Using Controlled Traffic to Engineer Seedbeds for Increased Water Conservation, Crop Production and Profit

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INTRODUCTION

The effects of compact soil on the growth and development of plants has been well known in the scientific literature for at least 50 years. These effects are:

- Physical impairment of emergence
- Restriction on the growth and proliferation of roots
- Reduction in the amount and availability of water to roots
- Reduction in the amount and availability of oxygen and the heightened probability of waterlogging.

Equally well known are the phenomena that cause soil to be compacted:

- Farm machinery - their weight, tyre width and diameter, track width, and tyre pressure
- The number of machinery passes and the lack of alignment of their tracks
- The points of tillage implements
- Excessive soil wetness
- Soil condition (undisturbed and loose)
- Grazing - the type and weight of animals, the number of grazings the and soil moisture when grazed
- Overburden pressure of soil as depth and water content increase
- Rain drop impact, which compacts the surface soil, causing it to form a thin seal.

Farmers have long been aware of most of these causes, but have not been able to assess their impact because they had no way of comparing the productivity of compacted versus loose soil, side by side on a field scale. With the advent of precision guidance and steering systems such comparisons are now possible, because the capability now exists of precisely controlling the location and number of tracks on which their machinery operates. This capability creates the opportunity for farmers to engineer seedbeds with near ideal physical, biological and chemical conditions and to compare the productivity of engineered seedbeds with that of ‘normal’ seedbeds.

This paper describes one means of deliberately engineering improved root-zone soil conditions in a controlled traffic regime and presents results that illustrate the levels of improved soil conditions and increased productivity that result from its application. This information provides insights that will enable farmers to make more-informed and better management decisions on how to gain substantial productivity improvements - improvements that cannot be maximised without controlled traffic (CT) operations.

The information provides a means of grasping an opportunity that is only available with precise control of farm traffic, because only under CT conditions can traffic compaction be reduced from about 52% of a paddock (with completely unaligned tracking) to around 15% (with even multiples of machine width, aligned tracks, trackwidths and narrow tyres). Readers should note however, that the practices described will produce their largest benefits where soils have compact layers within the top 25cm depth of soil.

HOW TO CREATE A NEAR-PERMANENT DEEP, LOOSE SEEDBED

To improve soil conditions of the root zone there are clear-cut management objectives that have to be achieved. These are:

- Increase the amount of soil organic matter
- Maintain good surface cover
- Reduce the density of the soil

If these objectives are met the soil will be:

- more stable to wetting and drying
- more permeable to water and air
- contain more plant available water and have
- a larger population of soil organisms and
- a larger soil nitrogen content.

The challenge is therefore to create a seedbed that is deeper, looser (rather than compact) with increased organic matter without

- inverting the soil, to minimise the loss of organic matter and soil nitrogen
- disrupting and exposing the roots of previous crops or pasture, to maximise the retention of a food source for soil organisms and to ensure the roots are present to act as reinforcing rods and minimise re-consolidation
- burying plant matter, to ensure plant tops and litter remain on the surface, to maintain a mulch to protect the soil against rain, wind, high temperatures and excessive evaporation
- incurring too much fuel, time and cost.

When assembling this technology the authors were aware that the chosen means of creating and maintaining a deep loose seedbed needed to be as practical and economic as possible, and so the decision was made to:

- limit the depth of disturbance to around 20-25cm., to constrain the cost and time required, and
- create a depth of about 30cm of loosened soil, a depth over which 90-95% of plant roots reside and from which 90-95% of water and nutrients are drawn.

The means chosen to create these conditions was to:

- rip the soil with a conventional ripper with tines spaced 30cm apart
- undertake the ripping when the soil moisture was moderately moist at 20-25cm depth (This moisture content is called the lower plastic limit (LPL) and can be judged by being able to roll a handful of soil into a rod that breaks up when it has a diameter of about 1cm. If the rod can be rolled into a smaller diameter it is too wet; if it can be rolled into a larger diameter, it is drier than optimum. Drier is better than wetter. When soil is disturbed at the LPL moisture content it breaks into a tilth rather than large clods (if too dry) or smeared grooves (if too wet.)

