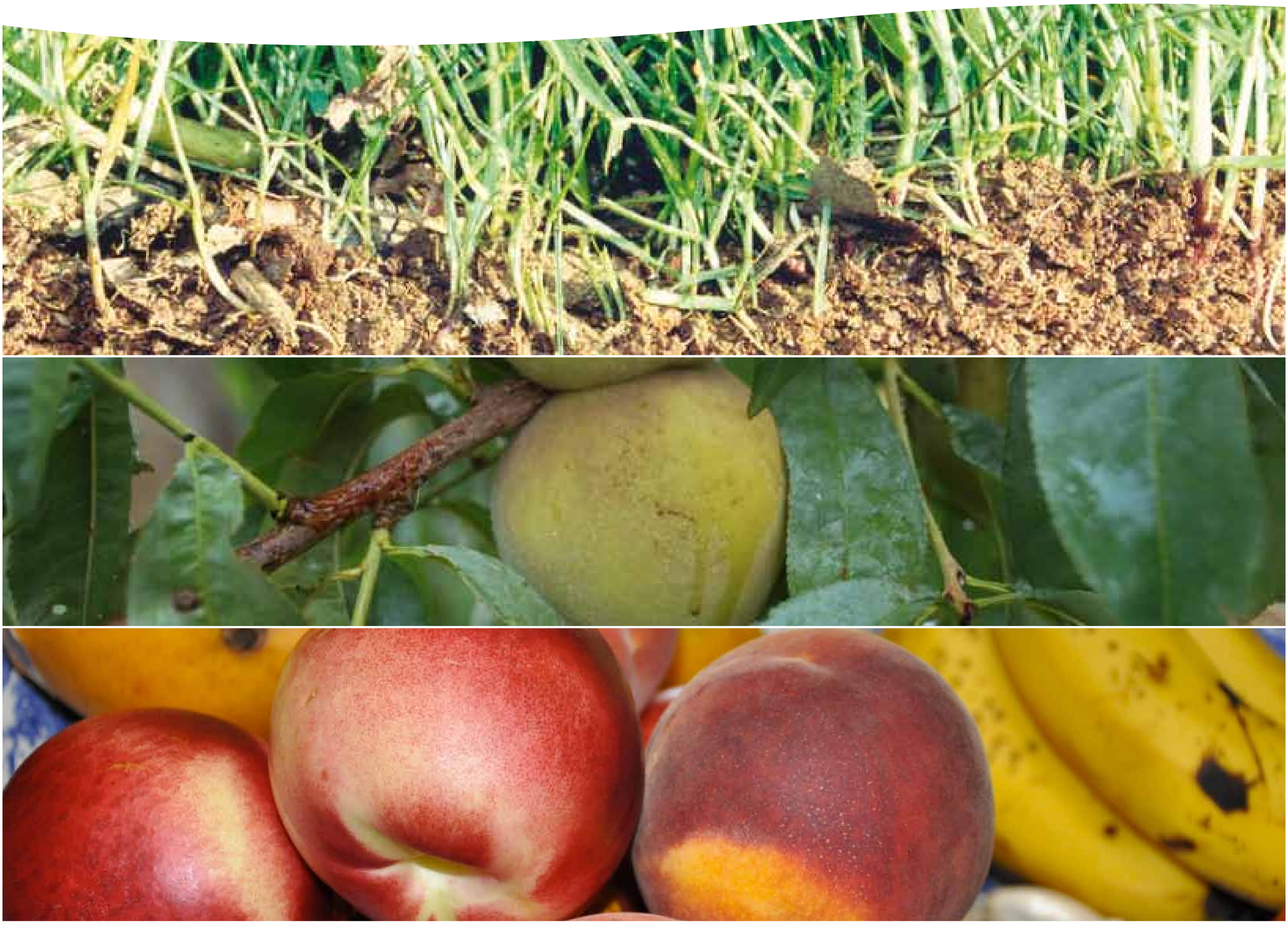


SOIL MANAGEMENT FOR AUSTRALIAN IRRIGATED HORTICULTURE

DR BRUCE COCKROFT

BRUCE COCKROFT SOILS RESEARCH PTY LTD

PROJECT SRP005026 February 2012

The National Program for Sustainable Irrigation is a partnership of Cotton Research & Development Corporation, Water Population and Communities, , Gascoyne Water Co-operative, Goulburn-Murray Rural Water Corporation, Grains Research & Development Corporation, Harvey Water, Horticulture Australia Limited, Lower Murray Water, Ord Irrigation Co-operative, South Australian Research and Development Institute, Sugar Research & Development Corporation, SunWater, and Western Australia Department of Water and the Australian Government Department of Sustainability, Environment,.

For further information visit the website www.npsi.gov.au

As part of its charter to improve technologies for water use, whether these are physical or biological technologies, the National Program for Sustainable Irrigation has supported the development of Bruce Cockroft's research and his extension of improved soil management to irrigators.

