SOIL COMPACTION: EFFECTS AND AMELIORATION

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Abstract

Soil compaction is widespread throughout southern Africa, especially under intensive cultivation. The paper reports on various research projects in which the author has been involved over a period of more than 30 years.

Soil compaction was identified as the cause of 'growth stunting disease' in sultana grapes and 'red death' in cotton at the Lower Orange River and Vaalharts irrigation schemes. In an experiment growth stunting disease was eradicated completely and yields of sultanas increased substantially by deep cultivation, which eliminated compacted soil layers. Ripping increased the quality of tobacco, and consequently the unit price and income per hectare, compared with conventional tillage. Phosphorus and potassium uptake by plants was severely reduced by soil compaction. Even very high P applications could not overcome the poor P uptake from compacted soil. In sandy soils compaction did not interfere with water infiltration into deep soil layers, but prevented roots from reaching and utilising this water. This led to poor water use efficiency, increased drought hazard under rainfed conditions and increased irrigation costs. The considerable residual effects following a single treatment to eliminate a compacted soil layer is noteworthy.

Keywords: compaction; root development; phosphorus uptake, potassium uptake.

Introduction

Subsurface soil compaction is a widespread and serious problem throughout the cultivated areas of South Africa and neighbouring countries such as Swaziland. It occurs under rainfed cropping and irrigated agriculture. Most soils in southern Africa are inherently vulnerable to subsurface compaction. Intensification of mechanised agriculture on these soils has led to severe compaction problems.

Much compaction research has been undertaken in irrigated areas in the central parts of the country (Vaalharts and Lower Orange River) and the Eastern Cape. It also included rainfed cropping areas like the Rûens and Swartland in the Western Cape and the Highveld. More recently severe soil compaction was unexpectedly found on granite-derived sandy soils in the Nelspruit area, which may also be relevant to the large granite derived soil areas in the rest of the Lowveld and Swaziland. A reconnaissance survey revealed widespread soil compaction at citrus estates in Swaziland also.

This paper will focus mainly on the effects and amelioration of soil compaction.

Effects of wheel traffic and secondary cultivations on soil compaction and root development

During the early 1960s Laker and others conducted various field surveys in rainfed maize fields in the western Highveld, mainly the Northwestern Free State. Compacted layers that were too hard to cut by spade were often found with their upper limits at depths of between 20 to 25 cm below the soil surface. They were found mainly on aeolian structureless sandy soils with less than 10% clay, almost no silt and a sand fraction totally dominated by fine sand.

Several subsequent unpublished studies in this area showed that these compacted layers could be eliminated by cultivation with tined implements that would break them up. Tines that penetrated the soil to a depth of about 45 cm were effective, as they only had to get below the compacted layer. Results were variable, however. In a fertiliser experiment with maize it was noted that yields differed per row and not per treatment (CD Koch, personal communication). Rows where the tractor wheels were closer to the row gave lower yields than where the tracks were further from the row. Root distribution studies by Koch clearly showed that roots could be boxed in above the compacted layer if the tractor wheel moved close enough to the row to recompact the zone between the ripped zone and the maize row.

This led to the introduction of the very important principles of rip on row, i.e. ripping directly below where the maize row was going to be planted, and controlled traffic, i.e. driving on the same tracks during all operations and keeping these tracks as far as possible from rows. The beneficial effect of rip on row on maize grain yield on a soil which was prone to compaction in the Northwest Free State is shown in Table 1. Du Preez *et al.* (1980) found that a simple cultivation system of controlled traffic gave the same volume of loose soil as ridging. They pointed out that "the main offender was the tractor wheel running in the open furrow". This has also been observed by the author in cultivation demonstrations where the tractor wheel ran in the plough furrow each time.

Table 1. Experimental results of rainfed maize yields under different cultivation systems on apedal sandy soils in the Northwest Free State which are prone to compaction (Results of work by Astrid Hattingh).

Cultivation system	Grain yield (t/ha)
Rip on row	5,2
Plough – 25 cm	1,5
Cultivator – 15 cm	1,2

Whether cultivation with tined implements to eliminate compacted layers will be beneficial or not thus depends on a number of factors related to (i) how the primary cultivation is done, and (ii) how secondary cultivations and other subsequent operations are executed. If a large number of secondary cultivations are done haphazardly with uncontrolled traffic, this will negate all possible benefits of the primary cultivation. This was clearly demonstrated in cotton at Vaalharts where deep ploughing at 25 cm was followed by up to nine secondary cultivations, which led to extremely dense pans at about 15 cm from the surface. Most of these secondary cultivations which compacted the soil were done before planting. The situation was aggravated because discs, which are extremely destructive implements, were used for the secondary cultivations. A similar situation was observed in Swaziland where soil was prepared for the establishment of a citrus orchard. Ripping was done in four directions – cross ripping and ripping in two diagonal directions. This was followed by eight or nine shallow disc cultivations without traffic control, compacting the soils to higher densities than ever before, before the trees were planted.

