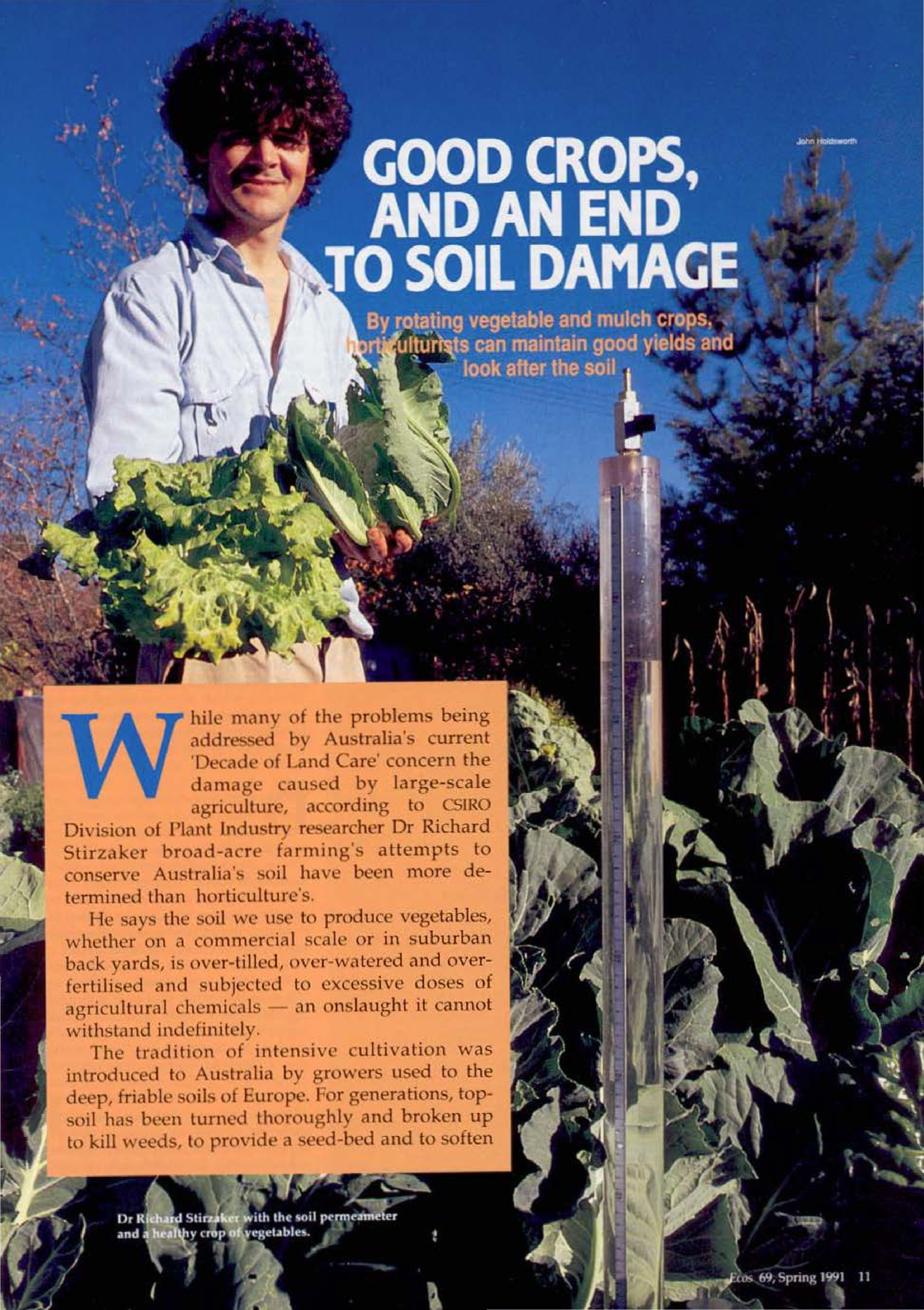
# GOOD CROPS, AND AN END TO SOIL DAMAGE

**By rotating vegetable and mulch crops, horticulturists can maintain good yields and look after the soil**



John Holdsworth

Dr Richard Stirzaker with the soil permeameter and a healthy crop of vegetables.