Soil improvement is a way of increasing food production without putting pressure on limited water supplies, according to soil scientist and author of this report, Bruce Cockroft (pictured).

The work he has undertaken over more than 50 years has highlighted challenges that exist with Australian soils and has led to practical means of addressing these challenges.
Dr Rob Murray, Visiting Research Fellow at the University of Adelaide, who has reviewed the more recent work, says a major contribution has been made to the key aspect of compaction, loss of larger pores and structural decline of soils, through the innovation of fibrous root cover crops.

Executive Summary

The fruit industry needs to increase its productivity to equal the world's best and to improve competitiveness.

This applies to all Australian horticultural industries. Our average yield of canning pears for example is 40 tonnes per hectare (t/ha) compared with best overseas yields of 180t/ha and a calculated potential of 220t/ha.

The major cause of low productivity is Australia's mediocre soils and the key properties needing to be developed are soil organic matter and biological activity.

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.

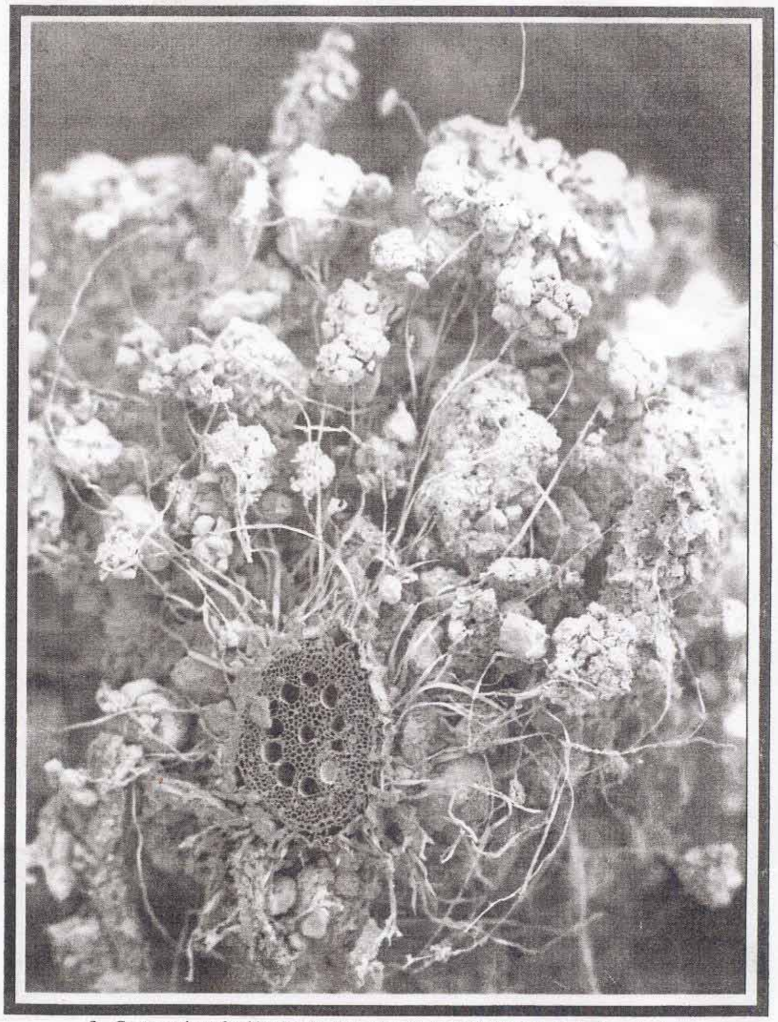
Presented in this report is a new system of orchard soil management that overcomes coalescence. It involves planting of rye grass, which produces rhizosheaths of soil around each of its roots to aid development of properties found in the world's best soils.

A newly established orchard using the rye grass system.

Loose, porous soil under rye grass.

Eight commercial fruitgrowers who have been involved in the research have set up fruit trees using the system. The oldest trees are three years and the soils have developed excellent structure, with many of the properties of the most productive soils in the world.

The project has resulted in a management list of soil inputs needed to achieve super soil. These include growing rye grass prior to the new planting, avoiding any fallow, hilling to beds, building beds in stages and incorporating dry straw from the rye grass.



Cross section of a rhizosheath. The rye grass root with its tubes that take water to the leaves is at the lower area of the photo. The root hairs and fungal hyphae radiate out from the root, entangling the soil aggregates and exuding the glues that bond the soil. These aggregates are porous and most of these pores are mesopores. SEM's by Dr Margaret McCully, CSIRO Division Plant Industry, Canberra.

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, namely organic matter and biological activity, required for rapid development of ideal soil structure.

Grower Case Studies

James Cornish and a group of likeminded growers, banded together to privately fund their own soil research and have since applied many of Dr Cockroft's soil and irrigation recommendations. They are now waiting the outcomes of his next stage of research.

