrutiner efter djupbearbetningen. Bästa sättet att reducera packskador är att använda sig av permanenta körspår. Slutsatsen från min litteraturstudie är att djupbearbetning inte har någon inverkan på skörden vid optimal vattenförsörjning men under torra förhållanden ger den ökade rotvolymen en signifikant ökning av skörden. Därför kan djupbearbetning vara att rekommendera i odlingar där bevattning inte används.

Introduction

Agriculture practices today include the use of heavy machinery both to prepare soil for cultivation and during growth and harvest. Heavy machines cause high pressure on the soil which leads to compaction. High soil strengths are known to restrict the root development and prevent the root from growing beneath the plough pan (Pierce and Gaye Burpee 1995; Miller and Martin 1986; Parker et al. 1988). The consequence may be reduced root system and limited area from which the plant can extract water and nutrients. The result may be stressed plants and reduced growth (Miller and Martin 1986; Ross 1979; Ibrahim and Miller 1989). The ideal soil for potato production is deep, well-drained and loose (Pierce and Gaye Burpee 1995).

The potato crop is sensitive to water stress and more sensitive to fluctuations in soil water than most other crops. It requires high water availability and minimum fluctuations between irrigations to produce high yield- and good quality (Buxton and 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 from deep soil.

Sandy soils, which often are used in potato production, seem to be especially susceptible to subsoil compaction (Miller and Martin 1990; Westermann and Sojka 1996). Plant roots can normally penetrate soils with strength up to 2 to 3 MPa, but potato roots are more sensitive to high strengths. Already at a pressure of 1 MPa the root growth is negatively effected (Miller and Martin 1986). Not only the roots, but also the tubers can be affected by high soil strengths. The soil compaction may physically restrict developing tubers (Westermann and Sojka 1996) and reduce both yield and quality (Parker et al. 1988; Pierce and Gaye Burpee 1995). Further more tuber set might be forced further up in the ridge where soil temperature are higher and moisture is more variable and may be limiting (Sojka et al. 1993b).

Figure1.a) Cross section of soil, showing how a subsoiler is working. b) A schematic drawing over the subsoiler. (http://www.agrisem.com/Newsite/photos.php5?prod=lame&lang=EN)

Subsoiling is a way to loosen up the plough pan by deeper tillage. The operation includes vertical fixed blades that are “cutting” the soil, in the end of each blade an angled extension is lifting the soil some cm to break the soil compaction (figure 1). If subsoiling is performed in between rows it is called inter-row subsoiling, the most suitable depth appears to be 38 to 46.0 cm (Halderson et al. 1993). In less compacted soils chiseling might be satisfactory to use. It is conducted with flexible metal rods instead of fixed blades, and lack lifting extensions. But the purpose is the same, to remove soil compaction.

In general, subsoiling decrease soil strength and bulk density which means an increase of large pores. The effect is that the roots can penetrate further down in the soil which may reduce stress caused by inadequate water and nutrient supply (Miller and Martin 1986).

Research in this field has been carried out in several different countries during the past 30 years. The purpose of this report is to make a review over these trials and try to answer the questions; how is subsoiling affecting the soil, the plant and the potato yields? Is subsoiling something that shall be recommended to Swedish potato growers? And if so, when is the best time?

Subsoiling: effects on soil

Penetration resistance and bulk density

Penetration resistance and bulk density is often used to describe the properties of a soil. Enhanced soil compaction means that the force needed to penetrate the soil is increasing. This force can be measured with a metal stick, called a Penetrometer (Figure 2). The metal stick is pressed in to the soil with a certain force; a calibrator is recording the pressure which the soil is generating in MPa. Since the soil strength is affecting root penetration, and potato roots are particularly sensitive to high soil strength, this is essential to know for potato growers (Pålsson 2006). Bulk density is directly connected to the porosity and is a way to describe how compact a soil is. When the soil is compacted e.g. by the use of heavy equipment, the pores are decreasing in volume and the bulk density is increasing.

