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POSTER PAPERS

CONTROLLED TRAFFIC - SOIL MANAGEMENT OPPORTUNITIES

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The prime objective when developing soil management systems for the future is to identify systems which will achieve the following:

1. reduced inputs in terms of time and energy

2. improved soil conditions for crop production, maintenance of soil fertility, and reduced erosion and environmental pollution.

Controlled traffic systems open up new horizons for the development of soil management systems to meet this objective and some of the opportunities and implications are discussed in this paper in terms of the conference themes.

Soil Management Development Through History

In both past and current situations where manual labour constituted the only energy input, soil tillage inputs are minimal, often amounting only to hole formation for seed placement. In these natural situations when water supply, drainage, weed control and temperatures are adequate, there is no evidence to indicate that crop production or soil conditions can be improved by increased soil cultivation; the result is often the reverse. If conditions for production are, therefore, satisfactory, there is no gain from unnecessary cultivation.

With the introduction of animal power, the amount of tillage increased, often ceasing to be local and almost always increasing in depth. This trend has continued following the introduction of tractors, although there has been the occasional reversal, usually of relatively short duration. Such a change occurred in the 1970's - 80's with the introduction of paraquat, allowing the direct drilling of cereals. The results achieved were successful initially, but tillage became necessary again later, as equipment size and soil compaction in particular increased.

The two major factors which have dictated this increased tillage and working depth trend, are the continuing increases in soil loading from larger and heavier tractors and equipment, and the action of the soil engaging tools themselves, particularly when working under moist or wet conditions. The tool effects, manifest in the form of soil pans and smeared layers, required only small increases in working depth to overcome them. The loading effect, however, extends much deeper, the relatively weak soil deforming and compacting to greater depths to support the increased loads.

Until recently, there have been two main management approaches to avoiding these compaction problems, the first being to reduce tyre and contract pressures to reduce the depth of compaction. The second, regular deeper loosening operations to alleviate the compaction itself. The combined use of both approaches has been successful up to certain loading limits, but it is not a permanent solution and is only achieved at the expense of increased energy and time inputs. The major problem affecting permanence is that the loosening operation unfortunately makes the soil even more vulnerable to recompaction, hence with uncontrolled subsequent traffic recompaction can occur very rapidly. By effectively removing loads from the cropping area, the controlled traffic approach offers the opportunity to avoid these problems, so reversing this most unsatisfactory trend of deeper and deeper tillage, with a continually increasing cost penalty.

Soil Management Aims

Prime soil management aims are to provide optimum soil conditions for the crop, water application systems, water conservation, drainage, erosion control and machinery operation wherever appropriate. The ease and extent to which many of these requirements can be achieved is very dependent upon the machinery operating system and the prevailing soil condition, particularly the nature of the soil structure and its stability. The aim must always be for a continuing improvement in soil structure, for everything stemming from a good soil structure is advantageous.

The risk of soil structural unit or aggregate breakdown is very dependent on the magnitude and timing of any loads applied to them and on soil organic matter content. The units are much more vulnerable to mechanical breakdown under a given load, when loaded under wetter conditions, particularly in more compact denser soil situations. They are usually very resistant to breakdown when dry. Greatest handling care, therefore, needs to be taken when working at higher moisture contents.

Whenever soil aggregates or clods are moved, even without being broken, they are weakened, making them more vulnerable to breakdown if re-loaded soon afterwards. Allowing a period of time. 2 - 3 days or more, without further disturbance, particularly if there is also some drying, will enable them to regain much of their lost strength and breakdown resistance. The timing of further disturbance has, therefore, an important influence on the final result.

Soil organic matter contents not only depend on the amount of organic material left after the previous crop, but also on the amount lost during soil preparation for the next crop. Soil cultivation and stirring is an ideal way of maximising organic matter loss and hence of reducing structural stability. Organic matter levels are critical for the safe working of soils when moist or wet, since it is the organic related bonds which provide most of the aggregate strength and breakdown resistance at higher moisture contents. This is the time when aggregates are most vulnerable to loading damage. Zero or minimal tillage techniques to conserve organic matter are, therefore, almost essential for a continuing improvement in structure with time.

The great challenge in soil management is to identify systems which satisfy, with a minimum of compromise, all the optimum requirements for the crop, water regime, aeration, soil conservation and tractor and machinery operation. This is extremely difficult to achieve with random traffic systems, where serious conflicts arise between traffic needs and almost all the other requirements. The ideal traffic requirement is for a very well compacted soil condition, very different to the other needs. Whilst a compromise soil condition may be reasonably satisfactory for low pressure, light to medium traffic and machinery , it certainly is not possible for heavier equipment. The adoption of a controlled traffic system removes this major conflict immediately, leaving only much more minor ones, such as conflicts between surface residues for erosion control and seeding machinery, to be resolved.

By removing the heavy loads from the cropping area, the controlled traffic approach is a very positive way of reducing direct soil structural damage, of significantly reducing if not eliminating tillage requirements, so improving soil structure through reduced organic matter loss and of enabling almost all the soil management aims to be met with a minimum of compromise. Whilst the ideal system to maximise the gains from these potential benefits is a permanent controlled traffic system, substantial benefits are still achievable with temporary systems, providing they are established on the first pass of seedbed preparation. Soil compaction, requiring later eradication, does occur in the wheeled area with temporary systems, but its location is clearly identifiable, thus allowing lower cost local rather than general alleviation measures to be taken.

Soil Management Opportunities

A change to a controlled traffic system changes the soil situation immediately and hence if maximum benefits are to be achieved, there is a need to re-look at tillage practices to see if modifications are needed. It is highly unlikely that traditional ideas on tillage depths, timings, frequencies and operations will necessarily be the most appropriate for the new situation. The changed circumstances are now reviewed to identify where pitfalls may occur, but particularly where opportunities exist for improving efficiency and production. Maximum benefit will, however, only be achievable, if strong well drained traffic lanes are prepared, allowing efficient trafficking as soon as possible after rainfall or irrigation.

Soil condition/compaction issues

The main current soil compaction concern is usually associated with excessive compaction, a condition which has arisen from general uncontrolled trafficking. Once traffic is removed, unless tillage practices are changed, there could in numerous situations be the opposite problem of under-compaction. Under-compaction can sometimes seriously reduce water availability and may in other cases induce nutrition problems such as trace element deficiencies. Early zero traffic trials in UK with the same cultivation systems, regularly reduced cereal yields on some clayey soils by about 15 - 20%, this was due to induced manganese deficiency. This is a change which certainly needs watching and rectifying as appropriate.

Removing the major cause of soil compaction namely, traffic should, certainly on the more stable structured soils, allow much shallower tillage and in some cases direct drilling. The need for and depth of tillage now is more likely to depend on requirements for crop residue incorporation, weed control or seedbed production. On weakly structured soils tillage depth will depend on the depth of soil slumping which has to be alleviated. In almost all cases working depth requirements will be less than previously, an advantage to be capitalised on .

Once into a permanent controlled traffic regime, soil conditions can be expected to improve with time. the intensity and depth of tillage operations required can, therefore, also be expected to change, decreasing with time and advantage should be taken of this. Soil improvement tends to be rather quicker in the surface layers than at depth and it would be unfortunate if improved topsoil was lost unnecessarily to depth. This can easily happen during deeper loosening operations, which may be necessary to overcome inherent deep compaction in the early transition years of the system. Deeper working tine depths, spacings and winged tine lift heights should be adjusted to lift and fissure the soil in the problem area at depth, but without rolling out large clods and creating major cavities at the surface, down which surface soil can fall. Progressive multiple depth tine arrangements loosening from the surface downwards can achieve this requirement and they are also most suited for loosening temporarily installed traffic lanes since they minimise the extent of large clod production.

Operating conditions and procedures

Although rarely recognised, in uncontrolled traffic systems, the earliest starting time for tillage operations following rainfall or irrigation, is governed more by the likely compaction and rutting damage that will be caused by the tractor wheels, than by whether the following implement will do its job. It is possible to work soils satisfactorily without causing serious structure and compaction damage, at higher moisture contents than would be the case if they were trafficked. With the wheels removed from the cropping area, much greater flexibility, therefore, exists in the timing of soil operations. There are obviously limits as to how moist or wet soils can be and still be worked satisfactorily, but within these limits, the moister the soil the lower the energy requirement and the easier it is to break clods, bonuses worth exploiting.

This greater flexibility in the timing of cultivations opens up two timeliness options. When weather conditions are likely to remain difficult or deteriorate, work can commence earlier with controlled traffic. If there is a strong chance of weather improvement, the start can be delayed to optimise conditions, with the knowledge that if the weather does go wrong an earlier start on drying again is possible.

The natural weathering processes are still the most efficient of all methods for producing optimum seedbeds, often at zero cost, but sometimes they need assistance. Leaving the soil in a condition after tillage, where after weathering it can be drilled without any further tillage operation, is the condition to be aimed for. This may require a little further soil manipulation to get the condition right, such as levelling a rough surface. Working from controlled traffic lanes, such operations can be easily carried out at the optimum time, without wheeling damage in the crop production area. The traffic lanes provide the flexibility to time other operations carefully, such as allowing the soil to age if necessary before further manipulation, thus preserving structure, or a rapid following operation to break excessively large clods before they strengthen.

Implement smear and panning risks increase when working under moister conditions. These risks are, however, much less in controlled traffic regimes, where the soil at depth is much less compact. Narrow tines fitted behind and operating slightly deeper than the discs on susceptible disc implements, will also effectively remove any potential disc panning problems immediately.

Production issues

The quality and uniformity of crops are becoming increasingly important issues influencing saleability and profitability. They are particularly dependent on having uniform soil conditions, which can readily be achieved with controlled traffic systems. Other critical issues influencing production include the timeliness of crop establishment, the ability to manipulate the soil to relieve crusting problems which could effect emergence and timely operations for mechanical weed control. The ability to work under moister soil conditions from traffic lanes significantly increases the chances of operating within the desired time periods for all these operations. Under intermittent rainfall conditions, the possibility of working even one day earlier after rainfall, could often avoid a delay of 1 - 2 weeks, if the weather pattern turns foul.

The harvesting and removal from the field of soil borne crops without severe soil structural damage, becomes much easier, whatever the moisture conditions, when working from traffic lanes. This system also offers an additional advantage in situations where the following crop has to be established rapidly after harvest. Even in wet seasons, the soil working necessary after harvest for the following crop will be much reduced with controlled traffic as compared with uncontrolled traffic, allowing much more timely crop establishment.

Erosion / water infiltration / drainage issues

Erosion control is closely associated with the management of crop residues. In certain circumstances, particularly under wet conditions on heavier soils, unfavourable seedling/straw interactions may occur in the presence of straw, reducing plant populations. This problem is greatest when the seed is placed in smeared slots in contact with straw or chaff. With appreciable rainfall during the germination and early seedling growth periods, anaerobic conditions can develop which can kill the seedlings. The risks of this occurring are very dependent upon seed drill coulter design and soil condition at the time of drilling, but they are greatest when the seed is drilled into compact soil with little seedbed tilth. These soil conditions are least likely to occur in minimum tillage, higher organic matter level controlled traffic situations. Increased possibilities, therefore, exist for the adoption of direct drilling practices with effective residue cover for erosion control in controlled traffic situations.

Erosion risk is likely to be highest in sloping areas in the traffic lane itself, due to water flow along the track. Experiments where chopped straw has been anchored into the track using the tractor wheels, are showing considerable promise in reducing this soil loss problem.

Conclusions

Controlled traffic offers many advantages for improved soil management, whilst at the same time reducing time and energy inputs. In particular, it offers opportunities for much more timely operations over a wide range of soil moisture contents, with reduced tillage inputs. Changes to traditional tillage practices will frequently be necessary to maximise the benefits from the system.

Controlled Traffic

Common Sense or Nonsense

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Introduction
If there is any one unit that characterises modern extensive agriculture, it is the large tractor. The tractor and the traction process are central to our mechanisation systems, so a great deal of time has been invested in the study of traction, tractive efficiency and the economic performance of tractors.

In working on tractor performance, its easy to miss the point of the whole exercise - to achieve optimal crop performance at minimum cost. This was missed in some of our early tractor performance/reliability surveys in the late 1970s, at least until performance was defined in terms of the minimum cost to plant a given crop area.

The defining moment in this work occurred when a grower pointed out that his new 15 tonne 4WD helped him avoid soil compaction by allowing him to start work later after rain. The idea of using a bigger tractor to beat soil compaction is not nonsense, but it helps concentrate the mind!

We took our first tentative steps in controlled traffic at about that time, aware of some of the original work on cotton in the USA, and potatoes in Scotland. When it was publicised, however, growers soon let us know that they thought; and a small number phoned to say they had been bed farming for some time. A much larger number pointed out all the reasons why it couldn't work!

In this paper I will describe what happens under a tractor tyre or track, then use result from our tractor survey to illustrate the magnitude of the costs of uncontrolled, 'random' traffic. A brief consideration of the options leads to the unsurprising conclusion that we must control tractor traffic, and discussion of the other 'system' benefits that follow from controlled traffic.

Traction, Compaction and Energy
Traction, or the development of thrust from wheels or tracks operating on yielding surfaces, is inherently inefficient. Tractive efficiency of 4WD tractors ranges from approximately 70% on tilled soil, to 85% on firm soil. For most practical purposes, in operations such as planting, we can expect tractive efficiency to be between 75% and 80%. Typically, about 10% of power is lost in slip, and about 15% of power is used to keep the tractor itself moving (i.e. lost in rolling resistance).

When we look at what is actually going on underneath the tyre or track, simple observation of rut depths and soil horizontal movement shows that trafficed soil is moved about 30-50 mm downward and the about the same distance backwards. It is this deformation within the soil that absorbs most of the wasted power.

Soil is highly non-uniform under normal tillage/planting conditions, because field operation can't start after rain until the surface soil is trafficable. The surface layer is usually quite dry, but soil within the tilled layer will be at a moisture content below field capacity, having drained for some days after rainfall. Soil at the bottom of this layer, and at the top of the sub-tillage layer might be at a greater moisture content. The precise moisture profile will depend on several factors, including time after rain, but moisture content and previous disturbance largely determine a soils susceptibility to deformation.

When trafficed, energy lost in the traction process is absorbed in deforming soil. At the dry surface, this is likely to amount to a grinding/powdering action, although tyre lugs can sometimes cause some loosening. As Peter Walsh has demonstrated, most soil movement occurs within the tilled layer, but some movement also occurs in the sub-tillage zone. In moist soil this will usually be a damaging shearing and densification, which will be a problem in soils that do not self-repair rapidly.

The implement following the tractor hides the surface and tilled layer wheeltrack effects very efficiently. We identify a "compaction" problem in the sub-tillage zone only because we can see it, i.e. we did not operate at sufficient depth to remove all of the wheeltrack effect. Its easy to forget that most soil 'compaction' occurs in the tilled layer and is broken up immediately by the implement.

Only recently have we started making measurements of the increased energy required to till trafficed soil. Initial measurements were made simply by lifting and lowering the wheeltrack tines of a chisel plough. The draft effect was so large, that we doubted our technique. Subsequently we have made a 3 point linkage unit which allows direct comparison of the draft of the wheeltrack tines with the draft of identical (control) tines, at the same depth, but well outside the wheeltrack.

At very shallow tillage depths, the draft of the wheeltrack tine can be less than that of control tines. At normal tillage depths (~100 mm) the wheeltrack effect can more than double tine draft, and when tines operate at depths >150 mm, the increased draft can be very substantial. In recent measurements, for instance, narrow (50 mm) tines operating at a depth of 220 mm required an additional 4 kN of draft each to till the wheeltrack centreline behind 16.4 x 38 tyres with an axle load of 5 t. The magnitude of this effect has varied with tillage depth, moisture content and prior tillage.

Our results suggest that the best generalisation of wheeltrack effects in normal broadacre tillage conditions is an increase in the draft of wheeltrack tines by a factor of two. At greater tillage depths the additional draft is often similar to the apparent rolling resistance of the tyres ahead of the tines. There is a nice symmetry in the thought that the additional draft of wheeltrack tines might be similar to the rolling resistance of the wheel that created the wheeltrack, when the tine is operating deep enough to break up most of the wheeltrack.

Wheel Traffic Costs

We can use data from our performance/reliability survey to assess the significance of this wheeltrack energy effect. These show, for instance, that the average broadacre 4WD tractor of 160 kW available power was delivering 120 kW to its axles, of which 90 kW was transmitted to the implement. The tractor was moving at 7.2 km/h, its mass of 13.0/tonnes carried on dual tyres wheeling a 1.8 m strip. The typical implement was a 9 m chisel plough requiring 45 kN pull, with a mass of more than 5 tonnes, itself wheeling a 1.2 m strip.

If we look carefully at this situation, in terms of where the power is going, our data indicates that the specific draft required for chisel tillage on non-compacted soil would be only 3.3 kN/m, which is 30 kN for the whole 9 m implement. In other words if we could fit our chisel tines to the linkage of a Nebraska-tested hovercraft, it would need a pull of only 30 kN!

This would represent a drawbar power of 60 kW. The other 30 kW were used in the wheeltracks produced by the tractor and implement, because:-

- prior wheeling doubled the draft on a 3 m strip, increasing pull by 10 kN, requiring 20 kW.
- rolling resistance of the 5 tonne chisel plough frame would exceed 5 kN, requiring 10 kW.

In other words, 30 kW, or one third of what we regard as implement input power, is used to no good purpose in the wheeltracks. These have already absorbed a 'tractive inefficiency' of 30 kW from the tractor, so the total power input to making and breaking up wheeltracks is 60 kW.

These figures are based on some approximations, and they have been rounded to keep the argument simple. It is nevertheless broadly true that <u>half</u> the power delivered to a tractor's wheels is wasted in compacting and decompacting wheeltracks.

The bad news becomes worse when we remember that our broadacre tillage doesn't remove deeper compaction, and re-loosening of compacted surface soil is unlikely to provide an optimal seed bed.

The good news is that <u>if</u> we can effectively control field traffic, we will achieve the same work rate doing the same job, with a tractor of half the size. This represents a major economy, which gets even better when we consider the reduction in tillage depth and intensity which will occur in the absence of wheeltrack effects.

<u>Compaction - Problems and Solutions</u>

Soil compaction has been identified as an important factor affecting yield of intensive crops, but information relevant to the broadacre situation is less convincing. For the purposes of this paper I regard it as a problem because:-

- Compaction does not always reduce yield, but it almost never increases it.
- Traffic compaction increases tillage/planting costs, as outlined above, <u>and</u>
- Compaction reduces infiltration, with negative effects on erosion and soil water availability.

Compaction is only loosely defined here in terms of the effect of existing tyre/track options on soil and crop. Options for avoiding soil compaction fall into three general categories:

- Reducing ground pressure: Current problems occur with tyre pressures of 80-120 kPa (i.e. 12-18 psi), so reducing pressure should reduce the problem. Some success has been achieved with lower pressures tyres, but these appear impractical for large tractors or harvesters. Within the range of pressures permitted in conventional tyres, most research indicates that soil damage is a function of axle load, rather than tyre pressure.

- Avoid operation on wet soil: Irrigators have some capacity to schedule operations in relation to soil moisture, but broadacre agriculture has no such flexibility. Tractor/implement operating capacity is determined by the time available between the ground first being trafficable, and the point when soil moisture content is too low. The fixed end point to this process means that delay in starting requires a bigger tractor to complete the job in time.
- Reduce trafficed area. We can reduce this by reducing the number of field operations with minimum or zero till, or by reducing the width of the traffic zone in relation to implement width. This is what we achieve by replacing dual tyres with steel or rubber tracks. It is effective in reducing trafficed area, but at some cost in terms of equipment purchase price. It is a step in the right direction, but we still have the problem of heavily loaded implement and grain harvester wheels.

Each option has major problems. We've got to get on the paddock at the right time to carry out cropping operations, and farming equipment is too heavy to carry on hovercraft, but the costs and consequences of random traffic are excessive. Controlled traffic, or the use of permanent traffic lanes, becomes the best option.

In most controlled traffic systems we sacrifice production from the soil zone used as a wheeltrack. This means there is some loss of area in which to grow crops. Yield loss is likely to be compensated by improved production from untrafficed soil, and reduced costs, but it is obviously desirable to minimise traffic lane the area. This can be achieved by spreading the lanes further apart, reducing lane width and improving steering accuracy. Given the practical minimum tyre width of 0.5 m, we could set our traffic lanes at 2 m, and sacrifice 25% of potential crop area, but if we need furrows at 2 m for irrigation, this is no loss. If we could spread wheels to 4 m, the area lost reduces to 12.5%.

Practical considerations will dictate the choice of spacing used, but it will usually be more flexible and convenient to have a modular system, in which wheeltracks are uniformly spaced across the paddock. Spacings around 3 m are often compatible with commonly available tractors and harvesters, although some modification is usually needed to one or the other.

Precision Controlled Traffic

Implement wheels currently serve to carry the weight of the implement and to provide depth control. In controlled traffic systems permanent traffic lanes are likely to be below the paddock surface. Unless they are depressed by a precise distance, some alternative depth control system will be required. Precision in steering and depth control represents the major problem and the major opportunity of controlled traffic.

- A problem, because without some reasonable level of steering precision, traffic cannot be effectively controlled.
- An opportunity because effective guidance and depth control will provide a range of new options for crop-soil management.

These are exciting times, because practical, precision guidance systems are being developed to reality at USQ, while UQG is looking at what can be achieved given greater precision. Precision controlled traffic will allow us to treat narrow-spaced crops like rowcrops in terms of weed and insect control. Planting between the previous crop rows will allow simpler planters to work in heavy residue conditions, and accurate depth control will change the nature of tillage.

Controlled traffic will also affect timeliness. In many cropping situations, the first time at which an operation can take place is determined by trafficability considerations. We can't plant immediately after rain, not because the planter won't work, but because the tractor would make too much mess. Controlled traffic on compacted, fixed laneways will allow access to a paddock more rapidly after rain, always provided those traffic lanes are self draining. Similar considerations apply to spraying, and even harvesting after rain.

Like any new system, controlled traffic sounds wonderful in theory. The problem is to put it into practice, and growers are rightly cautious about a new technology with some obvious risks. Fortunately controlled traffic will not usually entail a major investment in the initial stages: its more likely to involve a new implement than a new tractor, although tractor/implement -guidance systems will be recognised as increasingly valuable. The first priority is to get controlled traffic going using modified tractors, but the gantry will increasingly be seen as the obvious next step.

Controlled traffic will have a major effect on the farm equipment industry. Currently it would be easily to believe that weight and robustness are the most important characteristics of their products, but robustness and weight are really required largely as a consequence of the unpredictable loads caused by soil compaction and poor depth control. As controlled traffic systems become more common, we can expect to see a rapid increase in the level of technology used by the farm equipment industry. Precision controlled traffic will rely on guidance, rather than brute force, to provide optimum conditions for crop production.

Conclusion

Current random traffic cropping systems waste energy, money and good soil structure in the continuing conflict between the requirements of traffic and crop production.

Controlled traffic will enhance the economic and environmental sustainability of agriculture, as we manage permanent beds for optimum crop production, and compacted laneways for traffic and runoff control.