Changes made

Modifications made to his on-farm practices apply the 20 practices listed by Dr Cockroft as important to improve soil structure and ultimately improve yield potential. Changes implemented to date include:

- The use of lime and gypsum pre-planting for fruit trees.
- Deep ripping using a modified ripper to open the soil without degrading structure. The ripper wings are modified to fluff up soil without bringing clays to the surface.
- Banking soil onto tree lines for increased growing medium and improved drainage.
- Slashing grass in tree lines and throwing onto tree row, to ensure minimal cultivation of soils.
- Minimal traffic on tree lines to avoid compaction.
- Use of irrigation sprinklers with flow rates that do not compact soils and are compatible with soil permeability.
- Avoiding the use of tree line herbicide sprays in autumn in order to encourage the establishment and growth of winter grasses. The objective being to improve soil structure and assist drying the soil through winter.

"We are making more informed decisions about runoff and soil compaction"

****

Pomme and stone fruit grower Chris Turnbull has also made changes to his system

The changes made related to improving soil structure through:

- Heaping up/banking topsoil where new trees are to go to improve drainage
- Reducing herbicides that work against grasses
- Encouraging Rye grass (and other grasses) to grow along the banks/tree lines to improve organic matter/soul carbon in the soil, soil drainage and irrigation efficiency (quicker and more effective than traditional mulching and/or chicken manure etc.)

"We grow as much grass in winter as we can"

There is an opportunity to take changes further by actively planting rye grass and apply earlier watering.

Costs of making changes

Costs include banking and managing grasses – but reduced cost of herbicides.

"Banks improve penetration and drainage of irrigation water"

Background

Over a period of more than 50 years Dr Bruce Cockroft has conducted research aimed at increasing the productivity of irrigated Australian horticulture through improved soil and irrigation management.

Much of this work has been field-based research on red-brown earths with structurally fragile, shallow A horizons and impermeable clay B horizons in the Goulburn Valley, Victoria. These soils account for most irrigated production of peaches and pears and of tomatoes and vegetables for canning in the Goulburn Valley and also for a large amount of tree fruit, vines and vegetable production elsewhere in Southern Australia (Murrumbidgee Irrigation Area, Barossa Valley).

An enduring theme of this research has been the growth of plant roots and the identification and removal of soil constraints to the development of extensive root systems. Such extensive root systems have improved productivity and secured unrealized yield potential. In the past 15 years Bruce's work has largely focused on the creation and maintenance of soil structural quality in keeping with the concept of a "super soil", a soil which regularly produces 2-3 times Australia's best productivity.

The yields of nearly all crops and fodder are below their potential. Examples of actual Australian and best overseas yields include maize 10t/ha and 35t/ha respectively, and pears 35t/ha and 180t/ha respectively.

After a study of soils in Europe and the U.S. Bruce pointed out that Australian horticulture produces only a fraction of potential yield and is well behind that in the best soils elsewhere, despite yield improvements over 50 years involving fertilizer, irrigation, drainage, ripping, hilling and other practices. This may be due to soil coalescence. The best overseas soils were noted to be recent alluvial/loess soils, largely sandy loams with high organic matter content (>10%), very good structure and structural stability and no coalescence.

To consider potential productivity we should not confine this to what others can achieve as 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. 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 horticultural crops.

This, and comparisons with very best yields overseas, indicates that irrigated agriculture can generate far more than it does at present The important issue is that it is possible to greatly improve the total economic value of our irrigated agriculture.

Causes of low productivity

Australian irrigated agriculture has many advantages and thus real potential. Advantages include ample land that is easily irrigated, mostly high quality water, good climate, a clean and green environment, opportunities for year round production of various crops, good local infrastructure, experienced and able farmers, and 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, crop roots are restricted, yield falls off disastrously and the crops can become uneconomic to produce.

Soil structure can be improved, just as irrigation techniques and nutrient status have been improved.

Crop yields increase dramatically when soil improves. In Australian horticulture, crops grown on the poor soil types average 10t/ha and those grown on the best soils can achieve yields of 50t/ha. In the 1950s orchard soils were cultivated and trees averaged 15t/ha of fruit harvested whereas under current soil management they average 60t/ha (see table 2). This is still low compared to the world's best, however, particularly when potential differences due to solar radiation levels are considered. Real potential is demonstrated when total average yield is contrasted with the results of several individual northern Victorian plantings with an improved soil management system.

Properties of productive soils

As stated earlier, the cause of low productivity in irrigated agriculture lies in coalescence, a soil hardening process, and consequent low root activity which also restricts what happens above the ground. The best soils overseas remain loose, soft and porous even after centuries of growing crops.