While many of the problems being addressed by Australia's current 'Decade of Land Care' concern the damage caused by large-scale agriculture, according to CSIRO Division of Plant Industry researcher Dr Richard Stirzaker broad-acre farming's attempts to conserve Australia's soil have been more determined than horticulture's.

He says the soil we use to produce vegetables, whether on a commercial scale or in suburban back yards, is over-tilled, over-watered and over-fertilised and subjected to excessive doses of agricultural chemicals — an onslaught it cannot withstand indefinitely.

The tradition of intensive cultivation was introduced to Australia by growers used to the deep, friable soils of Europe. For generations, topsoil has been turned thoroughly and broken up to kill weeds, to provide a seed-bed and to soften the soil so plant roots can grow without hindrance. To the backyard gardener this means laboriously turning the soil, blending in organic compost and ensuring that clods are completely broken up: to the commercial horticulturist it means long hours on a tractor, deep ripping and ploughing, and often rotary hoeing to break up clods.

But while deep tillage is appropriate for soils nurtured by Europe's mild climate and the addition over hundreds of years of organic material, it does not suit Australia's harsh climate and topsoils — shallow, eroded and often almost barren of organic material.

So why do Australian horticulturists cultivate so intensively? The soft soil that cultivation achieves does indeed produce better plant growth than hard soil, but soft soil doesn't stay soft. Each successive cultivation breaks up 'crumbs' of soil, allowing organic matter previously locked up in those crumbs to be consumed by soil micro-organisms; and a reduction in organic matter leads to a reduction in soil stability, since there's less to hold the soil crumbs together. As its stability declines, the soil becomes prone to turn into dust when cultivated or mud when it rains... and to brick-like hardness as it dries... so it must be cultivated again before each new crop is planted. Thus cultivation actually involves the soil in a vicious circle: the enhanced growth it promotes masks the damage it causes, so more and more management is required to maintain the same level of productivity.

Whereas vegetable crops find it difficult to grow in uniformly hard soil, they can grow easily when that soil contains holes, called biopores, made by plant roots, earthworms and other soil fauna. These biopores can be measured by a 'disc permeameter' developed at CSIRO's Centre for Environmental Mechanics by Dr Ian White and colleagues (see the box on page 16). Indeed, Dr Stirzaker's experiments indicate that plants actually prefer soil with biopores that provide paths through which their roots can grow to find water and nutrients.

For his experimental plots at the University of Sydney field station at Camden, west of Sydney, and more recently in Canberra, Dr Stirzaker made innovative use of a common agricultural plant, subterranean clover (*Trifolium subterraneum*). Subterranean clover grows vigorously during winter to a height of about 30 cm (producing crops of 5–10 tonnes per hectare), shading out competing weeds. He chose a variety with a short growing season; it dies back naturally at the beginning of summer, setting seed below ground then collapsing to form a mat about 3 cm thick — and, incidentally, resulting in a level coverage, ideal for planting, that mechanical application of mulch could not achieve.