Australia has probably made greater strides than other countries in the development of extensive controlled traffic. It would be good to think this might result in economic opportunities for both farmers and machine manufacturers.

Controlled Traffic for Broadacre Dryland Farming: Better than Sliced Bread

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Research and farmer innovations have established many components of improved farming systems for dryland agriculture on large area, grain belt farms. But relatively little progress has been made to increase productivity towards potential levels. In part, this is due to a development psychology - increase production by developing more country - but a major constraint has also been the lack of efficient and effective mechanisms to apply improved practices on farm. This Conference was planned in the belief that controlled traffic offered these mechanisms. I will argue in this paper that with controlled traffic, broadacre farming can be as technically advanced as irrigated agriculture, and that latest developments in soil, land and crop management can be applied. Also "it's time", as economic, environmental and social pressures threaten the survival of dryland agricultural industries.

I wish to acknowledge the contribution made to this paper by the large number of farmers, researchers, extension officers, consultants, machinery people, etc., who have interacted with me over the years. In many ways, our current controlled traffic program is the culmination of my career to date. I can claim very few of these ideas, perhaps my contribution has been to recognise the potential for controlled traffic to bring together an enormous range of developments and initiatives into an integrated, functional system. The aims of this paper are to present a travel documentary on how these concepts developed and to encourage further development by revisiting our information base and challenging our current management perceptions. The rigour of controlled traffic systems is proven when growers say "I don't understand why we farmed any other way". My basic contention is that controlled traffic simply makes good sense.

DRIVING FORCES: PROBLEMS AND NEEDS

Soil Compaction

Soil compaction, and more generally, soil structural degradation, are obvious problems. It is very easy to demonstrate that the vast majority of agricultural soils have structural degradation caused by the weight of tractors. We cannot avoid this but we can control it. The importance of this issue is that it highlights the need to consider soil management and to examine the health of the soil. And this is not difficult - a 30 cm deep pit is usually enough. But, it is essential that soil management becomes a basic component of the farming culture.

It is usually considered that compaction is worse in irrigated than dryland soils, but every dryland farm examined in Central Queensland has evidence of serious soil degradation. If we challenge this perception about dryland agriculture, the result is not surprising. Dryland cultivation and planting are typically done as soon as possible after rain (when the soil will provide traction), but the soil is too wet and weak to support the tractor weight. By comparison, irrigators have more management options.

Low Productivity

Current productivity (yields and $/ha returns) must be examined in relation to our environmental potential. A conservative goal for dryland farmers would be 10 kg cereals/ha/mm of stored water plus rainfall. We have to challenge our "good crop" standards and push towards optimum use of the resources that are free - rainfall and sunshine. We also need to consider higher value crops and how to increase the dollar returns.

Farm Efficiencies

This is the cost side of the cost/price squeeze that is strangling so much of agriculture. It is just too easy to find inefficiencies at levels of 10 or 20% in current farming practices: overlaps and misses, double operations and cutting out headlands and corners, wheel the soil and immediately dig it up again, farming within contour banks, etc. Many of these inefficiencies occur with each operation in the paddock, some are cumulative. In addition to waste, these practices **constrain** or **prevent** the adoption of improved, innovative practices such as residual herbicides, plant population management, directed spraying, etc. We must challenge the perception of efficiency.

Soil Erosion

Soil erosion is an irreversible loss of resources and must be a dominant threat to sustainability. This has always been recognised but how much progress have we made? In March 1994, a small flood in the Fitzroy River carried six million tonnes of suspended sediment out to sea. This was the first time we have attempted the measurements! The cost to producers is difficult to quantify, but who can deny the magnitude of the problem. Soon, environmental legislation may enforce a massive change in performance. We must challenge the perception of responsible farm management.

WHAT DO WE KNOW? *The light at the end of the tunnel*

Soil Compaction

Our program in Central Queensland started as a soil compaction and repair project. Demands by funding bodies and our own priorities, made us consider adoption strategies from the beginning. This inevitably drove us to the concepts of controlled traffic, permanent beds, zonal tillage, etc., and introduced a philosophy of soil management.

I was involved with the irrigated cotton industry as it evolved into a soil management philosophy over the last 15 years. It started with the "rip some and gypsum" approach - deep ripping, profile inversion (massive mould boards), etc. and has now developed to minimal tillage, permanent wheel tracks and controlled traffic. The "high energy input" solution was challenged and the final product is a minimal energy input approach. A basic principle is that we must select inherently good soils for our farming soils, and good soils only need minimal modification to be sustainably productive. A key element of the cotton soil management philosophy has been the SOILpak package.

The rapid adoption of controlled traffic in the irrigated cotton industry over only five years is great support for the attractiveness and feasibility of these concepts. Cotton growers now value their soil. This change to a soil management culture must now happen with dryland growers.

Low Productivity

A dominant issue is our expectations. Productivity means turning rainfall into yield. Droughts tend to create a focus on negativity but they should heighten our focus on efficient use of rainfall. The potential gains are enormous. Average cereal yields in Central Queensland are 1 - 2 t/ha from more than 600 mm annual rainfall. Efficient use of this rainfall would yield 6 t/ha. Soil water accumulation during fallows rarely exceeds 20% of rainfall received. Typically 70% of fallow rainfall is lost as soil evaporation. Our challenge is to convert much more of this rainfall into yield.

We know that surface management (stubble management and tillage) has little effect on soil evaporation, so we need to plant more often. We need to re-examine what a planting opportunity is. How much stored water is needed? What are the future implications of the "to plant" and "don't plant" options? We have measured fallows with over 300 mm rainfall that was all lost to soil evaporation. We did not recognise planting opportunities that could have produced 1 - 2 t/ha; and we lost the water anyway. In general, the shorter the fallow the more efficient it is.

In Central Queensland, most productivity is lost in good seasons. Average yields increase with seasonal rainfall, up to about the average rainfall value. More rain then does not seem to increase average yields. Wet seasons have many problems; too wet to plant, too many weeds, insufficient fertility, more disease, losses at harvest, etc. But the challenge is to do much better in these good seasons.

Drainage is also a loss mechanism for soil water, but the impact of controlled traffic is likely to be small. The maintenance of high cover levels and the improvement in soil structure may increase drainage during wet periods, but if cropping frequency increases, the impact on an annual basis should be small.

Rainfall after crop maturity or soon after harvest provides considerable opportunity. Zero tillage (direct drilling) technology is now available to control weeds and crop regrowth, and to plant into stubble. Soil fertility, particularly nitrogen availability, may then become limiting and the ability to sidedress fertiliser in a controlled traffic system offers the solution. This technology has not yet been developed, although there are plenty of ideas.

Farm Efficiencies

We have known for many years how senseless random traffic practices are: the enormous weight of tractors, the poor traction of cultivated soils, the cost of cultivating wheel tracks, the idea of planting in wheel tracks. The benefits of controlled traffic in direct cost reduction have been quantified (up to levels of 50%), and other potential benefits, such as use of a smaller tractor to do the same job and increased speed of some operations, have been demonstrated.

Row cropping approaches, made possible by controlled traffic, provide another quantum leap forward in farm efficiency. Basically, the opportunity is provided to do a perfect job in only one pass - no gaps, no overlaps. However, there are inefficiencies associated with headlands.

Dealing with contour banks is a difficult issue. Three fairly unpalatable options exist. One is to traffic over the banks - this will pull downs the banks, may increase cross-bank cracking and the bank channel is a wet spot. The second option is parallel contour banks which are difficult to design on uneven slopes and the third option is sacrifice areas within the contour bays where weeds etc can proliferate. We must challenge our design criteria.

Soil Erosion

We have an enormous information base on soil erosion and yet catastrophes still happen. Soil erosion has been our greatest challenge in the development of controlled traffic systems. I will try to establish some basic principles and examine how they can be applied.

The first principle seems to be that water runs down hill. Also, for rainfall runoff, the further it runs the larger the flow, the higher the energy and the greater the erosion. Contour banks reduce this length of run. But, the concept of contour cultivation tries to fight this principle and encourages flow across the slope. This will concentrate water into any low spots where downslope flow occurs, and the flow volume depends on the contributing area across the slope not on the distance between contour banks. When runoff occurs, the goal must be safe disposal. There is no doubt that many small downslope flows are much less erosive than large, concentrated flows.

The second principle is to optimise high infiltration conditions. Contour cultivation will increase infiltration by ponding water across the slope. This can reduce runoff when infiltration rates are high but our soils can have infiltration rates of 1 mm/hour or less when wet. Most of our soils are cracking clays and while in India, I saw a controlled traffic system called broad bed and furrow (BBF), that had changed the soil cracking pattern. Large cracks formed in the furrows. When runoff occurred, it collected in the furrows and was directed to these cracks. After 150 mm rain in a few storms, there was no runoff and the cracks were still open. This is the infiltration process that flood irrigators use, but we have not observed it in normal broadacre farms. Typically, cracks are closed at the surface by cultivation or by rain wetting the top 10 - 20 cm of soil.

The third principle is controlled traffic layouts will strongly influence water flow when runoff occurs. Water will flow along wheel tracks, crop rows, any cultivation furrows, etc. We have established two rules for our designs:

- The CT lines must drain to a safe disposal point - no reverse flows, no low spots. Disposal could be into a waterway or contour bank.

- All the runoff generated within each CT line must be retained in it - no cross flows.

These rules effectively maintain the runoff distributed across the landscape, just like the rainfall. The idea came from the Emerald Irrigation Area, where downslope hills and furrows have been used since inception of the scheme in 1974. When tested using the KINCON model, the potential was demonstrated but it is essential to prevent cross flows in the designed layout.

Stubble retention and reduced tillage have been universally shown to reduce soil erosion by a reduction in runoff, combined with a larger reduction in sediment concentration. High cover levels can only be maintained with the use of herbicides and there are additional benefits from attached stubble compared to slashed or plowed out stubble. The sophistication with herbicide application possible in controlled traffic systems ensures high performance while minimising the total herbicide input to reduce costs and environmental impact. Accurately marked wheel tracks provide opportunities to inter-row spray, spray at night, use residual herbicides, etc. And I think one of the most important things for farmers - the foam marker goes to the dump! The maintenance of high cover levels is particularly important at planting time, when runoff can be the difference between a fully wet seedbed and a layer of dry soil. One of the essential benefits of controlled traffic is the ability to minimise tillage and this provides further insurance against erosion within the downslope configurations.

In summary, there are good reasons why soil erosion can be minimised in controlled traffic layouts, but we are researching these issues at Emerald, with a bed and furrow layout that is designed to ensure that our rules are kept. After two years, the results are very encouraging but it is fair to say that beds and furrows are not attractive to any of our broadacre collaborators. My current view is that a 3 m wide bed and furrow system is a good option in terms of erosion control, weed management, easily identified wheeltracks and compatibility between tractors and harvesters, but a 2 m wide system is better for some crops, for example, cotton.

ON-FARM EXPERIENCES

The adoption of these improved farming practices has been, at best, slow. An obvious constraint that little work has been done on effective ways to implement these technologies on-farm. And if each technology requires independent implementation, then the proposed system becomes too complex. The "better than sliced bread" part of controlled traffic is that it facilitates the implementation of all the technologies already discussed, and, we think, heaps more that have not yet been thought of. Controlled traffic is a unifying, encompassing farming system.

But is controlled traffic feasible and practical on broadacre farms? We established an R,D & E program on-farm to test this and to identify constraints to its use.

All expected benefits have already been demonstrated but it has not been easy. The major issue has been marking of the wheeltracks. Controlled traffic is a permanent set of parallel wheeltracks. They don't have to be straight, although I'm sure that helps, but they do have to be parallel with accurate guess rows. We think that the solution lies in automated tractor and implement guidance. The initial layout is crucial but wheeltrack identification has also been a problem, particularly in our self-mulching soils. Different planters and cultivators vary in their ability to fallow the tractor, hence the need for implement guidance and steering. Wheeltrack maintenance is also a problem. But our collaborators have all convinced themselves that this is their way of the future. As problems arise, they will be solved.

THE FUTURE

Controlled traffic looks like providing an integrated system that has a wide range of benefits with few, identified deficiencies. We think the most exciting thing however, is the opportunities for new inventions and innovative ideas. The ability to do the current operation in exact relation to previous operations is so powerful. Irrigators have demonstrated the benefits of interrow cultivation, directed spraying and precision harvesting. Dryland growers will benefit from these practices but we have already identified other opportunities such as furrow planting, planting between stubble rows and side dressed fertiliser. Some night time operations have advantages, such as herbicide efficacy. We should be able to design a tool to remove cotton and sorghum plants with minimum disturbance. Cotton and sorghum are very hard to kill after harvest, but with controlled traffic they could be ratooned and efficiently fertilised, sprayed, etc. Soil improvements between wheel tracks will take time to develop, but improved performance when moisture seeking and more even crop establishment have been reported.

This discussion has stressed the soil, land and crop management issues from a production viewpoint but the environmental benefits are consistent and complementary. Decreases in erosion, total chemical application and soil degradation, and increased productivity are all environmentally friendly. Control traffic supports the concepts of responsible resource management.

While the interest in Australia is uniformly enthusiastic, there is no apparent enthusiasm in overseas countries. Considerable R&D was done in USA more than ten years ago, much of it similar to what we are doing now. The results were positive but interest and adoption by farmers has apparently been negligible. I do not know if they had an integrated approach to extension. The BBF concept has not been adopted in India despite considerable subsidies. I think they forgot to talk to the farmers. The technology has been described as "perfected yet rejected" - a sobering thought for researchers.

Controlled traffic gives us the opportunity to challenge all the agronomic rules of thumb and redevelop them for the 21st century. The future will see new equipment specifically designed for the improved soil condition and to do specific jobs. Tractors and headers will have the same wheel spacing and same tyre size. Our main challenge will be to achieve widespread adoption because change to minimum tillage and downslope layouts is antagonistic to a whole generation of developed perceptions. And there are risks because careless adoption of these practices could lead to increased erosion.

The development of these concepts have been strongly influenced by my experience in the irrigated cotton industry. For dryland farmers it is always worthwhile to look at what intensive agriculture is doing. Cottongrowers now prepare for next season as soon as possible after harvest. Dryland growers should be more urgent than irrigators with post harvest preparations because they do not know when the next planting opportunity will happen. In the future, post harvest management will become more urgent as the value of each planting opportunity is better appreciated, and the cost of missed opportunities recognised.

Like many before us, we were driven into controlled traffic to control soil compaction. But when the potential to control soil erosion was identified and we realised that many, possible management improvements were cumulative, we concluded:

Controlled traffic is better than sliced bread. It just makes good sense and the only surprise is that someone didn't think of it earlier.

Will there be a dryland broadacre revolution?

PERMANENT BEDS: THE RIVERINA VERSION OF CONTROLLED TRAFFIC

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INTRODUCTION

The farming system known as Permanent Beds has developed in the Southern Irrigation areas of NSW ; controlled traffic is an integral part of this system. The system has gradually evolved since the late 1970s, to the stage where it has now been adopted by the majority of irrigated row crop farmers. Row cropping has been practiced in the area since the early 1960s and the district is currently the biggest producer of both Maize and Soybeans in NSW.

ENVIRONMENT

1] Climate: Hot dry summers with high evaporation and cold winters with 10-30 frost days Too short a season for current cotton varieties.

2] Topography: Flat Riverine Plain.

3] Rainfall: Average 350-450mm/annum, spread fairly evenly through the year but quite variable, from 100-1000mm / annum.

4] Irrigation: Reliable supply from river and bores. Furrow Irrigation. Most of the crop's water needs are applied through irrigation.

5] Majority of farms practicing permanent beds are landformed with row lengths of 400-1200 metres and grades of 1 in 1000, to 1 in 2500.

6] Soils: mostly heavy grey and red clays. They are semi-self mulching and break down well with wetting and drying but are fragile, often sodic at depth, are easily damaged when wet and become extremely hard when dry.

HISTORY

Permanent beds evolved from furrow irrigated row crops during the 1970s. Previously summer crops were grown on single 36 inch hills, and winter crops in border check bays. To achieve better drainage on winter cereals, we at first used "corrugations" made by dragging furrowers behind the seeder. At the same time we were successfully experimenting with leaving out every second furrow in the row crops to make a 72 inch "bed" with the idea of improving soil moisture characteristics. It seemed a logical extension to formalize the corrugation system and use the same pre-formed 72 inch beds for winter crops.

However, hills were routinely ploughed down, fields were levelled and hills reformed between each crop. This was expensive and time consuming and often resulted in delayed planting when wet weather intervened. Soils were deteriorating under the intensive heavy cultivation regime and we were looking for bigger and bigger gear to get the job completed on time.

We noticed that there was often an ideal seed bed immediately after crop removal, through the self-mulching of the surface, which was very hard to recreate after the major deep tillage which was required to put up new hills. So it became an obvious step to sow winter crops direct into the old beds after removing the stubble by burning. As this was successful, it became clear that we should also try retaining the old beds for subsequent summer crops.

A similar approach was being researched at Tatura in Northern Victoria. At the same time, John Thompson was also developing the system at Leeton Research Station, with a rotation experiment on beds with zero tillage.

Permanent beds have now, I believe, been adopted by more than 80% of row crop farmers in the area and are used for a range of both summer and winter crops.

PRESENT DEVELOPMENT at WOOLOONDOOL

Although there is widespread adoption of the general principles of permanent beds, there are probably as many variations of it as there are farmers in the district. On my farm, I have some beds that have not been knocked down for 15 years, but generally we knock them down every 8 years, to relaser.

All crops are grown on 72 inch flat-topped beds, with all winter crops direct drilled into burnt stubble. Most summer crop country is retilled, some of it quite vigorously, without moving the beds or changing the traffic lanes.

ROTATIONS

We maintain a fairly flexible cropping rotation determined by:-

- Crop prices
- Contracts available
- Water availability
- Gross margins
- Weed problems
- Chemical residuals
- Isolation of specialist crops such as seed crops waxy maize
- Fertility
- Seasonal conditions

We have grown maize, sunflowers, soybeans, sorghum, winter cereals, canola, faba beans and other crops under this system. Currently, we base our rotation around two maize crops, followed by canola or faba beans direct sown into the burnt maize stubble, with soybeans direct sown into canola stubble, if water allocation allows, with seed sunflowers replacing some of the maize, depending on contracts available.

From a total of 750 hectares of developed row crop, we plan this year to grow:-
400 hectares maize, 150 hectares sunflowers, 110 hectares soybeans, 110 hectares canola, and 100 hectares faba beans; with approximately 100 hectares of summer fallow, 540 hectares winter fallow, and 110 hectares being double cropped.

We aim to plan our cropping programme at least two years ahead.

MACHINERY

Although I started the transition to permanent beds with my normal row crop machinery, I, like many other farmers, have developed my own range of specialist machinery for permanent beds.

All my Machinery is standardised to six row, three bed or 18 ft.

1] *Disc Hiller Ripper* is used for fairly drastic ripping of the beds while reforming the furrows behind with single disc hillers. It also doubles for applying Anhydrous Ammonia.

2] *Bed Renovator* is a home made machine with twin gangs of offset disc harrows on each bed with heavy duty listers behind in each furrow. It is also fairly aggressive and is used to break up the soil on top of the bed and rebuild and shape the furrow.

3] *Power harrow* is the only machine that does not cover the full three beds. It is used to fine the seedbed and incorporate chemicals.

4] *Bed shaper* is used for final shaping of beds, solid fertiliser is also banded at this stage.

5] *Row crop planter,* we use a John Deere Maximerge row crop planter with double disc openers and a leading fluted disc for no till.

6] *Great Plains drill* slightly modified for cereals and small seeds.

7] *Mulcher* is also an integral part of our equipment, which allows us to deal with the heavy trash and get a clean burn.

8] *Inter row cultivator*

ADVANTAGES

1] *Timeliness,* due to the reduced tillage we are able to sow crops much closer to their optimum time. Also the option of double cropping is much easier.

2] *Improved soil structure.* The major tillage that was previously required to knock down and rebuild the beds was seriously damaging soil structure by compaction and physical forces. Now compaction is limited to the wheel furrows and crumb structure on the bed is much improved.

3] *Annual tillage costs* are much reduced with fuel consumption, labour and repairs all halved per unit of output.

4] *Capital requirements* are reduced with no requirement for heavy broad acre tractor or tillage equipment

5] *More intensive* cropping regime in a more *sustainable* way.

6] *Flexibility*

7] *Better drainage* both surface and internal

PROBLEMS

1] *Insect build up.* We are particularly concerned about the recent findings about Heliothis armigera overwintering on undisturbed fallow.

2] *Troublesome perennial weeds*

3] *Loss of some soil fauna* due to constant use of Counter which seems to be the only effective control of wireworm I have noticed a decline in earthworm numbers since we have been using Counter.

4] *Harvesting machinery* wheel compaction.Currently harvesting is the only operation where we do not use the traffic lanes due to problems in getting wheel spacing narrow,or wide enough to fit our beds.Currently we use wide flotation tyres at 9ft spacing on top of the beds, this works all right while it is dry but can cause serious damage to the beds when wet.

5] *Inability to incorporate stubble.* At present we rely on burning the stubbles to cope with the trash. It is probably only a matter of time before this practice is banned and we need to be developing other techniques for dealing with it.

6] *Chemical residues* Atrazine is an integral part of our weed control programme and, if it is to be phased out, we need replacements, preferably post-emergent, selective and non-residual.

Irrigated Cropping on Permanent Raised Beds in Southern New South Wales.

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Cropping with Raised Beds

Raised beds are a cropping system where the crop zone and the traffic lanes (wheel tracks) are distinctly separated. The flat-topped beds are constructed by moving soil from the traffic lanes to the crop zone. This raises the level of the cropped zone, leaving a furrow for the wheel traffic and for irrigation. Some of the advantages of raised beds are:

- the layout allows for improved surface and internal drainage of the cropped soil, reducing waterlogging in both winter and summer crops. More favourable root zone conditions assist plant growth as the greater depth of topsoil together with the close proximity of the furrows allows rapid re-aeration following irrigation or rainfall;

- wheel compaction is confined to the furrows;

- the range of crops is increased (less waterlogging, and can grow both summer and winter crops) and the grower can readily change crop sequences in order to obtain favourable market prices;

- the ability to operate a double cropping sequence combined with improved root zone conditions and the more timely conduct of cultural operations suggests improved financial returns are probable.

The raised bed system is rapidly gaining in popularity particularly on soil types where irrigation water moves readily from the furrow to the centre of the bed. These soils are usually clay soils that shrink and swell as moisture content changes i.e. cracks develop as the soil dries out.

The area of irrigated land in the Murrumbidgee and Murray Valleys cropped using the raised bed layout is estimated to approach 35,000 ha with virtually all of the maize and soybean production based on this layout.

Historical Background

In the mid 1970's, Martin Maynard of "Wooloondool Farms" Hay, changed his cropping system and began seeding winter crops directly into the previous summer crop beds. (Maynard *et al* 1991). New beds were still prepared for each summer crop, however, over time the system has evolved into one of cropping on permanent raised beds. With permanent bed farming a series of summer and winter crops can be grown in rotation without reforming the beds.