The author has undertaken field studies of some of the best soils in the world, and studied the literature relevant to them, including soil surveys. Locations have been visited in the United States (California, Nebraska, Iowa), Holland, Sweden, Italy, England (Kent), China, Northern Syria and New Zealand. The very best soils in each country revealed similar properties. Yields of nearly all crops are two to three times that of the highest in Australia. In Madera County, California, the soil survey in its comments on the best soil type, states "This soil is much prized in Californian agriculture." They have been called super soils and they do not naturally 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 that the super soil has medium to light texture and it is deep, loose, soft and porous. It has very high available water, high organic matter, and it is "young" soil (1000 years).

Table 1. Comparison of properties of Barming soil in the UK and Class 1 soil in Shepparton

Property	East Shepparton	Barming soil, UK
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/hr)	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 super soils are similar. They are less than 2000 years old, which contrasts with Australia's irrigated soils which are more than 80,000 years old. They are all alluvial loams or fine sandy loams. Many contain lime. They naturally contain a special mineral called montmorillonite, associated with soil looseness. Australian loams and fine sandy loams lack montmorillonite because they are old. Therefore, Australia needs to find its own way to produce a super soil.

Very small areas in several older orchards at Ardmona (Victoria) have been found to have soils that remain loose, soft and porous. They are rare (only three to four square metres in area), but they provide encouragement that Australian irrigated soils can be further improved. They also give clues as to how they can be improved because they have not been cultivated for more than 20 years, occur in tree-lined banks that have grown substantial stands of grass with no traffic, are irrigated by slow wetting, have lime added and are well drained. They contain about 8% organic matter, compared with normal orchard soils which have 1% to 2%.

The soil science literature states that to improve soil structure to the large extent required, the essential requirements are high soil organic matter, high biological activity (created by fungi, bacteria and other micro-organisms) and plants with ample 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 this project has been to find how to change irrigated soils into soils with the properties of the super soils.

Progress

Research started in 1989 and resulted in a new system of soil management for orchards. The current system (system 3) has doubled the yield of fruit from 30t/ha to 60 t/ha, is cheap to set up and run and is easy to manage.

The progressive development of management systems is show in the table below.

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

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	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 organic matter 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

Fruitgrower interest in research has been critical for progress to be made. For instance, during 2005, eight fruitgrowers and one tomato grower set up and grew their crops within one commercial area each for system 4 which is continuing to be tested. Another 50 growers involved in earlier stages receive quarterly bulletins about developments .

The research approach now being followed 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. Rhizosheath soil becomes especially porous and conducts water efficiently to the roots and the soil is very stable.

Rhizosheath soil is very different from normal soil and 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 can be produced.

Important interests are the actions of organic matter and biological activity in the rhizosheath of rye grass and the means by which these can be activated efficiently and permanently, the changes in the rhizosheath when the rye grass root dies and the development of super soil from the special soil in the rhizosheath.

Rye grass produces a mass of rhyzosheaths.

Current and future work is building on a long history of research which began at the Victorian Department of Agriculture's research centre at Tatura in the 1950s, resulting in scientific publications on the following subjects:

- Soils of irrigated Australia and their surveys.
- Pedology of irrigated soils.
- Physiography and geomorphology of Australian soils.
- Physical and chemical properties of Australian soils.
- Root distribution of orchard trees.
- Soil management
- Tree nutrition and fertiliser 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 the major soil problems were investigated and recommendations were made available to irrigation farmers. It was obvious that as growers managed their orchards better, fruit yields increased proportionally. The project tackled the remaining soil improvement needed to achieve a super soil.

While the system involving rye grass as an input has brought success, soil still coalesces and more work is required to make the next step (from system 4 to system 5).

The next step – System 5

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 achieve the desired practical outcome. A parallel can be drawn with a motor car or human body, where it is easier to fix problems when we understand how things work.

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 soil water will flow rapidly to the tree roots. In addition, 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.

Current work aims to increase the understanding of why grass is so effective in improving soil structure and how to best produce and maintain structure. This involves field experiments, studies of the soil science literature and interaction with research personnel, especially Professor M. McCully, Dr. J. Passioura and Dr. M. Watt at CSIRO Canberra.

Professor McCully and Dr Watt are 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 with a high amount of very fine grass roots as well as fungi, bacteria and other microbes. There is high organic matter (7% and more) and a high carbon turnover. The organic matter in the sheath is clearly very young and the soil becomes very stable. All these features act together to build the soil structure that is sought.

The latest aspect of the research started in July 2008 with funding from the National Program for Sustainable Irrigation. Funded activities which are aimed at a better understanding of the rhizosheath include use of a scanning electron microscope at CSIRO.

Over the last 12 months, in addition to broader orchard research, orchard and tomato plots and pot experiments have been established with a wide range of treatments. The treatment combinations plus the range of soil types and management across 15 orchards 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 developments.

Plate 1. Scanning electron micrograph of an early stage in the development of super aggregates.

