# A REVIEW OF SOIL DEGRADATION AND MANAGEMENT RESEARCH UNDER INTENSIVE SUGARCANE CROPPING

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## Abstract

Grey soils are the most extensive group of soils in the dryland cane areas of the South African sugar indusry and comprise about 60% of the total area under cane. Soil factors limiting the yield potential of these soils include low water intake due to surface crusting, soil loss through erosion, low available moisture capacity, soil organic matter loss, acidification and waterlogging during wet seasons. Many current ratoon cane management practices such as interrow ripping, burning of crop residues at harvest, harvesting under wet conditions and using heavy infield transport, are incompatible with the physical, chemical and biological properties of these soils. Recent research initiatives into the main soil degradation processes, as well as improved management practices for reducing physical damage to soils, are reviewed. Soil management strategies based on crop residue retention, nutrient recycling, minimum tillage, ridge tillage, cover crops and intercropping, will help to conserve soil and water more effectively, increase soil organic matter, improve fertiliser use efficiency and reduce physical damage to soils during harvesting.

## Introduction

In 1989, a report commissioned by the Consultative Group on International Agricultural Research (Lal and Pierce, 1991) identified soil degradation, decline in genetic diversity and pest and disease problems as the 'three most pervasive threats to sustainable agriculture'. In many cane producing areas, including South Africa, yield productivity has remained fairly constant for many years despite the improvement in yield potential from newly released varieties.

In South Africa, sugarcane is grown on about 400 000 ha under a wide range of climatic and soil conditions. The group of grey sandy soils, also known as Entisols, are the most extensive and account for 60% of the total area under cane (Beater, 1957). The red soils, known as Oxisols, comprise the second largest group (19%), followed by the black Vertisols (13%) and brown humic Ultisol soils (8%).

During the past two decades a number of studies have been carried out in South Africa on the effects of some of the main soil degradative processes on cane productivity. These include soil losses through erosion (Platford, 1979; 1982), compaction (Swinford and Boevey, 1984), surface crusting (Dewey and Meyer, 1989), intake rate decline (Meyer *et al.*, 1988), salinisation (Johnston, 1978), irrigation water quality (Culverwell and Swinford, 1986), waterlogging (van Antwerpen *et al.*, 1991), and acidification (Schroeder *et al.*, 1994).

In Australia, factors such as compaction, loss of organic matter and acidification of soils were identified as reasons for decline in cane productivity in Northern Queensland (Wood, 1985). More recently, yield decline has been linked with a number of biological factors of which soil-borne fungi and toxins appear to be the most significant, and the effect is greatest under adverse soil conditions. In Colombia, yield decline on mollisols has also been positively linked with intensive mechanisation. Yield reductions due to compaction and/ or cane stool damage have been as high as 42% (Torres and Villegas, 1993).

This paper provides an examination of some of the recent research initiatives concerning the more important degradative processes that limit sugarcane production in the grey soil group, as well as appropriate management strategies to prevent degradation.

### *Soil crusting and erosion*

Many soils in the sugar industry are subject to various degrees of crusting, under both rainfed and irrigated conditions, before crop canopy. Physical disaggregation of soil particles occurs in reponse to the impact of raindrops, causing compaction of the surface layer which limits water penetration into the soil. This physical breakdown is accelerated where the soil surface solution has an electrolyte concentration too low to maintain physical structure during raindrop impact (Shainberg, 1985). Soil crusting is a precursor to soil loss through erosion. Erodibility ratings of some South Afican sugar industry soils have been determined by Platford (1982) using run-off plot measurements.

The results of both laboratory and field experiments with rainfall simulators, conducted on Longlands form soils, have shown that strong crusts do not form under a surface mulch such as trash. Average results from five trials conducted with a rainfall simulator over a five year period showed that, burnt tops had been spread, trash retained 89% of the soil and 58% of the water that would have been lost from bare soil (Platford, 1982).

More recently, the results of both laboratory and field rainfall simulator work have shown that preventing surface crusting under raindrop impact is one of the main reasons for reducing soil loss and improving water intake rates (Meyer *et al.*, 1988). Where no cover was present measured soil loss was found to be seven times higher than on a surface protected by a trash blanket. Ameliorants such as phosphogysum, molasses meal, polyvinyl alcohol and various polymers were less effective and far more costly than a trash blanket in reducing runoff and increasing rainfall use efficiency.

