THE EFFECTS AND MANAGEMENT OF COMPACTION IN AGRICULTURAL SOILS

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Abstract

The compaction of soils used for crop production is becoming an increasingly important consideration in South Africa following the shift towards reduced tillage and increased mechanisation of in-season operations and harvesting. The intensification of dairying has also been found to have a deleterious effect on soil quality, particularly in terms of compaction by trampling, which results in losses of production, pasture quality and hydraulic conductivity. This paper considers the extent and impact of compaction together with management strategies for minimizing compaction in agricultural lands. Soils are most vulnerable to compaction when they are close to the field capacity water content. South African topsoils with clay contents of less than 15% are generally easily compacted, and careful management of these soils, such as controlled traffic in lands, regular testing for compaction and its rectification through tillage, will ensure that soil productivity is maintained. A common error when testing for soil compaction is to force a sharpened steel probe into the soil to test for hard layers. This method is only successful when the whole profile has been allowed to become wet to field capacity. Correct testing for compaction may help to reduce production costs through indiscriminate tillage. Land management techniques are vital in ensuring that soil physical conditions are not compromised and that practices which increase the organic content, reduce tillage and sustain utilization of agricultural land are encouraged.

Keywords: soil compaction, effects of compaction, managing compaction

Introduction

The soils in most crop production areas of KwaZulu-Natal have generally had a long history of intensive tillage using mouldboard or disc ploughs and disc harrows, the latter implement being particularly damaging to soil structure. The compaction of soils used for crop production is becoming an increasingly important consideration in South Africa following i) the shift towards reduced tillage and ii) increased mechanisation of in-season operations and harvesting. Compaction is undesirable in that it negatively influences the physical, chemical and biological properties of soils for crop production and results in conditions which are not optimum for plant growth. Compaction of a soil depends on the pattern of load and stress applied as well as the soil moisture content, particle size distribution, organic carbon content, aggregate stability and the initial condition of the soil prior to the application of pressure or stress.

Soil compaction is defined as a detrimental modification of the pore structure when total porosity, particularly air-filled porosity, is so reduced that aeration, root penetration and drainage are restricted, bulk density is increased and hydraulic conductivity and permeability are reduced (Hillel, 1980).

For agronomic purposes, the associated processes that are altered by an increase in bulk density directly affect crop production. In cultivated land, the compaction process (forcing solid soil particles closer together) occurs under the influence of an external force, such as that exerted downwards and laterally by the wheels of a tractor. In tilled systems for annual crops, 60% or more of the soil surface area of a field can be trafficked during planting, fertilizing, herbicide application, cultivating and other pre-harvest activities. Research has been conducted on both irrigated and rainfed cropping soils and has indicated the presence of compaction under both systems (Moolman and Weber, 1978; Mallet *et al*, 1985; Berry, *et al,* 1984, Mallett *et al*, 1987; Bennie and Burger, 1980a). Soil crusting under raindrop impact, has been extensively researched and documented, and while the effects on crop production and soil degradation are significant, only compaction associated with mechanical tillage and animal trampling will be discussed in this paper.

Soil physical properties influencing compaction

Soil texture

Tillage research conducted in South Africa has shown that soils with clay contents of less than 15% in the tilled layer are very vulnerable to compaction. Mallett *et al* (1985) reported that two of the over four million ha under maize had B21 horizon clay contents of 15% or less and of this area 300 000 ha had clay contents of 5% or less. Table 1 indicates the relationship between clay content of the tilled soil layer and the maximum number of seasons of no-tillage before tillage may be required to loosen compacted layers.

At higher clay content (>25%) the number of seasons under no-till, before tillage is required, increases dramatically.

Table 1. Suggested maximum number of seasons of no-tillage before tillage may be required.