Once ripped, the loose tilth is maintained by using a modified ripper with fewer narrow tines (spaced ~ 70cm apart) and flat, wide blades mounted at the base of the tines (Figure 1). This machine:

- has substantially less draft than a conventional ripper
- causes near-zero soil inversion
- cuts and retains roots in a near-undisturbed state
- retains surface plant cover
- provides a near ideal tilth that is 25-30cm deep.

Figure 1. Ripper with narrow, widely spaced tines and wide blades that is used to maintain deepened loose seedbeds with near-ideal physical conditions in soils with shallow, dense ploughpans or B-horizons.

RESULTS

This form of soil management has been used on large scale field sites (from 1ha to 200ha 'plots') in the Great Southern District of Western Australia (rainfed grain crops), and in Pakistan (irrigated maize and wheat crops). The soil types at the Western Australian sites are shallow duplex soils with very dense ploughpans and B-horizons at depths of 10-15cm. The soil types in Pakistan are deep silty loams with dense ploughpans at 10-15cm depth.

Penetration resistance profiles

Average penetration resistance profiles monitored monthly at Mindarabin WA throughout a dry season in 2002 and a wet one in 2003 show the deepened seedbeds maintain a soil environment that does not limit root proliferation. Deepened seedbed data are less than the limiting value of 2000kPa (Taylor, 1971), which contrasts markedly with the normal seedbed.

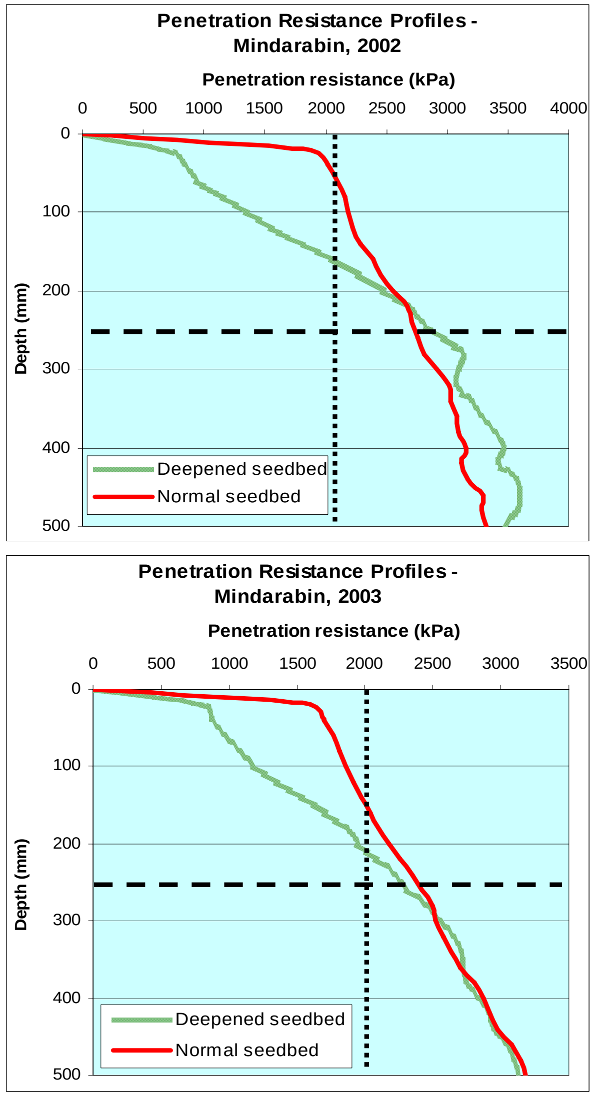

Figure 2. Average penetration resistance profiles for a grey clay at Mindarabin WA for 2002 (a very dry season) and 2003 (a wet season). The depth of the loosening is shown (horizontal dashed line), as is the penetration resistance that limits roots proliferation (2000kPa) (dashed vertical line).

Root mass and distribution

Root weights and distributions in normal and deepened seedbeds in Pakistan and WA (Figure 3) showed there was respectively 27% and 14% more root matter in the deepened seedbeds, most of which was in the 15-30cm depth layer, where the roots in a normal seedbed were very much less, as illustrated by Barnes (1971).