Timeliness of Operations

Under the conventional system the field was cultivated immediately after harvest to knock down the existing beds and prepare new beds for the next crop. Large tractors and heavy implements were used to plough, scarify, landplane and re-hill the field. These operations were often delayed or had to be repeated due to unsuitable weather conditions.

Due to pressure to get the next crop planted, the ground was often worked when it was too wet causing soil compaction and slicking. Alternatively, if worked too dry large clods resulted which then had to be broken down with additional cultivations to achieve a seed bed. In 40% of years the subsequent crop could not be planted because rain would delay ground preparation until it was too late to plant (Maynard *et al* 1991).

The permanent bed concept removes the need for all this ground preparation allowing immediate access to the field post harvest. Cultivation and/or reshaping of the beds is sometimes necessary before planting of the next crop, however the number of passes of machinery is dramatically reduced. By using the furrows as controlled traffic lanes the risk of compacting the soil on the beds by working after rain is negated.

Rotations

Crop rotation will play an important role. The establishment of an appropriate rotation to assist the control of weeds and diseases, and to maintain an appropriate nutritional balance of the soil is always important, even more so where the beds are permanent (Hutchins, 1987). Rotations are still evolving (Maynard and Muir, 1984; Maynard *et al*, 1991). If maize is involved it will usually be the first crop, as it is a high input crop that is less forgiving of inadequate management than most other crops that will be grown in southern NSW.

The likelihood of achieving a double cropping rotation is substantially increased with the permanent raised bed system. Success is dependent on timely sowing which is often affected by rainfall - too wet to harvest and/or plant.

It would seem unwise to double crop with consecutive legume crops. There is the potential for disease and weed buildup and loss of opportunity to benefit from N contribution from the legume crop.

Stubble Management

Experience with permanent beds has found that burning the stubble is often necessary to assist control of weeds and diseases and to reduce the quantity of trash (Maynard *et al*, 1991).

The stubble of irrigated winter cereal crops can be bulky (5-10 t/ha) and present significant impediment to the establishment of a succeeding double crop. Although summer crops can be successfully established into either slashed or standing cereal stubble by the use of a fluted disc coulter in front of the sowing tine, the most appropriate approach is to burn the stubble.

The stubble of winter legumes or oil seed crops has not been found to be disadvantageous to the planting of the following summer crop.

Investigations at Leeton Field Station (Thompson *et al,* 1989) showed that crops planted after burning or removing stubble consistently yielded more than where stubble had been retained or incorporated.

Economic Benefits?

McKenzie (1989) using Whole Farm Gross Margin analysis and Operating Profit analysis indicated favourable returns, especially from intensive double cropping where 10 crops were grown in 6 years.

A detailed economic analysis comparing a rotation on permanent beds has been described by Maynard *et al* (1991). The analysis, prepared from an actual case study, revealed a return to capital of 8.9% for permanent beds compared with 5.4% for the conventional system. The authors believed that the analysis was conservative in that more intensive rotations than used in their case study were possible with permanent beds.

Leeton Field Station Experiment

A permanent raised bed experiment was established in 1984 at the Leeton Field Station (lat. 34°28'S) in the Murrumbidgee Valley. The main objective was to ascertain any agronomic limitations to the system. Raised beds (1.5 m from furrow to furrow) were constructed in April and planted to wheat in the first week of June.

The following crop rotation, where all crops were direct drilled, was established.

1984 - wheat

84-85 - soybean, sunflower, maize, millet

1985 - wheat

85-86 - soybean, sunflower, maize, millet

1986 - wheat

86-87 - fallow

1987 - rapeseed

87-88 - soybeans, sunflower

1988 - barley

88-89 - soybean, sunflower

1989 - barley

89-90 - soybean, sunflower

1990 - wheat

The soil type was a grey semi-self mulching uniform textured clay (62%). The flat topped beds supported either 6 x 15 cm of winter crop or 2 x 65 cm rows of summer crop.

Plots were split for stubble management - burnt (removed if too wet to burn) or retained on the soil surface.

The following comments refer to the winter cereal/soybean rotation although other combinations responded similarly.

Grain yields from winter cereals ranged from 5-6 t/ha and soybeans achieved consistent yields of 3 t/ha. The yield of soybeans is encouraging especially as planting was delayed to late December (the preferred planting date is late November).

Retaining winter crop stubble usually reduced soybeans yield. On each occasion winter cereal yield was higher where soybean stubble was burnt - range 11-35%; average increase 21%.

Measurements of infiltration rate from the furrow, soil strength, soil water extraction patterns, bulk density and organic matter content were undertaken during the final 3 summer crop seasons. In spite of considerable effort, no significant differences were detected between the stubble management systems.

Provided plant establishment was not limiting to yield potential, there were no obvious agronomic limitations. A number of growers, particularly in the Murrumbidgee Valley, are now successfully double cropping relatively large areas on permanent raised beds. Yields have been as high or higher than those reported for the Leeton Field Station experiment.

Recommendations for Success

- Construct the raised beds on a field with an even slope - preferably after laser guided landforming
- Commence with a weed free seed bed
- Sow the first crop on time
- Adjust seeding rate to ensure an adequate plant stand
- Adopt a planned sowing "window" and do not be tempted to plant later - even if this means foregoing a cropping opportunity
- Minimise soil disturbance when direct drilling especially for the summer crop (apply the bulk of the fertiliser, other than N, to the winter crop)
- Burn or remove bulky stubbles

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References

Hutchins, N., (1987) Bedfarming *I.R.E.C Farmers' Newsletter*, No **130**, p.11-13

Maynard, M., Beattie, B., Hutchins, N., and Muir, J. (1991) Permanent beds - their potential role in soil management for the future. *I.R.E.C Farmers' Newsletter*, No. **137**, p.14-18

Maynard, M., and Muir, J., (1984) Multiple cropping using direct drilling on permanent beds. In "Root Zone Limitations to Crop Production on Clay Soils". Eds. W.A. Muirhead and E Humphreys) pp. 175-178. (Australian Society of Soil Science Inc., Riverina Branch: Griffith, NSW)

McKenzie, D., (1989) Economics of irrigated bedcropping rotations. *I.R.E.C Farmers' Newsletter* No. **134,** 27-29

Thompson, J.A., Beecher, H.G., and Bacon, P.E., (1989) Irrigated crop rotations on permanent beds at Leeton Field Station - 1989 update. *I.R.E.C Farmers' Newsletter* No. **134**, 25-26

SPECIFIC DESIGN LIMITS FOR TATURA PERMANENT BEDS

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Tatura Permanent Beds (TPB) were constructed from soil which was modified so that the chemical, physical and biological properties met specific design limits. The specifications were used to develop a crop rotation and design farm equipment to create a soil which is soft, stable and permeable. Laser beams were used to create straight and graded furrows and traffic was controlled by confining compaction to the furrow. Soil tilth and porosity were improved by tillage at the Lower Plastic Limit and crop rotations. Plant roots, calcium and an organic mulch from crop residues decreased the strength and improved the stability of the soil.

Introduction

Many of our experienced farmers can produce a high yielding crops in the first year on land that has never been under crops before. But these yields are difficult to maintain year after year on the same land. After the second crop yields decline, weeds and diseases spread, forcing the grower to move to a new site (Adem *et al.*, 1984).

There is no standard spacing for wheels on tractors and equipment forcing the operator to run over the raised beds (Tisdall and Adem, 1989). Tractor traffic, inter-row cultivation and wetting of the furrow breaks down and compacts the soil. In a wet season, tillage causes pugging of the soil, which creates a cloddy seedbed when the soil dries. In a dry season, tillage produces large clods, which when broken down, create a high percentage of dust particles mixed with clods, making the soil set hard and become less porous which in turn restricts the growth of crop roots. In a soil where the structure has been degraded, the soil becomes difficult to manage and weeds become aggressive competitors with the crop.

Tillage makes the soil softer by loosening but the effect is temporary (Stirzaker and White, 1995). Wetting and drying of the soil will cause it to become harder with time. Traditional cultivation practices are thought to be a factor in declining yields but if we stop cultivation altogether the soil becomes too hard. Tillage can pulverise soil, oxidise organic matter, cut roots and fungal hyphae and destroy micro-organisms. In extreme cases, the soil is almost sterile i.e. low in useful flora and fauna which help to stabilise it.

Yields can be maximised and sustainable by integrated research on several factors which make up a management system or package (Collis-George and Lloyd, 1978; French, 1985; Hillel, 1980; Schafer *et al.*, 1985; Tisdall and Adem, 1989). The ideal levels of soil physical properties for each of the stages of seed germination, seedling emergence, movement of water and air and root growth must be defined (Adem, 1993; Hillel, 1980).

The TPB were developed with the aim of producing and maintaining the desired specification in specific zones in the soil (Tisdall and Adem, 1989). These zones were the seeding-zone, which was the soil around the seed and developing seedling, the root management-zone which was the soil containing the bulk of the crop roots, and the traffic-zone which supported the farm machinery.

The desired aggregate size in the seeding zone and root zone was produced by tillage at the Lower Plastic Limit with a rotary hoe and a spring-tined cultivator respectively.
Wheat roots and the straw mulch from the wheat stubble were used to create pores in the soil through the biological activity of roots and earth animals (Table 1).

Table 1 Pore dimensions of biological origin or significance (After Hamblin, 1985).

Mean pore diameter (μm)	Biological significance
2,000-50,000	Ant nests and channels
1,500-8,000	
500-3,500	Wormholes
2,000-11,000	
6,000	
300-10,000	Tap roots of dicotyledons
500-10,000	Nodal roots of cereals
1,000	Root plus root hair cylinder in clover
100-1,000	Seminal roots of cereals
50-100	Lateral roots of cereals
30	**Field capacity (-10 kPa)**
20-50	1st- and 2nd- order laterals
5-10	Root hairs
0.5-2	Fungal hyphae
0.2-2	Bacteria
0.2	**Permanent wilting point (-1500 kPa)**

The Tatura Permanent Beds system

The TPB were constructed to specifications, from the literature or from our own research, which described the optimum range for each property (Table 2). The aim was to modify soils so that the chemical, physical and biological properties meet these specific design limits. The specifications are not fixed nor are they a complete list but are refined and added to as more information becomes available. Where information is limited, the specified range may be broad or may only relate to a particular crop.

Table 2 Specifications for Tatura Permanent Beds

Purpose	Property	Specification
Controlled traffic	Wheel compaction	<25 %
	Directing index	<1 cm
Water management	Matric potential	-10 to -50 kPa
	Levelling index	<1 cm
	Aggregate size	>0.5 mm
Germination, emergence and root growth	Air-filled porosity	15-20 %
	Aggregate size (germination and emergence)	10-20% diameter of seed
	Aggregate size (root growth)	1-10 mm
	Bulk density (germination)	1.3 g cm^{-3} (wheat)
	Temperature	29^0 C (wheat)
Root growth	Penetrometer resistance	<1 MPa
	Bulk density	1.0-1.3 g cm^{-3}
Soil stability	Organic carbon	>2 %
	Water stable aggregation	>75 %
	Clay mechanical dispersion	<1 %

In the first autumn we used a hiller to set up the land into beds separated by a furrow. A laser receiver, mounted vertically on a mast at the centre of the toolbar, received a beam from a transmitter in the middle of the field. A second receiver mounted horizontally over the front axle of the tractor received a second beam from another transmitter at the edge of the field. In this way, laser beams controlled the depth of the hilling shovels and guided the tractor so that the levels and the direction of the furrows were accurate. The pre-irrigated beds were tilled with a spring-tined cultivator at the Lower Plastic Limit to create a high proportion of aggregates in the range of 0.5-10 mm in diameter. Cereal was drilled into the beds and furrows to stabilise and improve the porosity of the soil and to provide a grain crop. To control soil dispersion, gypsum (Ca SO_4) was spread at the rate of 5 t ha^{-1}. Immediately after the cereal was harvested, the stubble was shredded with a flail mower and the straw directed into the middle of the bed. On each bed and in the one pass, two 5 cm wide rotary hoes and two precision seeders were used to prepare a fine tilth (10-20 % the diameter of the seed) and sow a summer crop.

Benefits of Tatura Permanent Beds

* Improved trafficability.
* Crops can be grown repeatedly on the same land with a short crop rotation.
* A well-structured soil which is soft, stable and porous.
* Lower cost in land preparation.
* Less risk of poor soil conditions due to wet weather or drought.
* Less wastage and more uniform application of irrigation water.
* Decreased risk of root disease.
* Investments in land improvement and structures are optimised.
* Weeds can be managed better.
* Timeliness of sowing.
* Yields are optimised and sustained.
* Income stability through minimised fluctuations in production.

Conclusion

This paper describes a recipe based on specific design limits which combine to create a useful management system with the potential for high and sustained yields. Adoption of the specifications would give direction to and challenge many of the traditional activities which make up the preparation and maintenance of land for cropping. The approach differs from some traditional management systems which apply to a particular soil, climate, location and crop. The focus has been shifted away from the activity of farming to the end result, regardless of where the system is applied or what implements are used. This may eventually lead to a lower energy input, fewer operations, increased accuracy, more predicability and better returns from farming. More research is needed to extend and refine the list.

References

Adem, H.H. (1993). Effects of soil physical properties on germination and emergence of wheat (*Triticum aestivum*). *M. Agri. Sc. thesis*, La Trobe Univ.

Adem, H.H.; Tisdall, J.M. and Willoughby, P. (1984). Tillage management changes size-distribution of aggregates and macro- structure of soils used for irrigated row-crops. *Soil Tillage Res.* **4**: 561-576.

Collis-George, N. and Lloyd, J. The basis for a procedure to specify soil physical properties of a seedbed for wheat. *Aust. J. Agric. Res.* **30**, 831-846.

French, R.J. (1985). Future trends and water management. (Dryland). Australian Institute of Agricultural Science, Jubilee Conference, Melbourne, Australia. 21-23 August.

Hamblin, A.P. (1985). The influence of soil structure on water movement, crop root growth, and water uptake. *Adv. in Agron.* **38**, 95-158.

Hillel, D. (1980). Tillage and soil structure management. *In*: 'Application of Soil Physics'. New York, Academic Press. pp. 234-376.

Schafer, R.L.; Johnson, E.E.; Elkins, C.B.; Hendrick, J.G. (1985). Prescription tillage: the concept and examples. *J. Agric. Engng. Res.* **32**: 123-129.

Stirzaker, R.J. and White, I. (1995). Amelioration of soil compaction by a cover-crop for no-tillage lettuce production. *Aust. J. Agric. Res.* **46**, 553-568.

Tisdall, J.M., and Adem, H.H. (1989). An example of custom prescribed tillage in south-eastern Australia. *J. Agric. Engng. Res.* **40**: 23- 32.

EFFECTIVE PRODUCTION AND MARKETING OF IRRIGATED GRAIN CROPS USING PERMANENT BEDS

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"Woodlands", Darlington Point, NSW.

Woodlands was purchased in 1987 by the then SFIT to augment its grazing enterprises on Tubbo Station. Woodlands was expanded by purchasing a neighbouring property in 1989 and it became independent of the other property, however the primary enterprise was still to be wool production.

With the down turn in the wool industry we needed to change quickly. Some consultants were engaged to ascertain how much it would cost to enter into irrigated row cropping. A figure of $1.5 M did not help our chances of getting the funds to do this. We did however, proceed and managed to beg, borrow, build and buy enough machinery to get underway. We spent $173,000 and we have done all other expansion within our cash flow ever since. The machinery was not pretty but it served our purposes and much of it still does.

Something else which served us well were the goals we set back in 1989 which were:

> "To make the best of human, physical and technological resources by maintaining a viable farming system which gives satisfactory returns, both in cash flow and capital gain to superannuees, without compromising our fiduciary, social or environmental responsibilities.
>
> To seek out premium domestic and export markets and service them so that the long term viability of Woodlands is maintained and improved.
>
> We do this by having enterprises which are managed using appropriate and sustainable farming practices, taking into account our physical, social and economic environments.
>
> We aim to remain flexible and have an enterprise mix which reduced agronomic and financial risk, but is successful and innovative enough to provide leadership in the agricultural industry."

We are undertaking ISO 9002 accreditation this year which will enable a management system accepted throughout the world to be implemented that will cater for the demands and potential growth of our markets. This QA program will also provide for succession of key management personnel and operators which will ensure the farms ongoing viability.

We are actively involved in expanding export markets for their own sake. We belong and network with a number of groups such as the Riverina Faba Bean Grower Association, the Riverina Food Group and the NSW Chamber of Manufactures. We are also developing relationships with major clients whereby we use their processes to add value to our produce and directly market into the retail, wholesale and particularly the food service sectors. In doing this however, we ensure that we do not tread on our client's market territory.

This gives some background into our operation at Woodlands, for us to be able to be effective in marketing, we have to be effective in producing.

In practical terms this means using a permanent bed farming system where enterprises are chosen on performance from within agronomic groups. These groups fit into a rotation where, after relasering, beds are formed into which is planted an initial high performance crop such as Maize. If lasering is not necessary beds are simply renovated using the same traffic lines.

Subsequent crops such as Wheat, Soybeans, Faba beans and Canola can follow. These subsequent crops have reduced establishment costs and unproductive fallow periods are minimised.

These crops are directly drilled into the previous crops' stubble with reduced chemical and fertilizer input. The permanent beds allow the maintenance and improvement of soil structure, facilitate water application and drainage and reduce overall capital cost in machinery. They also allow operations to be carried out in circumstances that conventional farming techniques would not. All of these benefits can result from this type of farming together with the achievement of higher yields.

The rotation of crop types aids pest and disease control with a balance of minimum, reduced and conventional tillage. Chemicals used in maize can control troublesome weeds such as Bathurst burr, broad leaf weeds can more easily be controlled in cereal crops and vice versa. Legumes improve soil fertility, retained organic matter with reduced tillage improved soil conditions, and crops such as Canola can have a tremendous benefit against soil compaction ready for a new rotation.

12 DSE's of Wethers and 8 DSE's per hectare of steers are run on irrigated pastures established on soils less suited to cropping. Crop stubbles are also incorporated into the annual feed budget for sheep; (cattle are not grazed on beds). The wethers are valuable in the farming enterprises for their ability to control weeds, utilise crop residues, dry-land and other non-crop areas. This system gives us the flexibility we want and simplifies the choices we face at the planning and budgeting stage.

The resource we have which makes the whole system possible is a supply of underground water. This water is of the highest quality (less than 200 EC) and yield (between 18 and 25 megalitres per day). It enters the aquifer from a fault beneath the Murrumbidgee River about 50 kilometres from Woodlands and has been carbon dated to 15 000 years old at the pump site. It is expensive compared to surface water at around twice the price with capital and operating costs, however it is reliable and fits in well with permanent bed rotations which utilise water throughout the year.

The use of the neutron probe helps us make a range of decisions. We are able to prolong irrigation intervals without loss of water-use through the plant. This results in less irrigations over a season allowing limited water resources to be better utilised. That means more area can be cropped without risking yields or overall water costs can be reduced.

It is important to note however, that under good soil conditions the use of the probe does not alter the amount of water used by the plant. It will in fact increase it by maximising the number of days the crop can actively grow. Under good soil conditions, this will reduce the number of water-logged periods, channel and drainage losses etc. Where compaction or soil conditions hinder water infiltration and uptake, the probe will actually indicate the need for more frequent irrigations.

These are important points to remember when using permanent beds. The information we have obtained from the use of the probe has prompted us to address compaction problems on fields where we would not have thought we had a problem. Change crop watering systems from through-the-bank pipes to syphons. We have also irrigated crops when we did not think they needed it and held off water when we thought they did.

Woodlands is marketed as an operation which aims to produce regular supplies of quality grain and produce where quality and continuity are rewarded with appropriate prices. I believe with our soils and environment our returns the use of permanent beds provide a better and less risky option than any other alternatives.

Details of "Woodlands" Operation

	Ha	%
Total Area	**1 344**	
	(3 319.68 ACRES)	
Crop Area	723	53.795
Pasture Area	200	14.881
Regen Area	7	0.5208
Dryland Pasture Area	170	12.649
Noncrop Area	244	18.155
	1 344	100

	$	%
Opening Capital Value	2 292 111	
Operating Return		14.40
Capital Growth		2.80
Total Return		17.20

Typical Gross Margins Excluding Overheads	
	$ / Ha
Culinary Maize	1 448
Popcorn	868
Feed Maize	662
Faba Beans	318
Canola	311
Sheep / Cattle	100

Water is supplied from 3 deep bores delivering between 18 and 25 Megalitres per day.
Water is recirculated on-farm for reuse.
Rainfall is around 400 mm

Soils comprise approximately 50% excellent grey self-mulching soils, 20% Transitional red brown earths and the balance of hard setting red soils with timber and prior stream formations unsuited to cropping.

Vision-Guidance of Agricultural Vehicles

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Abstract

A vision guidance system has been designed, built and commissioned which steers a tractor relative to the rows of a crop such as cotton. It was required to be insensitive to additional visual "noise" from weeds, while tolerating the fading out of one or more rows in a barren patch of the field. The system integrates data from several crop rows, testing for image quality. At the same time, the data processing requirements have been limited by the use of frame-sequential strategies to reduce the image space which must be processed. The design has been developed to the stage where six evaluation systems are about to be installed to test farmer-acceptance. The present prototypes employ a 486 PC motherboard embedded in a custom housing, together with a 68HC11 microcomputer to which the task of closing the steering servo loop is delegated. The system shows great promise for cost effective commercial exploitation.

Introduction

There is a need for automated guidance of agricultural vehicles, not to remove the presence of a driver but to allow greater attention to be given by the driver to the cultivation operation. Automatic steering also promises to improve the effectiveness of "controlled traffic", a technique where vehicles seek to use the same "footprint", every time to minimise compaction damage to the soil. Under manual control, this increases the pressure on the driver to maintain precise control of the track of the vehicle. The experimental vehicles are already capable of much more accurate sustained control.

For spraying operations, high speeds are desirable to enable a ground vehicle to challenge the role of a crop-spraying aircraft. Once again, the driver's task is made more demanding and an "autopilot" becomes highly desirable.

Many guidance methods can be considered, ranging from buried leader cables to beacons, surveying instruments or even satellite navigation. All have their drawbacks. The most appealing method is to follow human practice and take guidance from the crop itself, steering the vehicle by means of the view of the rows ahead.

There are, however, many complications as the condition of the crop changes through the growing cycle. Initially the plants appear as rows of small dots among scattered random dots which are weeds. Later they fuse to form a clear solid line. Before long, however, the lines have thickened and threaten to block the laneways. Many variations of the vision algorithm are thus required to fulfil all the seasonal requirements.

Existing System

Within a single 486 computer, software has been implemented for both image analysis and on-line control of the tractor. In early experiments a stepper motor was used as the steering actuator, but the very restricted steering slew which this could achieve meant that limit-cycle instability was prone to occur at all but the lowest velocities. The use of a variable-structure control algorithm gave substantial improvement, but the system was still sensitive to the accuracy of initial calibration.

Funding of A$150,000 was at that stage granted by the Cotton Research and Development Corporation and J I Case donated the long-term use of a Maxxum 100 horsepower tractor. The research which had up to then proceeded with minimal resources was put onto a sound footing.