Clay content of tilled layer (%)	Number of seasons		
	Dryland grain crops	Irrigated grain crops	Silage crops
1 - 8	1	1	1
9 - 16	2	2	2
17 - 24	4	3	2
25 - 32	8	5	3
33 - 40	16	8	5
> 41	32	11	7

Soil particle size and soil moisture content

A more accurate evaluation of soil compactibility may be obtained using soil particle size analysis data to predict the soil's tendency to be compacted by an external force. Figure 1 (van der Watt 1969), relates soil compactibility to the proportion of soil particles < 0.02 mm in size (silt + clay) and those particles 2 -0.2 mm in size (coarse sand). The research used to generate Figure 1 was based on mixtures of coarse, medium and fine soil particles in various proportions, which were brought to a moisture content at which maximum bulk density would occur, and then compacted in a compaction mould. Only non-swelling samples were studied, and soils very high in silt, clay and organic matter were excluded. The more coarse-textured (sandier) samples were maximally compacted at about 0.033 MPa matric suction, and the finer-textured (30% or more clay) samples at about 0.10 MPa matric suction. In other words, the sandier soils were maximally compacted at relatively higher soil water contents than the clayey soils. The standard matric suction estimate for field capacity (the upper limit of plant available soil water) is 0.010 MPa matric suction, and the permanent wilting point is at 1.5 MPa matric suction. These results indicate that soils are most vulnerable to compaction when moisture availability is close to the optimum for plant growth. This explains why Table 1 indicates that irrigated crops, which are kept at close to optimum soil moisture status and yet trafficked during the in-season by operations such as post-emergence weed control and side-dressing of nitrogen, are likely to have a shorter duration under no-till than dryland crops on soils with equal clay contents.

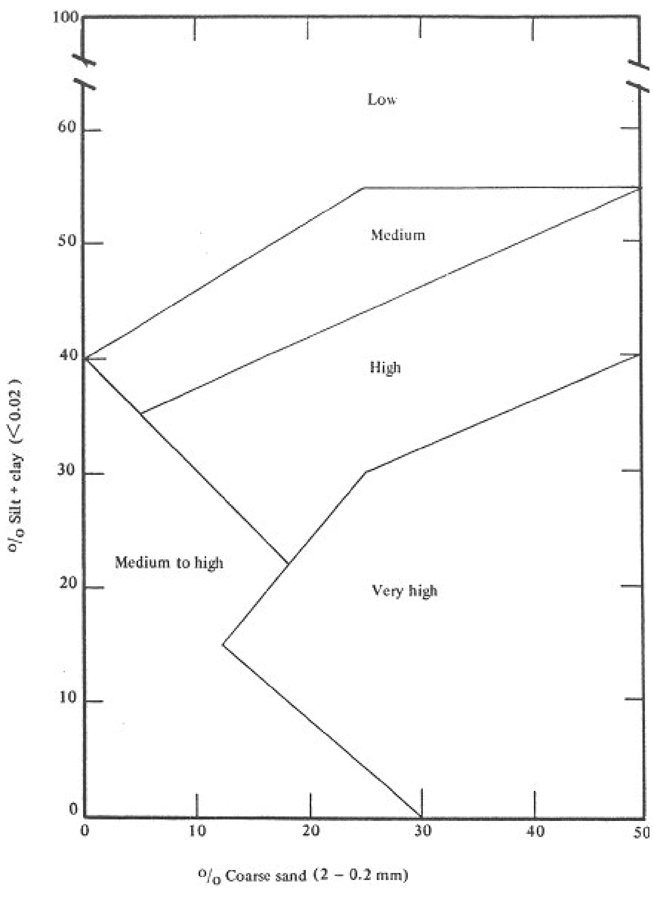

Figure 1. Soil compactibility diagram. Source: van der Watt (1969).

Organic carbon content

Soils with a high fine sand fraction are generally low in organic carbon levels and are found to be highly susceptible to compaction (Moolman and Weber, 1978; Moolman, 1981). Especially damaging is the practice of ploughing with the tractor wheel running in the open furrow where there is generally a higher soil moisture content and a lower organic matter level (Mallett *et al.,* 1985). The effects of various tillage implements and vehicular traffic will not be discussed further.