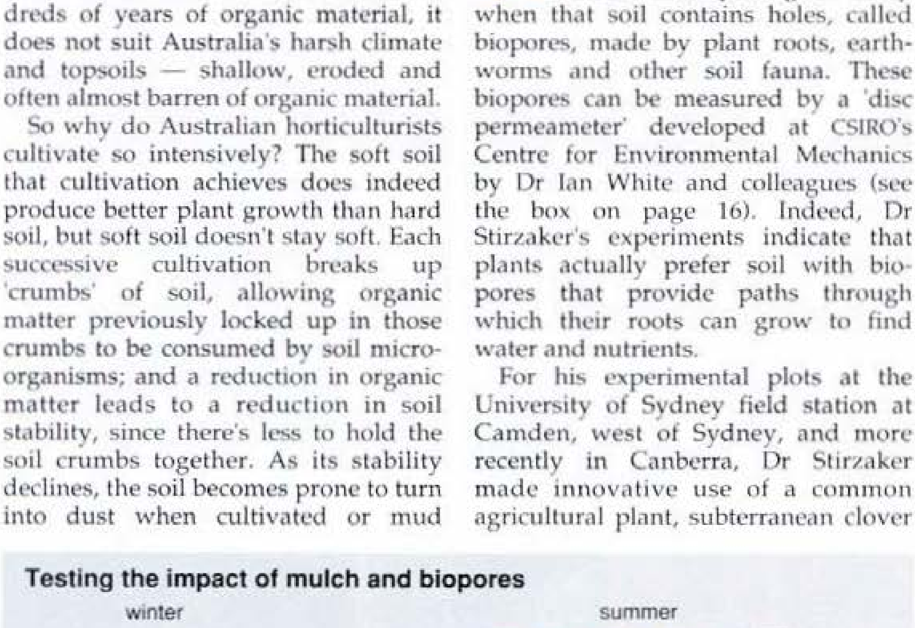
Dr Stirzaker has developed an effective approach to sustainable horticulture based on controlled crop rotation, using the clover as *in situ* mulch. This system combines the benefits of not tilling the soil (protecting it from the sort of degradation tillage produces) and the formation of biopores and mulching (controlling weeds and erosion; protecting the soil from overheating; and reducing evaporation).

Controlled rotation adds to those benefits by growing mulch as an integral part of the system. By relying on mulch grown where it will be needed rather than taking it from another location (and thereby removing nutrients from that location), the horticulturist avoids 'robbing Peter to pay Paul'. Growing mulch after harvesting a crop also retrieves the nutrients not utilised by that crop, holds them in the organic fraction of the soil and stores them for future use.

Dr Stirzaker planted tomato and lettuce crops in the resulting mulch, disturbing the soil only enough to make room for seedlings... whose roots penetrate and widen existing biopores through which they take up water and soil nutrients. After vegetable crops are harvested in autumn, the clover regenerates from seed reserves and the cycle continues.

He looked at three soil management treatments: conventional cultivation (C), zero tillage (Z) and *in situ* mulching (M). The C plots were tilled to a depth of 25 cm prior to planting, using a rotary hoe to produce soft soil, while the Z and M plots were left undisturbed — in other words, with hard soil — after construction of raised beds. All were drip-irrigated and monitored daily to ensure an adequate water supply, and fertilised with regular side-dressings to 'switch off' clover's nitrogen-fixing action so that the benefits of mulch were limited to its physical effects on the soil surface or the production of biopores in the soil.

**Testing the impact of mulch and biopores**




**To investigate the relative importance of surface mulch and the formation of biopores, Dr Stirzaker grew lettuces and tomatoes in cultivated (C), *in situ* mulch (M) and zero-tillage (Z) regimes, then removed mulch from M plots and added mulch grown elsewhere to C and Z plots. He found both the mulch and the biopores made big contributions to yields.**

He grew lettuce — a simple plant that is very responsive to changes in soil structure — to investigate whether mulch confers its benefits above or below ground. As he expected, lettuce grown in soft, cultivated soil yielded well... but lettuce grown in uncultivated M plots also yielded well, while yields were poor in Z plots, even though both contained hard soil.

The hard soil of the Z treatment seemed to slow root growth, so plants in these plots found it difficult to extract water and nutrients. Indeed, Dr Stirzaker's measurements of root length, soil water and nutrient status and rates of water use revealed that root length was slightly reduced in the Z treatment. However, his calculations showed that Z lettuces had developed more than enough roots to take up all the water and nutrients they needed, given the wet, well-fertilised soil in which they grew — but that they wouldn't have enough to survive if the soil dried out, because plants need more roots to take up water from dry soil. The Z lettuces grew very slowly, while lettuces in M plots grew as quickly as those in C plots, even though (like lettuces in Z plots) they had been planted in hard, uncultivated soil; and at harvest, yields were high in both C and M plots, but low in Z plots.

