SOIL HEALTH

Alan Garside, Rob Magarey and Mike Braunack

THE soil is the basic resource upon which the sugar industry is reliant. The long-term survival of the industry depends on its maintenance. Hence, maintaining the soil in good condition should be the highest priority of the industry. A healthy soil is one that can sustain long-term productivity through maintaining a desirable balance of chemical, physical and biological properties.

In an era of rapid technological change and ever increasing economic constraints, it is easy to overlook, or take for granted, many of the basic components, including soil, that contribute to a sustainable sugarcane cropping system. The focus is often on using the latest technological advances to maximise economic returns in the short term. High inputs of fertiliser, chemicals, water and improved varieties, to name a few, are combined in such a way to maximise productivity in any one season. The productive capacity of the soil is often forgotten, yet it will only be maintained and enhanced if it is managed in the most appropriate way. There is a real need to adapt technological advances so they address long-term resource sustainability, as well as short-term economic imperatives.

Even though production strategies have been focussed on short-term economic outcomes, the practices employed are not necessarily producing the desired outcomes. Poor soil health is being reflected in economic losses associated with increased pest and disease damage and degraded soil physical and chemical conditions. Although it is difficult to quantify the economic effect of decline in soil health, it has been estimated that annual losses to the industry due to soil pathogens, soil insects, soil compaction and lost fertiliser (much of which is nitrogen) are \$180M, \$15M, \$110M and \$15M, respectively.

In this chapter, the impact of past and present sugarcane cropping systems on soil health is discussed and adverse effects are identified. The outcomes of recent research are used to suggest means by which these adverse effects can be minimised. Although some of the identified remedies may not necessarily be immediately practical, they point to directions in which the production system should move to ensure resource maintenance and long-term sustainability.

MAJOR FACTORS INFLUENCING SOIL HEALTH IN SUGARCANE CROPPING SYSTEMS

If the basic differences between sugarcane cropping systems and those of other arable crops are considered, two factors unique to sugarcane can be identified. Firstly, sugarcane is grown as a long-term monoculture (same species grown continuously on the one area of land) with any block of land being under cane for about five years (one plant and four ratoon crops), usually followed by either a six-month fallow or by another cane crop (ploughout/replant). Hence, land is under cane for at least 90% of the time. This is aggravated when particular varieties of cane dominate the plantings on a farm or in a district (variety monoculture). This can have two important consequences for soil health: the *direct effect* of one crop species, and in some cases a particular variety of the one species, for extended periods, plus the *indirect effects* of practices used to maintain the productive capacity of that crop, for example, tillage.

Secondly, the sugarcane farming system is highly dependent on heavy machinery for harvesting and transport from the paddock. This can have important *direct effects* on crop growth through soil compaction and stool damage, particularly if harvesting is carried out in wet conditions, which is often the case in much of eastern Australia. In addition, there are *indirect effects* on soil health through tillage to reduce compaction.

DIRECT EFFECTS OF LONG–TERM MONOCULTURE AND HEAVY MACHINERY

Direct effects of long-term sugarcane monoculture

Monocultural cropping systems provide an ideal environment for the development of pests and diseases. In this respect, sugarcane is no different to any other species. Numerous experiments have clearly shown that there is a substantial increase in the number of organisms detrimental to sugarcane growth under sugarcane monoculture, e.g. pachymetra and pythium root rots and nematodes. That these detrimental organisms are a consequence of sugarcane monoculture is readily demonstrated in Table 1. In this case, soil from a long-term sugarcane field in the Tully area was subjected to fumigation or left untreated and then planted to either sugarcane or peanuts in a pot experiment. Fumigation increased the yield of tops and roots of sugarcane but had no effect on peanuts. Basically, fumigation removed the detrimental organisms that had built up under long-term sugarcane monoculture, enhancing cane growth. As peanuts had not previously been grown on the soil, there were no peanut pathogens present, so fumigation did not significantly affect peanut growth.

However, the effect of fumigation on sugarcane growth is likely to be transitory, as organisms pathogenic to sugarcane will rapidly re-colonise the soil after sugarcane is re-planted, partly because sugarcane has been re-established and partly because fumigation has also removed organisms that may be antagonistic to the sugarcane pathogens. For example, there is ample evidence of a rapid return of nematodes. The situation is made worse if varieties susceptible to sugarcane diseases and pests are used. For example, the monoculture of susceptible varieties may lead to substantial increases in pachymetra root rot and the incidence of earthpearls (Table 2).