The change from conventional to no-till systems leads to an increase in organic carbon levels in the soil. However, compaction can be a problem in no-till systems and can reduce crop yields. Over time nearly the entire surface of a field used for crop production under no-till can be covered with tracks, unless very deliberate management decisions are made to control traffic. The time interval before tillage is required may be extended by earthworm activity, the accumulation of organic matter in the surface soil layer over time under no-till, growing cover crops, and by soil loosening which takes place during the decomposition of the root systems of crops with tap roots, such as lupins. There is strong evidence to suggest that organic matter levels do increase under no-till, but the change is very slow. It may take up to 50 years of no-till production of pasture grasses for a previously tilled soil to return to the organic matter levels that were present when the soil was in its virgin state under natural veld. Choice of crop would also be important, as leguminous crops decompose more readily than most grasses, thereby contributing very little to organic matter levels.

Tillage trials have been conducted on the soils described in Table 2.

The second season of no-till on the Avalon sand at Dundee showed signs of compaction, as reflected by reduced crop growth and yield. A 0.5 ha block of the Doveton clay loam at Cedara, having a clay content of 35% in the 0-30 cm horizon, has been no-tilled continuously, and is currently in its 28th season. Excellent maize grain yields are still achieved on this soil, with an average yield of 6.9 tons/ha. The soil surface is very firm, but root growth lower down the profile is not restricted by compacted soil. Severe acidification of the soil surface developed after about 12 seasons under no-till, probably as a result of the acidifying effect of a side-dressing of nitrogen in the form of LAN applied to the soil surface between the maize rows each season. This acidity has been greatly neutralised by application of lime onto the soil surface.

Compaction from trampling by dairy cattle

Livestock treading under intensive farming systems can cause compaction which negatively influences several soil physical properties leading to decreased pasture root and shoot growth, decreased yield, increased bare ground patches and lower long-term sustainability of such farming systems. Trampling and compression by hooves occurs at low to medium soil moisture contents, while plastic flow (pugging) occurs around the hoof

Table 2. Particle size data for the 0-30 cm horizons of a sandy soil from Dundee and a clay loam soil at Cedara, and results from applying Table 1 and Figure 1 criteria for these soils.

Soil series and texture class	Coarse sand (500–2000 μ %)	Medium sand (200-500 μ %)	Fine Sand (20-200 μ %)	Silt (2-20μ %)	Clay (<2 μ %)	Application of Table 1	Application of Figure 1 (van der Watt, 1969)
Avalon sand at Dundee	18	24	55	7	8	Can probably produce no-till dryland grain crops for 1 season before tillage is required	Very high compactibility
Doveton clay loam at Cedara	16	1	23	21	35	Can probably produce no-till grain crops for up to 16 seasons before tillage is required	Low compactibility

in wet soil and damages the grass sward. Pugging during the wet season can reduce pasture growth by 20-80% (depending on soil type) for up to eight months after the event (Ledgard *et al*, 1996). Reduced grazing pressure at critical times by retaining a rested paddock for silage or grazing may be a method of reducing compaction on susceptible soils, and could be a practical way of allowing natural rejuvenation of compacted paddocks (Drewry and Paton, 2000; Nie *et al*, 2001). In studies in New Zealand, shallow mechanical loosening of the soil (aerating) to a depth of 22 cm reduced penetration resistance, bulk density and increased hydraulic conductivity, total porosity, macroporosity and aggregation. However, after 40 weeks, the soil showed some reversion to the compacted state, suggesting that aeration may have to be repeated annually, and the greatest effect is achieved if the operation is done when the soil is at the plastic moisture limit to avoid irregular soil disturbance and pasture damage (Burgess *et al*, 2000). Soil loosening has been shown to be most beneficial under dryland pastures by significantly reducing bulk density and increasing soil porosity, hydraulic conductivity and more rapid drainage. This resulted in more rapid root growth, a more extensive root system, greater root length (36%) below 30 cm depth, and greater pasture production in the first three months of spring (Harrison *et al*, 1994). A comparison of soils never trodden by dairy cattle with those previously pugged at a depth of 50 to 100 mm indicated that hydraulic conductivity had decreased by 80% and pore size by 46%. Soil physical conditions had not fully recovered 18 months after the pugging event, and it is suggested that avoidance of pugging should become imperative by on/off grazing practices or by using feeding platforms as this may permit recovery (Singleton and Addison, 1999).