Dr Stirzaker's findings confirm some fascinating insights into the dynamic relations between plants and their environment. Working with wheat plants at the Division of Plant Industry's crop adaptation laboratories, Dr John Passioura has found that plants seem to have an inbuilt 'early warning system' that tells them to slow their growth — while the soil is still wet — in anticipation of dry conditions at a later stage, when a larger leaf area and small root length would seriously reduce their chances of survival.

Plants appear to be very conservative in their approach to growth in hard soil, since even if the soil is kept wet they still activate their early warning system, responding as though they 'expect' dry conditions (this research will be described in greater detail in a coming issue of *Ecos*).

Intrigued by the differences in root lengths and the even more dramatic differences in yields, Dr Stirzaker identified three possible reasons for the benefits of clover mulch.

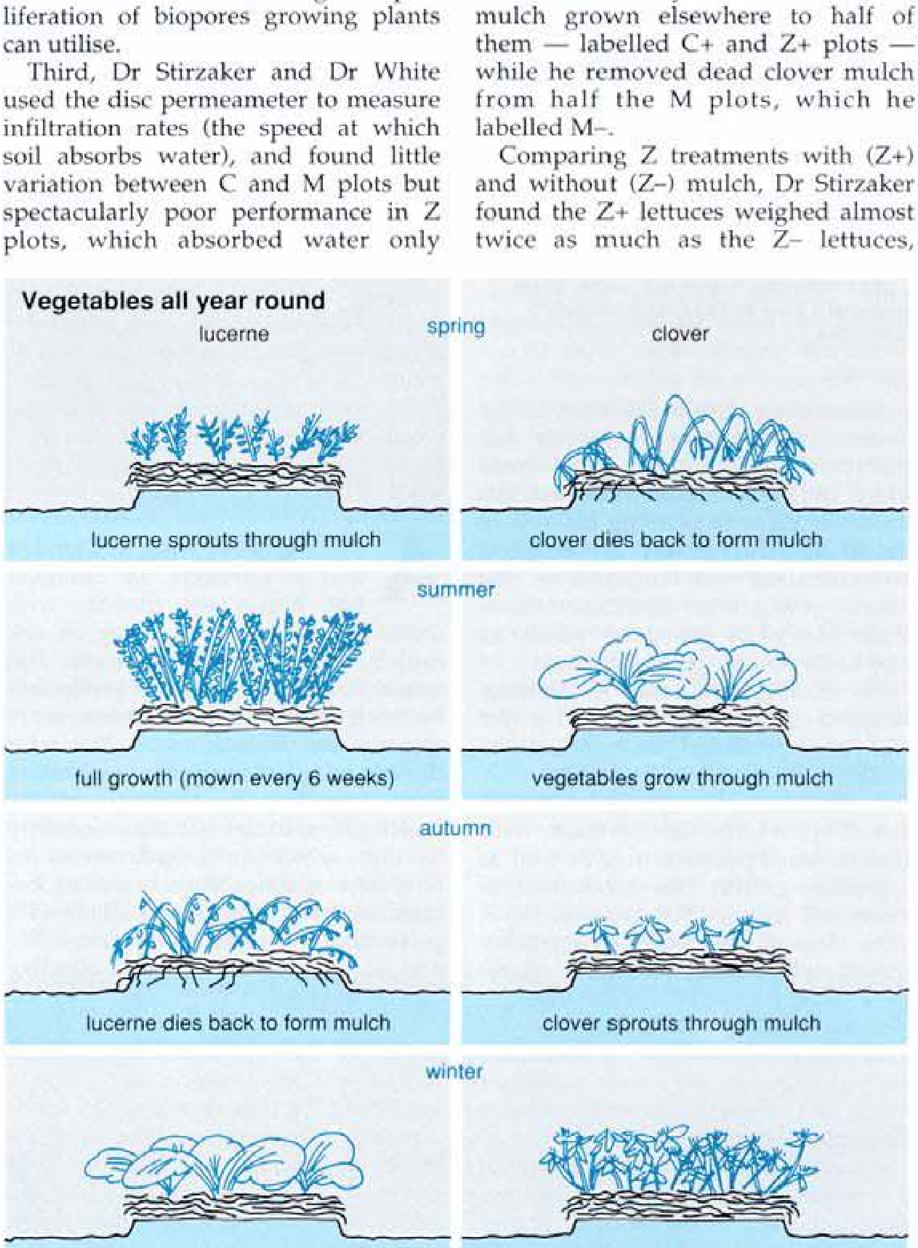
First, mulch on the soil surface keeps the soil cool and moist (soil temperatures in the topmost 75 mm frequently exceeded 38°C during summer in the Z and C plots before the crop shaded the soil, but were as much as 8° lower in the M plots).