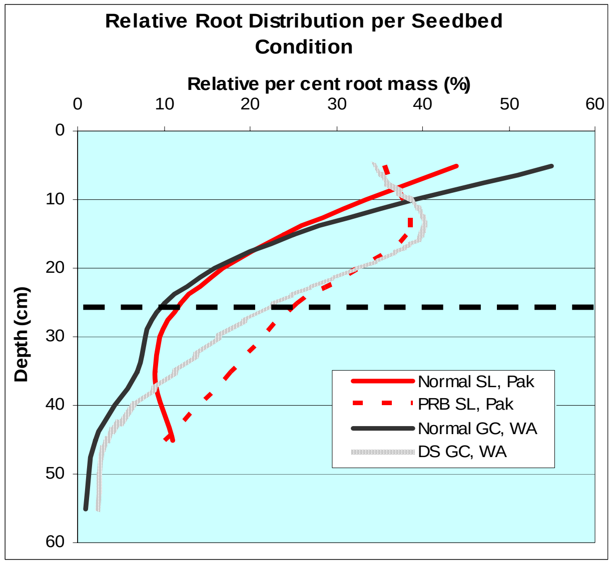

Figure 3. Contrasting relative root distributions and amounts in normal and deepened seedbeds in a silty loam soil (SL) in Pakistan and a grey clay soil (GC) in Western Australia.

Organic carbon and nitrogen content and distribution

Data from Pakistan and Woodanilling, another WA site where this form of soil management is applied (Figure 4) show that wherever root growth and depth is greater, so too is the amount and distribution of soil organic carbon. This soil constituent relates directly to soil nitrogen and the rate of mineralisation of this nitrogen is greater in loose soils compared to compact soil (Kemper et al. 1971; Parish 1971).

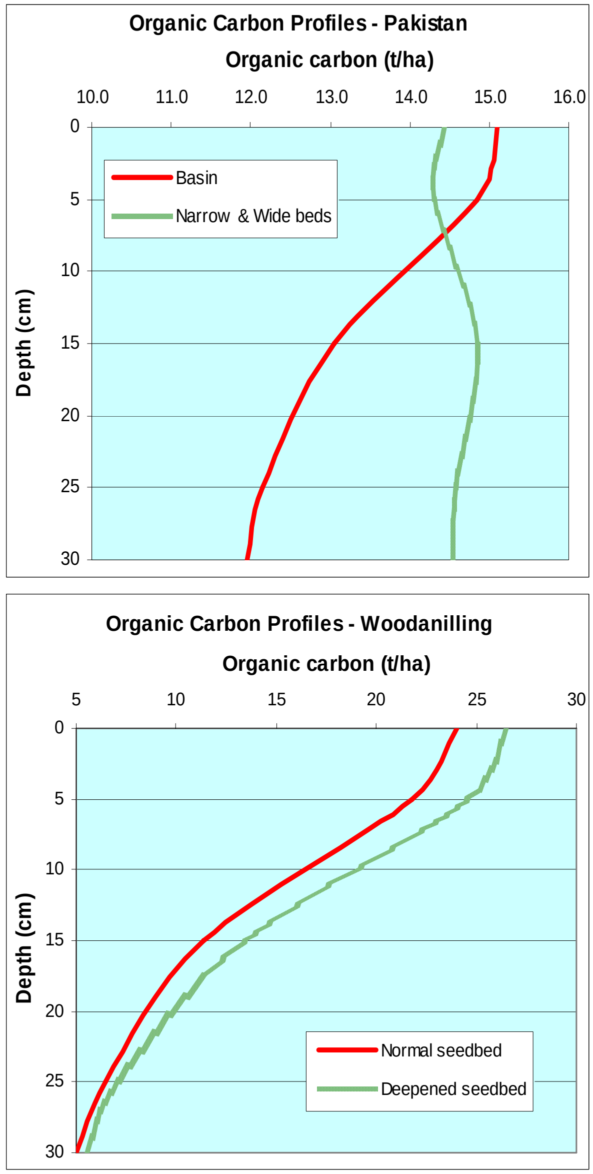

Figure 4. Organic carbon profiles in "normal" and loosened seedbeds in Pakistan and Woodanilling WA showing the increase that results from increased root growth in the top 30cm of deepened seedbeds.