### *Compaction*

Harvesting and cane extraction during wet conditions is an unavoidable practice in many cane growing areas and uncontrolled infield traffic will cause most of the damage in terms of soil compaction, sealing/capping and physical damage to cane stools. The effect tends to be exacerbated in irrigated areas where there has been insufficient drying off before harvesting or where soils are not adequately drained.

In South Africa, Maud (1960) showed that, for most sugarbelt soils, the tendency to become compacted is greatest when their moisture content is near field capacity. At Pongola,where a deep Hutton form soil was severely compacted, bulk density increased and the macro pore space of the soil was reduced in the top 80 mm of soil, but there was no adverse effect on the yield of ratoon cane (Johnston and Wood, 1971). A subsequent investigation of a low yielding field on a similar soil, showed that infield loading during wet conditions caused severe soil compaction and damage to stools.

Swinford and Boevey (1984) and Swinford and Meyer (1985) found that moderate and severe compaction on a grey structureless sandy loam caused an increase in bulk density and soil strength and decreased air-filled porosity. Traffic over the row had a greater effect on yield than compaction of the interrow. Amelioration through ripping was only slightly beneficial. Tines seem to have a detrimental effect due to root pruning, which affects growth of the subsequent crop. It was concluded that yield decline from infield traffic is as much due to physical damage to stools as to a breakdown in structure and sealing/capping from soil compaction, particularly under critical soil moisture conditions.

The results of recent trials conducted on a Mollisol in Colombia have also shown that compaction can have significant effects on cane growth and yield (Torres and Villegas, 1993). Highly significant differences in cane yield were found due to the effects of different infield transporters that were evaluated. Damage induced by conventional wagons and dumpers running over stools resulted in a yield decline of between 21 and 45%, compared with only 10% decline where wheel passes were confined to the cane interrow. Passage of the grab loader passing over either the stool or interrow did not cause a substantial yield decline. Although significant increases in bulk density were generally not associated with any of the treatments, marked treatment effects on infiltration were measured.

Changes in soil surface properties leading to surface crust formation, reduced water infiltration, increased run-off and erosion, have also been measured in the Australian sugar industry. Prove *et al.* (1986) and Davidson (1956), compared cultivated and virgin soils to determine the effect of compaction on bulk density. For subsoils the virgin area was lower in bulk density compared with the cultivated areas for both soil types studied.

*Salinity/sodicity*

The effects of soil salinity and sodicity in the low rainfall regions of the lowveld have been extensively studied (von der Meden, 1967; Johnston, 1977; 1978 and Wood, 1991). A primary cause of soil salinisation in these regions is the development of high water tables, which allow capillary rise of saline ground water into the rooting depth of the crop. Poor quality irrigation water may be another source of salts.

A serious decline in yield on an estate in northern Zululand was linked to soil degradation due to a build up of salts in the soil (Culverwell and Swinford, 1986). At Mhlume in Swaziland, yield decline on duplex soils was partly arrested by installation of subsurface drainage (Workman *et al.*, 1986). A more recent study of a cane yield decline in Swaziland showed that, under a system of monocropping, there was a deterioration in both physical and chemical properties of soils when compared with adjacent virgin land (personal communication Henry, 1995[1]).

*Soil acidification*

The detrimental effects of toxic levels of exchangeable Al levels on cane growth are well documented for sugarcane (Sumner, 1970; Sumner and Meyer, 1971; Moberly and Meyer, 1975; Turner *et al.*, 1992, Schroeder *et al.*, 1994). Traditionally, soil acidity problems have been confined mainly to cane growing in the high altitude areas. More recently, an industry wide survey of soil fertility trends indicated that sandy soils on the south and lower south coast have progressively become more acidic during the past decade (Meyer *et al.*, 1989). The results of a more recent investigation, based on the use of a soil profile acidification model, have shown increased soil acidification on an estate in Zululand and other areas (Schroeder *et al.*, 1994). Accelerated acidification of soils under cultivation is most often due to the combined effect of oxidation of ammoniacal fertilisers to nitric acid, mineralisation of organic matter and leaching of basic cations from the soil.