In the apedal fine sandy soils of Vaalharts, Du Preez *et al.* (1980) found that irrigation alone (without secondary shallow cultivations) caused the loose cultivated soil to settle to densities that were so high that root development was restricted by the high soil strengths that occurred under slightly dry soil conditions. They found no difference between flood irrigation and overhead sprinkler irrigation in this regard.

The type of soil will also have a large influence on the occurrence and magnitude of this effect. In unpublished preliminary studies on the identification of 'hard setting soils' Laker found that these were apedal soils with the following properties:

- More than 50% (fine sand + silt), with usually more than 20% silt *and*
- Less than 35% clay.
- The most extreme ones being E horizons.

Effects on water use efficiency

Soil compaction has a major negative effect on water use efficiency. This is undoubtedly its main effect in the case of rainfed maize in the Western Highveld with its low and erratic rainfall. Plants will suffer from severe drought stress in a soil with plenty of plant-available water where a compacted layer prevents roots from reaching water in the subsoil. This is particularly the case in soils with Soft Plinthic horizons, which have very high water storage capacities in the deeper subsoil. It is often erroneously stated that the benefit of ripping is to improve water penetration into the deeper soil layers, especially on the sandy soils where water penetration into deeper layers is not limited significantly by a compacted layer. In fact it is the ability of the roots to reach this water that is improved by ripping. This was clearly demonstrated in a Cartref form soil (having a deep E horizon) near Nelspruit. A trench was dug across adjacent ripped and unripped areas. In the ripped area the whole profile was slightly moist. In the unripped area the layer above the compacted layer was completely dry, while the soil below the compacted layer was saturated because the roots could not utilise this water. Similarly, under irrigation plants in a soil with a compacted layer can also suffer drought stress although the subsoil is waterlogged.

Table 2. Treatments applied in deep cultivation trials with sultana grapes on four farms at the Lower Orange River irrigation scheme (From: Laker, 1980).

Treatment	Description
1	Farmer's normal shallow cultivation – rotavator or disc
2	Ripper (45 cm); without organic matter
3	Trench (90 cm) between rows; organic matter only at bottom
4	Trench (90 cm) between rows; organic matter mixed throughout

Effects on yield and quality of specialized crops

During the 1960s so-called 'red death' in cotton became a very serious problem at the Vaalharts and Lower Orange River irrigation schemes. Simultaneously 'growth stunting disease' ('groeistilstandsiekte') became a very serious problem in sultanas (Thompson seedless grapes) in the Lower Orange River area (Du Preez *et al.*, 1980).

By the mid-1960s it was estimated that as much as 25% of the vineyards in the Lower Orange River irrigation area were affected by growth stunting disease and that as much as 90% of the vines in some vineyards were affected (Laker, 1980). Surveys by Theron (1955) and De Villiers (1962) found that extremely poor root systems and compacted subsoil layers, called 'plough pans', were the most striking features of the vineyards in the area (Laker, 1980). This was confirmed during extensive field surveys in 1967, which clearly distinguished for the first time between healthy vineyards, growth stunting disease and other specific problems, such as potassium and zinc deficiencies and salinity (Laker, 1980). Overseas Martin *et al.* (1961) increased grape yields from 7,9 to 18,6 t/ha by means of deep cultivation. In his standard text on viticulture Winkler (1965) stated that: "High soil fertility, it is generally agreed, is not so important as soil structures that favour extensive root development."

Laker consequently established field experiments in the Lower Orange River area in July 1968, which included three types of deep cultivation treatments, in four vineyards, two with growth stunting disease and two healthy. The treatments applied in the experiments are given in Table 2, and descriptions of the experimental lay-outs were reported by Laker (1980). Yields (fresh mass of grapes harvested) were determined for several seasons, while observations on growth stunting disease were also recorded at one vineyard in the 1971/72 season.