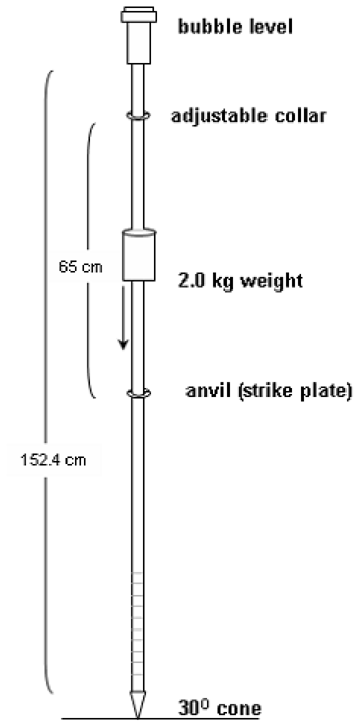


Figure 2. A Penetrometer. (http://www.regional.org.au/au/asssi/supersoil2004/s14/poster/1565_vanagsc-1.gif)

During the process of turning the soil over with a plough a compacted section, referred to as the plough pan is formed. The plough pan can be found at different depth depending on how deep the standard tillage usually is conducted. In the trials of Miller and Martins (1986) on a sandy soil, the plough pan with a strength of 2 MPa, was found at a depth of about 30.0 cm. Whereas in the standard tilled treatment of Bishop and Grimes (1978), soil strength near 2 MPa were established at 20.0 cm and extended through a depth of 50.0 cm. They (Bishop and Grimes 1978) report a reduction of soil strength to 0.6 MPa through 55.0 cm of soil when using inter-row subsoiling.

Buxton and Zalewski (1983) measured the penetrometer resistance 30.0 cm below the potato beds and found that it was significantly reduced in five of six fields after precision chiseling. Also Ibrahim and Miller (1989) found that, subsoiled plots had much lower soil strength than those not subsoiled except from the soil near the surface. But on the other hand Holmstrom and Carter (1999) conclude that subsoiling showed marginal success in loosening the soil below the plough depth.

Pierce and Gaye Burpee (1995) tested two different tilling machines, Bush Hog Ro-till and Tye Paratill, when performing inter-row subsoiling. Both types of tillage decreased bulk density and soil strength, and increased the volume of large pores in the zone of compaction. The treatment lowered the soil strength down to 45.0 cm depth, and had an effect extending to a point midway between the potato beds.

Measurements carried out by Pierce and Gaye Burpee (1995) showed that the bulk density in the soil depth interval 0.0 -7.6 cm and 10.0 -17.6 cm were not affected by subsoiling. But further down in the soil profile, at a depth from 23.0 to 30.6 cm, the bulk density were much higher in conventional tilled plots compared to the subsoiled ones. The trend in general was that zone tillage increased the amount of the larger pores, with radius classes over 36 µm. Similar results were also presented by Sojka et al (1993a) which found that the bulk density was unaffected by inter-row subsoiling within the top 15.0 cm, but reduced between 15.0 and 45.0 cm. However, Holmstrom and Carter (1999) reported a decreased bulk density in only five out of eight sites.

Infiltration rate

Soil compaction reduces the amount of pores, especially large pores. This is affecting the water holding capacity of the soil as well as the infiltration rate. Large pores are important when it comes to infiltration but also the moisture content in the soil.

Analysis of the soil in the plough pan suggests that the reason for slowed down water movement is the shift from coarse pores to fine pores across the plough pan border (Ross 1979). Since subsoiling increases the amount of large pores and lowers the bulk density

(Pierce and Gaye Burpee 1995) it is likely to believe that the water infiltration rate would be positively affected by subsoiling.

Haderson et al. (1993) also observed that less water were standing in the rows treated with inter-row subsoiling compared to conventionally tilled plots, but unfortunately no specific measurements were made to quantify this observation. Subsoiling may therefore be an effective way to decrease water erosion.