Although the rate of soil organic matter loss has not been specifically researched, its role in N mineralisation has received considerable attention (Wood, 1965) and any loss in organic matter will seriously impact on the N mineralisation potential of soils.

*Preventitive soil management strategies*

Although the consequences of various soil degradation processes are generally well known it is only in recent years that research has shifted from using various reclamation management measures to testing preventive or conservation management strategies to prevent problems arising in the first place. For example, past research into soil loss concentrated more on methods of trapping soil once the soil had started to move, whereas current research tends to focus more on measures that tend to prevent detachment of soil particles in the first place. To this end a knowledge of soils is extremely important in successfully implementing preventive strategies.

Results of research and observations carried out in South Africa have shown that sugarcane management should differ according to soil type. This includes practices such as land preparation, selection of varieties, soil amendments, fertiliser amounts, timing and placement, trash management, season of harvest and irrigation scheduling (Moberly and Meyer, 1984). Management practices in most cane industries tend to be inconsistent with differences in soil types and the long term management of soils that is needed for sustaining cane production.

*Cane establishment*

Historically, cane production has involved intensive cultivation and with it potential degradation of the soil. To achieve good ratoon yields and lengthy ratoon cycles, good crop establishment as a first priority is essential. Cane fields are most vulnerable to soil erosion when they are ploughed or fallowed without a cover crop before replanting and before the plant crop has formed a complete leaf canopy.

The highly erodible soils, which are usually also very shallow, are particularly vulnerable under conventional tillage practices. It has been shown that deep tillage of soil before replanting land is unnecessary in most soils of the South African sugar industry (Moberly, 1972). Evans (1963) reviewed the results of numerous tillage trials conducted in various countries and concluded that there was little or no difference in yield between the various treatments that were compared. Researchers from the Bureau of Sugar Experiment Stations have also shown little or no benefit from increasing the number of cultivations in plant or ratoon cane (Braunack, 1994).

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*Green manuring and fallow management*

In recent years there has been renewed interest in this practice as a means of improving soil physical and chemical conditions as well as decreasing the incidence of pests and diseases specific to sugarcane. As early as 1925, Dodds and Edelman reported on the benefits of velvet beans, sunn hemp, cowpeas, lupins, rape, buckwheat and mungbeans in rejuvenating old cane land in South Africa. Pearson (1958) also strongly supported a move away from monocropping of sugarcane, with the yield increases due to green manuring offsetting the economic loss incurred during the fallow period.

In Swaziland, green manuring and a system of rotation was proposed as a solution for arresting yield decline (Workman *et al.*, 1986). Since then some excellent work has been carried out on the effects of green manuring on mainly duplex soils, both at the field trial and commercial stage. Hill (1988) reported that the mean yields of 13 fallowed and green manured 40 ha blocks of land compared with the mean yields of 13 non-fallowed blocks of land improved by 45% in the plant crop with residual effects of 25% measured in the the first and second ratoon crops. Follow-up trial work by Nixon (1992) confirmed large responses to bare fallowing (11-29%) and green manuring (10-54%) in the plant crop with small but non-significant residual responses measured in the subsequent ratoon crops.

**Table 1**

**Priority in recommending green manuring according to soil group**

| Soil group | Air-filled porosity status | Erosion hazard | N mineralsn potential | Cover crop requirement |
|---|---|---|---|---|
| **Grey**<br>Longlands<br>Westleigh<br>Kroonstad<br>Katspruit<br>Estcourt | Very low | Moderate to high | Very low | Very high |
| **Grey**<br>Fernwood<br>Cartref<br>Glenrosa<br>Mispah<br>Swartland | Low | High | Low | High |
| **Black**<br>Bonheim<br>Willowbrook<br>Rensburg | Low | High | Medium | Moderate |
| Arcadia<br>Milkwood<br>Mayo | Moderate | Moderate | Medium | Moderate |
| **Red**<br>Hutton (light) | High | High | Medium | Moderate |
| **Red/brown**<br>Hutton (heavy)<br>Shortlands<br>Oakleaf<br>Inanda<br>Kranskop<br>Magwa | High | Low to very low | High to very high | Low |