No yield differences were found during the first summer season (1968/69), but during the next season (1969/70) the deep cultivations implemented in the winter of 1968 caused much higher yields than the control in the growth stunting disease vineyard labeled Experiment 2 (Table 3). Observations made in

Table 3. Effect of type of cultivation on yields of sultanas in Experiment 2 for three seasons after a single differential cultivation in July 1968 (From Laker, 1980).

Treatment	Yield (kg fresh fruit per vine)		
	1969/70	1970/71	1971/72
1	12,4	7,7	9,2
2	24,6	12,2	12,0
3	18,0	12,6	13,0
4	20,2	10,9	13,5
LSD (P = 0,05)	7,2	ns	ns

this vineyard in 1971/72 showed that in the control plots *23 of the 24* experimental vines (i.e. excluding the border rows) had severe growth stunting disease symptoms. In contrast *not a single one* of the 72 experimental vines in the three deep cultivation treatments showed growth stunting disease symptoms.

Surveys in tobacco fields in the Nelspruit area in the late 1990s by Laker revealed widespread soil compaction, especially on light gray sandy soils (mainly of the Cartref and Fernwood forms) derived from granite. The two main problems with tobacco in the area were reported to be related to quality and phosphorus uptake. Even very high P applications were reported to be unable to increase P uptake. In a pot experiment with tobacco in a light gray sandy soil from the area increasing the bulk density from 1400 to 1600 $kg.m^3$ reduced the dry leaf mass from 94.2 to 53.7 g/plant (Dreyer *et al.*, 2000), i.e. a 43% reduction in dry leaf mass. In a field experiment ripping under the planting ridge (similar to 'rip on row') increased the yield by 8,8% (Dreyer *et al.*, 2000) compared with conventional tillage. The rip treatment increased the quality of the tobacco statistically significantly, from a value of 955,97 cents/kg for conventional tillage to 1125,91 cents/kg for the rip treatment, an increase of 17,8%. Combining the factor for increased yield (1,088) with the increase in price per kg realised (1,178), gave a factor of 1,088 X 1,178 = 1,282 in terms of gross income per hectare for the farmer, i.e. the rip treatment gave a gross income increase of 28,2% over the conventional tillage.

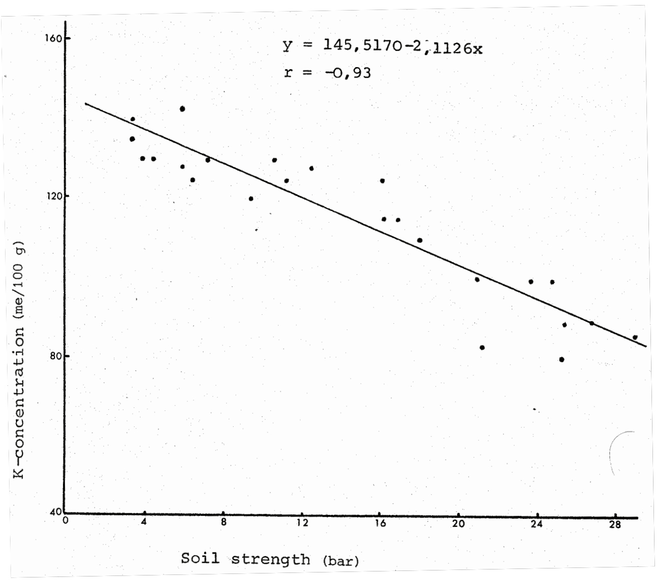

Figure 1. Relationship between soil strength and K concentration in wheat leaves (From: Bennie & Laker, 1975).

Effects on nutrient uptake by plants

Analyses of sultana leaves collected from healthy and growth stunting disease vineyards during October 1967 revealed low potassium levels in the leaves from the growth stunting disease vineyards (Laker, 1980). Topsoils from growth stunting disease vineyards had somewhat lower exchangeable potassium levels than the healthy vineyards, but this did not fully explain the low K levels in plants with growth stunting disease and it was concluded that an additional factor must be involved. Boynton *et al.* (1958) found no relationship between soil K levels and K deficiencies in grape vines in a study in California. They found that poor K uptake was caused by poor root growth due to unfavourable soil physical conditions. In view of the widespread occurrence of soil compaction in the Lower Orange River area it was concluded that this might be the additional factor involved.