Other direct species effects in a sugarcane monoculture are likely to be associated with soil pest increase and rooting habit. Many soil pests are species specific, or at least have species preferences. Long-term monocultures provide an ideal environment for pest multiplication, particularly if cropping practices discourage predators and susceptible varieties are grown.

Table 1. Effect of fumigating long-term sugarcane soil on the subsequent top and root weights (g/pot) of sugarcane and peanuts.

Practice	Sugarcane		Peanuts	
	Tops	Roots	Tops	Roots
Fumigated	19.2	13.7	6.3	2.9
Unfumigated	10.2	7.8	5.6	2.6

Table 2. The influence of varietal resistance on pachymetra inoculum levels in soil (spores per g of soil). Spore levels were measured after growth of a plant and first ratoon crop (averaged over five trials).

Variety	Resistance category	Spore level (spores/g)
Q138	Resistant	90
Q117	Resistant	104
Q114	Resistant	116
Q122	Intermediate	216
Q124	Intermediate	243
Q120	Intermediate	249
Q107	Susceptible	306
Q121	Susceptible	370
Q90	Susceptible	385
Q83	Susceptible	515

Sugarcane has a fibrous root system, and research suggests the root system is largely restricted to the surface soil. Hence, growing continual cane is likely to concentrate biotic activity in the soil surface and not encourage exploration and cycling of biota and nutrients into deeper soil layers. Other species with tap root systems are likely to have quite a different effect on soil properties. For example, decomposition of tap roots results in deep channels that aerate and drain the soil.

Direct effects of heavy machinery

Under the current harvesting system, each inter-row is run over at least twice by the harvester (weight up to 20 t) and a minimum of once, but usually more often by a haul-out (weighing 15 t empty and up to 30 t loaded). Up to 60% of a block may be run over by wheels or tracks during harvest, if the same pathway is followed; this can increase to 75% if the same pathway is not followed. Thus, some areas of a block are subjected to a machinery load of 50 t. This can have two important consequences. Firstly, when soil is wet, as is often the case, soil compaction, a form of soil structural degradation, is invariably the result. Soil compaction can have a number of adverse effects. These include: reduced porosity and permeability resulting in waterlogging, runoff, and erosion; restricted root growth leading to nutrient and water stress; increased cost of production (fuel, labour, fertiliser, irrigation) and/or reduced yield if inputs are not increased; and fewer management options and a narrower window for timing of operations. Compaction contributes to poor soil health by providing a less favourable environment for soil biota and crop growth. Secondly, indiscriminate driving of both harvester and haul-out equipment often results in cane rows being runover during the harvest operation, destroying stools and producing gaps in the subsequent ratoon. Cane yield is very closely related to the number of stalks. Stool damage is often made worse by poor matching of crop row spacing with wheel spacings of the harvester and haul-out equipment. For example, cane is most often grown in 1.5 m rows while harvesting and haul-out equipment is based on 1.8 m wheel spacings.

INDIRECT EFFECTS OF LONG–TERM SUGARCANE MONOCULTURE AND HEAVY MACHINERY

Although the direct effects of both the monoculture system and heavy machinery are severe and have significant consequences, it is really the indirect effects of both that operate most against soil health and sustainable sugarcane production. Many of the inputs employed and operations carried out are aimed at overcoming or managing the direct effects of the monocultural system. In a monocultural system: we do not fallow and provide the opportunity to break the reproductive cycle of pathogens and soil pests of sugarcane; we do not include a legume and provide the opportunity to fix organic nitrogen for the next cane crop; we do not allow a tap-rooted species the time to help in amending compaction and improving soil structure simply by its different rooting habit; we do not provide the opportunity to improve the organic matter status of the soil by returning fallow material nor, until recently, returning the sugarcane trash; and we create new pests through disruption of natural control mechanisms. For example, soldier fly became a problem in the 1950s after organochlorine pesticides applied to control canegrubs and wireworms severely reduced the populations of predatory beetles of soldier fly. These are not all of the adverse effects, but demonstrate the soil health deficiencies imposed by the way the monocultural system is practised.