The cordless drill motor was returned to the toolbox, to be replaced by a specially designed hydraulic valve system for direct actuation of the steering. A notebook computer with expansion rack was substituted for the tower case. The vision sensor was still a camcorder, neatly fixed to the bonnet with velcro, but the overall appearance was much more impressive. The vehicle was shown to be capable of travelling through a crop at over 25 kilometres per hour with only a few centimetres of waver.

The present state of the project sees the Maxxum tractor replaced with a 180 horsepower Magnum, the camera mounted in a stylish housing above the enclosed cab and the computing electronics built into a small cabinet located in a convenient corner of the floor of the cab. A monitor screen mounted just below the roof gives a continuous display of system performance. Software embellishments include automatic detection of the end of the row, with a warning tone to alert the driver, and automatic acquisition of the track when he has turned the vehicle.

Six prototype units have performed admirably in the field during the last twelve months. Two systems have also been recently installed in the USA for trial by the Case Corporation. Integration to new tractors will follow, with retrofit to existing machines a priority here in Australia.

Image acquisition

The actual transfer was performed by DMA - direct memory access - and allowed processing of the data to go on undisturbed. However each transfer had to pause until the incoming television image frame started so that some amount of waiting for synchronisation was inevitable. This time-loss was reduced by the use of a double-buffering technique. As soon as a frame of data was seen to have arrived, the "grabber" was primed to load the next image into the second buffer. Processing of the first image then started, and when all necessary actions had been taken the program checked for the filling of the second buffer and waited if necessary.

The system uses a camera interface targeted at the consumer market, the "Video Blaster". It is available at a relatively low price and has some very impressive features. A full colour image is captured in the on-board memory, and can be merged "live" as a window forming part of the VGA display. The image can be scaled horizontally and vertically with no use of the processor time of the host computer. Lines and other graphics can be superimposed on the screen image, so that the performance of the analysis system becomes very clear to see.

A great advantage of the new interface is the provision of colour. A field with a newly shooting crop may be littered with light-coloured detritus which makes discerning the crop rows difficult if brightness alone is used. Even the use of a green filter over the lens makes little improvement. With colour, it is possible to use the chrominance signal rather than luminance to capture an image based on the "greenness" of each point. The spatial resolution of chrominance is nowhere near as sharp as that of luminance, but resolution is not of the greatest importance.

In terms of its applicability to steering the vision system has given excellent performance, although some processing speed is lost in decoding the colour information. Commonality between the various hardware versions has been achieved by the use of a function, ***picbit(x,y)*** which presents the image in a standard form to the analyser whether acquired from the binary grabber, the luminance signal or the chrominance signal of the Video Blaster or from some future system.

Vision analysis

The task is to identify a row of crops and locate its displacement from some datum position. There will certainly not be a well-defined object with shape which could be analysed by outline methods, even if time permitted. In the early stages of growth, the crop takes the form of a spotty row of variously-sized blobs. At its best, it is a linearly-connected domain with a highly irregular outline. If a window can be established within which members of only a single crop row will be present, however, then a relatively straightforward averaging technique can be used.

The analysis method makes heavy use of information learned from previous frames. With knowledge of the location of a row, a window can be set for the next frame where movement of the vehicle should not have carried it as far as an adjoining row. If all goes well, the new frame will yield a new window for searching the following frame and so on. Now the task becomes one of making the best estimate of a line through a row of blobs within the frame - and for this sort of problem a technique akin to regression analysis can be used.

Regression is conventionally used to fit the best straight line to a sequence of points, usually pairs of measurement samples or readings from which statistics are to be drawn. The regression line minimises a quadratic cost function, the sum of the weights of the points times the squares of their distances from the line. In the present case, however, we have brightness values for a two-dimensional array of points and evaluation of the cost involves a double summation. This cost function can perhaps more appropriately be thought of as analogous to the moment of inertia of the data points, represented as masses corresponding to brightness values, when spun about the best-fit line.

At present, the output from the vision system takes the form of serial commands to a 68HC11 microcomputer. The steering loop can be turned on or off - allowing manual control to be unimpeded - and set-point values can be sent to set the steering target angle. A specially developed transducer measures the steering angle and the valves can be switched in a four-millisecond cycle which gives smooth and precise control.

Restrictors deliberately limit the steering slew-rate to a value which can be over-ridden by turning the steering-wheel. The hydraulic valves cause the steering to move but do not move the steering wheel. The steering action is the sum of the two effects, manual and automatic. For control-theoretic purposes a rapid slew-rate is desirable. Practical considerations dictate that the slew-rate should be slow, both to allow manual override and to limit the potential for disaster - it is undesirable that a software fault should be able to roll the tractor!

Continuing work

With a series of very successful demonstrations the project is by no means at an end. The final objective is a system which will be used literally "in the field" on a commercial basis.

Decisions have to be made concerning the nature of the camera and interface to be used. A packaged CCD unit is available complete with interface which is compact and robust, but at a price which exceeds that of a camcorder. The interface is extremely simple, but the perceived brightness is very sensitive to the speed at which the software reads out the CCD contents. A further drawback is that the image is "known" only to the computer and so any user display must be provided at the expense of processor time.

An alternative is to use a DMA system similar to the one used in the early stages of the project, specially designed to interface a composite video signal for this specific task. Into accessible memory, an array of data can be read which relates to any chosen combination of luminance or chrominance. An LCD pocket TV display can be run in parallel with the camera to reassure the user.

Boards similar to the Video Blaster or Video Clipper seem to offer the best prospect for cost-effective interfaces with easy replacement. The rapid evolution of "later models" might however threaten long-term software compatibility.

There are many decisions to be made, too, concerning additional sensors for operating in other modes. When the field is first to be marked out, the task of ruling straight furrows perhaps two kilometres long is a taxing one. A flux-gate compass unit has been interfaced to the system to address this problem.

At planting time, the furrows exist but no crop is present. It is possible that under suitable daylight conditions or at night with suitable headlights the furrows could be made to stand out with sufficient contrast. The attractive alternative is to use tactile sensing of the furrows with an electromechanical transducer.

When the canopy has closed in, no gaps can be perceived between the rows. The addition of tactile stalk-sensors can be used for more accurate guidance of harvesters and post-harvest stalk-pullers.

These and many other aspects are under investigation for the generation of a wide-capability system.

Conclusions

A programme of research combining theory and experimentation has resulted in the verification of a practical guidance system, despite early limitations of very meagre resources. Now that adequate funding has been allocated, the system can be prototyped to professional standards and its performance enhanced to achieve industry acceptance.

Six Case Magnum tractors have already been equipped with the system and have been delivered to farmers for evaluation. Initial reactions during the first year of operation are most favourable. Field trials will continue through the new growing season. The farmers have come to know the system as the "Steeroid".

The preliminary results presented here show that the target accuracy of plus-or-minus two centimetres has already been achieved in difficult circumstances.

References

Smith A.L, Schafer R.L, Bailey A.C (1987); Verification of Tractor Guidance Algorithms. Transactions of the ASAE, Vol. 30(2):305-310.

Smith A.L, Schafer R.L, Young R.E (1985); Control Algorithms for Tractor Implement Guidance. Transactions of the ASAE, Vol. 29(2):415-419.

Campbell N.W, Thomas B.T (1993); Navigation of an Autonomous Road Vehicle Using Lane Boundary Markings. Paper Preprint 1st IFAC International Workshop on Intelligent Autonomous Vehicles, Pgs. 169-180.

A Vision-guided Agricultural Tractor, J Billingsley, M Schoenfisch, Australian Robot Association Conference, Robots for Competitive Industries, Brisbane, July 14-16 1993.

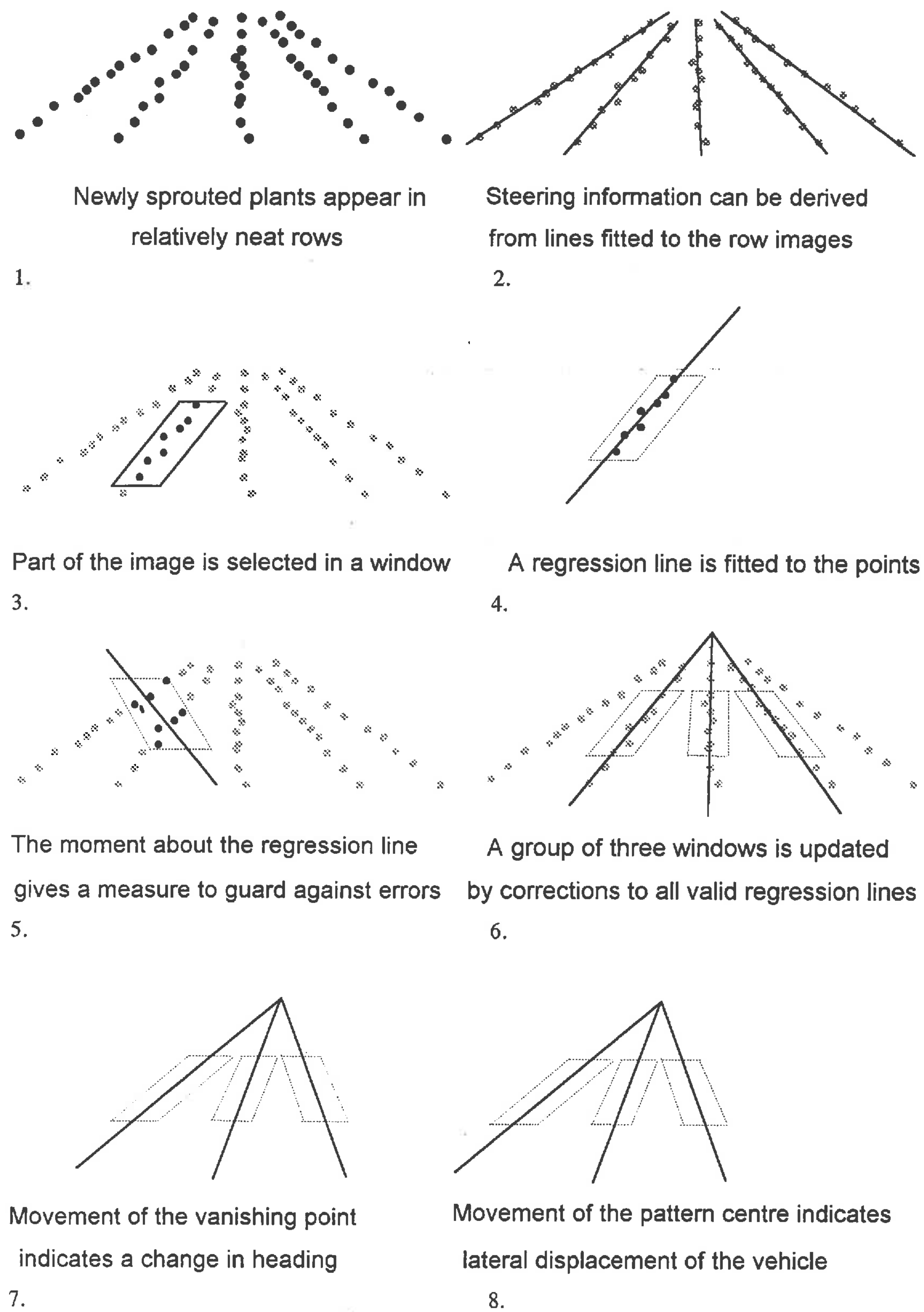

Fig. 5. Slides illustrating the image analysis algorithm.

An analysis of different permanent bed and wheel track configurations in cotton growing.

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Introduction

Permanent bed or controlled traffic systems have been widely adopted by the cotton industry as a soil management system. It minimises the occurrence of soil structural degradation, particularly after wet winters, by limiting the amount and the working depth of tillage operations. It particularly gained momentum after the wet harvests and winters in the late eighties. Reductions in tillage costs which includes less wear and tear of equipment and fuel consumption through a reduction in the number of tillage operations without affecting the yield is seen as great benefit. In addition, the permanent bed systems have improved the timeliness of the farming operations.

Several observations reported in literature (Thompson and Cull, 1989) and verbally by people in the industry would suggest that soil structural degradation can still be an issue in permanent beds, particularly in the rows adjacent to the wheel tracks. This is visible in the field as wave patterns in the height of the crop as well as irregularities in crop development. An improvement in the wheel tracks with the aim to minimise the effect of traffic on the crop would therefore have the potential to benefit the cotton industry.

Several experiences have been recorded where the special attention has been paid to the wheel tracks within the context of controlled traffic. Burt (1984) found in a soil bin that elevated lane ways had superior traction performance compared to level or recessed laneways. Darcey et al (1984) experimented with elevated lane ways in cotton, growing in a clay loam. A 2.5 m strip was sacrificed to construct two elevated traffic lanes which were positioned on top of two hills which normally would have had cotton. No advantage was found over the conventional system in terms of soil compaction and yield. Spoor et al (1988) investigated different shaped recessed wheel tracks aiming to improve the internal drainage. Although some improvement was made, none of the solutions was lasting. Monroe and Taylor (1989) trialed elevated laneways in the field to carry the weight of a 26 Ton gantry system. Significant differences were found between elevated and level and recessed laneways in terms of timeliness. However in order to build the elevated laneways they went to the extent of actually building a road. Closer to home Tullberg and Lahey (1990) reported on two different configurations wheel tracks, recessed and level, used in controlled traffic experiments in Gatton, Queensland. They concluded that the recessed wheel track performed best.

From the above it is evident that some benefit can be derived from elevated laneways but the experience is very limited. The main advantage of the concept of elevated or raised laneways in controlled traffic was seen to improve drainage. In an irrigated row crop such as cotton, the use of a raised wheel track would exclude the irrigation water from the wheel track and therefore improve traction, timeliness and reduce soil compaction compared to recessed wheel tracks which are being used simultaneously as irrigation furrows.

The concept of raised wheel tracks in cotton growing was investigated in the 91'-92' growing season on a commercial property on the Darling Downs. The elevated laneways were installed with a custom made laneway builder which produced the laneways in the required shape. This experiment has been discussed by Bakker and Harris (1992). Difficulties in the establishment of the crop in the elevated sections and limited height of the beds and wheel tracks did not lead to significant differences between treatments. The experiment was continued for two more seasons in another field and a comparison between the conventional 1m and the 2m bed configuration and the raised wheel track was made. This paper discusses the continued experiment, the observations and the results.

Experiment

The trial was conducted in the '92'-93 and the '93-'94 growing season on a commercial property on the Darling Downs, Queensland. The soil was a self-mulching heavy clay soil, classified as an Black Earth. Three blocks of one treatment each were installed consisting of 32 rows each. This was the equivalent of four passes with a tractor and implement which had a standardised width of 8 rows. The row spacing was 1 m while the length of the blocks was 750 m. Three bed/wheel track configurations were: 1m beds, 2m bed and the raised wheel track (RWT). The 1m bed configuration was the standard on the farm while the 2m bed was a configuration which has several advantages (Lucy, 1993) but has not yet been completely adopted by the growers. The RWT configuration consisted of an elevated wheel track, almost level with the top of the bed. Fig. 1 illustrates the three treatments.

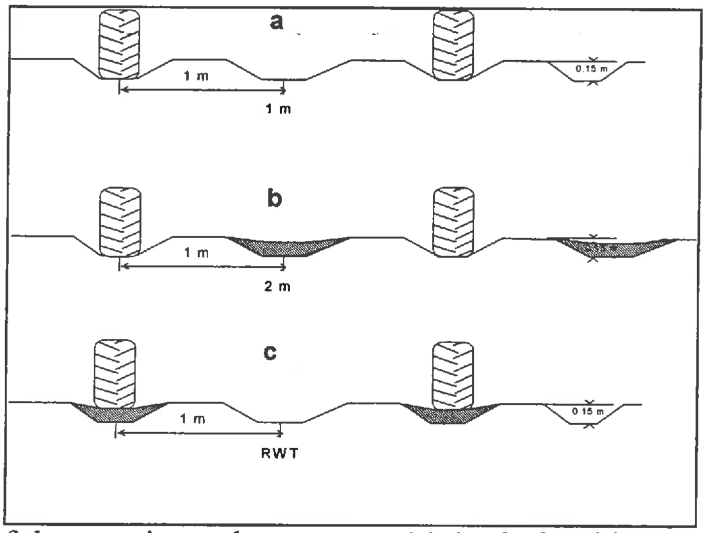

Figure 1 Cross sections of the experimental treatments. (**a**) 1m beds with recessed wheel tracks, (**b**) 2m beds, recessed wheel tracks and (**c**) raised wheel tracks. The hatched areas indicate the volume of soil added during the installation of the experiment, starting from a 1m situation.

Observations made during the '92-'93 season included: soil moisture content of the wheel tracks, crop water extraction (neutron probe), crop development and yield assessment, root mass, soil deformation following traffic, soil structure assessment of the hills and the wheel tracks using shrinkage curves. The observations carried out during the '93-'94 season included: rainfall simulator tests, soil moisture content and root mass, crop development and yield and soil structure assessment using resin impregnated blocks of soil.

Results and Discussion

Season, '92-'93

Soil Moisture Content.

The soil moisture content in the various positions have been summarised in Table 1. Large differences existed between the wheel tracks of the treatments shortly after an irrigation and a rainfall event. However these disappeared after several days. The recessed wheel tracks function as irrigation furrow during irrigation or as drain after substantial rainfall. On those occasions they carry a substantial amount of silt which is left behind as a slurry which increases the moisture content. This is does not occur in the raised wheel tracks and would therefore be beneficial when traffic has to occur under conditions similar to those found in this experiment shortly after irrigation or rainfall (eg. wet pick). Under drier conditions the raised wheel tracks do not have a lower moisture content.

Table 1. Soil moisture content at different dates, locations. For the top 0-10cm only. Value between brackets is the standard deviation. wt = wheel track, hill = plant row.

Occasions and specifications	depth, cm	1M, hill	1M, wt	2M, hill	2M, wt	RWT, hill	RWT, wt
22/09/93 Pre-installation average of head & tail	0-5	30.6					
	5-10	41.5					
03/10/93, 2 days after irrigation	0-5	51 (1.70)			57.6 (1.35)		50.9
11/10/93, 9 days after irrigation	0-20	48.7	46.3				
20/10/93, 22 days after irrigation	0-7	36.8 (2.2)	36.7 (1.00)	32.9 (2.1)	32.4 (1.5)	36.5 (2.5)	41.5 (2.7)
25/11/93, 51 days after irrigation,	0-10	31.8		29.5		32.0	
18/01/93, five days after 100 mm rain	0-5			39.2	38.5	38.5	28.7
	7-12			45.7	47.0	46.4	45.6
22/01/1993, nine days after 100 mm of rain	0-5				37.4 (2.4)		33.7 (2.1)
10/02/1993	0-5		52.5 (3.0)		47.1 (1.1)		41.5 (2.2)
10/02/93 (3 samples) five days after irrigation, bd rings	0-5		51.2 (1.5)		50.3 (0.9)		46.1 (1.1)
	07-12		49.9 (0.2)		48.5 (0.6)		46.8 (0.5)
17/09/93, two days after irrigation	0-5				65.1		52.5

Crop water extraction

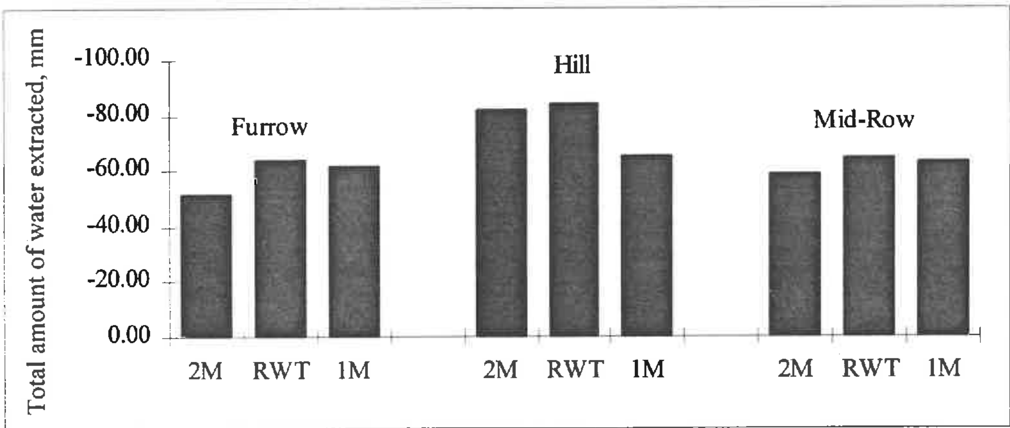

Figure 2 Crop water extraction patterns for various positions relative to the plant row and treatments

The crop in the RWT treatment extracted the highest amount of water with little difference between the furrow (wheel track) and Mid-row (non-wheel track) which indicated similar root activity in both locations. The higher amount of extracted water in the RWT was reflected in the development of the crop which is illustrated in Fig. 3.

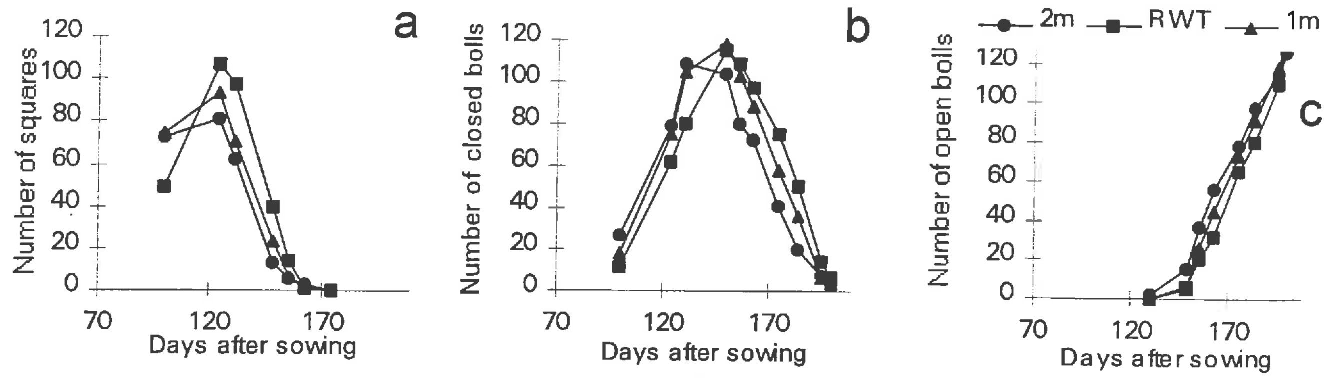

Figure 3 Crop development in days after sowing. (a) Number of squares, (b) Number of closed bolls and (c) Number of open bolls.

The RWT crop had a late start in terms of number of squares which further affected the timing of the peak in the closed bolls and initiation of boll opening, The difference in the number of open bolls was clearly visible in the field. Yield data also reflected the trends in the crop development with the treatments yielding: 3.40, 3.17 and 3.49 b/ha^{-1} for the 1m, 2m and the RWT treatment respectively. The yield in the 2m treatment was significantly less than the other two treatments.