Consequences of soil compaction

Soil physical properties

Compaction alters the pore size distribution in that, as compaction increases, there is a decrease in the number of macropores (air-filled porosity) which in turn affects the aeration and hydraulic properties of the soil. Air is more easily compressed than water and thus it is the air-filled pores that are compressed first when subjected to force. Bulk density changes are thus greatest in unsaturated soil (Bennie and Burger, 1979). As a soil compacts, the bulk volume of the soil decreases, the air volume decreases, and the bulk density increases. Soil bulk density is commonly used as a measure of soil compaction. Bulk density is the mass of a volume of undisturbed oven-dry soil. As soil contains pore spaces, the actual density of a soil is less than the particle density. Soil compaction may also be characterised in terms of soil void ratio or total pore space. Total pore space is a measure of the soil volume that holds air and water. This value is usually expressed as a percentage and is known as the porosity. Thus, a soil with 50% porosity is half solid particles and half pore space - usually the ideal ratio for the optimum rootbed. Sands rarely reach 50% porosity, while clays often exceed this (Liengme, 1994).

One of the problems associated with compacted soil is reduced hydraulic conductivity, as evidenced by lower infiltration rates. The change of pore-size distribution resulting from compaction will reduce both the saturated and unsaturated conductivity of soil. A reduction in number of large pores following compaction will lead to decreased water movement in soil. Because compaction increases the number of contacts between individual soil particles there is an increased tortuosity (path length) of water flow, and therefore a lower conductivity (Reicosky *et al.,* 1981). This can result in waterlogging and anaerobic conditions in the compacted and overlying layers, particularly in lands under irrigation (Bennie and Burger, 1979).

Reduced infiltration rates can result from compacted subsurface layers. In a study of infiltration into alluvial soils in Botswana, steady-state infiltration rates of 73.5 mm/h were measured for uncompacted soils(bulk density less than 1.45 g/cm^3, while a rate of 34.8 mm/h was reached for compacted soils (1.73 g/cm^3) (Dikinya, 1994). In a study of infiltration rates into a Hutton sandy loam under no-tilled maize rotated with soyabean for seven years, irrigated under centre pivot, it was found that final infiltration rates of 240 mm/h were achieved on the plant row, while 96 mm/h were achieved on the controlled traffic wheel row. On conventionally tilled Hutton soils in an adjacent field, also under maize rotations with soyabean for seven years, a final infiltration rate of 22 mm/h was achieved. This is a further indication of the value of controlled in-field traffic as well as the value of increased organic content in the soil as a buffer to compaction (Mitchell and Thibaud, 2001).

Root growth in compacted soil

Mechanical impedance, or physical resistance to root elongation and function, is often cited as a limiting factor to crop growth and yield (Taylor, 1971; Bennie and Laker, 1975; Bennie and Krynauw, 1985; Mallett *et al.,* 1985). However, recent research has shown that the limiting factor is not physical resistance *per se* but is rather the restricted uptake of water and/or nutrients or inadequate gaseous exchange. Recent reviews by Brown and Scott (1984), Hamblin (1985), and McCoy (1987) give detailed discussions regarding soil physical and chemical effects on root growth. There is much evidence of a linear decrease in root mass in the case of vines (Van Huyssteen and Van Zyl, 1981) and wheat (Bennie and Laker, 1975). Roots compensate for the loss of length by thickening in compacted soils (Bennie and Burger, 1980b). This results in weakened and poorly developed root systems which may have a number of negative consequences, some of which are mentioned below:

- Decrease in top growth mass and plant height in maize (Bennie and Burger, 1980a), groundnuts (Bennie and Burger, 1979) and vines (van Huyssteen and Van Zyl, 1981).
- Reduction in nutrient uptake particularly P and K and micronutrients Fe, Mn and Zn (Bennie and Laker, 1975; Bennie and Burger, 1979, 1980, 1981). By limiting root development, compaction reduces the soil volume accessed by the roots and thus the nutrients most affected are those less mobile (P and K) and restrictions of mass flow affects the micronutirents.
- Reduction in lower total plant available water, which severely reduces yields if moisture is limiting at critical growth stages. At tasselling, maize in uncompacted soil was found to have effective rooting depths of 1.8 m, while in moderately compacted soil only reached 1.1 m (Botha and Bennie, 1982).
- Crop water use efficiency and irrigation efficiency is reduced in compacted soils (Botha and Bennie, 1982).
- Yields are reduced, up to 30% in maize (Botha and Bennie, 1982) and wheat (Botha *et al*, 1981).

Plant roots and many soil micro-organisms require aerobic conditions for optimal growth. Under aerobic conditions, most of the energy needed for growth and the active uptake of certain nutrients, is generated from cellular respiration in mitochondria. An accumulation of CO^2 due to restricted diffusion in compacted soil will reduce root respiration. Under anaerobic conditions, the energy yield from respiration may be reduced by as much as 94%. Metabolic energy reduction will therefore restrict root function and survival. Respiration is the most sensitive aspect of plant activity with regard to soil aeration, and reduction of respiratory activity is the first step in the growth limiting effects of insufficient aeration.

Pore size, distribution frequency, and continuity of pores all influence O^2 and CO^2 diffusion at constant soil water content. As a first approximation, a 10% air-filled porosity is the minimum desirable value. Oxygen stress may result from a reduction in the total pore volume or pore continuity as a result of soil compaction, but is almost always caused by waterlogging in soil. Waterlogging is likely to occur more frequently in soils where compaction has reduced the natural drainage rate. The effect of reduced oxygen content on root and plant growth is essentially restricted to soils which are saturated or nearly saturated with water, resulting in a reduction of the oxygen concentration below 2%. In a plant, this low level of oxygen triggers a complex response which includes the production of ethylene. At higher than normal concentrations ethylene inhibits root growth and root geotropic responses (Ycas and Zobel, 1983).

Observations indicating compaction

Observation of soil surface conditions and crop growth can give clues regarding the extent of soil compaction:

- *Water ponding and runoff:* Water on the soil surface could indicate compaction and will be most evident on nearly level ground and in low-lying areas. Runoff and water erosion will increase for compacted soil because less water can penetrate the compacted zone.
- *Increased power requirement:* It may also be possible to detect compaction in the tillage zone. This is because a compacted soil has more strength than a non-compacted soil and will require more power for tillage. An increased load on the engine or the need to gear down in portions of the field to maintain speed can indicate compacted areas.
- *Crop emergence and growth:* Early signs of compaction and crusting in the upper 2.5 cm of soil can be seen as plants germinate and emerge. Also, if food reserves in the seed are used up before the plant establishes a good root system the seedling may not emerge or it may emerge and then die. This will result in an uneven stand.
- *Crop colour:* Crops growing in compacted soils may look purple in early growth stages, and may show some yellowing during the growing season. The yellowing may be due to compaction-induced nitrogen or water deficiencies. These symptoms will develop immediately after a heavy rain or irrigation.
- *Wilting of plants:* Another visible sign of compaction is unexpected or early wilting of plants due to lack of water. This can result from a shallow root system. Compaction can keep plant roots from deeper soil zones and thus prevent the plant from extracting moisture from these zones.
- *Reduced yields:* When fertility, pests, and other cultural practices have been eliminated as possible causes of yield reductions, consider compaction a likely cause. Compaction can cause yield reduction of 0 to 60%.
- *Abnormal root growth;* in particular, roots observed to be growing horizontally even though soil moisture and the chemical environment is favourable deeper down the profile, is a good indicator of compaction. Comparisons of root growth within tilled fields and virgin soil may be made using the in-field pit and a pit dug near the fence line.