Although water infiltration rates were extremely slow in many commercial fields, there were no indication that slow infiltration rates were associated with low yield and quality. One explanation can be that the growers were able to overcome the unfavorable effects of slow water infiltration rates by proper irrigation management, including frequent irrigations for long periods (Buxton and Zalewski 1983).

It seems reasonable that the increased infiltration rates which subsoiling gives would be beneficial during periods of excessive precipitation. But according to results reported from Soane et al. (1987) it seems to be the opposite, the yield is reduced in wet seasons when subsoiled.

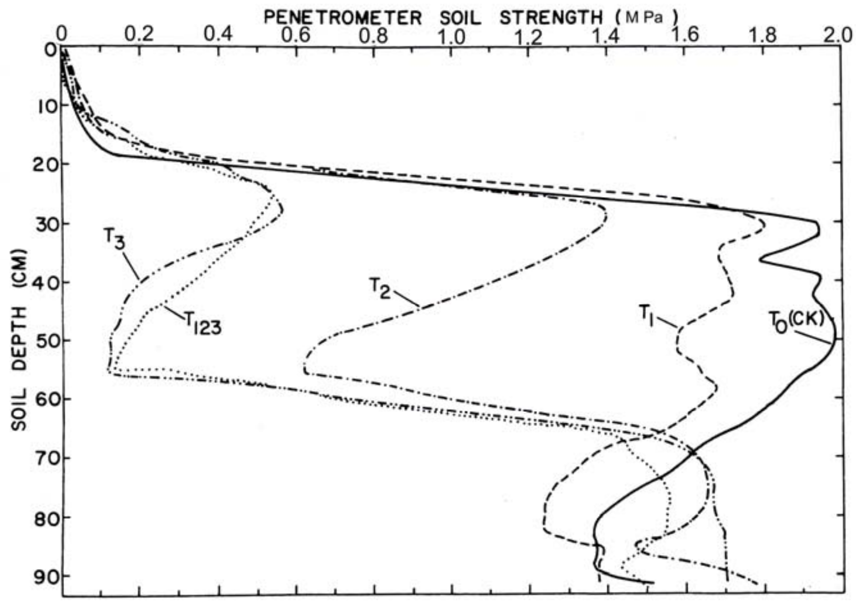
Persistence and recompaction

There is a gradually recompaction taking place in subsoiled fields. The persistence is dependent on several factors such as soil moisture at the time of subsoiling, the choice of subsoiling equipment and tillage- and traffic practices following the subsoiling. For e.g. recompaction caused by heavy machineries are less likely in drier soil. Soane et al. (1987) tested two different subsoiling equipments and found that both had a consistent effect upon the percentage of reductions in density and penetration resistance. However, subsoiling equipments which leaves an unbroken surface provides a protection to the loosened soil volume below against the effects of surface compacting loads. Therefore subsoiling equipments which disturb the upper most soil layer reduces its capacity to support surface loads, thus increasing the risk for recompaction (Soane et al. 1987).

Holmstrom and Carter (1999) and Soane et al. (1987) found that trafficking, particularly mouldboard ploughing soon after subsoil loosening can cause significant recompaction of the loosened subsoil.

Measurements done by Parker et al. (1988) three months after subsoiling showed reduced values of soil bulk density and penetration resistance. Further on, there was little evidence suggesting that any recompaction occurred during the following growing season. Pierce and Gaye Burpee (1995) found positive effects on soil physical properties immediately after zone tillage and the effect still remained in the second year after tilling.

If compactions by machines are prevented by controlled wheel traffic the effects of subsoiling could last for three years (Miller and Martin 1986); (Soane et al. 1987). Bishop and Grimes (1978) on the other hand has reported an intermediate level of soil strength already after one year of standard tillage operations and after two years of standard treatment the soil strength was almost back to the original level. Soane et al. (1987) found that the largest recompaction occurred between the second and third crop and the procedure went faster when root crops was grown in the fields.



Bishop, J.C. and Grimes, D.W. (1978)

Figure. 3. Diagram over soil strength showing five different treatments.