So how do we cope with the consequent effects of these practices? We contain increases in pests, diseases and weeds through chemicals or the breeding of tolerant/resistant varieties; we apply high rates of nitrogen as inorganic fertiliser, which has the side effect of increasing acidification; we temporarily manage compaction through repeated cultivations while often destroying soil structure with equipment such as the rotary hoe; and we regard organic matter as of little consequence. The present system is extremely exploitive and one that is continually degrading soil health.

The adverse indirect effects of monoculture and using heavy machinery in the sugarcane production systems can be linked closely with two practices—*excessive tillage* and a failure to return adequate quantities of *organic matter* to the system. Both are inextricably linked, as tillage further degrades an often-depleted organic matter status. Organic matter is a critical factor in aiding the repair of soil physical properties damaged by soil compaction and is vital in maintaining the biological diversity that suppresses pests and diseases of sugarcane.

Adverse effects of tillage

The use of tillage in the sugarcane production system has been reduced substantially in many production areas over the past 15 years. Very little tillage is now carried out in ratoon crops with green-cane harvesting and retention of trash becoming an established practice. These practices provide definite improvements in soil health as indicated by increased earthworm activity, improved soil structure resulting in better water infiltration, and less need for nitrogen fertiliser. However, many tillage operations are still used in land preparation for planting a cane crop and, in the process, many of the soil health improvements generated during the ratooning period are lost.

Deep tillage is used to break down the compacted layer developed during previous harvesting operations. Instead of being left on the surface, where breakdown can be relatively slow, the remains of accumulated trash over a number of ratoons are either incorporated with, or burnt prior to, the tillage operations, presumably to facilitate easier land preparation. The more tillage, the faster the breakdown of organic matter in the soil and the disturbance of beneficial organisms such as earthworms, which maintain soil structure, and mycorrhizae, which benefit plant growth through aiding in nutrient uptake. Further, without a trash blanket, plant crops are prone to soil erosion during heavy rainfall. In effect, tillage provides short-term manageable soil, but long-term degraded soil by adversely affecting soil structure through reduced aggregate stability.

A reduction in soil organic matter, the consequence of frequent and aggressive tillage, has implications for many of our soil regenerative processes. Organic matter is the basis of a healthy and diverse soil biology, enhanced chemical status, and improved physical structure. The more organic matter is degraded, the less resilient will be the biological, chemical and physical status of our soil and the more reliant we will be on artificial amendments, e.g. chemicals, fertilisers, and more aggressive tillage.

There is mounting evidence of the relationship between tillage, organic matter and the prevalence of various insect pests such as greyback canegrub, the most important pest of sugarcane in Australia. A number of soil organisms, including *Adelina* and *Nosema* protozoans, *Metarhizium* fungus, *Bacillus* bacteria and entomopox viruses, are known pathogens of greyback canegrub. The most important of these, *Adelina* and *Metarhizium*, are readily damaged through intensive cultivation. In recent years, greyback canegrub has been a particularly important pest in the Burdekin, mainly because of burning, tillage of ratoons, short crop cycles and intensive tillage between crop cycles (Table 3).

Table 3. Population density of greyback canegrub (mean number per stool in autumn) where five sugarcane blocks were split in two and subsequently managed separately as green-cane trash-blanket (GCTB) and burnt/cultivated ratoons.

Location	GCTB	Burnt/ cultivated
Tully 1	0.2	0.9
Tully 2	0.4	0.7
Burdekin 1	0.6	2.2
Burdekin 2	0.2	2.6
Burdekin 3	0.3	1.3

Damage by greyback canegrubs can be substantially reduced with subsequent yield increases (20–30 t/ha) by using a green-cane trash-blanket system with minimum tillage, compared with burnt and cultivated ratoons. Grubs grow more slowly under a trash-blanket system, are more susceptible to diseases, and diseases are better contained.

There is evidence from comparisons of paired old and new sugarcane sites in north Queensland that old cane land, which has almost certainly been under frequent and aggressive tillage, is likely to be more acidic, have lower cation exchange capacity, more exchangeable aluminium and manganese, less copper and zinc, less microbial biomass, greater soil strength, lower infiltration and water holding capacity, and have more root pathogens. All of these factors are characteristic of degraded soil conditions.

STRATEGIES FOR IMPROVING SOIL HEALTH WHILE MAINTAINING PRODUCTIVITY

If soil health in the sugarcane production system is to be improved, we must break the monoculture, diversify sugarcane varieties, minimise chemical usage, become more reliant on legume nitrogen, improve the organic matter status of our soils, substantially reduce tillage, and minimise compaction by heavy machinery. As we will discuss below, it is feasible to accomplish all of these requirements to some extent.