Hydraulic conductivity and infiltration

Roots and the soil organisms that live in proximity with them soil create a more porous and stable soil, with enhanced water and air movement. Conversely, waterlogging susceptibility and poor oxygen supply characterise compact soil (Grable, 1971). Figure 5 illustrates the substantially improved infiltration of rainfall that occurs in the root zone of plants. Water that penetrates deeply is conserved for longer and if this is still within the root zone it will be largely used by plants rather than lost to the atmosphere as evaporation.

Figure 5. A profile showing enhanced rainfall infiltration in the root zones of a wheat crop.

Plant water use and average soil moisture profiles

Average soil water content profiles of regularly monitored root zones of crops grown on normal seedbeds and deepened seedbeds at Mindarabin in the wet season of 2003 show distinct differences that infer greater plant water use by the crops grown on the deepened seedbeds (Figure 6 left hand graph). When the effects of contrasting soil densities in these seedbeds are taken into account, by expressing the data as percentage of the total pore space in each, the interpretation is confirmed with extra insight. The “normal” seedbed is shown to have effectively waterlogged conditions below 15cm depth, which would limit root growth on its own, irrespective of the root limiting density of this layer.

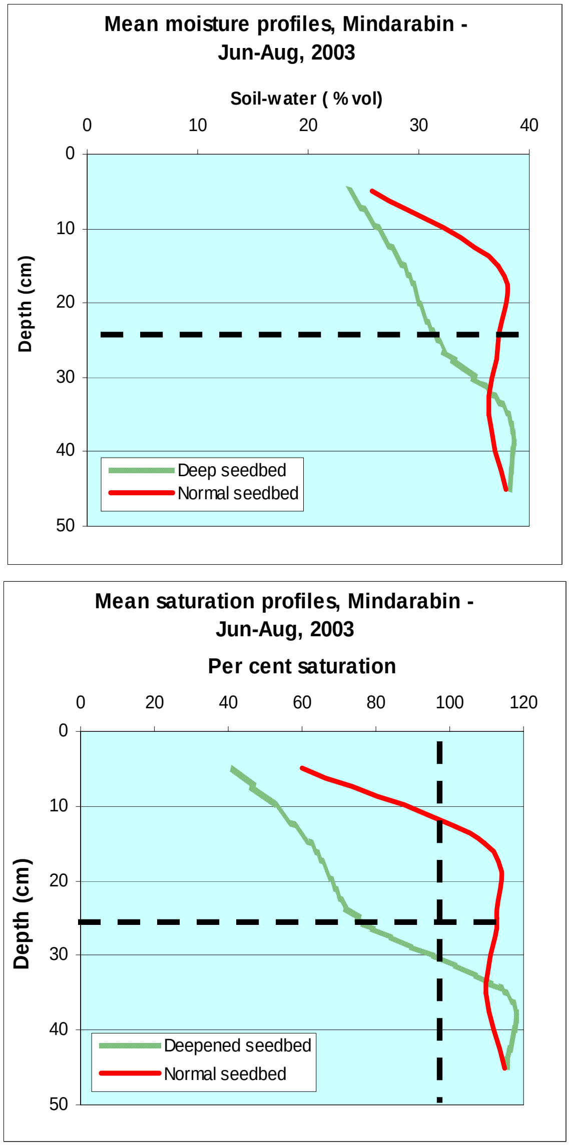

Figure 6. Average soil moisture profiles in a deepened seedbed and normal seedbed in a grey clay soil at Mindarabin WA

Production

All locations where this form of soil management has been practised have produced substantial yield increases. In Figure 7 yield data are presented for the Mindarabin grey clay soil in WA for 2001, 2002 and 2003. All of these seasons experienced abnormal distributions and amounts of rainfall: 2001 was dry early and wet late; 2002 was dry early and sparingly moist late; 2003 had above average rainfall all season. The deepened seedbeds easily performed better in all seasonal conditions, confirming their ability to conserve and enhance the availability of water to plants in all conditions.

