NATIONAL PROGRAM FOR SUSTAINABLE IRRIGATION

PROJECT SRP005026

SOIL MANAGEMENT FOR AUSTRALIAN IRRIGATED AGRICULTURE

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Cover page caption

Newly planted fruit trees in beds with rye grass. No rye grass near trees, traffic lane separate, slow rate spray irrigation.

SUMMARY

The fruit industry needs to increase its productivity too equal world's best and thus compete in the market. This applies to all Australian horticulture industries. Large potential exists: e.g. the average yield of canning pears is 40 t/ha compared with best overseas yields of 180t/ha and calculated potential of 220t/ha The major cause of low productivity is Australia's mediocre soils. Our soils go hard in orchards. This is called coalescence and it severely restricts the growth and function of tree roots. The most productive soils overseas remain loose, soft and porous to depth. Coalescence restricts the size of the tree root system, but also very much restricts the flow of water from the soil to the root surface. The project has developed a new system of orchard soil management that overcomes coalescence.

The key properties to develop in the soils are the build up of soil organic matter and greatly increased biological activity. The project had developed a detailed list of inputs for soil preparation and subsequent management. These provide the organic matter and biological activity and the main input is to grow rye grass. The grass produces rhizosheaths of soil around each grass root and it is here that the soil changes to the properties of worlds best soils.

INDUSTRY SUMMARY

The project's research has developed a new system of soil management. Eight fruitgrowers have set up fruit trees in commercial areas using the system. The oldest are three years and their soils have developed into excellent structure, with many of the properties of the most productive soils in the world. In the meantime, The project developed management list of soil inputs needed to achieve super soil. The additional inputs, additional to the project's last Final Report, include growing rye grass prior to the new planting, avoid any fallow (no grass), hilling to beds, build beds in stages, incorporate dry straw from the rye grass.

The key aims are the build up of soil organic matter and greatly increased biological activity. The project's experiments have shown that by applying these practices, the soils are close to the properties of super soil – the most productive of the world's soils. The rye grass provides the means. Rye grass roots develop rhizosheaths of soil particles, attached to each root and up to 2mm in diameter. Because of the enhanced supply of organic metabolites, soil nutrients and water, organic matter builds up in the sheath, and within the sheath the organic matter is protected from being consumed by the normal soil microbes. The rhizosheath therefore supplies the key inputs – organic matter and biological activity – required for rapid development of ideal soil structure.

BACKGROUND

Irrigated agriculture in Australia performs rather poorly in the dollars it generates. This is because the yields of nearly all crops and fodder are very low compared with potential; but also because low cost, low return (per ha and per Ml) grazing industries dominate. For example, irrigated Victoria produces $430 per ha per year, California $3,500 and Israel $13,700. Examples of actual Australian and best overseas yields include maize 10t/ha *v* 35, grapes 4 *v* 20 and pears 35 *v* 180.

To consider potential productivity we should not only compare our results with what others can achieve: the ultimate limitation to plant productivity is the available solar radiation. This is expressed as the conversion of incoming solar energy to plant dry matter: 6% conversion is possible on farm, 12% has been achieved. A 4% conversion in southern Australian irrigation areas to plant dry matter would give 64t/ha which is 15 times the current yield of, for example, perennial pasture. Cockroft and Mason (1987) discuss this and give examples of a range of crops, especially horticulture.

This, and comparisons with very best yields overseas, indicate that irrigated agriculture could generate far more than current. The important issue is that it is possible to greatly improve the total economic value of our irrigate agriculture.

Causes of Low Productivity

Australian irrigated agriculture has many advantages and thus real potential: Ample land, easily irrigated, mostly high quality water, good climate, clean and green, year round production, good local infrastructure, experienced and able farmers, soils with few difficult nutritional problems. The main cause of low productivity is soil structure. Australian soils rapidly deteriorate when put under agriculture – they go hard, then restrict crop roots, yield falls off disastrously and the crops become uneconomic. Soil hardening causes the low yields of most annual and perennial crops; it also forces animal industries to grow pastures and graze in order to sustain feed production.

In the early days of irrigated agriculture, many areas including northern Victoria and southern NSW, farmers grew crops: in the late 1800's crops occupied 100% of irrigated land; by 1910 they occupied 70%, 1925 it was 50%, and currently it is 20%. This swing to pastures is not seen anywhere else in irrigation areas around the world and was caused here by our hard setting soils. In NSW the proportion of soils under crops is higher but most of this is either rice which requires soils of low permeability, or wheat which is grown in winter.

However, poor soils should not be looked on as a given. We have improved soil nutrients and water and we can improve soil structure too.