Orchard plot experiments

The project set up many small, simple, easily maintained experiments in orchards, on the assumption that some treatments would indicate the important issues, and together with a thorough study of the soil science literature plus discussions with soil scientists and growers, soil management methods that produce soils that equal the most productive in the world could eventually develop.

Using fertiliser, irrigation, lime and gypsum management of the growers, rye grass was established in tree lines. The work is ongoing and includes annual measurement of coalescence.

The research can be put into context by reflecting back to mid 2001 when a new series of orchard experiments was established to investigate possible treatments to keep soils loose, soft and porous and not coalesce into the hard mass typical of our soils. This involved 19 experiments over 15 orchards and a total of 285 plots. The plots were between 60cm x 60cm and 100cm x 100cm in area, set up in orchards of young trees. In each experiment soil was dug to 25cm, correct irrigation, drainage, fertiliser and liming were applied and rye grass was sown.

Consistent treatments were applied in at least 10 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 the amount of hardening is measured as the percentage coalescence (100% is complete coalescence to a solid mass while 0% is no coalescence). In a few cases all the soil from the plot was removed and a test soil (e.g. virgin soil from a nearby old fence line) was introduced for comparison. Rye grass was sown in almost all plots.

The treatments applied followed the results of earlier experiments in orchards, in pot experiments and in tomato experiments.

Table 3: Tentative list of inputs and practices

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

Clarification of terms used above:- "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 has started between the original aggregates). "Capillary wet" is to irrigate from the bottom of the surface soil, with water entering by buried drip irrigation pipes.

The list includes the order of applying each input in a new or replanted orchard. Only by including each of the inputs can aims be achieved.

Additional information on field practices can be found on the NPSI web site www.npsi.gov.au **Product code: ER071300.**

A review of Dr Bruce Cockroft's work for Australian irrigated Horticulture by Dr R. S Murray, University of Adelaide.

Practices to avoid	Practices to use
Traffic compaction	Rye grass[e]
Clay contamination[a]	Capillary irrigation[f]
Powdering[b]	Organic matter[g]
Ex-cropping soil[c]	Reaggresizing[h]
Ex-pasture soil[c]	Lime[i]
Poor drainage[d]	

Notes

a Clay contamination from subsoil causes hardening of the soil and better methods of subsoil ripping, land forming and careful tree grubbing are needed to avoid contamination of the surface soil.

b caused by cultivation of soil that is too dry and excessive cultivation in general.

c these soils may have been degraded by constant cropping or by stock and machinery and require rejuvenation with rye grass for 6 months prior to planting.

d improved by bed slope and ripping.

e roots interrupt what may later go on to become a strong, impenetrable soil matrix. Roots throughout the year is the first key practice to prevent coalescence and promote macro-aggregation and microbial activity; no fallow periods should be permitted.

f capillary irrigation is recommended over spray, flood or furrow (buried capillary irrigation is almost standard in some tomato and vegetable production districts). This may produce coalescence of the subsoil where the pipe is but avoids it in the top soil[36]. Note: This seems to conflict with recommendations of spray irrigation elsewhere.

g organic matter is a key practice to establish stable micro-aggregates and to stabilize structure. The 6-7% needed to produce a super soil is a huge amount which is difficult to access and apply and hard to sustain unless constant inputs are made. Grasses are considered a good source because of organic matter placement by the roots and the encouragement of microbial activity.

h This for soils that are either initially "difficult" to prepare or else require careful cultivation to break up coalescence after the initial cultivation and 6 months of rye grass but it is not known when or how often this should be practiced.

i The best soils contain lime and organic matter and are of medium texture. It is suggested that for soils with lime 3% organic matter is adequate but for those without lime 6-7% organic matter is required

Results

After applying all the inputs, the soil starts to change in a few weeks. The rye grass plants quickly develop a very large root system, extending to the subsoil B horizon. Roots then develop their root hairs behind the growing root tip. Irrigation water penetrates rapidly, without collapsing the soil, and drains within a 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 oxidised. 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.

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 associated with rain and irrigation events and subsequent swelling and shrinking, plus 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. There is provision of mucilage from the constant production of new roots and root hairs.

All this is aided by the special management of the bed which has no traffic and therefore no compaction. The bed is full of roots for much of the year and there is excellent irrigation and drainage, constant biological activity and organic matter built up.

These processes result in a 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, grass is grown in winter and autumn but the orchard is maintained free of grass and weeds in spring and summer.

The project now has several tree plantings and also row crops grown in commercial conditions.

Each rye grass root growing through the loose soil produces 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 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 and the root hairs lengthen and pick up more soil. In this way the rhizosheath develops to several millimeters diameter. The arrangement of the rhizosheath remains 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.

Conclusions

New systems of soil preparation and management with rye grass growing for at least six months of the year will improve production with the potential for lower water use.

It has been demonstrated that 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. An important property of the rhizosheath is that organic matter within it is protected from oxidation.