- *Shallow root systems;* due to a dense soil horizon need not imply reduced crop development and yield if the root zone is well aerated and constantly supplied with adequate water and nutrients. However, for crops grown under dryland conditions, as is generally the case in South Africa, reduced rooting density throughout the soil profile and particularly at depth, is likely to be extremely detrimental to crop growth when droughts are experienced during the growing season, due to a lower exploitation of soil water and nutrient reserves.

Measurement of soil compaction

While the observations mentioned above may indicate compaction, symptoms may also be associated with disease, fertility, or other problems. To guarantee that these observations are associated with compaction, soil investigations are necessary.

Soil strength, measured as the resistance to penetration of a probe, has been widely used as an index of a soil's resistance to root elongation. Penetrometer readings, as well as the degree of difficulty of pushing a probe into the soil, are subjective measures and have not been calibrated to yield performance. A dry soil is more difficult to probe than a wet soil. Soil probes and penetrometers only indicate that a compact layer may exist but give no indication of how extensively the plant roots penetrated the soil layer. Because soil strength is inversely related to water content, as mentioned above, it is important to have soil water contents at field capacity when conducting tests of soil strength using a probe. Bennie and Burger (1980) suggest that the greatest benefit from deep cultivation will be achieved if penetrometer resistance is maintained below 1.25 MPa (measured at field capacity) throughout the season.

The best way to identify compaction problems is to dig a soil pit and then to chip away at the exposed pit walls in order to test for hard soil layers. This often affords a good view of root penetration and possible restrictive layers within the profile.

An indication of hydraulic conductivity may be obtained by measuring the infiltration rate of water into a soil which is already at field capacity water content, using double-ring infiltrometers, and taking undisturbed cores for the measurement of bulk density.

Management strategies to minimise and reduce compaction

An effective method of loosening compacted soil is by deep mechanical cultivation. Deep ripping or ploughing has resulted in increased maize yields of about 30% once the compacted layer was shattered (Botha and Bennie, 1982; Berry, 1987**)**. Rip under row was found to be effective in reducing root impedence and improving access to soil moisture held at depth (Mallett *et al.,* 1985). There are several deep cultivation practices which are effective in breaking up a compacted layer, but most deep cultivation is expensive. Once compacted soil has been loosened, it is essential to ensure that compaction does not reoccur. The following suggestions may be of value:

1. Maintain organic matter levels. Soil organic matter has a profound effect on the structure of soils. Aeration, water holding capacity, aggregate stability and permeability are increased by increasing soil organic matter levels. Soils with high organic matter levels do not compact very readily. Some success may be achieved in preventing compaction using cover crops with strong fibrous roots, which help to support the loads applied to the surface by the wheels of farm machinery. Cover crops are only an option where rainfall exceeds 850 mm per annum in the summer rainfall areas, or where irrigation is available. Timing of 'burndown' herbicide sprays to kill the cover crop is critical to prevent the cover crop from consuming too much of the soil water reserves intended for establishing the cash crop (Berry, 1987).
2. Earthworms could possibly assist in moving surface applied lime down into the soil profile. Improvement in earthworm numbers in no-till soils can be achieved by using pyrethroid insecticides which have relatively lower toxicity to earthworms than those insecticides belonging to the carbamate group of chemicals.
3. Soil strength is the ability of the soil to resist or endure an applied force. Most soils have insufficient strength to resist the loads commonly applied at the surface during agricultural operations. Soil strength is inversely related to water content for the range of water contents commonly encountered in the field. Therefore trafficking of fields by agricultural machinery should preferably take place when the soil is relatively dry in order to limit increases in bulk density.
4. Where hydraulic conductivity has been reduced by compaction, the natural drainage of soils to field capacity takes longer. This will prolong anaerobic conditions in the soil. Where soils are naturally poorly drained, conservation tillage systems such as no-till are unlikely to produce a benefit in yield because improved rainfall capture and reduced evaporation could cause periods of near saturated water capacities.
5. On intensive pasture systems, compaction can be reduced by shallow aeration of the surface soil using a tined implement at the plastic moisture limit. Also, keeping stock off saturated soils by using a short grazing period then moving stock to a sacrifice or silage paddock until conditions improve. Allow sufficient rest period for pastures to naturally regenerate soil structure with wetting and drying cycles and earthworm activity by decreasing the duration of soil wetness. Careful irrigation management is vital in this regard.
6. Matching tractor weight to power requirements, using wider tyres if row spacing allows it or lower the tyre inflation pressure (Engels, 1994). Use tyres which give the greatest 'footprint'. The larger tyre will compact more of the soil surface but lower pressure will help reduce the depth to which the compactive forces will penetrate.
7. Controlled trafficking of fields: an attempt is made to match implement working widths so that the same tractor wheel tracks are used during all field operations during crop management, and also extending into subsequent seasons.
8. Use low volume spray technology so that large areas can be treated with relatively small and therefore lighter trailed or tractor-mounted herbicide and pesticide tanks.