Crop yields increase dramatically when soil improves. Thus, in Australian horticulture, (1) the poor soil types average 10t/ha and the best 50t/ha; (2) with soil management, in the 1950's orchard soils were cultivated and trees averaged 15t/ha; under current soil management they average 60 (see table 2). However, this is still low compared to world's best, to several individual northern Victorian trees and to estimates calculated from solar radiation. The cause of this low productivity in irrigated agriculture lies in coalescence, a soil hardening, and consequent low root activity restricting the plant tops. The best soils overseas remain loose, soft and porous even after many years of growing crops and even for centuries.

Properties of Productive Soils

I have studied the properties of some of the best soils in the world, by visiting them, examining them in the field, discussing them with local soil scientists, reading the literature relevant to them, including soil surveys; in California, Nebraska, Iowa, Holland, Sweden, Italy, Kent, China, Northern Syria and New Zealand. The very best soils in each country showed similar properties to each other. Their yields of nearly all crops are two to three times the highest in Australia. In Madera County, California, the soil survey in its comments on the best soil type, says, "This soil is much prized in Californian agriculture." I call them Super Soils. They are extremely rare in all areas. They do not exist in Australia.

Table 1 sets out some of the properties of a super soil in Kent and contrasts it with a Class 1 soil in Shepparton. The important differences are, in the super soil: medium-light textures, deep, loose, soft, porous, very high available water, high OM, young (1000yr).

Table 1. Comparison of Properties of Barming Soil in UK and Class 1 Soil in Shepparton

Property	East Shepp. fsl	Barming sl
Macroporosity (%)	11	20
Mesoporosity (%)	9	18
Microporosity (%)	24	33
Total porosity (%)	47	71
Water Stable Aggregation (%)	75	100
Dispersion (%)	2	0
Slaking (%)	9	0
Coalescence (%)	100	0
Friability (%)	20	100
Infiltration (mm/ha)	20	50
Hydraulic conductivity (mm/hr)	9	36
Available water capacity (%)	8	25
Penetrometer resistance (MPa)	3.6	0.8
Bulk Density (g/cc)	1.4	0.8
Coarse sand (%)	27	12
Fine sand (%)	48	48
Silt (%)	12	24
Clay (%)	13	16
Organic Matter (%)	2.7	9.4
pH	6.5	6.3
Fine Roots (cm/cc)	4	30

Mechanics of Future Soil Change

All the super soils are similar to each other. They are young - < 2000 years - in contrast to our irrigated soils at over 80,000. They are all alluvial loams or fine sandy loams. Many contain lime. They naturally contain a special mineral called montmorillonite which would be associated with soil looseness. Australian loams and fine sandy loams lack montmorillonite because they are old. Therefore Australia is forced into finding our own way to produce super soil.

We have found very small areas in several older orchards at Ardmona whose soils remain loose, soft and porous. They are rare and each only three to four square metres in area. But these give us encouragement that Australian irrigated soils can be further improved. They also give a clue as to how: these soils have not been cultivated for over 20 years, occur in tree-line banks that have grown substantial stands of grass with no traffic on the banks, are irrigated by slow wet, have lime added and are well drained. They contain about eight percent organic matter in contrast to normal orchard soils of one to two percent.

The soil science literature tells us clearly that to improve soil structure to the large extent required, the essential two issues are high soil organic matter and high biological activity (fungi, bacteria, other micro-organisms and roots, especially very fine roots and root hairs). This is normally unachievable because most organic matter added to soil is quickly consumed by earthworms, other fauna and fungi, and because the beneficial biological agents cannot build up in our difficult soils.

So the aim of the project is to find how to change our irrigated soils into soils with the properties of the super soils.

Progress to Now

My current research work started in 1989 on orchards and resulted in a new system of soil management for orchards. This new system doubled the yield of fruit from 30 to 60 t/ha, was cheap to set up and run and was easy to manage. System 3, Table 2. It quickly became standard practice for almost all new plantings in irrigated Victoria, then in other states. It required no extension program beyond my instructing contractors – such as in subsoil ripping, irrigation method and bed forming. Growers quickly adapted their soil management, spurred by the high yields.

In the middle 1990's I started the background research for the next new system of soil management, with the same aims: double yields to 120t/ha, cheap and simple. Forty fruit growers and ten tomato growers assisted me with my plots on their farms. During 2005, eight fruitgrowers and one tomato grower set up and grew their crops within one commercial area each, using the new system. The rest of the original fifty growers receive quarterly bulletins from me and are thus aware of the new plantings.