The delay in squaring and the subsequent larger number of bolls in the RWT could have been due to the compensation phenomenon (Constable, 1995, pers. comm.). The RWT and 2m beds were established from well prepared seed beds. The top soil had been removed and deposited in a different position either in the mid-row or in the wheel track. Alterations in the immediate top soil of the seed bed affecting eg. VAM or micro-elements could have caused an initial stress to the crop which compensated for this at a later stage. However, it should be pointed out that only the RWT treatment reacted in a manner, similar to the compensation effect while the 2m beds and the RWT treatment had a similar history.

Root sampling in the various wheel tracks, indicated a significant higher amount of root mass in the raised wheel track compared to the recessed wheel tracks.

Soil Deformation

The effect of wheel track geometry on the soil deformation was assessed with the pin displacement method (Bakker and Davis, 1995). Space constrains do not allow a full discussion of the method but in short a soil pit is dug perpendicular to the direction of travel. Pins are placed in a grid pattern in both longitudinal walls of the pit. After back filling, a vehicle is driven over the soil pit and displaces the pins. After re-excavating the soil pit, the position of the pins is determined. The deformation of the grid pattern is then used to calculated changes in bulk density. Fig. 4 and fig 5, displaced grid points and changes in bulk density respectively, illustrate some of the results of this technique.

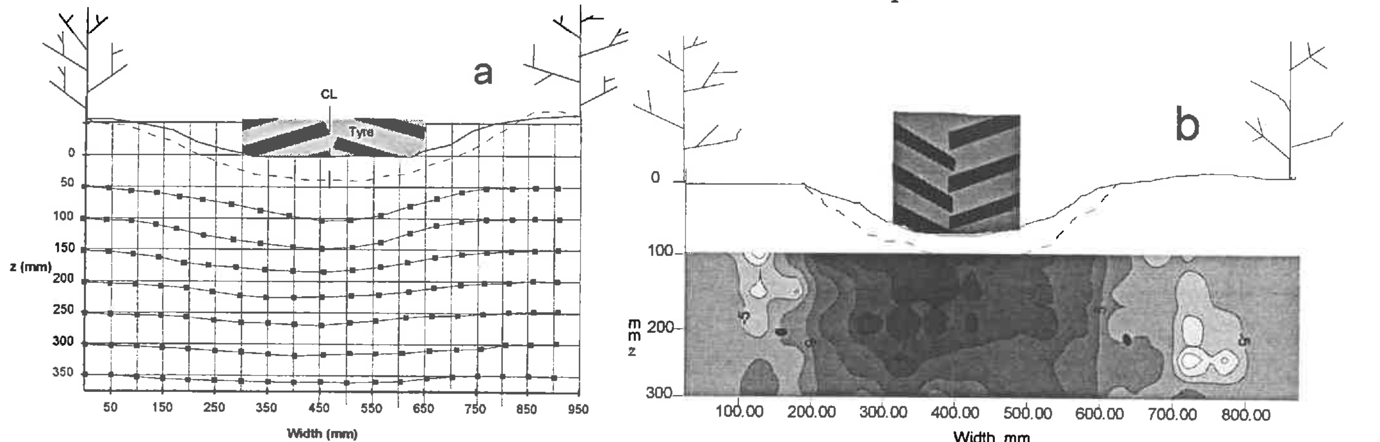

Figure 4 (a) Example of a displaced grid of pins and (b) changes in bulk density, calculated from the displaced pins.

The displacements of the pins can be separated into horizontal and vertical displacements. For every depth these displacements in both directions can be added up. Little difference in vertical displacement between the raised and the recessed wheel tracks was found but the sum of the horizontal displacements in the RWT treatment was significantly less than the recessed wheel tracks. This was contributed to the different shape of the wheel tracks. In recessed furrows, the tyres are more likely to run slightly on the shoulders of the beds which increases the horizontal displacements compared to the reasonable level surface of the RWT.

McGarry and Daniells (1987) used shrinkage curves of natural aggregates as an indicator for the soil structure. On regular occasions, four clods were collected from the wheel tracks and the adjacent hills. A 'Two-Line' model was fitted through the data and the several parameters of the model were calculated for the various data sets. From the statistical analysis of the parameters it was found that after one year of operation the RWT's had a better soil structure than the recessed wheel tracks.

Season '93-'94

This season was severely affected by lack of rainfall and limited irrigation water allocation. During this season, rainfall simulator tests were carried out, crop development observation and soil structure determination using resin impregnated blocks of soil.

Rain fall simulator tests.

These tests were carried out with the QDPI (Dalby) simulator covering an area of $2m^2$ during two different stages: a bare soil, just prior to sowing and in January (1994) when the canopy of crop was nearly closed. On neither of the occasions was there any difference between the timing of initial run off or the total amount of run off. It is often attributed to 2m bed system (Lucy, 1992) that short sharp storms are better utilised (ie. less run off), this was not confirmed during the simulator tests. The bare soil slaked rapidly, creating an impermeable surface which led to significant run off regardless the internal soil structure. On the second occasion the field had dried out substantially and large cracks appeared at the surface which captured any run off. Interestingly, 24 hours after the second test was carried out , a storm of similar intensity ($100mm.hr^{-1}$) fell on the experimental area without generating any run off in the treatments thus confirming the results of the second test.

Crop Development, Yield and Root Mass

The development of the crop was severely affected by the lack of soil moisture with no significant differences between the treatments. The RWT treatment was again behind in number of squares but remained behind in number of open bolls per metre. Internode length was also shorter for the RWT treatment. The crop developed fastest in the 1m treatment. This was reflected in the yield of 2.10, 1.86 and 2.00 $ba.ha^{-1}$ for 1m, 2m and RWT treatment respectively. Compared to the yield of the previous season this was extremely low.

Root mass was sampled in the wheel tracks and the inter-row space (non-wheel track) but unlike the previous season no significant difference was found between treatments nor positions.

Soil Structure Assessment

One large block of soil (90 x 20 x 40 cm: width x thickness x height respectively), which included a part of the wheel track, the entire width of the hill and a part of the non-wheel track was sampled in every treatment and impregnated with epoxy resin, mixed with a fluorescent dye. The blocks were positioned on the side and the surface leveled using a router, equipped with a diamond plated grinding bit. This was repeatedly done with increments of 2.5 mm. The exposed surfaces were illuminated with UV light and the image of fluorescent voids and cracks captured on slide. The slides were digitised, producing a binary image of the soil structure. Every image was partitioned into three sections, the wheel track, the hill and the non-wheel track. See Fig. 5 for an example of a cross section of the 2m bed.

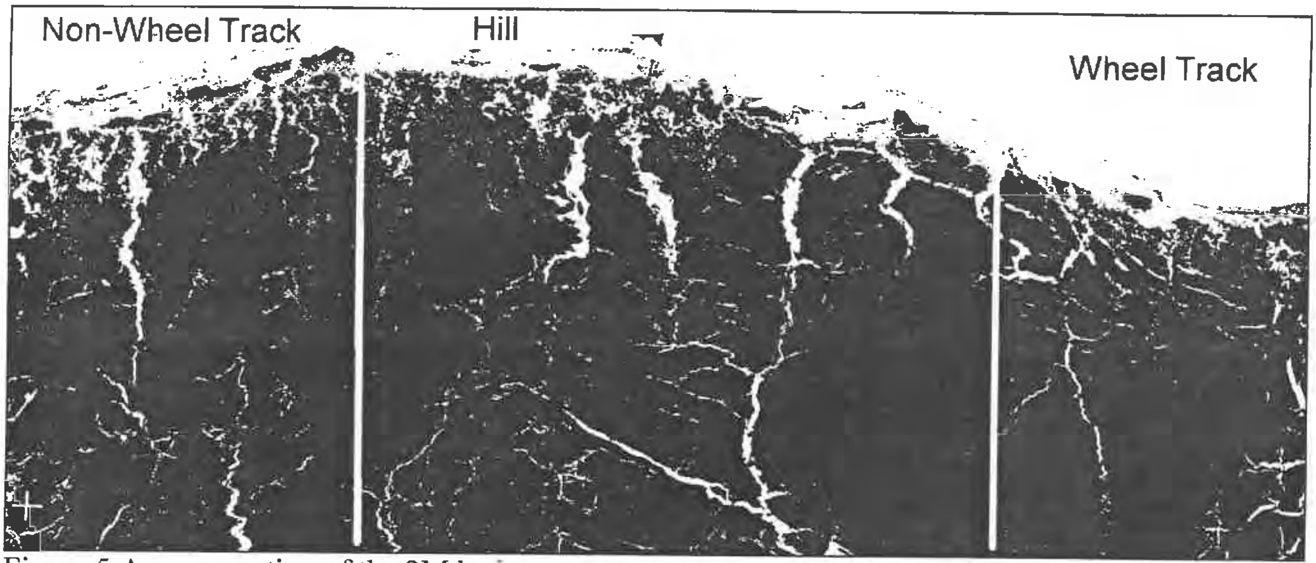

Figure 5 A cross section of the 2M bed

A program, STRUCTURA, (Moran and McBratney, 1991) which was modified to accept sloping surfaces was used to calculate several soil structural attributes for all three sections in every image. Statistical analysis of the attributes and visual observations revealed that the RWT had a significant poorer soil structure in the top 15 cm of the soil profile in the hill and the wheel track, compared to the other treatments. The hill of the RWT however had a higher moisture content which might explain some of the differences. The wheel tracks had a similar moisture content.

Conclusions

From the above it can be concluded that the raised wheel tracks (RWT) did offer some advantages in terms of reduced moisture content immediately after irrigation, better soil deformation patterns (less horizontal deformation) and crop performance (first season only). It was surprising that in the dry second season neither the 2m nor the RWT treatment seemed to have any advantage above the 1m bed, despite the larger soil mass available for root growth and moisture storage. The RWT's did have a better soil structure according to the clod shrinkage data at the beginning of the second season but this had disappeared and the soil structure was slightly more deteriorated compared to the recessed wheel tracks at the end of that season, according to observations on resin impregnated blocks.

The tractor operator did not experience problems travelling over the raised wheel tracks but was not particularly impressed since more concentration was needed to stay on track. An tractor guidance system would be beneficial under such conditions. In summary, differences between treatments were observed and were translated into yield differences but they were not sufficient and consistent enough for the grower to change his practices which were based on 1m beds with recessed wheel tracks.

Acknowledgment

The authors are thankful for the contribution made by mr. H. Bligh for making land, machinery and man power available for this experiment and the cooperation received from staff from the QDPI Pittsworth and Dalby. D. M. Bakker was supported by a postgraduate scholarship from the CRDC.

References

Bakker, D.M. and R. Davis, 1995. Soil deformation in a Vertisol under controlled field traffic. Australian Journal of Soil Research in press.

Bakker, D.M., Harris, H., 1992, "Design and implementation of laneways in irrigated cotton farming ", *Proceeding conference on engineering in agriculture*., Aubury, Australia, 1992.

Burt, E. C., J. H. Taylor, L. G. Wells. 1986. Traction characteristics of prepared traffic laneways. *Transactions of the American Society of Agricultural Engineers 29(2)*, 393-401

Darcey, C. L., L. H. Wilkes and K. E. Watkins. 1984. Elevated lane for controlled wheel traffic. *American Society of Agricultural Engineers Paper No.* 84-1539, St. Joseph, MI 49085

Lucy, M. 1993. Permanent wide beds- a controlled traffic system for irrigated vertisols. Information series QI93051, Queensland Department of Primary Industries.

McGarry, D. and I.G. Daniells. 1987 Shrinkage Curve Indices to Quantify Cultivation Effects on Soil Structure of a Vertisol", *Soil Science. Societyof America Journal*, 1987, Vol. 51, No. 6, pp. 1575-1580

Monroe, G. E. and J. H. Taylor. 1989. Traffic lanes for controlled-traffic cropping systems. *Journal of Agricultural Engineering Research* 44: 23-31

Moran, C. J. and A. B. McBratney. 1991. Structura: A C program for estimating attributes of two-phase, heterogeneous structures digitized from planar specimens. *Computers & Geosciences* 17(3): 335-350

Spoor,G. S. M. Miller and H. T. Breay. 1988. Timeliness and machine performance benefits from controlled traffic systems in sugar beet. *Prodeedings 11th International ISTRO Conference on tillage and traffic in crop production. 11-15 July, 1988, Edinburgh, Scotland.* Vol 1: 317-322

Tullberg, J. N. and Lahey, G. V. 1990. Controlled traffic cropping. *Summary report NERDDC.*

Thomson, H. and P. Cull. 1989. Wheel track compaction,.the effects on plant growth and yiled of cotton. *The Australian Cottongrower* 10(4): 50-53

DEVELOPMENT OF COMMERCIAL MACHINERY AND THE FARM

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We formed the company Multi Farming Systems to market our agricultural products to fulfil the needs of the Australian farmer well into the 21st century. Our slogan is 'Setting the standard for long term, cost effective, viable farming systems and probably, the heart of system is the equipment that we can make to suit individual farmer's needs into tramline permanent bed and roadway situations. We make 11 different agricultural, high performance, low maintenance, trouble free machines.

Just last January, we installed a dealer network throughout Australia, which is now giving us Australia wide exposure. We find out what the farmer needs for his individual property and design machinery to suit these needs. We are able to advise on just what is possible. One of a few options that are available is Controlled Traffic, Banana Farming Company style.

The concept of controlled traffic can take on many forms. We have the situation, in Australia, where the furrow irrigation farmers drive down the same set of wheel tracks all the time. That is a form of controlled traffic if they don't disc offset the whole field to eradicate cotton or other crop roots that happen to be there. If this is done, then it is normal cultivation farming.

Cotton farmers are leading the way with the largest number of farmers using the same furrows year after year. This practice can be called controlled traffic. If they are working with all 8 metre equipment, everything matches.

For controlled traffic in broadacre cereal crops, farmers need to change from intensive farming to no-till farming. For this, the farmer only needs a boomspray and a no-till planter both the same width. It is this concept that has had the industry exploring the possibility of gantry modules etc. to keep everything on the same wheel tracks.

The gantry concept, we believe, will not be the way to go in its present presentation. A multiple gantry concept has very little traction capacity for load requirements of ground engaging equipment. We had decided to use the Multiplanter frame concept to be the host frame for controlled traffic application. The farmer pulls the machine, whether it be 8 metres or 32 metres wide with the tractor size of his choice. We are not discarding the possibility that the farmer may want to self propel these planter frames for some jobs, such as carrying cotton picking or stripping heads on them, or carrying cotton mulchers under their frames.

At present, we make and use these controlled traffic Multiplanter frames at whatever width required and pull them with a tractor and precision steer them to follow accurately their tracks constantly.

The run down below of what we have done on Honey B Ranch from being a raw scrub property right through to farming tramline no-till to future irrigation is to show you how, when pressures come on farmers, changes take place to survive and improve.

Below is a quick explanation on how I started on the property we call Honey B Ranch. This property is the base for both businesses that have complemented each other over the years.

In 1959, I drew my property as a brigalow scrub block surveyed off at 830 hectares. This block is nearly a square with the Police Camp Creek being the South Eastern boundary. The land fall is in all four directions. We have no run off from neighbours. The crest of the property has only about 1 metre fall over a kilometre of distance, running lengthwise and parallel to the north western boundary.. One third of the property was whipstick brigalow, melon hole country - very clayey soil.

The Government of the day put 13 blocks here up for selection to be developed as dairy farms. Thus, we had a fight on our hands when we applied for a loan from the QIDC (The Agricultural Bank) to pull the scrub and develop the whole property into a broadacre grain farm. Within 5 years, we had the whole property ploughed up and growing wheat, barley, sorghum and dryland cotton.

We farmed our land 6 to 7 times, including planting each year. We had some good crops, but a few of them failed to make it from the lack of rain to put down the secondary roots of cereal crops.

We noticed the farmers on the Darling Downs starting to build ring tanks (or water storages) to catch the overland water flows and to pump out of rivers. This gave us the idea to do something for ourselves. The situation of our Police Camp Creek is such that, if we construct an earth dam wall 8.5 metres high and 1,260 metres long using 400,000 cubic metres of soil, we could hold approximately 2,200 megalitres of water.

We estimated that, as we went through the motions of trying to grow a crop each year by working the soil 6 times, buying seed then planting it and some years harvesting nothing or 2 bags per acre, then the cost of watering once to enable the surface roots to reach the good subsoil moisture and harvest 10 bags per acre, wasn't a bad idea. Then, if we watered again at flowering time to boost the yield to 20 bags per acre, that was all extra income from the applied water.

So, we figured that this water storage was the way to go. Diesel was about 19 cents per gallon (4.3 cents per litre) at the time. By the time the Water Commission had granted our licences to build an earth dam, and 4 pump site licences etc., 4 years had elapsed and Malcolm Fraser had imposed World Parity Fuel Pricing. Then we had interest rates that eventually, for us, increased to 22.8%. A further blow was the crash of world grain prices.

All the above hassles seemed to block us from progressing and we were worried how to keep farming. With the high use of fuel, the cost of labour and the soil being constantly bombarded by farm machinery of all descriptions (tynes, discs etc.) we started to rethink everything.

We had noticed the condition of the soil in the virgin scrub areas. Covered as it was with twigs, old leaves and trash, it seemed to stay soft and fluffy and to absorb the rain well. We decided to grow our crops the same way.

By this time, we were building farm machinery commercially for all over Australia. The no-till, precision depth type planters that we had designed and were selling over a wide area, proved to be the right machine to be the host frame for what we now call tramline farming.

That season, we were spraying dryland, skip 2 cotton rows, planted in 8 metre increments. We were spraying three and a half 8 metre widths with our approx. 28m boom spray. The next season, we built a new version of boom spray that would spray an even four 8 metre swathes of cotton. While doing this, we noted varying row widths on the guess rows and thought it would be a good idea to build a Multiplanter 32 metres wide, seeing that we only have to plant 16 rows on skip 2 cotton. So, we made the planter and put rear steering on it, so, not only could we plant with it, but we could use the modular frame to shield spray the rows of cotton and also we could carry water tanks on the ends and pull paddle dyke chains etc. Our chemical costs were halved with this method.

Today, our farm is premarked out to 84 tramlines running parallel to the longest (North Western) boundary. It takes 4 x 10 hour days to cover the property using 264 gallons (1200 litres) of distillate, travelling at 4.3 mph. Our tractor is 275 hp throttled back.

Since we started tramline farming, we now call our farming operation opportunity cropping. We plant cotton in November to January if there is enough moisture to get a good strike. Then, if it rains, the crops grows and we pick it. If there is good rain, we can plant barley into the standing cotton bushes, then slash the bushes. One year, we had the barley 6 inches high while we were still picking cotton. Crops can overlap sometimes.

Up to this point, we felt we had progressed quite well with probably 60 to 75% savings in fuel. There was one planting per crop twice per year, sprayed Sprayseed @ 1 litre per hectare(using rainwater only) to kill weeds before planting, shield sprayed the cotton in 4 days with Sprayseed or Roundup etc., then sprayed the barley with 2, 4 D to control turnip and cotton regrowth.

These last 4 years of drought at Banana have made us reconsider the concept of irrigation from the creek storage mentioned earlier. We are trying to get started immediately with the earth works. We'll need to flood for now with layflat hose a right angles to our tramlines down the slopes both sides of the crest of the farm where the main water channel will be.

We have observed the improvement to trickle irrigation buried 15" or 1/2 metre under the soil. We envisage burying all our huge water mains and the sub mains at right angles to the existing tramlines. Then the trickle hoses will go in along the tramline. We will delete the trickle hoses under the tractor tracks of the tramline, so that we have hard, dry and weed free roadways.

That will then place the property at its best long term condition for the future, producing profitable crops leaving the trash on top. As this property is a plateau, we collect all the runoff - any silt that moves will always end up in our storage dam. Over the years ahead, we'll be able to cart the silt back and put it on the bad clay areas that have been exposed when levelling the melon hole areas.

Summary of the Above

No till makes it easier to tramline, looks after the soil, cuts fuel, machinery etc. costs and makes it possible for wide widths to be achieved per horsepower requirement, thus using less wheel tracks (tramlines).

With the trickle irrigation, it eliminates furrowing up, and allows all the trash to stand on the field, while still being able to water extremely efficiently and with nearly 50% saving in water use over flood watering.

WHY HI-TECH NO-TILLAGE IS INEVITABLE

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INTRODUCTION

The inevitability of hi-technology no-tillage arises from the uncertainty which still surrounds crop performance by the technique using existing equipment, together with the increasing (an unwelcome) trend towards complexity of drill and planter designs. While increasing numbers of farmers world-wide are reporting good and even outstanding results, these successes hide the failures which are still occurring. To be a sustainable technique the rate of failure for no-tillage farmers who can hold their hands on their hearts and say they have more predictable and successful emergence with no-tillage than they used to have with tillage, is still normal.

And yet that is exactly what no-tillage must do to be of short term benefit as well as to achieve its much-publicised benefits in the medium to longer terms. In the 15 year research program which underpinned the development of the Cross Slot™ no-tillage technologies in New Zealand, and to the consternation of early adopters, scientists insisted that they were more interested in seeing failed no-tillage fields than successes which the early-adopters were justifiably proud of. The scientists felt that only if they could identify why failures occurred and correct the underlying problem(s) could they truly claim to fully understand the requirements and limitations of no-tillage and therefore begin to design equipment which was anywhere near fail-safe.

Even at that time the concluded that hi-technology no-tillage would be necessary to minimise the risk factors from the technique.

PRESENT TRENDS

In North and South America, Australia, New Zealand and other temperate climates where residue-retention is synonymous with no-tillage (such is not the case in some countries of the world where crop residues are collected as a source of fuel) the most pressing drill and planter technological problems are condition-specific. The most common of these problems however, are unreliable germination and emergence, the need for separate fertiliser placement, avoiding residue hairpinning (or tucking), "instant" adaptability to a wide range of residues and soil conditions, inconsistent seeding depth, low speeds of operation and (at least in USA) the perceived difficulty of handling sod in anticipation of this being an option for expired CRP land.

None of these problems are new but most of the answers to them seem to have involved ever-increasing complexity of machine design. For example a recent survey of 12 sophisticated designs of no-tillage openers available in North and South America, showed that on average each opener assembly comprised 9 separate soil-engaging components for each row drilled or planted (range, 7-12) with up to 14 different adjustments on each of these to accommodate varying soil and residue conditions (C J Baker, unpublished data, 1994).

By contrast the Cross Slot™ hi-tech no-tillage opener has just 5 soil-engaging components per row and only 3 adjustments are necessary, one of which is controlled from the tractor cab anyway.

IN WHAT WAYS DOES HI-TECHNOLOGY CONTRIBUTE TO BETTER NO-TILLAGE?

No-tillage ins not a complex undertaking but it requires openers with incredible adaptability because, by definition, operators must forego the opportunity to manipulate the soil conditions through incremental tillage to optimise them for the critical operation of drilling or planting. The notion that there will always be an element of "horses for courses" amongst no-tillage openers and machines is simply not tenable. What use is it to a farmer if one machine suits his / her soil when it is dry and covered with cotton residue while another machine is best when it is wet and covered with wheat? Or worse, how does an operator cope with the necessity to stop and adjust the machine when passing from one soil type to another within the same field, or cope with the effects of an over-night shower or even in some cases dew? And what about the possibility of drilling into sod? In the "old days" almost all of these variables would have been nullified by tillage and burial or burning of residues, but not so under no-tillage.