Yield increases were related more to prolific rooting brought about mainly by improved soil physical properties, particularly the air-filled porosity at 10 kPa suction (AFP) which increased on average from 11,9% (control) to 16,1% (fallowed). Infiltration rate and resistance to penetration were also significantly improved. Soil organic matter levels were adversely affected by bare fallowing but increased slightly with green manuring. Nitrogen availability was improved at low or zero N fertiliser inputs from green manuring. 15N tracer studies conducted in Taiwan indicated that green manuring contributed up to 15% of the N taken up (Prammanee, 1995). The contribution depends very much on the legume used. In Australia there has been considerable success in using soya beans on the wet tropical coast around Tully. It is believed that this legume is not only more efficient in taking up nitrogen, but also conserves N from leaching and denitrification.

Hill (1988), in Swaziland, using a discounted cash flow analysis over a 30 year period, showed that green manuring was on average 12,4% more profitable when compared with conventional cropping. Cover crops such as lucerne or cotton would be even more profitable, although irrigation would be necessary. In Australia, there is currently considerable interest in testing sugarbeet as a winter rotational crop in the Bundaberg area.

A potential benefit that has not yet been researched in the South African industry is the effect of green manuring in controlling pathogens such as RSD and mosaic, and nematodes. This could further improve the economics of green manuring. Undoubtedly, the biggest benefit from green manuring will be in the rainfed parts of our industry on soils prone to erosion. This includes mainly our grey sandy soils on slopes in excess of 5% where there is insufficient clay and organic matter to keep the soil together. Bottomland soils with low air-filled porosities would also benefit. The priority in recommending green manuring according to soil type is shown in Table 1.

*Minimum tillage*

In South Africa, research has shown that the minimum tillage system (strip tilllage), in which glyphosate is used to kill the old crop, results in minimal soil erosion and improved cane yield when compared with the conventional methods of land preparation (Iggo and Moberly, 1976). The benefit in terms of cane yield varies according to soil type, being considerable in some instances and negligible in others. Other measured benefits included increased soil organic matter content and reduced soil bulk density. A comparison of soil and water losses from conventional and minimum tillage replanting methods on a range of soil forms, using the rainfall simulator technique, showed that soil and water loss under a minimum tillage system could be reduced by 60% and 30% respectively, provided the crop had grown to the sixth leaf stage at the time of spraying (Haywood and Mitchell, 1987).

**Table 2**

**Recommendation for minimum tillage based on soil group**

| Soil group | Soil form | Erosion hazard | Minimum tillage |
|---|---|---|---|
| Grey sands to loams | Cartref<br>Fernwood<br>Glenrosa<br>Kroonstad | Severe, also prone to wind erosion | Strongly recommended |
| Red loamy sands to clay loams | Hutton<br>Red Oakleaf | Moderate | Recommended where < than 15% clay |
| Black clays | Arcadia<br>Bonheim | Low | Recommended where slope >20% |
| Brown humic | Inanda<br>Kranskop | Low | As for black soil group |

In Mauritius, four trials with minimum tillage conducted on sloping land have also shown increased yields over conventional systems (McIntyre *et al.*, 1984; McIntyre and Barbe, 1989). Yield increases in subsequent ratoon crops have also been recorded in South Africa, Mauritius and Australia. Minimum tillage has been widely adopted in the South African sugar industry, not only as an important soil conservation measure, but also in preventing the spread of disease by eliminating volunteer plants. The priority in recommending minimum tillage is very much dependent on slope and erodibility of soils, and is summarised in Table 2.

*Filtercake management*

Filtercake is a very much under-utilised resource in the sugar industry. Traditionally, its main benefit has always been regarded as a source of phosporus, and the results of past research have revealed that the most worthwhile growth responses were obtained on high P fixing soils of the Inanda and Hutton forms (Moberly and Meyer, 1978). However, the results of recent research have shown that decomposed filtercake can also act as a very effective conditioner of hardsetting duplex soils. Trials have shown that vertical mulching with filtercake to a depth of 450 mm in the planting row following minimum tillage, resulted in significantly higher yields and an increased number of ratoon crops (Meyer *et al.*, 1992). In a trial conducted at Mtunzini, the cumulative reponse to vertical mulching after a plant and eight ratoon crops amounted to 98,1 t cane/ha or 11,1 t sucrose/ha (Figure 1).