Second, the biopores manufactured by clover roots or earthworms create zones of weakness through the hard soil. While root growth — measured by comparing the growth rates of pea radicles, or initial shoots — was, as he expected, highest in the C plots (an average of 109 mm), it was also strong in the M plots, in which roots averaged 75 mm in length compared with 57 mm in the Z plots, indicating that *in situ* mulch does in fact encourage the proliferation of biopores growing plants can utilise.

Third, Dr Stirzaker and Dr White used the disc permeameter to measure infiltration rates (the speed at which soil absorbs water), and found little variation between C and M plots but spectacularly poor performance in Z plots, which absorbed water only 25% as quickly. The evidence provided by infiltration measurements of the clover's effects on biopore formation and the food provided by clover was supported by Dr Stirzaker's measurements of earthworm numbers: these averaged 521 per sq. m in M plots, 22 per sq. m in C plots and only 6 per sq. m in Z plots.

He designed his next set of experiments to test whether surface mulch or the formation of biopores was the most important facet of the M treatment. He set up C and Z plots in the conventional way and added clover mulch grown elsewhere to half of them — labelled C+ and Z+ plots — while he removed dead clover mulch from half the M plots, which he labelled M–.

Comparing Z treatments with (Z+) and without (Z–) mulch, Dr Stirzaker found the Z+ lettuces weighed almost twice as much as the Z– lettuces,




**The *in situ* mulch technique can be expanded to provide a year-round supply of vegetables on a domestic or commercial scale; growing clover in winter provides mulch for summer crops, while summer-growing lucerne provides mulch for winter crops. Using compost and garden mulch also allows for short-season spring and autumn crops.**

**Although *in situ* mulch serves a number of purposes, not all of them are visible. Its weed-control function, however, is revealed in these photographs, showing a virtual absence of weeds in M plots...**
**... and competing weeds in C plots. These weeds will have to be controlled with herbicides.**

demonstrating that mulch even in the absence of biopores improves soil quality; those grown in plots from which mulch had been removed immediately prior to planting (M–) were almost as large as the Z+ lettuces, demonstrating that biopores in the absence of mulch are also important — while M+ plots produced yields as high as Z+ and M– plots combined.

On average, M and C lettuces weighed significantly more (901 g and 1025 g respectively) than Z lettuces (652 g).

Dr Stirzaker also experimented with tomatoes, which, in contrast with lettuces, must produce fruit as well as vegetative growth (the production of stems and leaves). Tomatoes in the Z plots showed the slowest vegetative growth, whereas both M and C plants grew very quickly. These results were essentially the same as those for lettuce; but in the case of tomatoes, fruit growth — the most important result for tomato-growers — was similar in all treatments.

It seemed the smaller leaf canopy of Z tomatoes was more efficient than the large canopies in M and C plants, which produced more leaves than they required for the number of fruit they set. And while the energy, money and environmental costs — including preparation, watering and fertilising — of the *in situ* mulch treatment were lower than those required by conventional tillage, the weights and marketable numbers of tomatoes at harvest were essentially identical.

Mulching also significantly reduced plant disease and weed infestation. Dr Stirzaker compared tomatoes in weeded and unweeded plots to test the effectiveness of mulch for weed-control, and found that yields were 22% lower in unweeded than in weeded C plots; weeding raised yields by 15% in Z plots, but by only 6% in M plots.