T_0= no subsoiling.
T_1= First one year of subsoiling followed by two years of conventional soil preparation.
T_2= First two year of subsoiling followed by one year of conventional soil preparation.
T_3= one year of subsoiling.
T_{123}= three years of subsoiling.

Negative effects of subsoiling

The result of subsoiling is closely connected to soil moisture content during and after subsoiling performance. It is well known that if the soil is wet machine operations can lead to an increase in soil compaction instead of loosen it. If precipitation occurs immediately after subsoiling the loosened soil might collapse (Henriksen et al. 2007).

Subsoiling can cause other unexpected problems, which Holmstrom and Carter (1999) experienced. In five out of eight experimental fields, subsoiling resulted in an increased amount of surface stones, which were brought up from below. These caused extra work since they had to be removed before planting.

Another problem that might occur when subsoiling is carried out in the spring or when the soil is too wet is the formation of clods; autumn tillage usually results in fewer soil clods at harvest than spring applied tillage practices. The clod formation is of concern because it requires extra labour at harvest to separate the clods from the potatoes (Buxton and Zalewski 1983).

Subsoiling: effects on plants

Seed tubers and shoot emergence

Inter-row subsoiling may improve the drainage, and when less water is occupying the pore space more air is kept in the soil. According to Sojka et al. (1993a) and Westermann and Sojka (1996) that may have contribute to the higher soil temperatures of 0.5 °C observed in the depth of 5.0 to 15.0 cm of the subsoiled ridges. As subsoiling was done before planting the warmer and looser soil probably contributed to the earlier and more vigorous shoot emergence that was observed (Sojka et al. 1993a; Sojka et al. 1993b; Westermann and Sojka 1996). The seed tubers on the subsoiled plots emerged three to four days before those in the conventional tilled plots. The earlier emergence observed resulted in a larger average dry weight of 45% measured about two weeks after emergence, at one of the six sites. Neither autumn tillage nor subsoiling seems to have any effect on the number of shoots per ridge (Sojka et al. 1993a); (Sojka et al. 1993b).

Subsoiling can be applied before or after seedbed preparation. Sojka et al. (1993b) tried inter-row subsoiling after emergence (2.5 cm sprouts) and found that there were no substantial damage to the neither the seed tubers nor the sprouts. Although the soil-root contact seemed to be disturbed by inter-row subsoiling, the emergence appeared undisturbed. However these results seem to be valid only at an early stage of the plant growth. Halderson et al. (1993) found that delayed inter-row subsoiling gave a reduced plant size; looking at the period from emergence until full canopy, which probably was due to root disturbance.

Other problems with late application were also detected in their trials. The height of the ridges was reduced by 1/3, and the tuber sprouts were exposed as much as 5.0 to 8.0 cm during inter-row subsoiling application in one of the experimental years. This led to a yield reduction especially of large tubers, but there were no increase in malformed tubers seen (Halderson et al. 1993).

Roots and water uptake

By removing the plough pan the roots may penetrate further down in the soil than what they could have done otherwise. Bishop and Grimes (1978) and Ibrahim and Miller (1989) found a considerable increase in root density below 30.0 cm when the soil was loosened by subsoiling. With standard tillage, no roots extended below 61.0 cm, whereas inter-row subsoiling allowed significant rooting through 76.0 cm. The lower soil strengths also improved root growth vertical throughout the entire cross-section area of 20 and 40.0 cm measured from the bed center (Bishop and Grimes 1978). The increased root penetration might not have any significant influence on the size of the total root system (Ross 1986).

The increased root penetration lead to an improvement in water uptake compared to no subsoiling, and by that the plants avoided water stress (Miller and Martin 1986; Ibrahim and Miller 1989). A verification of the prevented water stress was increased leaf water potential, reduced stomata resistance and canopy temperature measured in those plants (Ibrahim and Miller 1989).