The project has achieved a method of preventing coalescence. Under rye grass, organic matter quickly builds to 8%, the level required to prevent soil coalescence.

Fruitgrowers should note that full potential for increasing yield and quality relies on tree management as well as soil management. Tree management on soil that has become more responsive after treatment may require changes to such practices as pruning and reduction of the leaf to fruit ratio.

Practices to establish the system

The following information can be used as a guide to establishing and using rye grass to maintain or enhance soil structure in orchards.

Soil stability and structure

Many Australian surface soils are prone to breaking down or slaking under irrigation. The surface soil runs to a mud and sets hard on drying. This problem is exacerbated by excessive working of the soil which adversely affects soil structure.

Applications of organic matter, and especially the build up of organic matter by growing grass as a cover crop in winter, is one way of reducing this slaking and hard setting. The roots of cover crops are the best forms of organic matter, because they enmesh the individual soil grains into aggregates, supply organic matter as they rot down, and produce exudates which are powerful organic gums. It is in this way that the roots help stabilise the soil and improve soil structure by increasing organic matter. Good structure is evident when the soil is loose, soft and porous.

Ryegrass in orchards

In south eastern Australia it is important that fruit growers encourage winter grass in their orchards.

- Grass adds organic matter to the soil.
- It opens the surface of the soil to let irrigation water in.
- Grassroots keep the soil loose, soft and porous.
- They penetrate into the subsoil, producing pores and increasing stability.
- Grass helps dry the soil in wet winters.
- Grass forms a mulch in summer to reduce high soil temperatures.

Grass is much better at doing these things than clovers or weeds. Rye grass is the most effective of all the grasses. Ryegrass is suited to the climate of this area and in fact is a weed here. It will self seed each year if managed properly and will grow well.

When to use ryegrass

Not only is winter ryegrass important in maintaining good soil structure in existing orchards, it is also important to grow rye grass in soils prior to planting fruit trees. It is not possible to improve our soils to the high quality structure that we aim for once the trees are planted. This demands that we grow rye grass for up to two years initially, over the complete area, on the flat before tree planting. However, the trees can be planted earlier than this if the grower avoids competition to the new trees with weedicide sprayed around each tree. The grower must first cultivate to the full depth of the surface soil, including with nitrogen fertiliser. The grower must then cultivate every six months to depth, incorporating the rye grass. This starts the build up of organic matter, now protected by the next rye grass. The cultivation also re-aggregates the soil, breaking up any beginnings of coalescence. In addition, it ensures fine and very fine aggregates of soil (< 1 mm) for the new rye grass roots to build the ideal porous, stable aggregates that will become the soil in the future tree lined bed.

The grower can start building the future tree line bed and even plant the trees during this initial two years of continuous rye grass. The grass must grow right across the area including over the new small tree line bank. Every six months the grower should cultivate the soil to the subsoil, incorporating the grass and bed up more surface soil. The grower should double the size of the bed at each cultivation, seeking to have all the surface soil into the bed within two years.

The aim is to build the tree line bed to the largest volume possible using all of the surface soil that is above the clay subsoil. Also aim to have the tree line bed full of incorporated rye grass plants with subsequent growing rye grass roots.

The process of using rye grass to stabilise orchard soils therefore includes:

- Build the soil structure, using rye grass before planting trees.
- Develop the tree line bed in stages, maintaining rye grass between each cultivation and bank building.
- Incorporate the rye grass plant with each cultivation and hilling.
- Re-aggresize (by the cultivation) to break up any early coalescence and to provide fine, structural building particles of soil.
- Set up the tree lined beds with as large a volume of surface soil as possible.
- After the trees are planted and as they mature, grow rye grass in autumn and winter and avoid grass in spring and summer.
- Throughout the process of rye grass growth and soil stabilisation, ensure appropriate fertilisation, irrigation and drainage.

Rye grass varieties

A mix of rye grass varieties is typically employed to ensure adequate germination and growth under a range of climatic variables. A combination of at least three and even up to six rye grass varieties are used and these should consist of both perennial and annual species with a range of germination and maturation timing.

Varieties include Matilda, Kingston, Victorian, Crusader, Nutecia, Bronson, Feast, Concord, Kangaroo Valley and Ellet. This list is not exhaustive as new rye grass varieties are continually being developed and more suitable and more vigorous rye grass varieties are being released and some of these new varieties maybe just as suitable if not more so. A local agronomist or seed supply merchant should be consulted to help determine the most appropriate species of rye grass.

Sowing rates

To ensure a good heavy cover of rye grass is established and to help choke out weed competition, heavy sowing rates of rye grass seed are used. While rates as low as 50 kg/ha may suffice in certain situations, it is recommended that the rye grass is sown at a rate of 100 kg/ha.