In some cases the problem is self-perpetuating and cumulative. For example in many dry and / or low-organic matter soils no-tillage will increase yield levels, thus increasing the level of residue to be handled for the next crop which, if utilized correctly, will further optimise the conditions for even greater yield increases, and so on. Eventually it all levels off at a new sustainable yield level but in the process no-tillage will have made increasingly sophisticated demands on the machinery which was probably not anticipated at the outset.

In his keynote address to the 1994 World Congress of Soil Science, Nobel Prize winner Norman Borlaug reported the estimated current and projected world demand and yield requirements for cereals to be as follows (Table 1. Borlaug, 1994).

Table 1. Current and Projected World Cereal Production, Demand and Yield Requirements

	Current Production	Projected Demand		Yield		
				Actual	Required	
	1990	2000	2025	1990	2000	2025
	million tonnes	million tonnes		tonnes / hectare		
Wheat	600	740	1,200	2.2	2.6	4.0
Rice	520	640	1,030	2.2	2.9	4.8
Maize	480	620	1,070	3.3	3.7	5.3
Barley	180	220	350	2.2	2.4	3.7
Sorghum / millet	85	110	180	1.3	1.8	2.4
All Cereals	**1,970**	**2,450**	**3,970**	**2.2**	**2.6**	**4.2**

On this basis world cereal production alone (which accounts for 69% of world food supply) will need to be doubled by the year 2025 (and along the way, raised by 24% by the year 2000). More importantly however, to achieve this, taking account of the limits to creating new arable land, Borlaug estimated that grain yields will need to increase by 80% over the same time span.

Until now yield increases have come largely from increased fertilizer and pesticide use and genetic improvement to the species grown. *The challenge now is for no-tillage to contribute to the future increases.* But this is only going to happen if no-tillage is practised at the highest possible technology levels.

It has always seemed a nonsense that although the practice of no-tillage arms farmers with the greatest soil protection and rebuilding tool nature has ever devised in the form of surface residues, the majority of machinery designers have been content (or "forced") to treat this residue differently in the row zone than for the field as a whole.

In the row-zone no-tillage openers variously chop it up, bury it, push it into the slot, or sweep it aside for the mechanical expediency of solving a residue-handling problem (Baker and Choudhary, 1988). From this frustration the word "trash" developed indicating that surface residues were an unwanted commodity. But clear evidence has existed for many years that not only are surface residues the field's greatest ally but they are also the sown seed's greatest ally in controlling the germination and emergence micro-environment within the sown slot (Baker, 1976; Baker & Afzal, 1986; Baker & Mai, 1986; Baker *et al*, 1988; Choudhary & Baker, 1981; Lynch *et al*, 1992). No other resource, either man-made or provided by nature, comes anywhere near being as important and influential on germination and emergence as the micro-management of residue over, in or close to the sown rows.

This is where hi-technology equipment has its greatest potential - to eliminate the unwanted nature of trash and instead utilize its undoubted potential in all facets of crop agronomy - and in so doing, to raise the level of reliability of yields, and lower the risks commonly associated with no-tillage.

WHAT IS HI-TECHNOLOGY EQUIPMENT ANYWAY?

Since not all no-tillage drills or planters which are expensive or complicated can be considered hi-tech, it is important to establish the criteria which distinguish hi-tech from other drills and planters.

As a result of the 20 years of research in New Zealand and USA into the causes of no-tillage failures which was referred to above, a detailed list of requirements can be drawn up, most of which have the objective of providing optimal conditions for seeds, seedlings and growing plants regardless of the intervening weather or soil conditions or how difficult the consequential engineering designs might be. All of the criteria have arisen from specific scientific studies and / or extensive field experience, and can be shown to have had a measurable and positive biological effect. Most of these effects have been published in the international scientific literature and are described in detail in a forthcoming book by the author and colleagues (Baker *et al*, 1995).

1. The openers of a hi-tech drill should create seed slots which protect the seed (and just as importantly, the sub-surface seedlings) from desiccation (in dry soils) low oxygen status (in wet soils) and birds and other pests (in all soils). Realistically these demands can only be met by inverted-T shaped slots. This is the only slot shape developed especially for no-tillage (Baker, 1976) and has been shown to promote significantly more seedling emergence in soils which are otherwise hostile to seeds, seedlings or plants, than any other known no-tillage slot shape.

2. In creating seed slots the openers should avoid mixing and inverting the soil and residue in the slot zone. This is partly to avoid stimulating weed seed germination but most importantly a properly layered cover traps moisture vapour in the slot zone. The openers should be capable of re-layering loose or standing residue on top of loose soil to cover the slot, or fold back more structured (and even damp and "plastic") soils and sod or stubble layers, or re-layer a dry soil mulch on top of more damp soil beneath it where no residue exists.

3. The drill and openers must handle without blockage, any form of surface residue, even when the openers are configured in narrow (6 inch) rows. The range of residues should include dry and wet lying straw on hard or soft soils, fibrous and woody stalks as well as crisp brittle material, and at concentrations of up to 10 tons per acre.

4. The openers must either avoid hairpinning (tucking) the residue into the slot or they must separate the seed from contact with such hairpinned residue.

5. The openers must not compact or smear the slot in such a way as to restrict root growth. If smearing is unavoidable (as is often the case) the opener must create the slot in such a way that the internal surfaces of the slot do not dry to form an internal crust.

6. The slot shape should avoid the creation of near-vertical walls in the root zone which restrict root exploration outside of the slot especially when such walls are also smeared or locally compacted.

7. Each opener must close the slot as it travels rather than rely on slot closure being achieved by a separate machine and / or operation.

8. Each opener must effectively separate the seed from the fertilizer in the slot so that the two do not contact one another to avoid toxicity effects but are so placed as to maximise utilization of the nutrients by the growing plant. Horizontal, vertical and diagonal separation are all acceptable but greater distances are required for vertical separation than for horizontal separation.

9. Each opener must be capable of faithfully following ground surface variations as large as 500 mm (20 inches) and to sow seed at a consistent depth throughout this range of travel.

10. In order to assist the openers in maintaining a consistent depth the drill design must be capable of reducing the bounce of the whole machine to a minimum as it travels at speed over uneven terrain.

11. The machine must be capable of storing, metering and delivering seed, fertilizer and pesticides to the openers in the manner which is most appropriate for each crop.

12. The machine must be capable of performing all of these functions without compromise at speeds up to 16 kph (10 mph).

13. General maintenance and especially the replacement of soil-engaging components should be rapid and inexpensive.

14. As many as possible of the functions of the machine and its openers should be self-adjusting and unaffected by wear and changing soil and residue conditions. There should be a minimum of adjustments necessary when changing from one soil or residue conditions to another.

15. The machine should be robust and durable with a design life of at least 10,000 hours.

SUMMARY AND CONCLUSIONS

There has never been a stronger case hi-technology no-tillage machines. The fact that they were not available from the outset of this still-relatively-new farm practice 30 years ago, is understandable since it has taken at least 15 years to establish what those criteria should be let alone design and solve all of the engineering problems too. It is also commendable that the no-tillage industry has expanded without the benefit of hi-technology. In doing so however, it has yet to convince the majority of drill and planter purchasers in any country that no-tillage is truly cost-effective, sustainable and "fail-safe".

The inevitability of hi-tech machines was signalled early in the evolution of no-tillage when the no-tillage industry embraced the then more expensive but broader-spectrum (some would say higher-technology) herbicide glyphosate in preference to the more limited-spectrum but then cheaper herbicide paraquat. Machinery adoption will surely follow the same trend as herbicide adoption on a cost-benefit basis since in no-tillage herbicides play a role of similar importance to drills and planters.

Until recently no readily available commercial machine had fulfilled all of the criteria for hi-technology. One, at least (the Cross Slot™) is "in the pipeline". It is time now to move on the next phase in development of international, sustainable and "fail-safe" no-tillage practices and machines.

REFERENCES

Baker, C.J. 1976. Experiments Relating to the Techniques of Direct Drilling of Seeds into Untilled Dead Turf, Journal of Agricultural Engineering Research, 21(2): 133-145.

Baker, C.J. and Afzal, C.M. 1986. Dry Fertilizer Placement in Conservation Tillage: Seed Damage in Direct Drilling. Soil and Tillage Research, 7: 241-250.

Baker, C.J. and Mai, T.V. 1986. Physical Effects of Direct Drilling Equipment on Undisturbed Soils: V Groove Compaction and Seedling Root Development. New Zealand Journal of Agricultural Research, 25: 51-60.

Baker, C.J., Chaudhry, A.D. and Springett, J.A. 1988. Barley Seedling Establishment by Direct Drilling in a Wet Soil. A Comparison of Six Sowing Techniques. Soil and Tillage Research, 11: 167-181.

Baker, C.J. and Choudhary, M.A. 1988. Seed Placement and Micro-Management of Residues in Dryland No-Till. Proceedings International Conference on Dryland Farming, Amarillo, Texas, USA, pp 544-546.

Baker, C.J. 1994. The Case for High-Technology No-Tillage. III Congreso Nacional de Siembra Directa. Villa Giardino, Argentina, pp 145-159.

Baker, C.J., Saxton, K.E. and Ritchie, W.R. 1995. No-Tillage Seeding: Science and Practice (CAB International - in press).

Baker, C.J. 1995. Is Hi-Tech No-Tillage Inevitable? Proceedings Third National No-Tillage Conference, Indianapolis, IN.

Borlaug, N.E. 1994. Feeding a Human Population that Increasingly Crowds a Fragile Planet. Supplement to Transactions 15th World Congress of Soil Science, Acapulco, Mexico.

Choudhary, M.A. and Baker, C.J. 1981. Physical effects of Direct Drilling Equipment on Undisturbed Soils: III Wheat Seedling Performance and In-Groove Micro-Environment in a Dry Soil. New Zealand Journal of Agricultural Research, 24:189-195.

Lynch, J.M., Ellis, F.B., Harper, S.H.T. and Christian, D.G. 1980. The Effects of Straw on the Establishment and Growth of Winter Cereals. Agricultural Research Council Report - Agriculture and the Environment, 5: 321-328.

National Controlled Traffic conference, Rockhampton, Queensland - September, 1995.

Equipment industry implications of Controlled Traffic.

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Summary.

Adoption of Controlled Traffic in Australia has major implications for its equipment suppliers, especially in a context where the major field equipment items are currently imported, and the local industry, along with its customers, has been suffering financial stress.

Effective adoption of Controlled Traffic is likely to require two quite separate phases ;

- attached local equipment which allows use of imported major field equipment,
- a possible local development of an integral Australian sourced 'whole system'.

Pressure for a widespread adoption of Controlled Traffic in Australia, in an environment which allows the possibility of a significant re-structuring of the Australia agricultural equipment industry, might well see the former proving to be a major catalyst of the latter.

Controlled Traffic in Australia - and tractors as we have come to know them.

Some in Australia's equipment industry have a feeling that the evolutionary process where 'tractors' were simply inserted as a draft tool in lieu of their animate predecessors, and then grew larger, has now evolved to an outcome which anyway makes little engineering sense - and Controlled Traffic seems likely to accelerate the rate of in-field demonstration of that.

Australian agriculture has unique requirements in several respect, one of these being the need to allow the adoption of high productivity and sustainable practices on Australian farms sizes that range from European in scale, to North American, and then to (broad-acre) Australian.

Many of the most viable and productive Australian broad-acre farmers need to manage several thousands of hectares, and in an environment which dictates very precise timeliness,. That scale of farming has caused Australian adoption of large, heavy, and powerful tractors - with wide trailed equipment - to meet the broad-acre need.

Controlled Traffic doesn't change the needs, but its reduced power requirement does perhaps provide a choice between even wider widths with current power, or of reduced scale tractors.

Controlled Traffic the hard way.

Equipment manufacturers will still need to provide machines with widths up to at least 20m.

If we are to allow the maximum amount of flexibility in terms of total width of the various machines to be used in the field, and hence of which Controlled Traffic traC.s are to be used ;

- *we need a uniform traC. spacing across all traC.'s.*

If we are to provide equipment up to a width of 20m in width, and we don't want to make that equipment any more complicated than having it consist of FIVE sections ;

- *we need the traC. spacing to be not less than 4m.*

Most of our current large (generally articulated) tractors can physically accept single wheels at a 4m spacing - but the question of engineering integrity at that spacing remains.

Equipment industry implications of Controlled Traffic.

Modification of imported equipment.

It is hoped that the established suppliers of major field capital items will make available tractors and harvesting equipment which can be more flexible in relation to the wheel traC. spacings at which they can be applied. Our local attached equipment suppliers likewise.

During the early introductory period, it is likely that the tradition of Australia adaptation will again be required to modify its equipment to meet the need ;

- tractor wheel traC.'s, with single wheels, perhaps at a 4m spacing,
- tractor axle assemblies perhaps modified to maintain their structural integrity.

It seems likely that an Australian trailed equipment manufacturer wishing to promoted the broad-acre adoption of Controlled Traffic will need to offer some such 'tractor conversion' kit as a part of a total equipment package.

Trailed Controlled Traffic (Australian) equipment.

Apart from the obvious requirement of providing wheel locations which can be matched with a farmer's chosen traC. spacing, suitable equipment will need to offer ;

- an ability to also operate in a conventional 'full tillage' mode during transition,
- ability to ensure precision tracking in the Controlled Traffic traC.'s,
- an ability included to maintain the desired form and depth of traC.s, by reference to the crop producing beds between those traC.'s,
- an effective means of mechanical weed control in those traC.'s,
- and probably an intelligent implement wheel steering system which can maintain accurate tracking around field curves in beds, as well as on hill-side slopes,
- and perhaps, even wider equipment, as farmers seek to exploit the reduced power consumption characteristic in conjunction with existing high H.P. tractors.

While all of the above factors are additional complication by comparison with current practice alternatives, a range of Controlled Traffic trailed equipment will also be simplified ;

- less expensive and less intrusive wheel equipment will be required as a result of the reduced need to offer 'high flotation',
- depth control will be improved by operation of those wheels on firm traC.'s,
- special equipment which is presently required to try to compensate where ground engaging tools follow tractor wheel tracks will no longer be necessary,
- more equipment can be integrated into a single machine as a result of the improved wheel load bearing characteristic of the traC.'s,
- the range of required alternative implement sizes may be reduced by evolution of some agreed standards of Controlled Traffic traC. spacing,
- today's wide range of alternative 'digging ability' equipment should be reduced by elimination of the need to be able to remove prior soil compaction effects,
- the need for, and cost of, high levels of 'trash handling', as it is now measured, may be reduced by the inherent 'precision location' feature of Controlled Traffic - which can allow precision inter-row placement of consecutive crop plantings.

The new equipment required by the above will severely tax an agricultural equipment industry which has suffered a number of years of depressed market conditions, and which will find a need, alongside the above, for new conventional 'non Controlled Traffic' equipment.

Equipment industry implications of Controlled Traffic.

Achieving 'critical mass'.

As is common in the commercial world, the introductory phase of a cycle having *"no adoption, means no equipment, which means no adoption"* will be difficult to break.

Small scale research demonstrations of the benefits of Controlled Traffic are unlikely to create the necessary demand on their own. 'Farm scale' demonstrations, at the hands of leading and respected farmers are likely to be necessary. Some applications of this type have been placed with G.R.D.C. in the hope of accelerating the realisation of the evident benefits.

Alternatively perhaps, the more widely established recognition of the benefits of Controlled Traffic within Australia's cotton industry, in conjunction with an established willingness to invest in justified - even if costly - capital equipment, might be fruitful in assisting adoption.

Australia's financially healthy sugar industry, seeming also to provide potential to benefit from Controlled Traffic, should also provide some mutually beneficial opportunities.

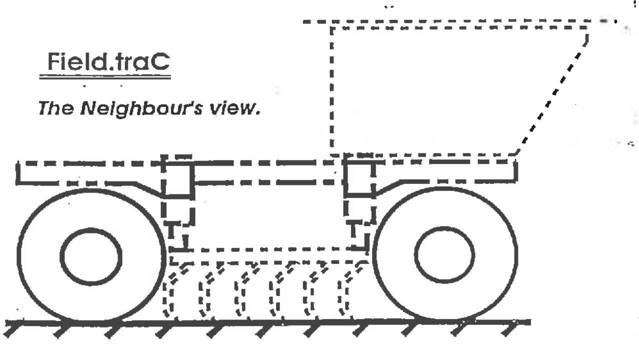
A logical Controlled Traffic equipment alternative.

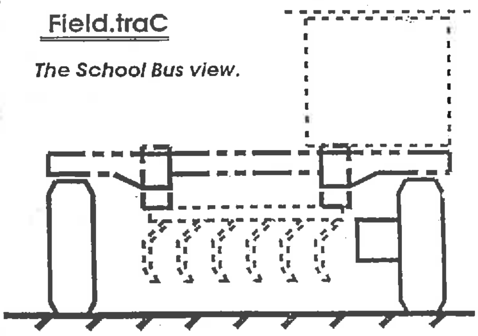
If it were accepted that today's state of evolution of a separated draft (net input) element (tractor) and draft consumer (implement) were illogical and inefficient anyway, and that Controlled Traffic will create a demand for a whole new generation of field equipment, it might seem logical to now completely review what would constitute logical equipment.

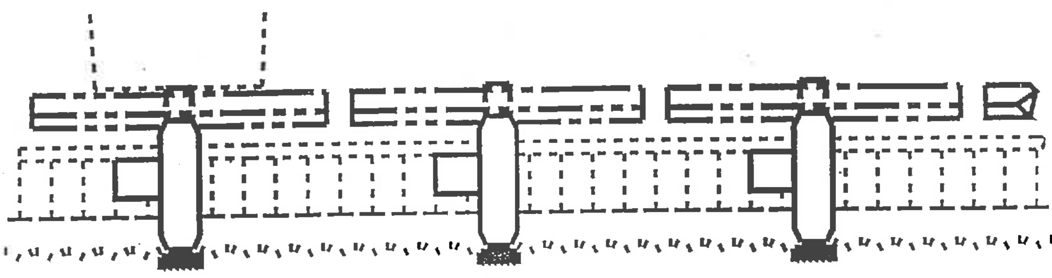
A debilitated condition within a key economic input element (agricultural equipment) of 'Australian Agriculture Inc.' might support an argument for such a review. Reviews of the factors that sustain 'natural advantage' industries in the economies of the world highlight the importance of having multiple, healthy, competitive, and local sources of all of major inputs.

Even if Controlled Traffic were to be widely adopted in the agricultural sectors of those Northern Hemisphere countries that now supply our major capital equipment items, the outcome equipment is unlikely to be closely matched to the wide range of different conditions that are the agricultural sector of Australia - but, only 3% of the world's equipment market.

Illustrations below are included as an example of one kind of new concept that might be an outcome of such a review seeking a logical new Controlled Traffic equipment approach.







Equipment industry implications of Controlled Traffic.

A logical new configuration might be called a Modular Agricultural Gantry, where ;

- the number of modules can be chosen and adjusted to match the requirements of any farm size of this year or next - or contractor's program,
- with an integral power source being provided within each module,
- with the width of each module being readily offered as a variable to suit the diverse farming conditions across Australia,
- with the cost of each of the under-carriage modules being around half of the equivalent trailed implement of today's technology,
- with the under-carriage nature of the modules avoiding most of the problems listed previously in relation to the adoption of Controlled Traffic with trailed equipment,
- with the same prime-mover element being employed for all field operations - tillage, seeding, spraying, and harvesting,
  - automatically ensuring reproducible location of equipment for each task,
  - providing equally high rates of productivity for the harvesting operation,
- with intelligent control systems that can allow operation of modules at 'multiples of the basic spacing' - to enhance productivity, for example for spraying,
  - with the inherent high load bearing capability of the concept allowing, for example, the use of more effective, heavier, high productivity sprayers,
  - and that ability also allowing a possibility of carrying out more on-board functions on the machine - for example, compacted cotton shipping units,
- with the same basic configuration being applicable in a wide range of Australian crops - broad-acre grain, cotton, sugar, viticulture, etc. - providing a potential breadth of market that can justify Australian development of such a product.

While Controlled Traffic is not a wholly essential component in determining the logic of such an equipment development, it does seem highly fortuitous that the advent of Controlled Traffic should coincide with several others factors that indicate a fundamental review of our Australian agricultural equipment inventory ;

- little R. & D. for a decade which means that many of the products being offered from Australia suppliers are less productive than they might be,
- similarly low levels of investment in manufacturing resources - the replacement of which would best be done in the context of a 'next generation' of products,
- an advanced age of the inventory of agricultural equipment on the farms of Australia, which will dictate replacement as economic conditions improve - obviously with that replacement being more effective if it occurs with a new generation of more productive equipment.

However, an Australia realisation of such a major new equipment development is a major R. & D. investment in the context of today's Australian equipment industry. That industry nevertheless recognises its key role in facilitating the realisation of the benefits of adoption of Controlled Traffic in Australian agriculture.

That same industry, in return, would wish to receive whatever support other sectors of 'Australian Agriculture Inc.' can provide in assisting that equipment realisation.

The Value Of Track-Type Tractors In Agriculture

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Abstract

Rubber belt track-type tractor features of pull capability, tractive efficiency, and less compaction resulting in greater crop yield are described. Using these features in a controlled traffic environment with wide tools results in significant yield increases and lower costs. Low pressure tire performance is compared to rubber belt track performance.

Keywords: Rubber belt track, compaction, yield, controlled traffic, low pressure tires

Introduction

Farming is changing significantly around the world. Budget pressures are causing governments to cut back or at least reconsider the amount of subsidy that is provided to their farmers. Farmers are now looking around the world for machinery and farming practices that will reduce costs while increasing productivity. Capital investment to reduce costs and increase productivity is becoming a necessity in agriculture as it is in most other businesses. Changing farming practices to control the amount of traffic in the fields is becoming a necessity. There are too many wheels, running too often with too narrow equipment.

In 1987, Caterpillar introduced the first model of the Challenger line of tractors with the Mobil-trac System rubber belt track. Many farmers immediately recognized that an investment in track-type tractors would increase their productivity and lower their costs. The purpose of this paper is to briefly present data from around the world to show the value of track-type tractors in farming applications.

Tractive Performance

Evans and Gove (1986) reported the results of extensive rubber belt track tractive performance tests. Fig. 1 shows pull ratio vs. slip in tilled soil, typical of agricultural type soils. (Pull ratio is the ratio of drawbar pull to machine weight.) This is a classic set of curves, duplicated by many researchers, which shows that a track machine will inherently pull a higher ratio of its weight, at much less slip, than will a wheel machine. If the soil condition is softer, the wheel performance decreases; if the soil condition is harder, the wheel performance increases until it is essentially equal to rubber track on concrete surfaces. An interesting feature of tracks is that they are less sensitive to soil conditions than wheels and maintain their high performance in a wide variety of conditions.