Connection between subsoiling and irrigation

Since potato crop is sensitive to water stress, an adequate supply of water is essential to get a strong, vital plant that will produce high yields. Sandy soils, which are known to have low water holding capacity, are commonly used in potato production. On these soils four days interval between irrigation is usually enough for visible water stress symptoms to develop (Ibrahim and Miller 1989; Miller and Martin 1990) and cause reduced yields (Ibrahim and Miller 1989). A comparison between daily irrigation and irrigation every fourth day showed that daily irrigation increased total tuber yield, number of tubers and specific gravity. But at the same time the tubers became smaller since the average tuber weight decreased (Miller and Martin 1990). If a plant is stressed by the lack of water the stomata are closed and the photosynthesis slowed down. The plant produces less energy that can be stored in the tubers and in the end this leads to smaller yields.

If the irrigation interval of four days was applied but the plants were allowed to develop deeper root systems due to subsoiling, water stress were avoided. This led to an increase in yield and percentage of U.S No 1 (United States´ quality standards) tubers (Ibrahim and Miller 1989; Miller and Martin 1986). The percentage of U.S No 1 tubers was low (46%) even with daily irrigation if no subsoiling were conducted and might be due to that the cultivar used, Russet Burbank is especially sensitive to water stress (Ibrahim and Miller 1989).

On loamy soils the results were similar to those on sandy soils. But since a loamy soil have a higher water holding capacity than sandy soil; the irrigation interval has to be longer to see any results. With weekly irrigation there was no significant outcome on tuber yield or grade due to subsoiling. If the period between irrigations were extended to two weeks this was enough for water stress to develop and both yield and percentage of U.S No 1 tubers were higher on the subsoiled than on the not subsoiled plots (Ibrahim and Miller 1989).

Under near optimum irrigation levels subsoiling were of no benefit to the yield but during more drought conditions the additional rooting volume significantly increased potato yields, but had no effect on the quality (Ross 1986). Therefore subsoiling can be of importance in areas were irrigation is not used. The extensive rooting can be essential for water uptake throughout the soil profile during periods of limited rain fall. When irrigation is applied frequently, the need for large amounts of stored water in the soil profile is not that crucial, and the subsoiling may not be needed (Buxton and Zalewski 1983).

Tuber quantity

The removed plough pan and the increased rooting might help the plant to avoid water stress. If this leads to improvements in tuber quality and quantity, it is important for the grower since it influence the economical outcome.

Bishop and Grimes (1978) found that the improved soil physical conditions, due to inter-row subsoiling, increased tuber yield with 6-10% and Pierce and Gaye Burpee (1995) reported generally increasing total yields (2.9-8.7 Mg ha^{-1}) but that it was only valid at seed tuber spacing of 25 and 28.0 cm, not at 36.0 cm. Henriksen et al. (2007) on the other hand saw no effect from inter-row subsoiling on the average total yield in two of three experimental years. The year when a significant increase in total yield was seen, the summer was very hot and dry. The connection between yield responses due to subsoiling and the climate and irrigation management has been investigated by Soane et al. (1987). They found that yield benefits were obtained when all the following interaction factors occurred in combination: a droughty soil, a drought sensitive crop and a dry summer, and that the yield benefit was primarily due to the alleviation of moisture stress. When there was an absence of significant water stress or was there was no significant compaction in the unloosened subsoil nil response was obtained.

There are no benefits in applying excess water to the crop; this has been shown by Halderson et al. (1993). They compared irrigation levels based on the evapotranspiration (ET) rate; the tested levels were 1.0, 1.2 and 1.4 times ET rate. The results showed that the total yields from inter-row subsoiled plots were equal to, or lower than the total yields from conventional tillage plots at all irrigation levels and tillage depth (30.0 cm, 38.0 cm, and 46.0 cm). A factor that might have contributed to the negative result was that the roots could have been disturbed during the inter-row subsoiling. A positive result from this study was that the yield of large tubers increased at optimal irrigation (1.0 times ET).