Breaking the monoculture

Intensive research during the 1990s has focussed on the results of breaking the sugarcane monoculture with either bare fallows, other annual crop species (soybean, peanuts) or mixtures of grass/legume pastures.

The results strongly support better cane production following a break, and this productivity appears to be clearly associated with enhanced soil biological and physical conditions. Different types of breaks resulted in different soil conditions. A bare fallow, maintained by the use of herbicides, produces a break that has *no tillage* and *no plant growth*. A pasture, maintained by slashing and leaving the slashed material on the surface, provides a break that incorporates *no tillage* and *plant growth*, and a return of organic material (about 20 t/ha/year dry matter).

The most conducive of these treatments in promoting improved soil health, as measured by soil biological and physical properties, is always the pasture break, which incorporates no tillage and the return of large amounts of organic matter. A balanced biology is the result along with improved soil porosity, which allows better infiltration of water. In addition, the development of a diverse soil biota under a pasture system aids in the suppression of pathogenic soil organisms.

Few improvements in soil physical properties have been measured under the annual cropping breaks or the bare fallow, the former being regularly tilled while the latter was devoid of organic matter inputs. The bare fallow represents a situation where soil biological activity decreases substantially, probably because of the lack of organic matter input. However, this is of short-term benefit, as the dominant biota before establishing the bare fallow were species pathogenic to sugarcane. The situation under the annual cropping breaks represents a population somewhere between that under the pasture and that under a cane system. There are the benefits of diversity of species but, under the conditions of these experiments, not diversity of soil management as tillage was used on an annual basis.

In all rotation experiments, shoot development and early growth have directly reflected improvements in soil biological and physical properties. Subsequent yields have also been greater following breaks, any breaks, compared with continual sugarcane. However, subsequent management quite often modifies the size of the yield increase, particularly where legume is grown and this is expanded on below. Cane yields for five major rotation experiments located at Bundaberg, Mackay, Burdekin, Ingham and Tully are shown in Table 4.

Table 4. Plant cane yield (t/ha) for ploughout/ replant cane compared with cane planted after a break.

Site	Plough-out/ Re-plant	Break	% Yield increase
Bundaberg	112	128	14
Mackay	60	114	84
Burdekin	118	154	31
Ingham	48	71	51
Tully	44	75	58

Influence of legume fallows

The most popular break, and one that has been widely used by the sugar industry, has been a six-month crop of legumes between the plough-out of the last ratoon and planting the next crop. This six-month break has been used on average one year in every six (following a plant and four ratoon crops). The fallow has generally consisted of very poorly managed cowpea, being traditionally established by broadcasting seed onto roughly ploughed ground, possibly followed by a discing. Many fallows suffer from waterlogging, disease, and severe weed competition. In many situations, a major fallow weed is sugarcane, which negates the potential benefit of breaking a disease cycle. Poor results from legume fallows, in combination with the lifting of assignment restrictions, have resulted in much less land fallowed each year. There is little doubt that reduction in fallowing has had an adverse effect on soil health.

Research shows that the benefits of fallowing will only be realised if the fallow is managed properly and grown as a crop. Using a planter to establish the legume, growing it on raised hills to avoid waterlogging, and spraying with a pre-emergent herbicide to control early weed competition will all enhance the benefit of the fallow legume. The effect of using a planter and a pre-emergent herbicide to establish cowpea on raised beds (improved management) is compared with traditional broadcast planting in Table 5. More dry matter is produced and more nitrogen is returned with improved management.

Table 5. Dry matter yield and nitrogen returned (kg/ha) for a traditionally established cowpea fallow compared with one planted on ridges with a pre-emergent herbicide (improved management).

	Dry matter (kg/ha)	Nitrogen returned (kg/ha)
Traditional		
Cowpea	1966	31
Weeds	1347	19
Total	3314	50
Improved Management		
Cowpea	4689	140
Weeds	NIL	NIL
Total	4689	140

Soybean has proven to be a better fallow legume than cowpea for sugarcane land, producing more dry matter, fixing more nitrogen, and withstanding wet soil conditions considerably better. Table 6 shows the comparison between a number of different legumes in their capacity to return nitrogen to the soil. The range for soybean and peanut covers a number of crops that have been grown in different areas and with different levels of management. Soybean and peanut also offer potential as grain crops in a sugarcane cropping system. However, if harvested for grain, much of the nitrogen is removed in the grain. The remaining stubble will return between 80-100 kg/ha of nitrogen to the soil.