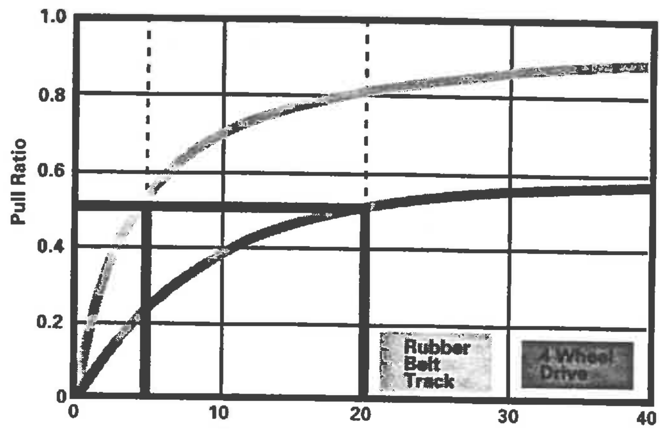


Fig. 1

Fig. 2 shows tractive efficiency vs. pull ratio. (Tractive efficiency is the percent of axle power delivered to the drawbar.) A track machine is significantly more efficient, at lower slip, over a very wide range of pull ratios, than the wheel machine. This results in several advantages to the farmer:

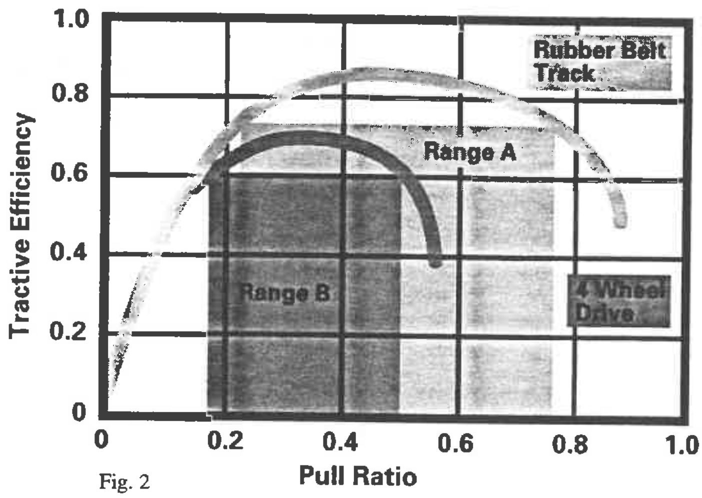


Fig. 2

1. He does not need to be overly concerned with proper match of tools to a tracked tractor. His efficiency will remain high.

2. However, he can match to wider tools, an important concept in controlled traffic, and still have plenty of reserve pulling power to till hard areas of his fields.

3. He does not need as much engine horsepower to do the same drawbar work.

4. The less powerful engine with the increased tractive efficiency results in a considerable savings in fuel on a field area basis. Many owners report 20% or more in savings.

5. Higher pull capability means a tracked tractor can be lighter for less compaction, better flotation, and less motion resistance.

Low Pressure Tire Tractive Performance

In an effort to try and control sometimes severe wheel tractor power hop problems with radial tires, some tire and tractor manufacturers developed the concept of lower tire inflation pressures. This is a rather elaborate and intensive tire and tractor management procedure, which in some tire handbooks is up to 12 pages long.

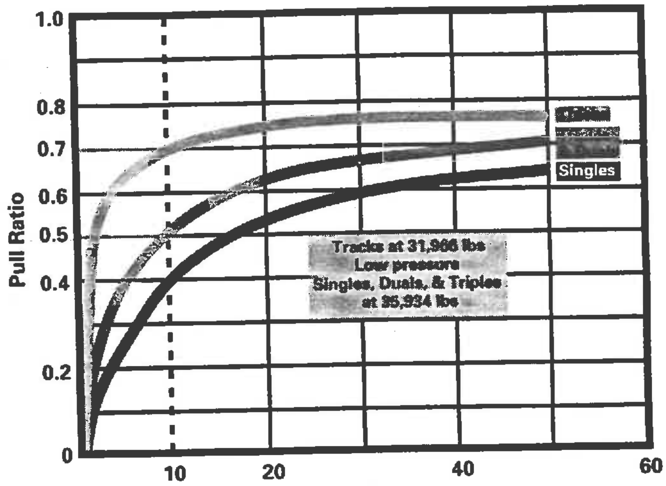


Fig. 3

Turner (1993) reported on several years of low inflation pressure tire tests conducted by the Alberta Farm Machinery Research Centre in Canada. Fig. 3 shows the results as pull ratio vs. slip in tilled soil for low pressure tire combinations and rubber belted track. Although reducing inflation pressure increased the pulling performance of tires in the very important less than 10% slip operating range, the increase was insignificant.

In Fig. 4, Turner plotted power delivered (drawbar power divided by PTO power) vs. pull ratio. Note that at low pull ratios, low pressure tire efficiency is equal to or even better at extremely low ratios. However, at these low ratios, the tools are so narrow that they barely exceed the width of dual tired wheel tractors. Since today's farmer must be in a controlled traffic environment, it is imperative that the performance must be high enough to allow the use of wide tools.

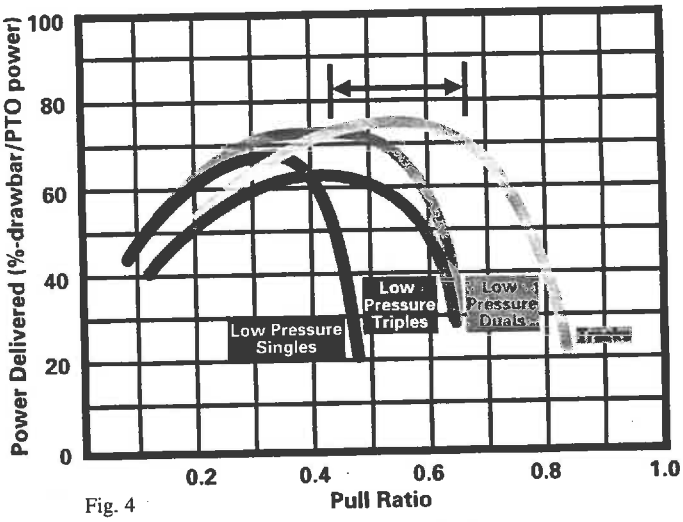


Fig. 4

Most interesting is that triple tire efficiency was only 83-94% of the dual tire efficiency. Triples are sometimes promoted as equivalent to track, and clearly they are not. In terms of controlled traffic, triples establish six compacted traffic lanes with each trip across the field.

Another very interesting point is that rarely do the tire handbooks allow tire pressures below 55 kPa (8 psi) and the front axle must have much higher inflation to control the power hop. Turner reports that increasing inflation pressure from 55 kPa (8 psi) to 96 kPa (14 psi) reduced power efficiency by 7%. Wiley, et al, (1992) reported that with 62 kPa (9 psi) rear pressure, increasing front pressure from 90 kPa (13 psi) to 138 kPa (20 psi) resulted in an efficiency loss of 4.4% and a pull loss of 9%. In other words, in most cases, it is not possible to achieve the performance claimed for low pressure tires.

There are many disadvantages in using low pressure tires, not the least of which is the constant monitoring and adjustment of pressure because, do not forget, underinflation is the number one cause of premature tire failure. There is no margin for error with low pressure tires.

Soil Compaction

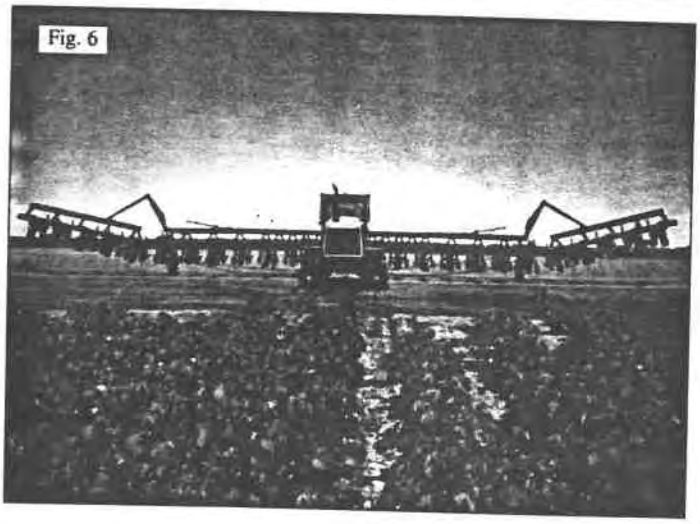
This is a huge subject that is difficult to cover in a short paper, but it is a very large part of the value of tracks in agriculture. The two most comprehensive studies to date were reported by Erbach, et al, (1988 and 1991). To briefly summarize, a good average yield increase, attributable largely to tractor operation, is 14% in corn. This number is confirmed by farmers who own track; but they also report a wide variation in results, from no increase to 50%.

If no yield increase is reported, it is almost always due to the soil already being compacted from previous wheel machines which probably were used for decades prior to the use of track machines. Many researchers have found that it is a very slow process for nature to loosen soil that has been compacted by years of wheel traffic, even in climates with freezing weather. It is recommended that soils should be deep ripped, at least 36 cm (14 inches), with the introduction of tracks. If tracks are then used exclusively, ripping may not be needed again for many years.

Another point to keep in mind is that soil parameters, in most cases, do not represent the changes in yield that occur with differences in compaction of tracks vs. wheels. For example, the Erbach studies showed very little difference in bulk density between the wheel and track fleets, yet the yield difference was very significant. A compaction comparison test that does not include yield measurement will not give the farmer the information he needs to judge the value of less compaction with tracks.

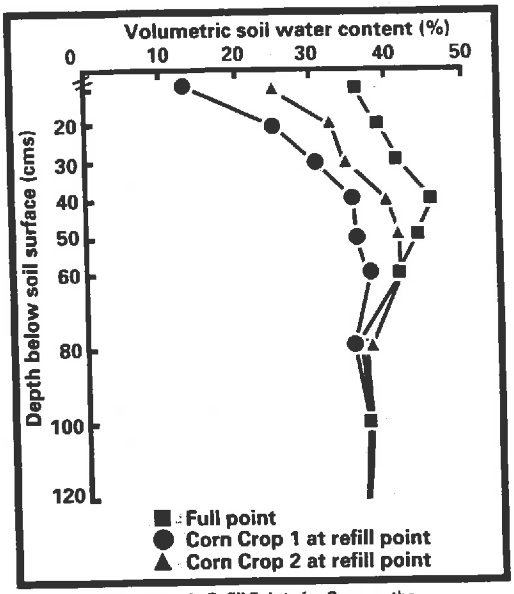
Fig. 5

Fig. 6



In terms of controlled traffic, there is an excellent example in Australia. Ken Arnott, National Mutual Cotton, in Moree, NSW, determined that he would realize a considerable cost savings and yield increase if he could use wide 24-row equipment pulled by narrow track instead of 12-row equipment pulled by wide dual tires. Figs. 5 and 6 show the tracked equipment he is now using. He had planned on permanent traffic lanes; but as you can see, the cotton grows nearly as well in the traffic area of the tracked machine as it does in the no traffic area. Cotton yields have increased very significantly, with little variation from traffic zones to no traffic zones. Similar reports have been received from other farmers. In fact, many farmers in the USA have planted row crops in the traffic zone of tracked machines and reported no apparent loss in yield.

Data from neutron probe soil moisture measurement conducted by Cull (1986) of Irricrop Technologies, Narrabri, NSW illustrate the advantages of reducing compaction with tracked tractors. Fig. 7 shows the full point, the refill point for corn crop 1 (track tractors) and the refill point for corn crop 2 (wheel tractors). The difference between the full point line and the refill line is the amount of moisture that the crop was able to extract without yield reducing stress. The crop in the track field was able to extract more than twice as much moisture and deeper into the soil profile due to less compaction. Corn crop 2 requires an early refill to restore moisture and prevent plant stress and resultant loss in yield. With corn crop 1, the irrigation cycle can be extended; at irrigation, more water is retained deep in the soil and proportionately less water evaporates. In fact, a casual observation of surface moisture on the track field would perhaps cause a farmer to panic, thinking that his plants were in danger, because the surface of the track field is drier (12% vs. 25%) when, in fact, the wheel field is in great danger of plant stress and yield loss. These types of moisture plots are similar for virtually all crops.



Differences in Refill Points for Corn on the Same Clay Soil at Griffith NSW

Fig. 7

A consultant company in our area of Illinois, Key Ag Consultants, will assure a farmer that if he would use wide tools, he will immediately realize an increase in yield. With a 24-row planter and cultivator and an 8-row combine, they have measured average losses of 22% in the 8 corn rows in the traffic zone of a dual tired 2WD tractor compared to the 8 no traffic rows on each side of the tractor. Losses can be as high as 44%. Using tracked tractors with the wide equipment results in almost all of the loss being recovered in the middle 8 rows.

Perhaps the biggest advantage of tracks is the ability to plant crops on time. Purdue University, Lafayette, Indiana, has developed a parameter called "shadow price" based on data provided by farmers on the value of farming on time. This price is the value of an hour of planting time during the optimum weeks for planting a crop considering the yield that can be achieved at harvest. In the USA "corn belt", a typical shadow price is $475.00US/hour for the best two weeks. If it should rain during this time, which is very common, and assuming that he operates 14 hours a day, he will lose $6650.00US a day of income for each day that he does not plant. It is common to lose 3-5 days due to rain during the best two weeks. The value of being on time is so great that this feature of track alone will return any premium associated with a track-type tractor in the first year or two of operation.

For example, a few years ago, one farmer figured that planting part of his soybean crop two weeks late, cost him $24,000.00US. Another farmer lost 25% of his yield because he could not plant everything on time. This year, the midwest had almost continual rain during the two best weeks and even for two additional weeks. In these circumstances, the track machine becomes like an "insurance policy" and the entire cost of the tractor is recoverable in one year rather than just the price difference compared to a wheel tractor.

Low Pressure Tire Compaction

The Erbach, et al, (1988) report is the only multiyear study to date that included 48 kPa (7 psi) inflated tires in a yield study. There was no advantage in yield for the low pressure tires. Yield is conspicuously absent in all other claims that low pressure tires reduce compaction.

Tire load is more significant in determining yield than inflation pressure. Bailey, et al, (1993) reported on a series of tests with low and high pressure tires at various tire loads. Fig. 8 is a bar graph plot of a table of results in the report. When the high load tire pressure was reduced from 124 kPa (18 psi) to 41 kPa (6 psi), a reduction in bulk density increase occurred. (However, the tire is not rated for this load, 25.3 kN (5,685 lb), at low pressure so this is not a farmer option.) Most important, reducing load, at high pressure, caused a much greater reduction in bulk density increase. With less load, a reduction in pressure is feasible. Unfortunately, wheel tractors cannot operate effectively at low loads. Although the study was not intended to verify track parameters, it is clear that only track can achieve the desired results. Rubber belted tractors have typical roller/wheel loads of 9.8-12.5 kN (2,200-2,800 lb) and 41 kPa (6 psi) or less of ground pressure.

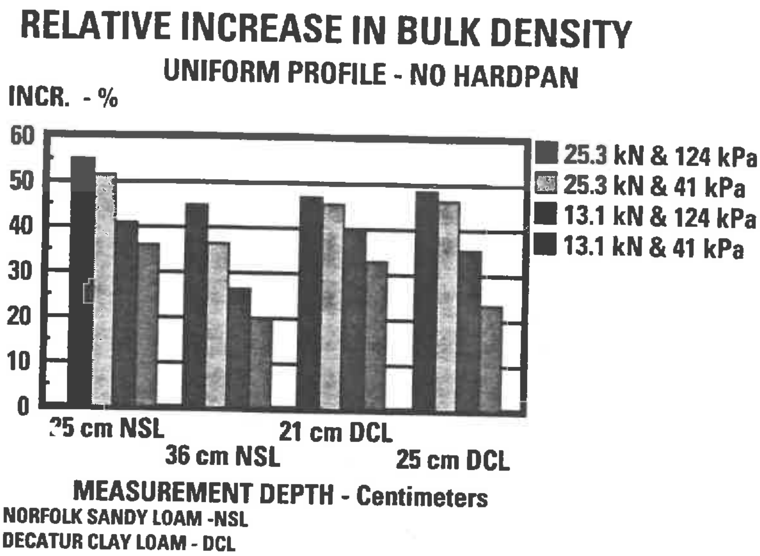


Fig. 8

Summary

The obvious conclusion is that tracks are very valuable to the farmer. Some farmers report they now have the lowest cost per hectare (acre) or tonne of produce that they have ever had. These lower costs were achieved by buying more expensive machinery, that really works well, rather than simply buying less expensive machinery. This situation is rather common in both the business and consumer world.

References

Bailey, A.C., R.L. Raper, T.R. Way, E.C. Burt, and C.E. Johnson, 1993. Soil Stresses Under Tractor Tires at Various Inflation Pressures, Alabama Experiment Station Journal No. 2-933483.

Cull, Dr. Peter O., 1986. Factors to Consider When Setting Refill Points for Irrigation Scheduling, Irrigation '86, Darling Downs Institute of Advanced Education.

Erbach, D.C., S.W. Melvin, and R.M. Cruse, 1988. Effects of Tractor Tracks During Secondary Tillage on Corn Production, American Society of Agricultural Engineers, Paper No. 88-1614.

Erbach, D.C., S.W. Melvin, and R.M. Cruse, 1991. Low Ground Pressure Equipment Fleets For Corn Production, American Society of Agricultural Engineers, Paper No. 91-1517.

Evans, William C. and Daniel S. Gove, 1986. Rubber Belt Track in Agriculture, American Society of Agricultural Engineers, Paper No. 86-1061.

The Goodyear Tire and Rubber Company, 1992. Optimum Tractor Tire Performance Handbook.

Turner, Reed J., 1993. Single, Dual, and Triple Tires and Rubber Belt Tracks in Prairie Soil Conditions, American Society of Agricultural Engineers, Paper No. 93-1516.

Wiley, J.C., B.E. Romig, L.V. Anderson, and F.M. Zoz, 1992. Optimizing Dynamic Stability and Performance of Tractors with Radial Tires, American Society of Agricultural Engineers, Paper No. 92-1586.

Controlled Traffic- The Potential for Precision

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Introduction

Current reasons for adopting controlled-traffic systems are largely based on the crop, soil, energy and timeliness benefits resulting from optimisation of soil compaction in the crop and traffic zones. In practice, permanent and highly compacted traffic lanes provide good machine mobility, higher tractive efficiency and improved timeliness of operation. Removing traffic induced compaction from the crop zone reduces or eliminates the need for deep tillage, improves the efficiency and effectiveness of necessary tillage, and allows more control over soil conditions affecting crop growth.

Enhanced computability with automated and non-random operations is a relatively unquantified, but potentially significant, additional benefit of control traffic. Fixed traffic lanes provide areas where components of irrigation systems or elements of guidance/mapping systems can be permanently located. In addition, fixed traffic lanes (alone, or in conjunction with other guidance devices) facilitate more precise operation through improvement in machine location, stability and ease of operation.

Precision in machinery operation determines how accurately agronomic inputs can be delivered to cropping systems and has major implications for a wide range of cultural practices. For example, improvement in depth control influences tillage energy requirements and seed placement. Improvement in lateral spatial control influences targeting of crop chemicals and facilitates inter-seeding and inter-row cultivation. Precise spatial and temporal control is a prerequisite for the application of sophisticated 'mapping' techniques for addressing aspects of field spatial variability .

Practical applications made possible under precision controlled traffic systems could include, for example:

- Application of row-crop technology to swath-crops
- Freedom from implications of 'guess-rows', 'overlap' etc.
- Improved flexibility in use of current susceptible/non-compatible crop chemicals
- More efficient and effective utilisation of system inputs and reduction in their environmental impacts.

The commercial exploitation of enhanced precision technology is clearly dependent on the outcome of a cost benefit analysis - the economic balance between the cost of acquiring a given level of precision and the sum total of the agronomic, environmental and management benefits realised.

The cost of acquiring precision will be primarily dependent on the level of technology employed and the commercial implications of supply and demand. Both the level of technology/precision required and the likely commercial implications are clearly dependent upon the assessment of the benefits of enhancement in machine operational precision.

At the University of Queensland Gatton College, funding has been allocated for the establishment of a large scale experiment to investigate controlled traffic effects on machine system performance, management, soil condition and crop yield. Assessment of precision effects on aspects of tillage, planting and crop chemical application are central to this experiment. Although the statistical and logistical requirements are yet to be finalised, the general layout of the experimental area and the methodology to be used to evaluate precision effects are briefly discussed below.

Research Program (Assessment of Precision Effects)

1 The Objectives of the Program

The objectives of the research program are, for both horticultural and grain crop production systems, to:

- Determine the current status of machine operational precision in conventional and controlled traffic cropping systems
- Identify opportunities and benefits of increasing levels of operational precision under controlled traffic conditions
- Assess the economic benefits of increasing operational precision and use this information to identify optimum levels of precision for controlled traffic cropping systems
- Determine the likely economic/agronomic benefit from improved operational precision as a result of a change from conventional cropping systems to an optimally precise controlled traffic system

2 Major Items of Equipment

The major items of equipment to be used and their primary role in respective cropping systems are as follows:

- Dowler Gantry with a 12 m track width.
  In the horticultural crop production system the gantry will be used for all crop chemical spray operations, general tillage and as a harvest aid. In the grain

production system the gantry will be used for crop chemical spray operations and sward crop planting.

- John Deere 4040 tractor on 3 m track width.
  This tractor will be used for track maintenance in both systems and for all tillage and row crop planting in the grain production system.

- Fendt 360 GTH with a 1.5 m track width.
  This tractor will be used for specialist tillage, bed forming and planting in the horticultural crop production system

- Purpose built Sampling Frame.
  Essentially this purpose built frame will be a semi mounted mobile platform compatible with 3 m traffic lanes and incorporating a pto powered carriage with side shift capability. This frame will facilitate soil sampling and be able to perform precise planting and tillage and crop chemical application operations over a 5 m row length. Re-positioning this frame over the bed at subsequent intervals will provide the basis for accurate measurements of plant displacement, tillage disturbance etc.. The frame will be used for these purposes in both cropping systems.

3. Experimental Layout

The experimental layout of the research plots and the traffic lanes within them are shown in Figures 1 and 2 respectively. The 24 m wide plots are compatible with two passes of the gantry and are separated by a lane way to facilitate product removal when the gantry is used as a harvest aid. Each block allows two replications of conventional and controlled traffic treatments and three blocks will be allocated to each of the horticultural and grain cropping systems.

4 Methodology

While the actual methodology is still to be determined it is proposed to investigate the tillage (e.g. depth, weed control vs plant proximity), planting (e.g. depth, inter-seeding) and crop chemical (e.g. fertiliser placement, pesticide application efficiency) benefits as a result of increasing levels of machine operational precision. The levels of precision are to be those resulting from (a) rail guidance of tractor and machine, (b) tractor and implement guided by local features, (c) tractor free and implement guided by local features, and (d) tractor and implement free. In this context (a) and (d) represent the highest and lowest levels of machine operational precision respectively.

Methods of assessing the agronomic/economic benefit are still being determined but are likely to include: specific inputs (chemicals, energy etc); plant establishment, survival, and growth; weed kill and application efficiency etc. as appropriate.