The Rhizosheath

The research approach to be followed now, comes from Professor McCully of CSIRO Canberra who has studied the rhizosheath (rhizo = root). This is the sheath of soil particles that develops around grass roots, especially rye grass, consisting of fine soil particles glued to the root surface by root exudates and fine fungi, roots and root hairs. Water and nutrients from the bulk soil, flowing to these roots, are forced to crowd together before they enter the root. This concentration of water and nutrients increases the biological activity next to the root surface. Populations of root hairs and microbes grow to enormous numbers and the soil next to the root becomes very stable and porous and so forms the rhizosheath. At the same time, as organisms grow and eventually die, they add organic matter to the sheath. For a range of reasons, organic matter within the rhizosheath becomes protected. The total result is that the rhizosheath soil becomes especially porous and would conduct water efficiently to the roots. The soil is very stable.

So the rhizosheath soil is very different from normal soil and we suggest it is the mechanism by which our future crop soils can become more porous, high in organic matter and stable. The sheath, when the original root dies, breaks up, leaving super-aggregates and in this way we suggest, super soil.

The future directions of our project must include a careful study of the rhizosheath of rye grass: the action of organic matter and biological activity in it; the means by which these can be activated efficiently and permanently; the changes in the rhizosheath when the rye grass root dies; the development of super soil from the special soil in the rhizosheath. Then we can manage our soils properly.

Table 2. The progressive development of the new systems of orchard soil management by Bruce Cockroft

System	Year Commercialised	Best Commercial Yield (t/h)	Description
1	Pre-1960	15	Cultivated, flood irrigated, winter cover crop.
2	1965	30	Zero till, flood irrigated, tree line weed spray, permanent surface drains.
3	1980 (current)	60	Zero till, spray irrigated, tree line bed, loosened subsoil, winter grass, summer mulch, drains.
4	2005 (under test)	120 (aim)	New Inputs e.g. Pre planting build up of OM and soil structure, additional lime, no contamination with subsoil clay, drainage, tree-line bed, zero till, rye grass autumn/winter, summer mulch.
5	Future	150 (aim)	Super soil from rhizosheath

METHODS

My approach to research is to work on major issues where Australia needs development; in particular to advance regional Australia. To improve our soils is an essential issue to the future of Australia. All of our soils could be improved but especially our irrigated agriculture productivity. Soil management is the obvious change now that we fixed plant nutrition, water supply, salinity, drainage and soil born diseases; and we have soil surveys of most of our irrigated areas. But soil management is very much a complex long term journey.

At the Department of Agriculture research centre at Tatura, starting in the 1950's our group studied and produced results that led to scientific publications, in the following subjects;

- Soils of irrigated Australia and their surveys.
- Pedology of irrigate soils.
- Physiography and geomorphology of Australian soils.
- Physical and chemical properties of Australian soils.
- Root distribution of orchard trees.
- Soil management
- Tree nutrition and fertilizer use.
- Water infiltration and soil permeability.
- Soil survey method.
- Fruit tree productivity and soils.
- Irrigation timing.
- Soil structure.
- Soil strength and crop rooting.
- Salinity.
- Soil compaction.
- Soil coalescence.
- Fruit tree waterlogging and ground water problems.

By 1980's the major soil problems had been investigated and recommendations made available to irrigation farmers on these subjects. It was obvious that as farmers managed their soils to the now best practice crop yields increased proportionally. The research next tackled the remaining soil improvements needed for best productivity.

In Table 2, this stage has become System 4. It is under commercial test and development on several northern Victorian orchards.

It had become clear that rye grass as the main Input will not suffice on its own; the soil still coalesces. Many more management details are required.

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NEXT STEP – SYSTEM 5

The Rhizosheath

Technical Background

It is important to undertake basic research that gives an understanding of processes. Once we understand what the mechanisms of an issue are, we can then achieve the desired practical outcome. We have more chance of fixing an engine or a heart attack, if we understand how it works.

John Constable said

“It is the soul that sees; the outward eyes
Present the object, but the Mind succeeds in discerning.
We see nothing till we truly understand it.”

The way to produce soil with excellent structure is to put it under rye grass with no traffic. Within a few months the structure improves amazingly, so that the soil will readily accept water, drain quickly and the soil water will flow rapidly to the tree roots. But also, the new soil structure allows the tree to develop a very large root system, so that the total flow of water to the tree will be greatly enhanced, for maximum productivity.

Our current work aims to increase our understanding of why grass is so effective in making the best soil structure; then we can find how to best produce and maintain the best structure. Hence my recent field experiments, my studies of the soil science literature and my interaction with research people, especially Professor M. McCully, Dr. J. Passioura and Dr. M. Watt at CSIRO Canberra.

To achieve the very best soil, in this regard essential are 1) high organic matter (7% plus), 2) huge biological activity from soil microbes and roots, and 3) the Inputs/Practices discussed earlier.