The value of a well-managed six-month fallow in a sugarcane cropping system is now becoming clear as various rotation experiments are returned to sugarcane. In all cases, legume fallows have improved cane yield compared with ploughout/replant. Further detail and data are provided in the Sugarcane Cropping Systems chapter. In terms of sugar yield per hectare, we are seeing an increase in yield that cannot be simply attributed to nitrogen nutrition. In an experiment at Tully, when plant cane following soybean or plough-out/re-plant was fertilised with either 0 or 140 kg/ha of nitrogen, a sugar yield increase of 1.5 t/ha was recorded following the soybean, which was independent of nitrogen. This response is most likely due to an improvement in soil health.

Table 6. Nitrogen (kg/ha) returned for different legume species from experiments in north Queensland.

	Nitrogen
Traditional Cowpea	31
Traditional Lablab	76
Improved Management Cowpea	140
Improved Management Mungbean	80
Improved Management Peanut***	180-250
Improved Management Soybean***	150-310

*** Based on whole crop being returned. No grain removed.

The other area where we see potential is the use of pasture legumes such as Pinto peanut (*Arachis pintoi*) as a permanent understory in a sugarcane farming system, providing the legume does not compete with sugarcane for nutrients and water. Pinto is a low-growing non-twining legume that grows very well under shady conditions such as would be experienced under a sugarcane canopy. It fixes nitrogen well and is a very hardy perennial legume. In the rotation experiments mentioned above, it was used in combination with signal grass (*Brachiaria decumbens*) as the pasture break. When the pasture plots were returned to cane, the Pinto re-established from seed reserves in the soil and formed a dense understory. In some experiments, it had an adverse effect on the plant cane crop while in others it was beneficial. Its management as a ley legume under sugarcane needs to be better developed.

Organic Matter

Organic matter is the basis of soil health. Chemical, physical and biological soil properties are all influenced by the amount of organic matter cycling in the system. In this respect, the sugar industry has made a major move towards a more sustainable system by adopting GCTB. However, there is evidence that this is not enough and that intensive land preparation practices between crop cycles largely destroy much of the organic matter increase during the previous crop cycle. Organic carbon, the main component of organic matter, is made up of a number of fractions from a labile or available fraction to inert or unavailable fractions such as charcoal. Until more recent times, the impression has been that organic carbon status was not changing under a sugarcane cropping system, as the total amounts tended to remain stable. However, with the development of technology to measure organic carbon fractions, it is becoming clear that there have been substantial changes in these fractions. In particular, the burnt cane system has seen an increase in charcoal at the expense of the labile fraction. Nowhere is this more obvious than in the Burdekin where almost all crops are still burnt. Conversely, the labile fraction increased substantially following several years of pasture break in a number of rotation experiments conducted throughout the industry. In these experiments, the pasture was managed by periodic slashing, which returned all the organic material to the soil. In addition to measured increases in the labile carbon, increases in the population and diversity of soil biota were measured, as were increases in cation exchange capacity (a measure of the nutrient holding capacity of the soil), and aggregate stability (a measure of soil physical properties). In recent studies, preliminary evidence is pointing towards suppression of the adverse effects of root pathogens such as pachymetra following a break, particularly a pasture break, compared with a cane monoculture or a bare fallow (Figure 1). From Figure 1, it may be seen that, when all soils are fumigated, the response in terms of rotten roots to adding pachymetra spores is similar. However, when soils are not fumigated, the percentage of rotten roots is considerably less in the pasture soil. This is believed to be largely due to the development of a diverse soil biota containing organisms antagonistic to pachymetra under the pasture soil and is thus a form of biological control. Similar responses in root growth can be seen when monocultured sugarcane land and land that has had a legume break are pasteurised (Figure 2).

Earthworms are an indicator of soil health and depend on organic matter for their survival and activity. They play a major role in distributing organic matter throughout the soil profile, leading to increases in aggregate strength and structural stability, water holding capacity, and microbial activity of the soil. Earthworm burrows and casts increase the porosity of the soil, allowing better drainage and infiltration, while the casts contain high levels of plant available nitrogen and other nutrients. Further, high populations of earthworms provide a food source for predators such as ground beetles and centipedes, which also prey on soil pests as pest populations increase. Within the cane system, there are considerably higher populations of earthworms under GCTB systems (Table 7) than under burnt systems, and where pesticides are not applied. In addition, numbers of earthworms increase substantially under legume fallows (Table 8).