9. Stay out of wet fields. Perform field operations in driest fields first, which will allow more drying time for fields that tend to remain wet.

10. Reduce tillage. One pass of the tractor increased soil strength from 0.57 to 1.43 Mpa and, after three passes, soil strength increased to 2.05 MPa. The greatest compaction occurs during the first pass (Bennie and Burger, 1979). A curvilinear relationship exists between the penetrometer resistance and root penetration. In cotton, 60% of the taproots studied, penetrated soil with resistance of 500 kPa, 35% penetrated zones of 1MPa and no roots were found in areas of 2.5 MPa (Taylor *et al*, 1966). No maize root elongation occurred in soils with resistance of 1.8 MPa (Barley, 1963). Thus, even one tractor pass can result in significant effects on root growth. Root and earthworm channels are not disrupted in no-till systems so channels can serve as paths for new root growth, and water, air and nutrient movement through compacted soil zones.

Conclusions

The effect of wheel-induced compaction in reducing root growth and thereby crop growth and yield is well documented. The least compactible soils are the clay loams found towards the interior of the Province but pockets of soil with low susceptibility to compaction occur amongst generally sandier soils and those along the coastal belt. Fortunately the perennial nature of sugarcane production and up to 10 ratoon crop cycles before new cane is planted diminishes the risk of compaction when compared with annual crops such as maize and soybeans grown in the interior of the province.

The use of tractors during side-dressing of nitrogen in the production of sugarcane could result in severe compaction if vehicles enter wet lands. This also applies to mechanical harvesters, infield loaders and transport equipment crossing wet lands. All mechanical field operations will cause some level of compaction. It is thus imperative that management practices be implemented to reduce tillage operation as far as possible or to utilize those operations that contribute least to compaction.The resurgence in interest in using legume cover crops such as lupins, sunn hemp and velvet beans to condition soils through increase of N from residues, could possibly help to reduce compaction through soil loosening provided by the decay of the tap roots of these cover crops. The effect of current dairy grazing practices are detrimental to pasture productivity and reduce soil permeability and hydraulic conductivity. Grazing practices which incorporate retaining paddocks for silage and supplements, used when paddocks are too wet to be grazed, reduced grazing pressure, careful irrigation management and adequate drainage can assist in reducing the effect of compaction.

Correct testing for compaction may help to reduce production costs through indiscriminate tillage. The age old mindset that a ploughed field exemplifies good farming is fortunately changing, and the sugar technologist and farmer need to use the soil and plant observations mentioned earlier, combined with soil investigations if compaction is suspected, to determine the soil's physical condition before resorting to tillage. Education is more appropriate than legislation and farmers must be involved in ensuring that strategies which are practical, profitable and sustainable are considered when identifying management guidelines to minimise the impact of farming practices on the environment.

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