The Rhizosheath

The action is within the sheath of soil clinging to each grass root; this is called the rhizosheath (rhizo = root). Most plant species do not produce rhizosheaths, but grasses do, and especially rye grass. When we gently pull a rye grass plant out of loose soil, we see that every root holds a sheath of fine soil, except at the growing root tip.

Professor McCully and Dr Watt at CSIRO Canberra are the world authorities on the rhizosheath and have published scientific papers that add greatly to our understanding of it. They show that the soil in the sheath is very different and special: high amount of very fine grass roots, fungi, bacteria and other microbes; high OM; a high carbon turnover; the OM in the sheath is clearly very young; the soil becomes very stable. All these features act together to build the soil structure that we are seeking.

Research to Date

The project started this research in July 2008; it is funded by Land and Water Australia. The main research in the orchards must continue at the same rate as in the past, aiming at System 5, Table 2. The LWA funds are used to run the Scanning Electron

Microscope at CSIRO for several years. The project will centre on the processes in the rhizosheath.

Over the last 12 months, in addition to our orchard research, Cockroft has set up orchard and tomato plots and pot experiments for this purpose. Previous research has indicated the kind of treatments that may provide super soil. We set up a very large number of experimental plots and pots with a wide range of treatments. Their combinations, the range of soil types and management that our fifteen orchards give will produce at least small numbers of super soils. Through these we can select those most likely to produce super soil and study them. The project aims to have an Electron Microscope account of this development.

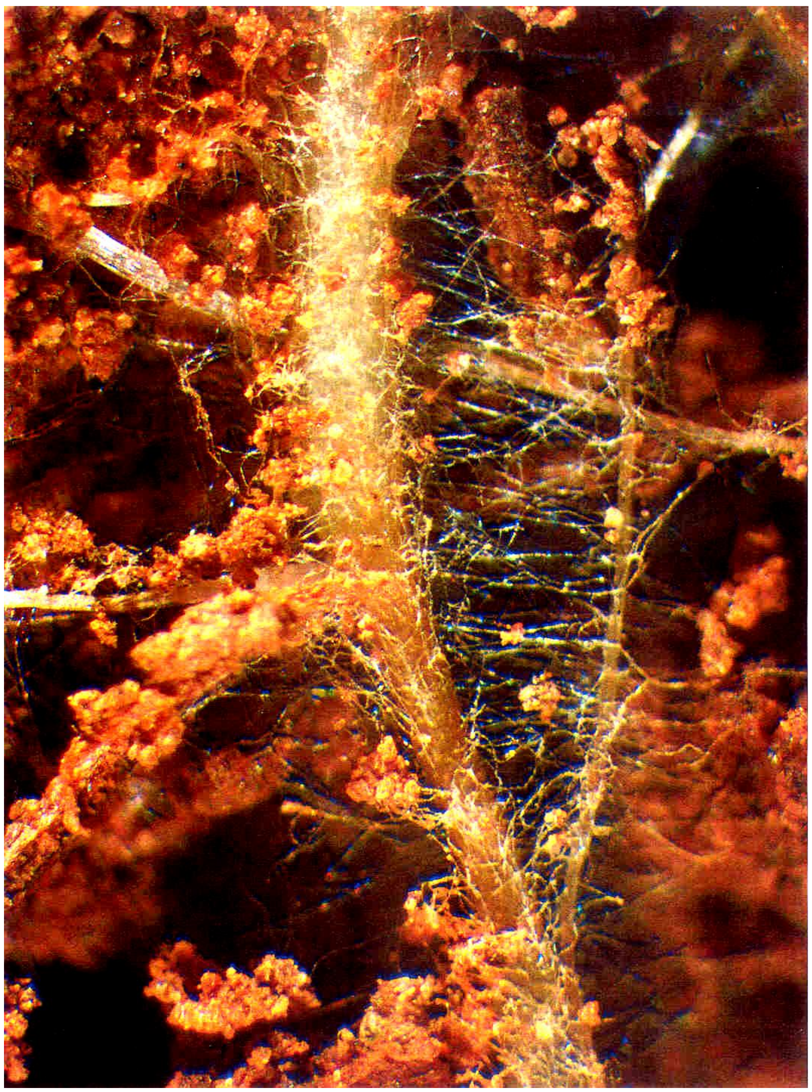

Plate 1. Scanning Electron Micrograph of an early stage in the development of super aggregates. Mat of root hairs, microaggregates adhering. M. McCully.