The main benefit appeared to be the aggregating effect of the organic matter from filtercake in binding soil particles. This led to an eight-fold improvement in infiltration rate, improved moisture holding capacity and cation exchange capacity, and an increased potential for nitrogen release. Buried filtercake lasts considerably longer than filtercke incorporated into the soil surface.

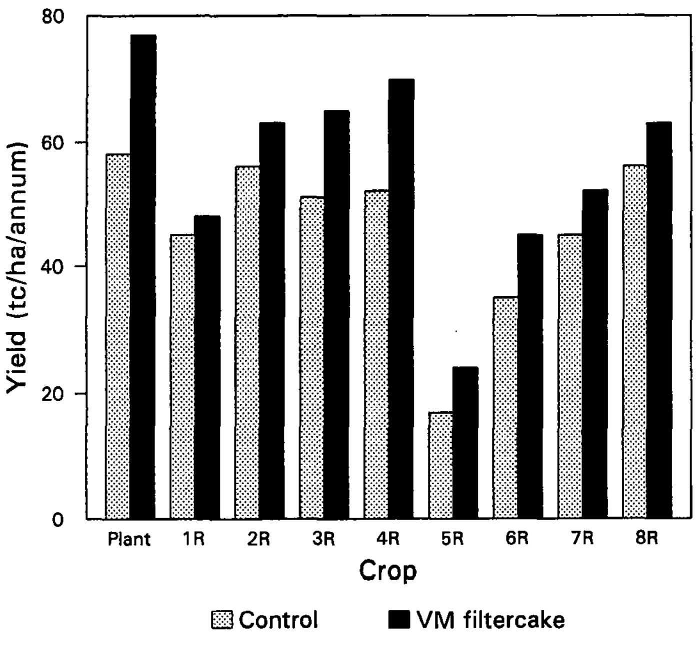


**FIGURE 1:** Long term response to vertical mulching with filtercake on a Longlands form soil at Mtunzini

*Trash management*

There is a clear trend in the industry towards more burning at harvest compared with trashing. There are logical reasons for this trend, but it is retrogressive in regard to conservation of soil and moisture, and also conflicts with growing public pressures regarding the pollution from burning. Green cane harvesting and trash retention are practised in many parts of the world. In South Africa, Thompson (1965) reported average yield responses of 10 tons cane per hectare per annum to trash retention in trials conducted under rainfed conditions on a cross-section of soils. He also noted significant increases in soil organic matter and cation exchange capacity, particularly in the top few centimetres of soil. Under irrigation the response to trash retention was found to be much lower (Thompson, 1966). In Zimbabwe, a substantial yield depression with trash retention was obtained under full irrigation (Gosnell, 1970). Trash conservation is a very effective means of reducing soil and water losses from sugarcane fields. This is particularly important in KwaZulu-Natal, where slopes are often steep and many of the soil types are highly erodible. It was shown that, on a grey Longlands form soil with 11% slope, a trash blanket prevented 90% of the rainfall being lost and more than 60% soil loss in ratoon cane during the precanopy stage (Thompson, 1966).

In Australia, extensive research has been carried out into the evaluation of spreading crop residues following green cane harvesting (Ridge *et al.*, 1979; Smith *et al.*, 1984; Wood, 1985, Dick and Hurney, 1986). Cane growers in the north of Queensland have responded to the positive outcomes from this research and today most of the growers have adopted this practice. The many advantages from worldwide research on trashing may be summarised as follows:

- increases dryland yields more than irrigated yields through improved infiltration and moisture conservation
- reduces soil erosion, compaction and organic matter loss
- reduces or eliminates the need for chemical weed control
- improves soil fertility such as increased N mineralisation potential, increased CEC, reduced P fixation
- reduces ratoon yield decline
- increases soil faunal and microbial activity.