After 5 years of work at Camden and in Canberra, Dr Stirzaker has begun experiments with controlled rotation employing *in situ* mulch on a commercial scale. His results to date indicate that yields will be at least as high as those from conventional techniques — but with the advantage of improving soil rather than degrading it. Although *in situ* mulch gives similar initial productivity to that achieved by cultivation, its long-term sustainability is greater because mulch combines zero tillage with protection of the soil surface, the addition of organic material and effective control of weeds.

In collaboration with Dr Bruce Sutton of the University of Sydney's School of Crop Sciences and CSIRO's Ian White, Dr Stirzaker is now experimenting with a refinement of his *in situ* mulch regime, planting lucerne and clover in alternating beds: while the clover is growing in winter, the lucerne is dormant.

Lucerne grows during summer to a height of about 40 cm and is mown at 6-week intervals. It defeats competing weeds because it develops deep roots — in fact, lucerne is one of the most deeply rooted of cultivated plants and in unusually deep soils can reach depths of 10 m — so it can obtain water and nutrients from far below the surface (coincidentally, bringing those nutrients to the surface where subsequent crops can use them and helping prevent soil salinisation by maintaining water tables at a healthy depth).

In summer, shallow-rooting weeds growing between the lucerne rows are out-competed during hot dry weather (which does not affect the lucerne's ability to obtain water). More established weeds can be controlled by strategic mowing and re-watering of the lucerne, since lucerne stores energy in its root system and thus re-emerges more rapidly than weeds, which store almost all their energy in above-ground vegetative growth. The grower need only wait until the weeds are about to flower, then mow again, since the lucerne recovers more quickly than weeds.

The lucerne is given a final cut in autumn (its mown leaves providing mulch and nutrients for winter crops and food for earthworms) before winter crops are planted, and remains dormant until warmer weather in spring.

Dr Stirzaker's work seeks to counter a biological problem with a biological solution, avoiding more drastic chemical and mechanical solutions. Both subterranean clover and lucerne can be employed as a 'first line of defence' against soil degradation. Even if the horticulturist's yields are no greater than those achieved by conventional horticultural regimes, the positive effect of *in situ* mulch on the soil that produces those crops represents a significant step toward sustainable agriculture.

*Carson Creagh*

Australian Overseas Information Service

Vegetable farming in Victoria.

Australian Overseas Information Service

## What can go wrong

Dr Stirzaker warns that all is not necessarily plain sailing with the *in situ* mulch treatment, and that there are several potential pitfalls.

• First, it is important to establish a vigorous subterranean clover crop that will compete strongly against winter weeds and produce a mulch thick enough to smother summer ones. Herbicides can be used to control weeds more easily during the clover phase than during the subsequent vegetable cropping phase.

• Second, it is not always easy to re-establish a pure even clover crop from seed reserves after harvesting vegetables in autumn. The seeds of some clover varieties will rot in wet soil over summer, when vegetable crops are irrigated, and some varieties can germinate before autumn. This can be a problem for low-growing crops such as lettuce (in such situations clover can actually act as a weed), although competition from clover is of little consequence for the majority of summer vegetable crops. An inexpensive way to tackle these problems is to grow a long-season clover that can be sprayed with a non-selective herbicide before the seed matures and re-sow the following autumn.