ORCHARD PLOT EXPERIMENTS

The project set up many small, simple, easily maintained experiments on orchards, on the assumption that some treatments will indicate the important issues, and together with a thorough study of the soil science literature plus discussions with soil scientists and growers, we can eventually develop soil management methods that produce soils that equal the most productive in the world. I used the fertilizer, irrigation, lime and gypsum management of the growers, applied by the grower. I grew rye grass on the plots. The plots were set up on the tree line bed. I measured coalescence every year and report here on the most recent results. This work is on going. The project also set up a large number of pots with similar treatments.

Method

In mid 2001 I started a new series of orchard experiments that investigated possible treatments to keep our soils loose soft and porous and not coalesce into the hard mass typical of our soils. I set up 19 experiments over 15 orchards, a total of 285 plots. The plots were between 60 x 60cm and 100 x 100cm in size set up in young trees. In each experiment I dug the soil to 25cm depth, applied the treatment, ensured correct irrigation, drainage, fertilizer and lime and sowed rye grass. I set up the same treatment over at least ten orchards to make up one complete experiment, all on the soil type Shepparton fine sandy loam, a red brown earth and the most important orchard soil in Northern Victoria. Once a year I measured the amount of hardening as the percentage coalescence: 100% is complete coalescence to a solid mass, 0% is no coalescence with the soil remaining loose soft and porous – see Cockroft and Olsson 2000 for method of measuring coalescence. In a few I removed all the soil from the plot and introduced a test soil – e.g. virgin soil from a nearby old fence - to compare with orchard soil and then to assist in understanding the processes involved in building excellent soil. I grew rye grass in almost all plots.

The treatments I applied followed the results of earlier experiments in orchards, in pot experiments and in tomato experiments. Reaggresize is to loosen the soil once it has started to coalesce but can still be transformed back into aggregates by gentle tillage. The action breaks the welding that had started between the original aggregates. Here the plots were set up from the soil of the site and grew rye grass. Capillary wet is to irrigate from the bottom of the surface soil, with water entering by buried drip irrigation pipes.

Table 3: Tentative List of Inputs/Practices

1. Avoid traffic compaction.
2. Avoid clay contamination.
3. Avoid powdering.
4. Avoid ex-cropping soil.
5. Avoid ex-pasture soil.
6. Avoid poor drainage.
7. Avoid soil that is too wet.
8. Avoid powdering the soil when cultivating.
9. Avoid excessive subsoil clay.
10. As trees mature avoid rye grass in spring and summer.
11. Reaggresize.
12. Cultivate with soil slightly moist.
13. Elevate the Nitrogen fertilizer
14. If ex-cropped or ex-pasture, fix the soil with rye grass.
15. No point in trying to improve traffic lane – compacted.
16. Pre-plant rye grass.
17. Grow for 1 – 2 years.
18. Cultivate and re-sow at 6 – 12 months.
19. Set up slow wet capillary irrigation.
20. Maintain rye grass over whole area 2 more years more, except near young trees.
21. Cultivate, incorporate rye grass, build up bank every 6 months.
22. Re grow rye grass immediately after.
23. Repeat every 3 – 6 months until all the surface soil is in the bed – say 3 x 0.6m.
24. Incorporate the rye grass during these operations. (Top and roots).
25. Cultivate and form up small banks – 40cm.
26. Plant trees.
27. Grow rye grass soon after all cultivations.
28. Use all the topsoil into tree line bed.
29. Build tree line bed in stages
30. In young trees keep area surrounding the trees bare.
31. In older trees grow rye grass in autumn-winter only.
32. Experiment with up to 10% subsoil clay incorporated.

RESULTS

The list of Inputs include the order of applying each Input in a new or replant orchard. These come from the earlier experiments. The project s indebted to Professor M. McCully, Dr. J Passioura, Dr. M Watt, the fifty participating orchard and tomatoes growers, Dr. K Olson and Dr. Jan Skjemstad of the Waite Institute in Adelaide.

When we set up experiments and commercial sized orchard sites and included al of these Inputs in combination, the project achieved its most important aim of no hardening of the soil – zero coalescence, even after 14 years. Only by including every one of the Inputs can we achieve these aims. Anyone can grow rye grass – it is a weed in many areas – but to ask it to produce super soil we must use a special preparation and management of the site – the Inputs listed.

Observations in the Field

After setting up the field site for an orchard and applying all the Inputs of the list, the soil starts to change in our aimed for way within very few weeks. The rye grass plants quickly develop a very large root system, extending to the subsoil B horizon. Very few roots penetrate the clay subsoil B horizon. The roots then develop their root hairs behind the growing root tip. Irrigation water penetrates rapidly, without collapsing the soil and drains within very few hours. The incorporated rye grass plants undergo very slow visible decomposition. The soil starts to take on a darker colour, from the organic matter that is available and not oxidized. The soil remains very stable to wetting at each irrigation and the rye grass roots intensify.