Disadvantages of trashing include:

- cane cutter output is reduced
- payloads can be markedly reduced
- extraneous matter increases at the mill, reducing cane quality
- lower soil temperature which limits this practice on the south coast and high altitude areas of KwaZulu-Natal in winter, through reduced ratoon vigour and stalk population
- severely stressed cane infested with the stalk borer eldana may not ratoon through a trash blanket
- increased N volatilisation losses where urea is applied onto trash blanket
- aggravates drainage in heavy soils, and bottom lands.

Where the strategic objective is to reduce soil degradation in the long term and provide a cleaner environment, the advantages outweigh the disadvantages. Soil type is an important factor in determining whether or not to trash. Where burning at harvest is considered to be necessary, it is strongly recommended that no side raking of the burnt tops be practised, as the scattered tops provide some mulch protection to the soil. Field experiments have shown this to be about 60% as effective as a full trash blanket (Moberly and McIntyre, 1983). The priority rating for trashing or scattered tops according to soil group is shown in Table 3.

**Table 3**

**Priority rating of trashing according to soil group**

| Soil group | Soil form | Soil taxonomy | Erosion hazard | Priority |
|---|---|---|---|---|
| Grey sandy loams | Longlands | Inceptisols | High | High |
| Red to dark loams | Shortlands | Oxisols | Low | Moderate |
| Black clays | Milkwood Arcadia | Mollisols Vertisols | Low | Moderate |
| Brown humic | Inanda Hutton | Oxisols | Low | Low |
| Valley bottom | Katspruit Rensburg | Inceptisols Vertisols | Low | Very low |

*Harvesting programme*

It is not easy to compare production systems throughout all sugar growing areas since some countries use manual harvesting and mechanised haulage and others use mechanised harvesting and haulage. Each system will have a different impact on the soil at the time of harvest. In South Africa, the system that is used is mainly manual harvesting and mechanical haulage, with the harvesting season usually extending from April to January. If it extends into the wet summer months, the danger of infield traffic causing soil compaction, smearing, capping and physical damage to stools increases. This applies particularly to infield traffic on the grey, structureless sandy loam soil group. Important management considerations are:

- Cane grown on these soils and in wet valley bottoms should be harvested during the dry season
- Match tractor and trailers and reduce the size and overall dead weight by using weight transfer from trailers onto the tractor's driving wheels for traction
- Match infield haulage equipment wheel spacing with cane row spacing so that trailer wheels run on the interrow and not on the cane row
- Improve vehicle mass to payload ratios
- Improve irrigation scheduling
- Use large diameter wheels and high floatation tyres
- Fields with free-draining soils are unlikely to compact severely and can be reserved for harvesting in wet periods. A suggested programme for harvesting fields according to soil group is shown in Table 4.

The widely used amelioration practice on many estates of ripping the interrows with tines or chisels after each harvest has not been corroborated by results from field trials (Moberly, 1969; Leibbrandt, 1985). Studies conducted in Colombia showed that the use of tines often had a detrimental effect on yields due to root pruning (Torres and Villegas, 1993). An investigation conducted in South Africa showed that severe compaction in the interrow could be partially relieved through shallow ripping, but it was not possible to restore the full potential of the soil (Swinford and Boevey, 1984).

**Table 4**

**Recommended harvest programme based on soil groups**

| Soil group | Soil form | Soil order | Suggested harvest season |
|---|---|---|---|
| Valley bottom | Estcourt Katspruit | Inceptisols Entisols | Winter |
| Grey sandy loams | Longlands Kroonstad Glenrosa | Alfisols Aridisols | Winter/Spring |
| Clay and clay loams | Shortlands Milkwood | Alfisols Mollisols | Spring/Summer |
| Brown humics | Inanda Kranskop | Oxisols | Summer |
| Recent Sands and alluvial soils | Fernwood Dundee Hutton | Entisols | Summer |

*Potential areas for future research*

With increasing demands on the soil environment, the key to sustainability in the 21st century will be the extent to which cane producers adopt preventive management practices using ecological principles. According to Hornick and Parr (1987), a sustainable system is any system in which the benefits from soil conservation practices are equal to or greater than the negative effects of the soil degradation processes (Figure 2).