Table 7. Mean number of earthworms per m^2 for samples taken on rows of cane in relation to trash treatment over three ratoon crops.

Sampling	Burnt cane	Trash blanket
8 Dec, 1994	15	23
6 Sept, 1995	24	49
1 Feb, 1996	41	93
4 Sept, 1996	73	171
11 Mar, 1997	98	242

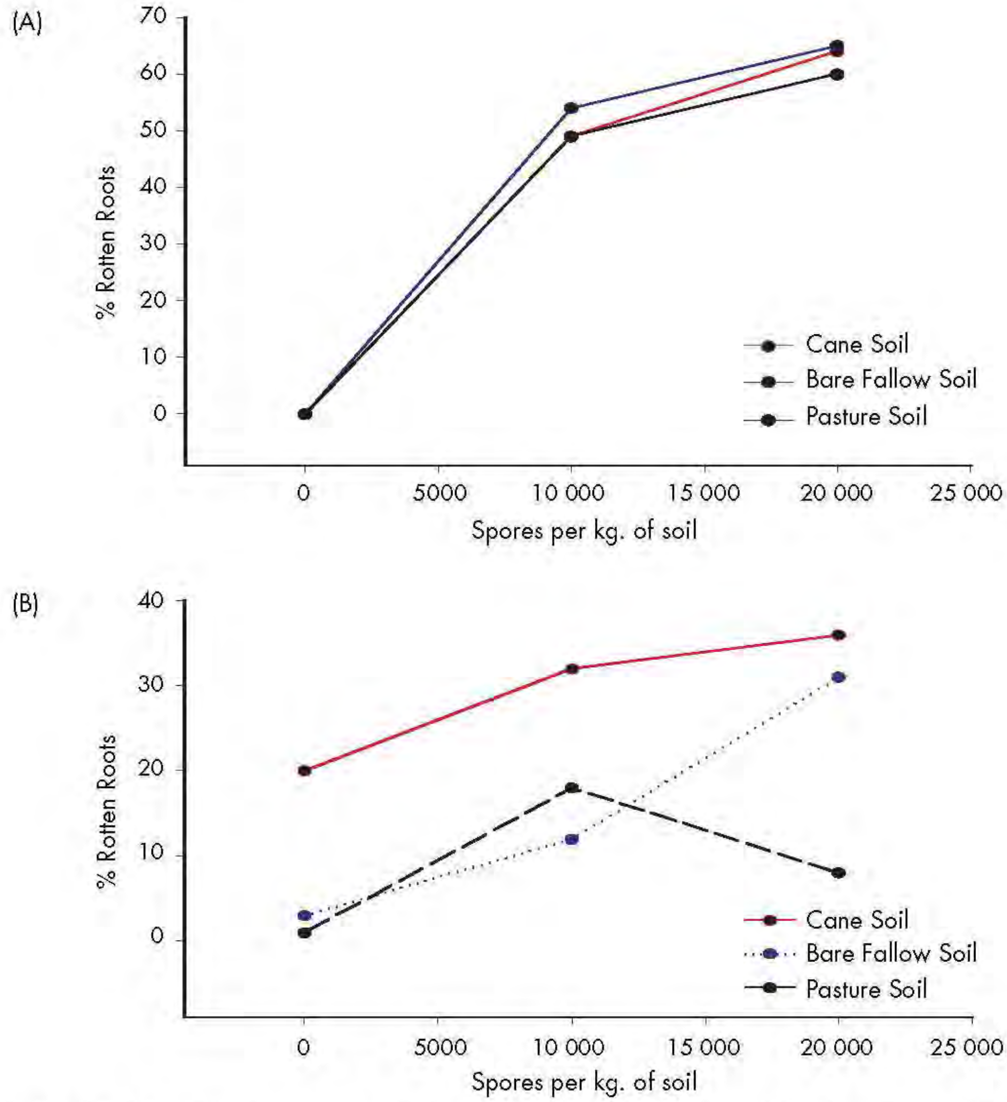

Figure 1. *Percentage rotten roots when sugarcane is grown in soil sourced from areas supporting sugarcane, bare fallow or pasture and inoculated with different quantities of pachymetra spores following fumigation (A) or no fumigation (B).*

Table 8. Population densities of earthworms and centipedes (a predator of earthworms and other soft-bodied prey) in a comparison of fallow practices near Bundaberg.