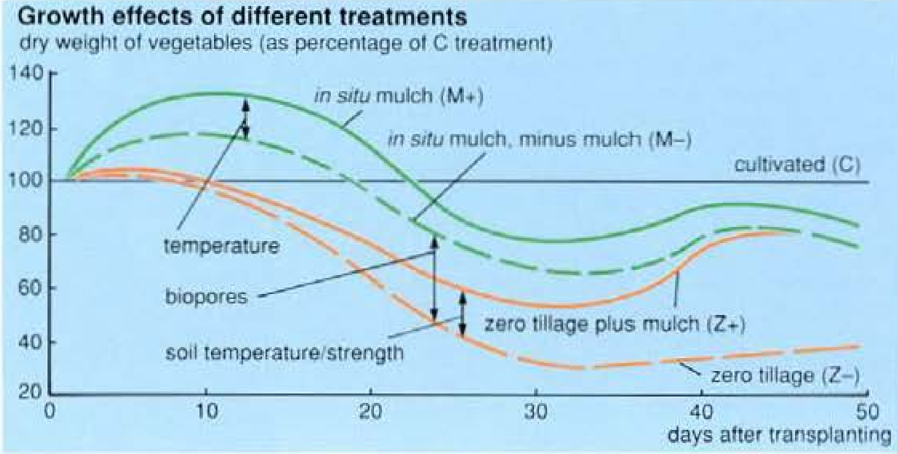

**More about the topic**

Sustainable systems of soil management in vegetable production. R.J. Stirzaker, B.G. Sutton and N. Collis-George. *Acta Horticultura*, 1989, **247**, 81–4.

The effects of surface residues and biopores resulting from an *in situ* mulch crop on tomato and lettuce production. R.J. Stirzaker and I. White. *Tillage for Sustainable Crop Production: Proceedings of the 12th International Soil and Tillage Research Organisation Conference*, 1991.

Soil management for vegetable production. 1. The growth of processing tomatoes following soil preparation by cultivation, zero-tillage and an *in situ* grown mulch. 2. The growth of lettuce under cultivated and zero-tillage conditions during periods of low and high evaporative demand. R.J. Stirzaker, B.G. Sutton and N. Collis-George. *Soil and Tillage Research*, 1991, **11** (in press).


**The effects of *in situ* mulch can be dramatic. If the growth of vegetables in cultivated (C) plots is taken as a straight line, vegetables in the *in situ* mulch (M) plots grow quickly at first, until vegetative growth cancels out the effects of mulch on maintaining even soil temperatures: this is confirmed by removing mulch prior to planting vegetables (M– treatment), which slows growth and reduces dry weight. The indirect benefits of adding mulch to zero-tillage (Z) plots (insulation, moisture retention and so on) also improve dry weight, but the effects of *in situ* mulch on biopore formation are even more dramatic.**



## An instrument for checking soil structure

Australia's ecosystems are ultimately the products of the continent's ancient and fragile soils. Degraded by cultivation and poor land use, and sensitive to a host of influences — among them fire, drought, clearing or introduced animals and plants — soils nevertheless provide a reliable indication of the health of the environment and the best indication of appropriate management strategies.

Until recently, assessing the structure of soils relied on cumbersome techniques that involved measurements of soil particles. In the late 1980s, Dr Ian White and Dr Michael Sully, both of the CSIRO Centre for Environmental Mechanics, and Dr Michael Melville of the University of New South Wales examined the problem afresh. They recognised that the spaces between soil particles — the pores — are more important than the arrangement, size and structure of the particles themselves.

It is the pores that determine a particular soil's ability to transport water, nutrients and gases, to support plants and to cope with natural and man-made pressures. In many cases, soil structure degradation involves a decrease in the number of large pores. This means less water and air can enter the soil and it is harder for plant roots and seedlings to grow. The constant cultivation practised in vegetable gardens and on farms usually affects the number of large soil pores close to the surface.

Dr White, Dr Sully and Dr Melville developed a portable, easily operated instrument that assesses pore structure by measuring how quickly water will soak into a particular soil, applying theory developed more than 20 years ago by Dr Robin Wooding, a CSIRO scientist now working at the Centre for Environmental Mechanics.

The disc permeameter, now manufactured under licence by A.L. Franklin Pty Ltd of Brookvale, N.S.W., was developed with the assistance of the National Soil Conservation Program, the New South Wales Soil Conservation Service and the University of New South Wales.

It has found a market in countries with soil problems differing as widely as those of Holland and the midwest of the United States, and offers major advantages over other instruments. It measures flow as it happens in Nature, where water spreads outwards as well as downwards (unlike instruments that rely on driving a cylinder into the soil); and it can operate even in 'problem' soils — crusted, self-mulching, cracking, saline or stony ones — because it obtains information without mechanically disturbing the soil, freeing researchers from the concern that their measurements reflect an artificial situation rather than natural conditions.