The effect on marketable yield was ambiguous, the first year it increased at both seed tuber distances whereas it decreased the next year at 36.0 cm and increased at 25.0 cm seed tuber spacing. In a summer with dry climate and high temperatures, the increase in yield by inter-row subsoiling was larger that other years, but there were no difference in marketable yield between the two treatments (Pierce and Gaye Burpee 1995). Also in the experiment of Henriksen et al. (2007) the results are unclear, only in one of three trial years an increase in marketable tuber yield was seen, in the other two it was unaffected by subsoiling treatment.

In a trial where furrow irrigation was used, the total tuber yield did not differ in the first year between the subsoiled and non subsoiled plots, but in the second year the total yield increased significantly. In both these years the total percentage of U.S No 1 tubers increased with 4.6 % and 5.7 % respectively. In the first year the U.S No 1 graded tubers increased most in the size range from 114-284g were as next year the trend was that the tubers over 284g increased (Sojka et al. 1993a). Sojka et al. (1993b) reported increased percentage of U.S. No. 1 potatoes weighing more than 284g in both their experimental years with sprinkler irrigation, due to inter-row subsoiling.

No negative results have been reported as a consequence of inter-row subsoiling. Buxton and Zalewski (1983) announced that both tuber yield and quality were unaffected by the treatment even on soils with severe soil compaction. Holmstrom and Carter (1999) concluded that subsoiling prior to the potato planting improved neither the crop yield nor the quality. Halderson et al. (1993) declare that inter-row subsoiling, applied after seed piece setting, tend to reduce total yield, while the yield of U.S. no 1 tubers were unaffected. Ross (1986) also found that potato tuber quality, as expressed by the percentage of U.S No 1 grade were not significantly affected by subsoiling for all irrigation rates. Neither the mean number of tubers per ridge nor root weight recovered was affected by any tillage treatment (Sojka et al. 1993a).

Tuber quality

Specific gravity is a measurement of the density of a material that it is conducted in water. If a material has high density it also has high specific gravity. When it comes to tubers the specific gravity is of interest because it tells how much starch the tubers contain; high specific gravity on the tubers is wanted in the starch industry. Two tubers of the same size can have different specific gravity depending on its internal composition.

Inter-row subsoiling cause no significant changes in specific gravity (Sojka et al. 1993b; Pierce and Gaye Burpee 1995; Sojka et al. 1993a; Halderson et al. 1993). However there was an indication of slight beneficial effect of subsoiling on tuber specific gravity at irrigation rates below 400 mm but this was not statistically significant (Ross 1986). Yields of undersized (<113g) and oversized (>283g) tubers were not affected by zone tillage. The yield of medium sized tubers (113 to 283g) was largely unaffected by zone tillage (Halderson et al. 1993).

Effects of inter-row subsoiling on malformed tuber yield were inconsistent. In one year there were no effect, but in the following seasons it reduced the percentage of malformed potatoes from 11.0 % to 8.3% and from 11.8 to 8.8% respectively (Henriksen et al. 2007). Halderson et al. (1993) found that inter-row subsoiling decreased the percentage of malformed tubers one year but increased it in the following year. Increased amount of malformation among the tubers weighing over 284g was also reported from Pierce and Gaye Burpee (1995) who also found an increase of hollow heart disease.

Differences between cultivars

Different cultivars have different genetic characters that might influence their responsiveness to subsoiling. Russet Burbank is the most frequently used cultivar in the studied trials, other cultivars might give other results.
Miller and Martin (1986) tested three cultivars, Russet Burbank, Nooksack and Lemhi, and found that there was a significant difference in how they responded to subsoiling. Nooksack and Lemhi often reacted similarly, while Russet Burbank was the one standing out. With subsoiling and no irrigation, both tuber yield and quality increased compared to no subsoiling, and the effect was largest in Russet Burbank. The best improvements from subsoiling were seen on the percentage of U.S No 1 tubers with the most pronounced effects occurring during a dry summer.