After each cultivation and bed building the rye grass regrows quickly and the rye grass roots fill the bed within its greatly enlarged volume of soil. By the time the bed is fully built, with no A horizon soil left in the traffic lane, all the bed soil remains loose, soft, porous and completely stable to irrigation and any other orchard activity. The depth of surface soil in the bed is now 60cm.

DEVELOPMENT OF LOOSE SOFT POROUS SOIL

The soils in orchards are always coalesced to a hard dense mass. The project has achieved a method of preventing coalescence. Plate 1 shows the difference between the normal coalesced soil and the uncoalesced soil of the new system of soil preparation and management that is loose, soft and porous.

The cultivations and bed building plus the sequence of rye grass plantings provide organic matter, rearrangement and contact with the root surfaces. The surfaces of the root, root hairs and microbes produce mucilage to which the fine soil particles adhere. This starts the development of the new aggregates consisting of aggregated original particles now adhering as a result of entanglement of soil particles with the root hairs and very fine roots of the rye grass. This rearrangement is assisted by the wetting and drying rain and irrigations and subsequent swelling and shrinking; the movement of infiltrating and transpirational water and disturbance by the root hairs and roots. As the biological activity and the organic matter build up the new aggregates undergo slow changes – they become more stable to water, they develop more and more strength by such processes as development of girders and cables from filaments of micro organisms and very fine roots. Also by the developing stability of the aggregates by the initial stability of the soil as a result of the cultivation, bedding and rye grass sequence of plantings, the provision of mucilage from the constant production of new roots and root hairs. Drying and the particles come together from shrinkage. All this is aided by the special management of the bed: the bed has no traffic and so no compaction, is full of roots for large periods of the year, excellent irrigation and drainage, constant biological activity and organic matter built up.

These processes result in the bed of loose soil particles being changed into aggregates, up to 5mm in diameter as shown in plate 2. Once the soil becomes very friable, maintenance of this structure is cheap and simple – in orchards, grow grass in winter and autumn but maintain the orchard free of grass and weeds in spring and summer.

The project now has several tree plantings and also row crops under a commercial situation.

DEVELOPMENT OF SUPER SOIL

The loose soft porous soil of System 4, although much more productive than in current orchard plantings, it is still no where near as productive as theoretically possible and it is important that the next, final system of soil management is developed. This would involve the production of super aggregates of soil and similar to the super soils overseas. Table 1 gives soil properties of such a soil, in Kent, and contrasts it with the best soil in irrigated Australia. The scientists at CSIRO Canberra are convinced that the way to make this change is through the rhizosheath.

Of the 800 plots and pots set up several have developed into super soil with the properties of the Barming super soil.

Observations by Microscope

Each rye grass root growing through the loose soil, produces the mucilage and the small soil particles are captured by the mucilage and stick to the roots. At the same time, the roots start to produce root hairs along back from the root tip. These are also sticky and the soil particles adhere. Eventually the whole length of rye grass root is covered with soil particles. The root secretions continue and the hairs grow so that mucilage develops into the soil. More soil particles adhere; the root hairs lengthen and pick up more soil. In this way the rhizosheath develops to several millimeters diameter. The arrangement of the rhizosheath remain open due to the mucilage changing to a stable cement on drying, all assisted by the micro organisms. The mucilage also captures fragments of organic matter and micro organisms.

ADDENDUM
SOIL MANAGEMENT FOR AUSTRALIAN IRRIGATED AGRICULTURE

Crop Loading

The necessary increase in fruit yields comes from two sources – soil improvement and tree management improvement.

1. SOIL

Water supply to the leaves of the trees from the water in the soil. In all Australian orchards and other cropping the crop leaves start transpiring, to draw the water up through the roots starting soon after day break. However, by mid to late morning photosynthesis starts to decline and soon stops. This is because the soil is not permeable enough to supply the tree roots at the rates determined by the level of solar energy. Essential here for increased fruit productivity is to increase the mesoporosity of the soil – the available water. The aim is to have high mesoporosity so that the trees photosynthesize all through the daylight hours. This requirement of the trees is also assisted by a larger root system that comes from increasing the volume of surface soil by bedding.

2. TREE MANAGEMENT

Trees and other crops that are growing in the very best soils always respond to the good soil conditions by increased vegetative growth – orchardists call this growth, water shoots. If though the trees in excellent soils are managed for more fruit, that fruit competes strongly with the shoot growth and the vegetative growth reduces markedly.