To operate the disc permeameter, the researcher places water on the soil surface, from either a shallow pond or a wet disc (both of which are about the diameter of a dinner plate), which is then forced into the soil under pressure or allowed to flow into the soil under suction. By measuring the rate at which water flows out of the instrument's reservoir, scientists can work out the soil's sorptivity (ability to absorb water) and its hydraulic conductivity (a measure of how water moves through the soil under the pull of gravity). By comparing how quickly water flows under pressure with how quickly it flows under suction, they can assess the degree to which the soil has become degraded.

Soils are riddled with macropores, cracks and tunnels formed by earthworms or old root tracks. Compaction of a soil — say, by heavy traffic, by a steamroller or by agricultural practices — reduces the macropores' size, in the same way that squeezing a sponge forces air out of its pores. Researchers can predict the effect of compaction on soil structure by using the disc permeameter.

The instrument can serve a variety of purposes. It allows scientists to measure: soils' ability to absorb rainfall; their performance under crops; and the impacts of different management practices on water uptake, run-off and erosion. At Tamworth in north-western New South Wales, it is being used to assess different soils' ability to soak up effluent.

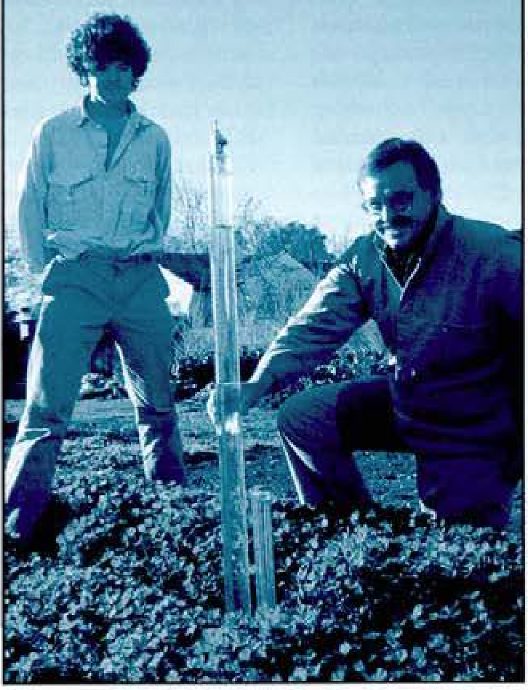
It allows engineers to measure the performance of mining dumps and reclaimed land or assess the permeability of construction materials such as concrete or bricks (including mud bricks), roadways, dams and the clays used to line landfill. It even has applications in industry, providing manufacturers, consumer bodies and scientists with a means of measuring the performance of absorbent materials such as nappies.

• Third, no horticultural equipment has been commercially developed for sowing or transplanting into mulches, although suitable equipment does exist. Zero tillage will also require changes to conventional management of crop residues.

• Fourth, the benefits of mulch change throughout the year. Mulches are most important in summer, when soil temperatures are high, while in spring the slower warming of soil beneath mulches can slow growth in early-sown crops. Growers must also leave enough time between the death of the clover and the planting of vegetables to allow for the initial decomposition of clover roots.

• Fifth, some horticultural operations grow crops all year round and cannot afford to have land tied up in the production of mulch crops. This is a difficult problem; short-term economic considerations often dictate that farming methods make the soil less economically viable in the long term, and in some parts of Australia vegetable-farmers are practising shifting cultivation. It may be possible to reduce the length of time the mulch crop is in the ground to about 4 months; on the other hand, the benefits of a good mulch crop can last for more than a year.

**Dr White shows how the soil permeameter can be used to provide information on soil strength and structure.**



John Holdsworth

### Want to try it?

A 'Clever Clover' kit containing two packets of both clover and lucerne seeds and full planting instructions, plus a follow-up questionnaire, is available for $10. Send your order, with payment, to: C.E.M. Clever Clover Kit, G.P.O. Box 821, Canberra A.C.T. 2601.