In another trial conducted by Miller and Martin (1990) the cultivars Russet Noekotah, Norgold Russet and HiLite Russet were used. They found that yield and the size of the tubers were decreasing most in HiLite Russet when subsoiling was not applied. Noekotah and Norgold yielded about the same but Noekotah had fewer tubers, higher percentage of U.S. No. 1´s and fewer undersized tubers.
Internal defects and specific gravity were generally unaffected by subsoiling, but there were some minor difference among the cultivars. HiLite had more vascular necrosis than the other two cultivars and that resulted in a lower percentage of tubers without internal defects. The specific gravity was about the same in all cultivars (Miller and Martin 1990).

Discussion

Subsoiling seems to have positive effects on soil properties if it is conducted under optimal condition, which means dry soil. However, if the soil is wet, subsoiling can lead to impaired soil conditions. It is more likely to have dry soil in the autumn which therefore is the best time to conduct subsoiling. On the other hand, if the soil is prepared in the spring after subsoiling, the heavy machines may cause recompaction of the loosened subsoil. Subsoiling should therefore, according to my opinion, be carried out in the spring when the soil is dry and after the potatoes are planted. However, if the soil does not dry up enough, subsoiling may be impossible to carry out without causing any negative effects on the soil structure. Subsoiling must not be carried out too late after emergence since it may cause persistent damages to the growing roots.

The effects of subsoiling will decline with time, although it seems like the effect, at least to some degree, can persist in two maybe three years. To me this seems quite natural that recompaction is taking place if you apply conventional practices. Subsoiling is only a way to loosen up a compacted soil and do not serve as a protection. One way to minimize recompaction is to apply controlled wheel traffic then you restrict the recompaction to small areas in the field. However it seems like subsoiling must be applied each year if one shall be sure of getting best results (figure 3).

High soil strength and high bulk density are results of compacted soil that might limit the plants root system. I think it is important not only to focus on how we get rid of the problem but also how to prevent them. The possible to construct machines that are as effective as today but causing less soil damage can be investigated. However, the easiest way to prevent soil damages is to avoid all operations when the soil moisture content is high and extra susceptible to high pressures.

It can also be of interest to look at the crop rotation. Today many growers are applying a very intensive crop rotation that might damage the soil structure by consuming much organic material without any input. In a soil with high level of organic matter more microbiological activity is taking place and that is contributing to a good soil structure. If a more sensitive crop rotation is applied, with some crops contributing to the organic material rather than consuming it, the soil structure can be improved.

Subsoiling reduces the soil resistance which allows the roots to penetrate deeper but seem to have little effect on the size of the total root system (Ross 1986). It seems like the deeper rooting can be of advantage in avoiding water stress in periods of drought and thereby give a higher yield than conventional treatments. But when sufficient water is supplied by irrigation the shallower root system do not seem to inhibit the tuber production.

The clear interaction between irrigation and potato yield were shown in the experiment of Ross (1986) where the yield quantity at different irrigation levels were investigated. Subsoiling showed significantly (0.05 probability level) improvements on total yield if the irrigation was below 200 mm. However it had little effect at irrigation levels of intermediate levels and even tended to decrease the yield at water application exceeding 550 mm.

The yield reduction occurring with high amounts of water is surprising. Since subsoiling is improving the infiltration in the field, one could expect a positive effect on the yield. The opposite results may be due to that the improved water movement increases the leaching of mobile nutrients such as nitrogen from the field. Another explanation might be a failure in the drainage system, resulting in reduced oxygen levels.

The difference between cultivars might be due to differences in water stress sensitivity, since water stress is affecting the yield. In the article of Errebhi et al. (1999) some cultivars biomass partitioning between root, fruit, shoot and tubers were investigated. It appeared to be quite large variation between them, and that might be an explanation. Cultivars that give priority the roots might stand times with limited water supply better the others.

The conclusion from this is that proper irrigation management can overcome the need of subsoiling. However, subsoiling can have positive effects on yields if irrigation is not used or not frequently applied, though it reduces water stress under drought conditions.

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