Fallow treatment	No. earthworms per m^2	No. centipedes per m^2
Sprayout (no tillage)	214	113
Soybean (tillage)	528	100
Short fallow (ploughout-replant)	100	25
Long bare fallow (tillage)	75	25

Figure 2. *A glasshouse experiment comparing sugarcane root growth and responses to soil pasteurisation in soil from monocultured sugarcane (left-two root systems) and legume rotation (right-two root systems). Within each pair the root system on the left is from soil that has been pasteurised. Note the better growth where the cane monoculture has been broken, and when the soil has been pasteurised.*

Strategic tillage and controlled traffic

Strategic tillage is based on the premise that tillage should only be carried out when absolutely necessary. Controlled traffic is based on the premise that it is best to separate crop growth zones and traffic zones in a permanent arrangement. Together they provide a powerful tool to improve chemical, physical and biological properties in the crop growth zone through minimising the adverse effects of compaction and the degradation of organic matter that occurs with regular tillage. In a controlled traffic system, all traffic passes down permanent traffic lanes that are severely compacted while the rows are not trafficked. Removal of the old ratoon and land preparation for planting is carried out with herbicides or by only cultivating a narrow strip of row and then cultivating this area as little as possible.

Research into strategic tillage/controlled traffic has been underway during the 1990s with some very encouraging results. Substantial cost savings have been achieved by not cultivating the whole paddock and not attempting to remove the compacted interspace (see chapter on Sugarcane Cropping Systems). More importantly, these changes can occur without loss in yield and without any obvious adverse effects on crop growth. Soil structure in the rows improves and there are indications of an improved soil biota, particularly increases in numbers of earthworms. Strategic tillage offers the possibility of improved soil structure through considerably reduced tillage of the crop row and further improvements in chemical, biological and physical properties through trash blanketing. Establishment of legume fallows in the permanent cane rows can be readily achieved. Further, with such a system, it may be possible to include a legume on an annual basis while the ratoon is establishing.

It is unreasonable to expect immediate crop yield improvements with a strategic-tillage, controlled-traffic system. However, substantial soil repair will occur over time, and all the indications are that the strategy will improve soil health and contribute to a more profitable and sustainable cropping system. It is when this is achieved that substantial yield advantages will be realised.

A strategic-tillage, controlled-traffic system will achieve little if equipment wheel spacing and row spacing are not matched and if plant operators do not drive only in the traffic lanes. Driving on rows will undo all the benefits of the system. At present it appears that this may be best achieved with dual row cane (0.5 m apart) on 1.8 m centres.

COMBINING STRATEGIES INTO A FARMING SYSTEM

Real improvements in profitability and sustainability will result from improved soil health, and better management of the individual components of the system is likely to result in improved productivity. It is clear that monoculture, excessive tillage, low inputs of organic matter, routine use of persistent insecticides, heavy traffic, and high inputs of nitrogen fertiliser produce unhealthy soil. Individual strategies can no doubt be developed to improve each of these components. However, regardless of what individual solutions can be developed for these deficiencies, their utility is unlikely to be long-term if they are not combined in a practical cropping system. The technology is now available to propose such a system.

A system can be developed based on strategic tillage and controlled traffic, where traffic lanes are maintained, and stools are removed with herbicides or a narrow line of cultivation. Legumes can be directly seeded into the old sugarcane line after the last ratoon. The legume can be allowed to mulch down at an appropriate time or be lightly incorporated into the surface of the row. The next cane crop can be directly planted into the same area and grown under a green-cane trash-blanket system. Strategies to manage root diseases may be needed, although resistant or tolerant varieties along with the potential for the development of suppression may greatly reduce the impact of soil-borne diseases. Persistent pesticides should be used only when a pest outbreak is likely to warrant it. This whole system approach is the most appropriate means by which soil health can be restored while maintaining and improving productivity.

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FURTHER READING

Anon. 1999. Report on sugar yield decline joint venture Phase 1 (July 1993-June 1999).

ASSCT 1999. Papers on yield decline, Proc. Soc. Sug. Cane Technol., 21: 63–108.