Soil nutrition

General soil nutrition - In reference to agricultural production, the soils of south eastern Australia are usually deficient in nitrogen and phosphorus only and soil analysis is best used prior to planting for pH (lime requirement), gypsum requirement, salinity and available phosphorus as soil tests for these characteristics are reliable and these factors are more easily manipulated before the rye grass and/or fruit trees are established.

Base soil status - As is typical orchard practice, it is assumed that optimum soil chemistry status is achieved prior to the establishment of orchard trees and/or rye grass. Optimum soil chemistry for rye grass would typically include the following :

- **Soil pH** - Surface soil pH (in water) of 6.5 to 7.5.
- **Salinity and chloride** – Soil salinity levels, measured as $EC_{1.5}$ (Electrical Conductivity), < 0.16 dS/m. Soil chloride levels < 100 mg/kg.
- **Phosphorus** – Soil phosphorus levels, measured as Olsen Available Phosphorus (Olsen P), > 30 mg/kg.
- **Nitrogen** – Nitrate nitrogen levels > 20 mg/kg; ammonium nitrogen levels > 10 mg/kg.
- **Potassium** – Soil potassium levels, measured as Skene Potassium (Skene K) > 250 mg/kg.
- **Sulphur** – Soil sulphur levels, measured as Sulphur KCl 40, > 16 mg/kg.
- **Calcium** – Soil calcium/magnesium ratio (Ca:Mg) > 2.0.
- **Sodium** –Soil sodium levels, measured as the exchangeable sodium percentage (ESP) < 6.
- **Organic Carbon** - Soil organic carbon > 3.5 % - the higher the better.
- **Copper** - Soil copper levels > 2.0 mg/kg
- **Zinc** – Soil zinc levels > 2.0 mg/kg

Soil nutritional requirements – Surface soil analysis should be undertaken to determine the existing soil nutritional status and the result should guide soil ameliorant and fertiliser applications prior to rye grass and/or fruit tree establishment. Soils typically require lime to raise pH levels with applications typically in the order of 2.5 t/ha.

A base application of phosphorus is also typically required at rates approximating 500 kg/ha of single superphosphate (NPKS = 0,8.6,0,11.0) or an equivalent amount of phosphorus. To ensure adequate soil calcium levels, an application of 3.0 t/ha of gypsum is also typically applied. While lime, phosphorus and gypsum can be applied without soil analysis, it is recommended that the rates are guided by soil analysis results. This provides the basis of soil nutrition for an orchard and for the rye grass. Further nutrients are applied in the annual nutrient maintenance fertiliser applications and occasionally with the application of trace elements where required based on tree leaf analysis results.

Annual maintenance fertilisers - It is assumed that through typical practices, soil nutrient levels are adequate for the germination and growth of rye grass. It is assumed that annual nutrient maintenance applications of fertilisers are made to the orchard each year. Typical annual maintenance application rates are:

Annual applications in kg/ha of actual nutrient		
Nutrient	**Range**	**Typical**
N	100 - 300	200
P	30-40	40
K	20-30	30

Additional nitrogen for rye grass – In addition to annual fertilisers applications, nitrogen fertiliser should be applied to ensure high soil nitrogen levels to facilitate vigorous rye grass growth. Nitrogen application rates are similar to those that would typically be applied to irrigated perennial rye grass pastures; this approximates 250 kg/ha of nitrogen. While the form of nitrogen is not critical, nitrogen is typically applied as a product such as calcium ammonium nitrate (CAN) (NPKS = 27-0-0-0) which would be applied at a rate of 1000 kg/ha of CAN fertiliser.

Irrigation

Irrigation design - Irrigation should ideally be through low rate microsprays if high yields are the aim. The microsprays should give a uniform distribution of water over the hilled row without wetting the traffic lane too much. It should also apply the water at a slow rate; less than 6 mm/hour precipitation is best to prevent surface slaking and crusting and to prevent soil slumping. Under the tree microsprays usually apply water at these rates. It must be noted that weed control is critical with microsprays because if weeds or ryegrass are allowed to smother the emitter or interfere with the wetting pattern the trees/ryegrass will suffer from a much reduced wetted area. Trickle or drip irrigation, which applies the water to a limited area, is not a good method of irrigation to achieve high yields. They cause a small root zone to develop, have little flexibility and cause hardening of the soil. Excessive water applied rapidly is more likely to cause the soil structure to slump to a hard mass.

Irrigation management - While water penetration should not be a problem, to help ensure adequate penetration, it may be necessary to increase organic matter levels and ensure careful cultivation of the surface soils to improve soil structural stability and to prevent slaking and hard setting. To ensure the rye grass maintains growth free of water stress, the correct amounts of water need to be applied at the correct times. It is recommended that climatic variable measurement (rainfall and evaporation) and irrigation scheduling are undertaken and this is combined with regular soil moisture assessments. Water applications should be based on methodical irrigation scheduling using the predicted plant water use, recent water application volumes supplemented with regular soil moisture assessment. It is beneficial to know how deep an irrigation application has penetrated the soil profile and how wet the soil is at any given time. Manual assessment of this is often sufficient but it may be worthwhile installing soil moisture monitoring equipment to provide assessment of the soil water status at depth.