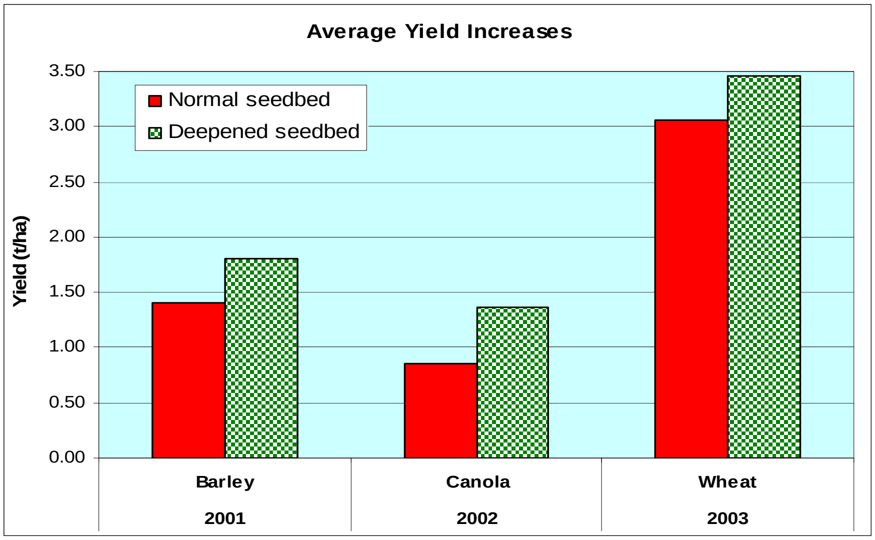

Figure 7. Average production data from tri-replicated 1ha plots at Mindarabin WA. The average yield increases, 29% in 2001, 63% in 2002 and 13% in 2003 are highly significant.

Costs and benefits

Gross margin analyses of no-tillage crop establishment on a normal seedbed and a deepened seedbed illustrated the benefits of using deepened seedbeds easily exceed the extra costs involved. These used the 3-year average yield increases over a 5-year rotation of wheat, barley, canola, peas and wheat, and 2003 on-farm commodity prices for the grains and crop inputs. This produced a conservative 5-year average increase in gross margin profit of $85/ha or 28%.

This result is deliberately conservative because: (a) the analysis included the cost an annual renovation of the deepened seedbed (at $50/ha), which is probably too frequent; and (b) it did not include an off-setting reduction in the operating cost of this practice in a CT environment, i.e. improved trafficability of permanent tracks and the substantially reduced draft of seeding into a loose seedbed. For example, observations from the broad-acre practice of seeding 200ha of deepened seedbed indicate a substantial reduction fuel in fuel usage, from 6-7 l/ha on a settled, compact no-tillage seedbed to 2-3 l/ha on a deepened seedbed.

DISCUSSION AND CONCLUSIONS

This form of soil management was deliberately formulated to build on the soil improvements that accompanied the no-tillage crop establishment revolution – increased soil organic matter and soil nitrogen, improved water conservation and efficient seeding and in-crop operations. It has been demonstrably successful in this respect, as all these attributes have been improved, with no loss in accessibility.

It also sought to seize the opportunities of provided by CT - operational precision - to raise the condition of root zone soil to levels that approach theoretical limits. Whilst these maximum limits may still be a little way off, the root zone environment for crops has been improved to a point where the level and reliability of its productivity over highly varying seasons is beyond those currently existing and well beyond those existing when the land was first cropped.

How often does one need to renovate?? There is no universal answer for this management question. The need or benefits of renovating will be determined by the rate and extent to which the soil of a deepened seedbed reconsolidates. Seasonal conditions and traffic control will determine this need and frequency. Wet seasonal conditions and compaction caused by farm traffic and stock will increase the need for and frequency of renovation. Dry seasonal conditions and good traffic control will decrease the need and frequency of renovation. Experience and field testing will reveal when a renovation will be worthwhile.

Although not deliberately included in the objectives of this work, the beneficial environmental aspects of deepened seedbeds should be realised and appreciated. Clearly, in times of climate change with fewer, more erratic rainfall events, improvements in water conservation, waterlog prevention and increased plant availability of soil water make this form of soil management much more robust than existing forms of management. Also, its ability to reduce emissions of the greenhouse gases carbon dioxide and nitrous oxide whilst using less fuel should be recognised as progress toward a more sustainable environment.

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