The photo of an apple limb with excellent soil and proper crop loading, shows a heavy crop developing and very little vegetative growth – no water shoots. Goulburn Valley orchard trees can be changed on good soils, from 350 leaves per fruit, down to 6 leaves per fruit as in the photo. Apart from the greatly increased yield of fruit, the cost of pruning is reduced. But most important, water use for unit of fruit is markedly reduced.

Tree with less than 10 leaves per fruit

ADDENDUM
SOIL MANAGEMENT FOR AUSTRALIAN IRRIGATED AGRICULTURE

The Future of Regional Australia

In discussing **Regional Australia, Meyer** said:

On the future of Regional Australia,
The crucial importance of Regional Australia,
We must bring fresh thinking to innovation,
Imagination, Creative endeavor,
People provide the drive and the action,
Education is the most important tool.

Our research project "Soil Management for Irrigated Australian Agriculture" guides orchardists and farmers into a new system of soil preparation and management that will treble crop yields. With row crops it will give three crops each year, in perpetuity.

The result is a substantial increase in yields and thus a huge lowering of costs per tonne. In most forms of agriculture, including non-irrigated, this would assist the growers because the system is simple, cheap to set up and run, lasts into the future, uses less water per tonne of fruit, and lowers costs of tree management, including pruning and thinning. Less fuel, fertilizers and water use per tonne. Ensure no salinity. The system sequesters carbon to very high levels, using the only possible way to increase soil carbon under agriculture.

The system is under test on several farms.

Bruce Cockroft.

ADDENDUM
SOIL MANAGEMENT FOR AUSTRALIAN IRRIGATED AGRICULTURE

Row Crop Experiments

I set up a vegetable experiment at Kialla in 1994 to study soil management under vegetables. The aim was to prevent the coalescence and hardening that soils normally undergo after only one or two years under row crops such as tomatoes. The experiment included thirty three treatments. It grew three crops per year over the life of the experiment, to now. The soil type was Shepparton fine sandy loam; plus four plots of swelling clay soil from the tomato growing areas at Rochester and Boort.

The soil improved in all plots during the course of the experiment. The best treatments include those with a period of rye grass in the rotation, and organic matter added.

The explanation for this excellent result under very heavy cropping lies in: the good condition of the soil at the start of the experiment following a short period under rye grass; soil management that provided no traffic on the beds, slow spray irrigation, good drainage, careful tillage, best fertilizer practice. Most important was the continuous cropping, that provided roots within the soil for 365 days of each year, mainly crop roots. The roots provide a continuous supply of organic matter, protection for that organic matter, and very high biological activity within the soil. These are the ingredients for ideal soil structure. I shall continue the experiment.

Discussion

That none of the experimental plots resulted in full soil coalescence (100%), even after 13 years of triple cropping, is very surprising but very pleasing. This contrasts with all farmer cropping where soils coalesce to 100%, in vegetables, fodder crops, grain crops, fruit. This is especially exciting due to the parallel result in our orchard research, where in our new System 5 the soil remains loose (coalescence < 40%). The important development in the soils of all these successful experiments is the large build up of natural organic matter and of biological activity.

We can suggest the action of the treatments in improving the soils:

- Best treatment was rye grass within the rotation, due to the grass roots building OM and biological activity and protecting both.
- Adding OM increased the soil OM, with the continued plant roots protecting the OM as it built up. The added OM plus the protection by vegetable roots is an important new issue.
- The row of plots with subsoil clay added gave some positive results, presumably because the clay changed to an active state in stabilizing the soil aggregates over the years of the experiment.
- No tillage averaged higher coalescence because incipient coalescence was not broken up as in the cultivated soils.
- Mulching often <u>increased</u> coalescence as a result of earthworms ingesting the mulch, whence the gut puddles the soil and produces a hard mass.
- Adding lime had a small effect.
- Incorporating the residues did not improve the soil beyond the ‘Commercial’ possibly because I buried the residues too deeply.

ADDENDUM
SOIL MANAGEMENT FOR AUSTRALIAN IRRIGATED AGRICULTURE

Mesoporosity – Continuing the Project

In any attempt to achieve high yielding soils (super soils), mesoporosity (Available water) is an important issue. Mesopores not only store water they conduct it to the root surface and the greater the quality of water flowing to crop roots the greater the crop productivity. The larger mesopores are the most important because of their higher conductivities. Hall et. al. classify Available Water in terms of productivity thus:

Available Water (% volume)	**Soil Quality**
< 10	Poor
10 - 15	Moderate
15 - 20	Good
20 - 25	Very Good
> 25	Excellent

Australian soils tend to poor AW, with northern Victorian soils moderate to poor and after some years of cropping decline to under 5%.