Dry autumn - In a dry autumn a light irrigation can be important to produce good growth of grass before winter cold slows this growth. Some rye grass growers often have no need of post harvest irrigation even in dry years except in early fruits.

In average climatic conditions, sufficient rain falls to provide for the ryegrass water requirements. Where this does not occur, supplementary irrigation should be applied to meet plant water demands.

Weed spraying rye grass

If orchardists allow grass or weeds to grow in spring and summer the grass will compete with the trees for water, nutrients and soil space, the trees suffer and fruit size will be small. All spring and summer competition must be eliminated.

Frost

If orchard grass is high in spring it may present a risk of increased damage to blossoms by frost. The cold air blankets the top of the cover, so tall grass lifts the level of cold air compared to bare compacted earth.

Drainage

Ensure good surface and soil profile drainage across the whole orchard as this is important for good fruit tree and rye grass growth. Orchards are typically set up with good surface drainage with hilled tree lines, sloping traffic lanes and exit points at headlands for excess surface water to ensure any excess surface water leaves the orchard. Deep ripping and hilling of the lines help to ensure good soil profile drainage.

To help prevent waterlogging orchardists employ strategies such as micro-irrigation and good irrigation management to control water intake, they ensure good surface water control to prevent excess rainfall entering the soil profile, they hill the tree rows, they ensure adequate slope down the centres of the rows and the subsequent removal of excess surface water away from the trees, they don't irrigate after early April, they establish perennial grasses in the inter-rows (traffic lanes) and they establish ryegrass in the tree lines in autumn and winter to help utilise excess rainwater. Obviously, a proper surface drainage system over the whole orchard is essential and this typically employs drainage infrastructure to ensure removal of excess surface water.

Key references

- Cockroft, B. and Dillon, C. (2004). A Soil Survey Method for Productivity in Irrigated Agriculture. Agricultural Science. AIAS 17. No.2. 14-20.
- Cockroft, B. and Mason, W.K. (1987). Irrigated Agriculture. In "Agriculture in Victoria" by D.J. Connor and D.F. Smith. AIAS.
- Cockroft, B. and Olsson, K.A. (1972). Pattern of New Root Production in Peach Trees Under Irrigation. Aust. J. Agric. Res. 23. 1021-5
- Cockroft, B. and Olsson, K.A. (1997). Case Study of Soil Quality in SE Australia: Management of Structure for Roots in Duplex Soils. "Soil Quality for Crop Production and Ecosystem Health." Ed. E.G. Gregorich and M.R. Cater. Elsevier.
- Cockroft, B. and Olsson, K.A. (2000). Degradation of Soil Structure Due to Coalescence of Aggregates in No-Till, No-Traffic Beds in Irrigated Crops. Aust. J. Soil Res. 38. 61-70.
- Hall, D.G.M., Reeve, M.J., Thomasson, A.., Wright, V.F. (1997). Water Retention, Porosity and Density of Field Soils. Soil Survey of British Soils. Tech. Monograph No. 9.

- Greenland, D.J. (1981). Soil Management and Soil Degradation. J. Soil Science. 32 301-9
- McCully, M.E. and Cockroft, B. (2012). (Draft) Soil Aggregation by Fine Grass Roots: A Key Step in the Prevention of Coalescence.
- Passioura, J.B. (2002). "Soil Conditions and Plant Growth'. Plant Cell and Environment 25. 311-318.

Further Reading

Further reading can be found on the NPSI web site. These include;

- A review of Dr Cockcroft's research by Dr R Murray http://npsi.gov.au/products/pn21945
- A grower (C Turnbull) case study http://npsi.gov.au/products/npsi1411
- A grower (J Cornish) case study http://npsi.gov.au/products/npsi1811

Research and grower guidelines of soil management in vineyards

- A grower (Brian Caddy) case study http://npsi.gov.au/products/npsi1511
- A technical research bulletin R Murray et al http://npsi.gov.au/products/npsi2211
- And guidelines for managing soils in vineyards http://npsi.gov.au/products/npsi2311

What do you do in an established orchard as opposed to establishing a new orchard ? Further information can be found for established vineyards in "Guidelines for Managing Soil Structure in Irrigated Vineyards" (NPSI2311) – see the section How can good subsoil structure be restored in existing vineyards? (pp 6-9). The principles are the same except for the suggestion about mounding; this may have to be managed carefully with grafted trees and a 'dished' mound might be an option.

There are some video links also on the NPSI website.

More general soil management information can be found;

Soil health knowledge bank

http://soilhealthknowledge.com.au