The concept is equally valid for low-input and high-input systems. Research into management by soils (MBS), that is, matching management practices to specific soil conditions, should be given a high priority. Advances in microprocessor technology in the USA now makes it possible to use digitized maps in the cab of chemical spreaders, enabling changes in fertiliser

and herbicide applications to be made at predetermined amounts as the machine passes over the field. When management practices are applied according to soil type, the result will be

improved efficiency through the better control of chemicals, particularly on soils that are more sensitive to leaching and surface run-off, as well as areas near streams or water storage dams.

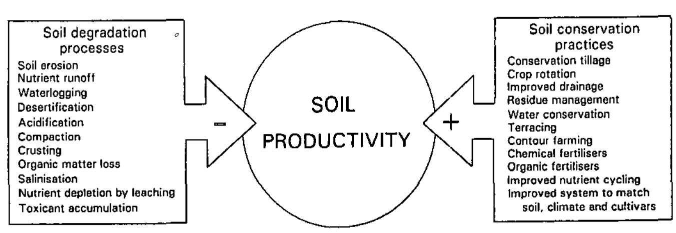


**FIGURE 2:** Relationship of soil productivity to soil degradation processes and conservation practices. Adapted from Hornick and Parr (1987)

The second area that holds considerable promise in future research programmes is the concept of managing zones in the field (Larson and Robert, 1990). The principle is to manage the row area differently from the area between the rows. The row area should provide a good soil structure, good rooting depth, and nutrient and moisture availability for plant growth and the interrow should be managed to create a surface to maximise intake rate of water, erosion control and be firm for wheel traffic. Tramline and ridge systems for the control of infield traffic have proved very successful in other industries for managing soil compaction (Spoor, 1983) and needs to be exploited in the South African industry. The use of controlled traffic zones is currently under investigation in Queensland. One of the systems that looks very promising is planting soya beans as a green manure crop into ridges, destroying the soya beans with glyphosphate six weeks prior to establishing sugarcane, followed by planting the cane setts into the old soybean stubble in the ridge using zero tillage.

The merits of ridge and vertical mulching tillage are currently being assessed in the local industry for further improving the quality of duplex soils. Apart from increased yields, ridging resulted in improved surface drainage, less compaction damage to the cane row, better aeration and healthier root development and generally improved moisture conservation (van Antwerpen *et al.*, 1991). Further work is needed in testing the efficacy of combination treatments of vertical mulching on the row at crop establishment followed by ridging up in the ratoon crop. Other areas that warrant further research include the testing of ridging and vertical mulching in combination with green manuring. The merits of using more disease resistant strains of sugarbeet as a cover crop in a minimum tillage system also warrant a re-evaluation.

Intercropping, which has been researched and practised in Mauritius now for a number of years (Antoine, 1979) also needs to be researched, especially as a means of sustaining smallholder farmers.

While much research has been conducted with green cane harvesting, detailed research is still needed to evaluate the nutrient contributions from sugarcane trash and the long term effects on soil organic matter and N mineralisation, as well as the soil microbial mass.

## Conclusion

Soil management systems for sugarcane production in the 21st century will have to incorporate ecological principles to an increasing extent in order to arrest the adverse effects of monocropping on soil degradation and yield decline. Strategies that are based on the principle of management by soils (MBS) as well as emphasising crop residue retention, nutrient recycling, row-interrow management based on minimum tillage, green manuring, vertical mulching with filtercake and green cane harvesting, will help to develop productive, profitable and sustainable production systems. If soil degradation is left unchecked the full potential of new cane varieties cannot be realised. Applied research on soil management and the maintenance of productivity of caneland has in general been underfunded compared with other disciplines. The Australian sugar industry has recently initiated a Co-operative Research Centre for Sustainable Cane Production enabling multidisciplinary teams of scientists from a cross-section of institutes to work on projects concerned with sustaining cane production. Environmental quality issues, particularly air, ground and surface water quality, will make it imperative to base soil management practices on an understanding of the ecosystem concept. The growing interest in Europe in 'biosugar production', using organic farming methods could well gather momentum and in future favour countries producing sugarcane using ecologically based management practices and including enviromental audits.

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