Porous aggregates have a low density, are rounded, soft and have a fuzzy surface in contrast to low porosity fragments resulting from cultivation of dense soil that are dense, angular, hard and smooth faced.

Field Experiments

I set up these experiments from 1996 in local orchards seeking a method of soil preparation and subsequent management for maximum crop yields. The most useful results on AW were from the pot experiments. I set up 840 experimental pots, some at Cliff Dillon's orchard and some at Stuart Pickworth's. The pots hold 7kg of soil, are properly drained and grow rye grass. We irrigate the Pickworth pots by sprinkler and the Dillon pots by capillary. I applied such treatments as different original soils, organic matter, lime, reaggresizing and other additives.

The OM was added at high rates – 4%; the lime at 1% or more. Reaggresize means to gently break up any coalesce within 6 months of the soil preparation. Capillary wet means to irrigate the soil from below as tomato growers, where the water spreads on the subsoil clay then wets upwards by capillary.

I measured the Available Water in 2004.

Soils that had been under cropping and pasture are the worst – presumably the cropping shatters the aggregates and oxidizes the OM and the pasture soil is compacted.

Many of the treatments gave us 'Very Good' Available Water. The common ingredient in these was that the original soil was in good condition – it was fairly high in organic matter. When we applied certain treatments to this kind of soil we achieved the best results of all. ('Excellent' Available Water). The amount of Available Water in our plots and pots tend to parallel the treatment results of coalescence; there is some consistence here. The generally good level of Available Water throughout most treatments must be a reflection of the setting up and management – mostly reasonable initial soil, careful irrigation and drainage, the continuous rye grass, no traffic compaction, no tillage, gypsum and fertilizers.

In the combinations the treatments build on each other, improving the Available Water. This gives us a novel approach and a real hope in our quest for the very best type of soil. Thus the 'Good orchard soil' treatment (best soil type, tree line bank, not tilled, years of grass, weed and tree roots, capillary wet from flood irrigation between the banks capillary wetting the soil above, build up of OM) is 'Excellent 'Available water, and as we add OM, reaggresize, lime, capillary wet, each gives an increase and finally equal to virgin soil – these results from soil under orchard and previously cropping for 120 years.

<u>Factors Influencing</u>

Salter and Williams, Hall et. al., Greenland, Batey, Oades, Dexter, Angers, Chaney and Swift, and others, discuss Available Water and the factors in formation and maintenance of the mesopores.

Texture – loams and fine sandy loams best
Organic matter – 4% but 6-8% best
Roots and hyphae – the most important
Wet/Drying cycles – for mellowing and drawing particles together
Air drying – occasionally for bonding
Drainage – for aeration, reducing slumping
No compaction
Lime – supply Ca, assist bonding
Zero tillage – less OM oxidation
N fertilizer – stimulates biological activity
Water stability – no dispersion, slaking
Moisture – maintains biological activity
Slow wetting – less slumping
C:N ratio – best to 20
Carbon turnover – presume very important
Building out fines – eliminating fines by aggregation
Reaggresizing – to break up cohesion
OM kick start – to rapidly start the structure building
Avoid fallow – it depletes OM and biology.

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Environment Aspects

1. Carbon Sequestration

The new system of soil preparation and management requires rye grass to grow in the soil for at least 6 months per year. The rye grass develops a rhizosheath of soil particles adhering to each rye grass root. The soil within the rhizosheath builds up organic matter, arising from root exudates, root hairs and microbial organisms, all in very large numbers. These eventually become organic matter. The important property of the rhizosheath is that organic matter within it is protected from oxidation. This is due to special properties of the rhizosheath, well documented in the soil science literature. Organic matter within non-rhizosheath soil is oxidized/consumed within several months of it being incorporated into the soil; so the level of organic matter remains low. Under rye grass, organic matter quickly builds to 8%, the level required to prevent soil coalescence. Levels of organic matter as high as 16% have been recorded in the North American prairies after prolonged periods under grass prior to agriculture.

2. Low Water Use

The new system relies on special tree/crop management to achieve the high yields; especially a high fruit to leaf ratio. We have records of Australian fruit trees and tomato growing in excellent soils can reach leaf to fruit ratios as high as 350 and as low as 5 - see plate. This means that the grower achieves not only large yields but also low water use.

3. Improved Soil

The new system improves soil structure equal to the worlds best and maintains it so, thus leading the way away from soil deterioration that occurs in much farming.

4. No Salinity

Because the new system demands capillary wetting and excellent drainage, the soil profile does not build up the surface waterlogging or water tables that result in salt build up.

5. Low Fertilizer Contamination

The system demands accurate fertilizer applications. In addition, the rye grass is very responsive to fertilizer and thus acts as a buffer against chemical build up.