In subsequent pot experiments with wheat as the test crop, it was found that K concentrations in top growth could be reduced by as much as 40% by simply compacting the soil (Figure 1), without any changes in soil K levels (Bennie and Laker (1975). In this specific experiment top growth, K concentrations in the plants and total K uptake were all highly significantly correlated with the mass of roots longer than 10 cm, i.e. with the mass of long, thin, efficient roots (Bennie and Laker, 1975).

In the pot experiments of Bennie and Laker (1975) with cotton the phosphorus concentrations in cotton leaves declined sharply with increasing soil strength (compaction) at relatively low soil strengths (Figure 2). In the pot experiment of Dreyer *et al.* (2000) with tobacco, P uptake by the tobacco plants was reduced from 116,2 mg/pot at a bulk density of 1400 $kg.m^3$ to 73,4 mg/pot at a bulk density of 1600 $kg.m^3$. This is a reduction of 37%, which is in the same order as the 43% reduction in dry leaf mass reported above.

Fertility factors, e.g. very high inherent soil fertility or extremely low fertility, can mask the effects of soil compaction and of

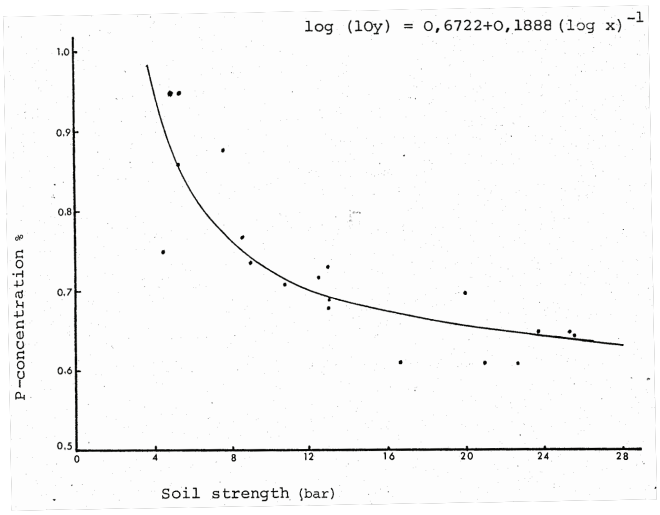

Figure 2. Relationship between soil strength and P concentration in cotton leaves (From: Bennie & Laker, 1975).

techniques to eliminate compacted layers. Laker (1980) indicated that the growth stunting disease vineyard which did not respond to deep cultivation (Experiment 3) had a very low soil potassium level, whereas the growth stunting disease vineyard which did respond (Experiment 2, discussed under yield) had a moderate K level in the soil. It is postulated that in Experiment 3 the soil K level was too low to give a positive response to the deep cultivation. If the soil has very high inherent fertility in the topsoil, on the other hand, crops may perform well on it even in the presence of severe subsoil compaction. Close scrutiny of the results of Du Preez *et al.* (1979) showed that maize yields were highest on the most compacted plots, but that these plots had a greater volume of fertile topsoil around the roots because the maize was planted on ridges which were made from fertile topsoil. (See also Du Preez *et al.*, 1980.)

Conclusions

It is evident that subsurface soil compaction and its amelioration are not simple problems and that results that appear to be anomalous or conflicting are often found. In the vast majority of cases close scrutiny of situations gives clear explanations for the apparent anomalies and shows that the results are, in fact, logical and not anomalous, conflicting or confusing. Relevant questions to consider include the following:

- Was ripping or another form of deep primary cultivation followed by a number of shallow cultivations during which random traversing of the field was done – and how many of these secondary cultivations were done before planting? Or was a strict system of controlled traffic followed during all cultivations and other field operations?
- Was a system of 'rip on row' employed or was there no coordination between the position of the rip line and the position of the plant row during field operations? Were there any wheel tracks of secondary cultivations or other field operations between the rip line and the plant row?
- What was the distance between plant rows and wheel tracks?
- Did tractor wheels run in open plough furrows or on top of the soil surface?
- Was flood or high intensity overhead sprinkler irrigation applied which could lead to dense settling of the soil subsequent to ripping?
- What was the inherent susceptibility of the soil to compaction? Was it a typical 'hard setting' apedal fine sandy soil (especially one with an E horizon and/or some silt) or was it a soil with an inherently stable structure, such as a Shortlands soil?
- What was the inherent fertility status of the soil, e.g. in regard to K and P?
- In the case of perennial crops, were yields, etc. measured in the season when different treatments were applied, or was enough time allowed to eliminate aspects such as the build-up of reserves in the plants, etc., taking into account that two or more seasons may be needed for this to happen?

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