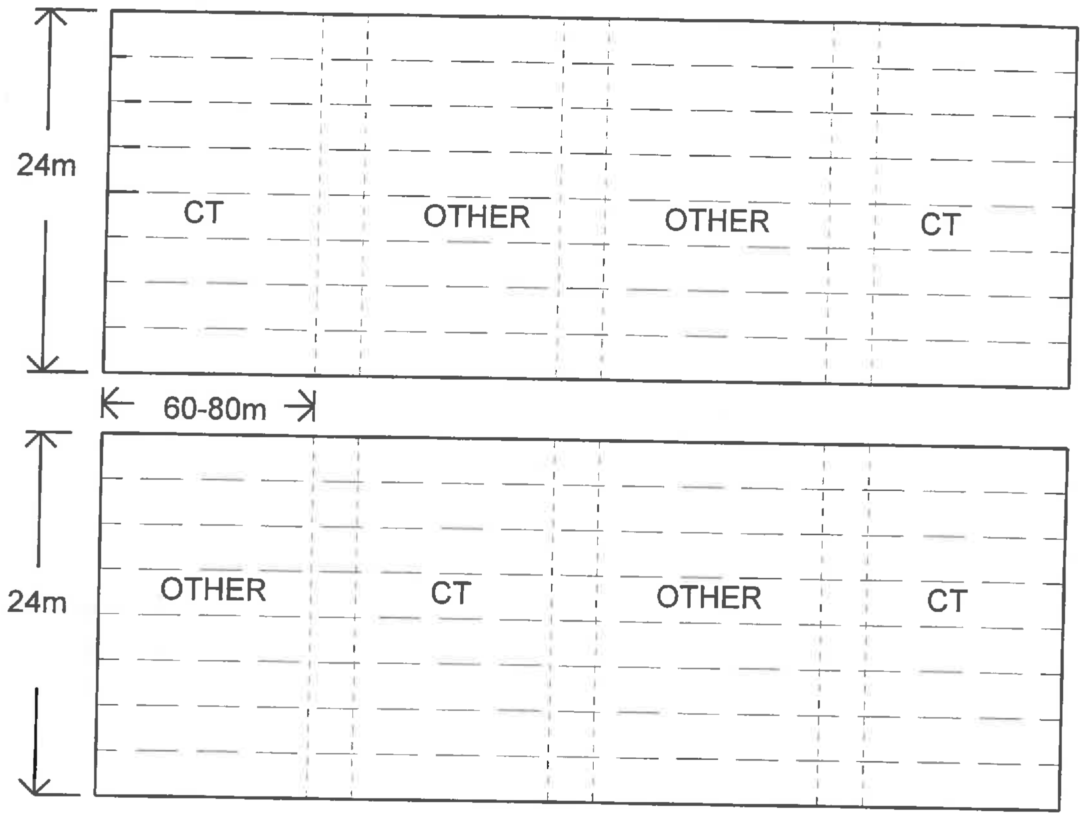

Figure 1. General layout of experimental area

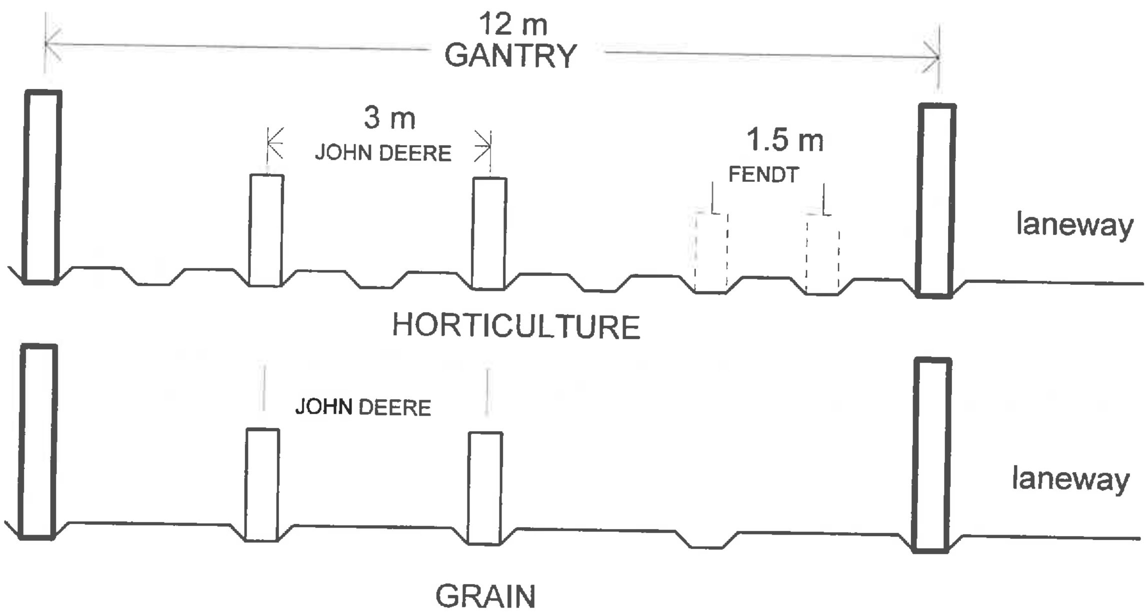

Figure 2. Traffic lane layout within horticultural and grain cropping systems

Six Years of Controlled Traffic Cropping Research on a Red Brown Earth at Roseworthy in South Australia.

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Introduction:

The sustainability of agricultural production is linked closely to surface and subsoil management. Both tillage and heavy wheel traffic cause a decline in soil structure. This is an unintended consequence of conventional agricultural practices using tillage and associated machine wheel traffic. The intensity, type of loading and soil moisture during compaction can affect tillage conditions and produce a hardpan layer below the cultivation depth. Compaction damage can be reduced by using lighter or lower ground pressure implements, or by using controlled traffic (CT) cropping systems which eliminate wheel traffic from the cropped zones by confining wheel positions to permanent wheel tracks. The future trend in weight of agricultural machinery is unlikely to result in lighter tractors and implements, in fact studies have shown that soil has sometimes to bear axle loads which would be banned on public highways (Spoor, 1988). Therefore one of the most suitable methods of approaching this technologically created compaction dilemma is application of Controlled Traffic Systems and use of gantries or the like.

Background to Controlled Traffic Project at Roseworthy:

The research on controlled traffic cropping at Roseworthy started in 1989 and thereafter was funded by the Grains Research and Development Corporation (GRDC) until the end of June 1995.

1. Project Aims:

- to examine the usefulness of controlled wheel traffic, as a practical method of preventing soil compaction, in increasing yield of cereals and grain legumes as well as its effectiveness in improving plant and soil properties.
- to investigate the benefits of the higher rates of water entry observed in controlled traffic treatments.
- to determine the influence of controlled traffic on beneficial and detrimental soil fungi.
- to investigate the effect of controlled traffic on medic pasture.
- to gain a better understanding of the causes of consistently higher yields and root densities measured on crops grown in the absence of wheel traffic.
- to develop approaches to validation and utilisation of this technology on farms.
- to demonstrate that controlled traffic is an important element of sustainable cropping systems.

2. Machinery and Experimental Treatments:

All operations on Controlled Traffic trials were conducted with a John Shearer self propelled prototype gantry using tillage, seeding and spraying implements modified to be carried by the gantry. This provided 4.4 m wide experimental plots with 4 m cropping beds which were not wheeled at all. For cultivating and sowing purposes a John Shearer 6-90 Trash-culti-drill, fitted with direct drill tynes, was modified to be suspended under the gantry. A 5m wide spray rig was also modified and mounted on a frame especially designed to be suspended under the gantry for spraying purposes. For harvesting purposes a Massey-Ferguson 585 header was modified, matching the gantry wheel spacing to enable harvesting the plots from permanent tracks. Prickle chains were also pulled behind the gantry for harrowing purposes. To maintain wheel tracks free from weeds, scrapers which were hydraulically controlled from the gantry, were mounted behind the wheels of the gantry.

A Conventional (C) cropping system was included for comparison. Conventional wheel traffic was applied during tillage, seeding and spraying operations using tractors and trailed implements. For cultivating and sowing purposes the same 6-90 Trash-culti-drill was pulled behind the tractor.

Deep ripped treatments of both C and CT were also carried out in the field to investigate the effects of subsoiling and disturbance of a hardpan on crop yield and other related plant and soil properties. Deep ripping to a depth of 300 mm was done in Autumn 1989 prior to start of the experiment with a John Shearer Trashworker chisel plough with tynes at 30 cm spacings and fitted with 50 mm points.

Experimental Treatments and Experimental Design:

C	Conventional wheel traffic Using tractor and trailed implements	**CR**	C, deep ripped to 300 mm prior to trial
CT	Controlled traffic using prototype gantry	**CTR**	CT, deep ripped to 300 mm prior to trial

These were replicated four times in a split plot design. The main treatments were"ripping" and "no ripping" and the sub treatments were "traffic" and "no traffic" (Ellis et al, 1992). The last three years of the project were concentrated on no ripped CT and C treatments only. In this case C and CT formed a Randomised Complete Block Design experiment.

The site occupied about 4 ha and the C and CT plots were 6 and 4 meter wide respectively. All plots were 275 meter long. Five meter wide borders separated all main plots to allow vehicle access. The size of each replicated plot was 0.1 ha. Each treatment was also represented by 2.5 ha management plots in the northern and southern side of the experimental site to address management issues such as weed control on permanent wheel tracks, stubble management, guidance of machinery and depth control of tillage and seeding implements. The northern management site was later on utilised for water-use efficiency studies.

Soil loss to wheel tracks and use of narrower tyres:

Permanent wheel tracks at Roseworthy were not sown to crop, for visibility and better manoeuvrability of the machinery, and represented 16% of the total area lost in permanent tracks in 1989 and 10% thereafter following the fitting of narrower tyres to the gantry. The benefits of the controlled traffic system were more than enough to compensate for the lost area of land to wheel tracks.

Cropping Sequence:

The cropping sequence was barley (*Hordeum vulgare* cv Galleon) in 1989, faba bean (*Vicia faba* cv Fiord) in 1990, wheat (*Triticum aestivum* cv Spear) in 1991, faba bean (cv Fiord) in 1992, wheat (cv Machete) in 1993 and medic pasture (*Medicago truncatula* cv Paraggio) in 1994.

Crop and Pasture Measurements:

seedling establishment, phenological development, crop biomass, grain yield, grain protein, effective rooting depth, root density and root diameter, root morphology, nitrate analysis in medic pasture.

Soil Measurements:

Bulk density, penetrometer resistance, soil hydrology - permeability, infiltration patterns, runoff, drainage, sorptivity, water extraction pattern, water stable aggregates (WSA) - recovery of soil aggregates from compaction, soil porosity and biopores and soil biological activity (earthworm numbers).

Extension:

Dissemination of results occurred through student seminars (Roseworthy Campus ,Waite Campus ,CSIRO), publications in state and national workshop proceedings (CRC for Soil and Land Management, annual tillage workshop), conference proceedings (National Soil Conference, Agricultural Engineering Conferences, etc), national journals, articles in stock journals and Kondinin magazines, radio talks, attending Paskeville, Hart and AGTEXPO (a joint field day run in conjunction with SARDI, CRC for Soil and Land Management and the University of SA) field days, presentation to visiting farmer groups and attending farmers' discussion nights. Given that there are existing commercialisation limitations to the extension of gantry-based controlled traffic and considerable cost involved in the adoption of the system by farmers, a part of the research has concentrated on axle modification of existing tractors and harvesters which can enable the on-farm application of a controlled traffic system at low cost.

Results and Discussion:

1. Crop Yield:

The harvest times for all crops were in late November/December. In all years the centre of the C and CR plots were harvested, leaving a 0.5 meter strip both sides to exclude any plot edge effect from the sample. The entire width of the CT plots was harvested because any edge effect caused by the permanent wheel tracks was considered to be normal for a controlled traffic system and not an artefact of the plot geometry. Yield transects transverse to the rows, were done by cutting 0.25 m^2 quadrats in 1990 and 1 meter length of row in 1991. Grain yields were calculated from the number of grains in each sample combined with 100 grain weight. The contribution of the edge effect to the final yield of the plot was about plus one percent. Crop yield in 1992 when the trial was under faba bean was estimated by finding the weight of 1000 beans. 1992 was a wet year (twice average annual rainfall) and this made harvest impossible because of severe weed infestation of the plots. The grain yield for 1993 was obtained by machine harvesting. In 1994 treatments were sown to annual medic pasture and its growth in a controlled traffic system was studied (Sedaghatpour et al, 1995). Samples for medic seed production were taken using a suction harvester in January 1995.

Positive yield responses were produced by controlled traffic treatments over 6 consecutive years. Data showed average yield increases of 12% in cereal and grain legumes and about 22% in parragio medic. Yield parameters like herbage biomass, nitrogen uptake, single grain weight, weight of thousand seeds, number of heads, and number of grains per head contributed to these increases in yield. Table 1 shows crop and medic pasture yield for each treatment. In all years there was a statistically significant ($p < 0.05$) interaction between main treatments.

Table 1: Effect of Wheel Traffic, Deep Ripping and their interaction on crop yield

Year of Experiment	Avg Yield C kg/ha	Avg Yield CT kg/ha	Diff. in yield (C & CT) kg/ha	Avg Yield CR kg/ha	Avg Yield CTR kg/ha	Diff. in yield (CR &CTR) kg/ha	LSD (0.05)	LSD (0.05)*	Avg yield C & CR (Wheel)** kg/ha	Avg yield CT & CTR (No Wheel)** kg/ha	Diff. in yield kg/ha	LSD (0.05)	Avg yield C & CT (No Ripping) kg/ha ***	Avg yield CR & CTR (Ripping) kg/ha***	Diff. in yield kg/ha	LSD (0.05)
1989 (Barley)	3130	3330	200	3140	3540	400	162.2	181.3	3135	3435	300	128.2	3230	3340	110	128.9
1990 (Bean)	1985	2327	342	2046	2121	75	101.8	114.3	2015	2224	209	80.7	2156	2083	73	80.2
1991 (Wheat)	2562	2872	310	2740	2775	35	108.2	86.9	2561	2824	263	61.4	2717	2757	40	115.5
1992 (Bean)	3964	4519	555	5538	3387	2151	1316.0	889.5	4751	3953	798	629.1	4751	3953	798	1503.4
1993 (Wheat)	3046	3157	111	3155	3320	165	400.8	377.8	3100	3238	138	267.2	3100	3238	138	388.6
1994 (Medic)	361.8	447.3	85.5	349.2	398.2	49	26.7	26.4	356	423	67	18.6	405	374	31	24.8

* Use this column when comparing average yields with the same level of traffic or ripping.

** This table compares the effect of wheel traffic on crop yield (group effect without reference to rippin** Results are significantly different in absence of wheel traffic**

*** This table compares the effect of ripping on crop yield (group effect without reference to wheel traffic).**There is not significantly different result between ripped and non-ripped treatments.**

Note: | difference in yield | > LDS(0.05)⇒significantly different result

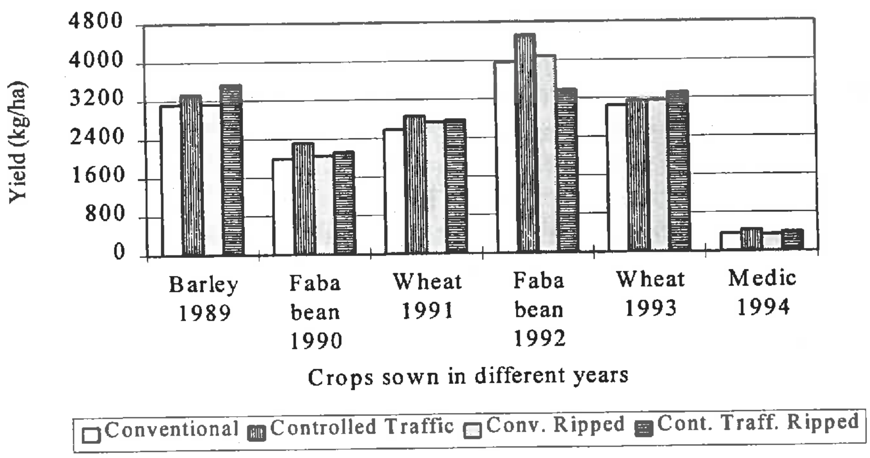

Figure 1: Crop and medic pasture yield in C and CT treatments from 1989 to 1994

2. Plant Root Characteristics:

Root densities of wheat(1991, 93), faba beans (1992) and medic pasture (1994) were studied. The results were consistent and were significantly different in CT comparing to C. Fig 2 shows the rooting behaviour of wheat in 1991, medic pasture in 1994, and root morphology of faba bean in 1992. Because of possible effect of water uptake on grain filling and yield, the effect of wheel traffic on rooting density and length was investigated.

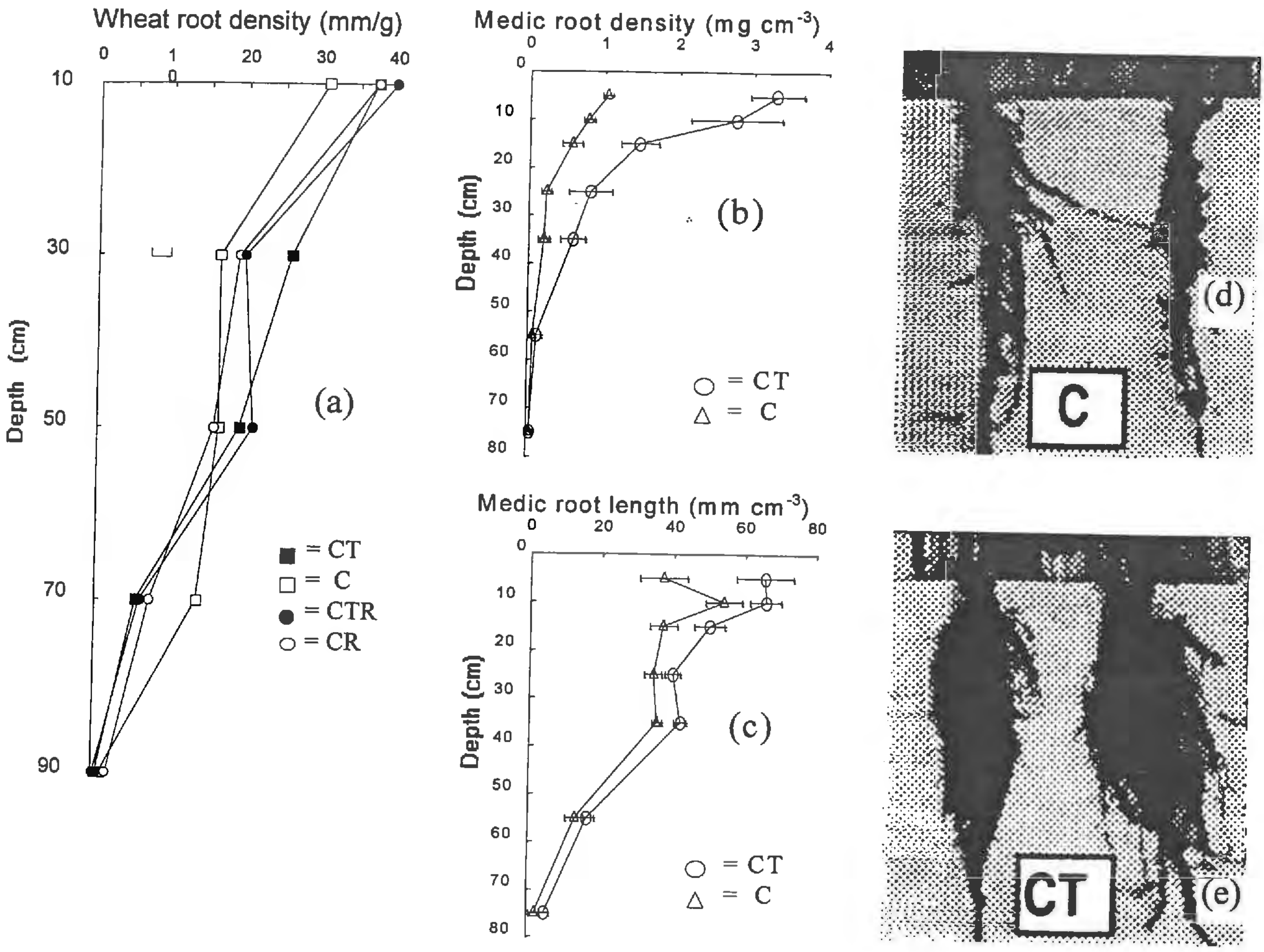

Figure 2: (a) wheat root density at anthesis in 1991. The bar represents significant differences at the 30 cm depth. (b) and (c), medic pasture root density and root length. (d) and (e) morphological study of roots of faba bean seedlings to 15 cm soil depth in 1992. Better root establishment and development and more lateral roots were observed in CT than in C.

3. Soil Strength:

Soil penetration resistance using a cone penetrometer was measured in each year. Fig 3 shows soil resistance to penetration by a cone penetrometer after 5 years of controlled traffic. Large differences in penetration resistance at soil depth (70-100 mm) between C and CT shows that zero traffic had ameliorated the soil hardpan. It is important to note that this occurred *naturally*, presumably due to the action of plant roots, soil fauna, wetting and drying cycles when there was no compaction because of wheel traffic on cropped zones.

4. Soil Bulk Density and Soil Porosity:

Bulk density increases when soil is compacted. The degree of compaction depends on soil water content at the time of compaction (Weaver and Jamison 1951) and a small increase in bulk density can cause a large increase in penetration resistance (Voohees et al, 1978) and decrease in size of large pores. There is a trend towards lower bulk density in both surface and hardpan zones under CT (Fig 4). Bulk density was consistently lower in CT in 1991 through to 1994 and supports the results of penetrometer experiments (Fig 3) which were done simultaneously. Soil porosity in CT was greater than in C (Fig 6) in top 100 mm of soil depth.

5. Soil Aggregate Stability:

Aggregate stability is an important indicator of the sustainability of agricultural practices. It has significant role in relation to wind and water erosion (Wischmeier et al, 1969), plant growth (Passioura, 1991) and yield.
Both tillage operation and wheel traffic causes a decline in soil structure as measured by soil aggregate stability. The results of early years were not significantly different and after 5 years of continous controlled traffic practices the differences between C and CT treatments started to show up. Fig 5 shows the effect of rain on Water Stable Aggregates (WSA). Cumulative percentage of aggregate sizes are significantly different in CT treatment in 1993-94 comparing with results from 1991-92 in which years treatments were sown to wheat.

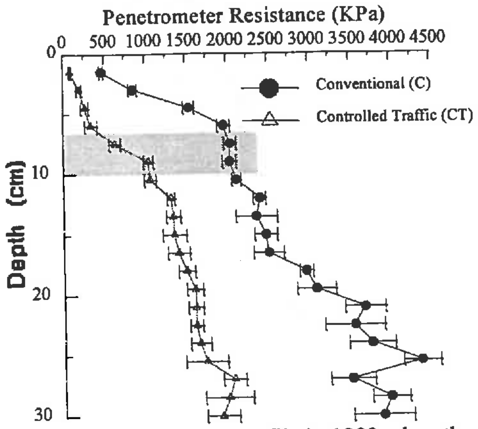

Figure 3: Core penetrometer profile in 1993 when the experiment was sown to wheat.

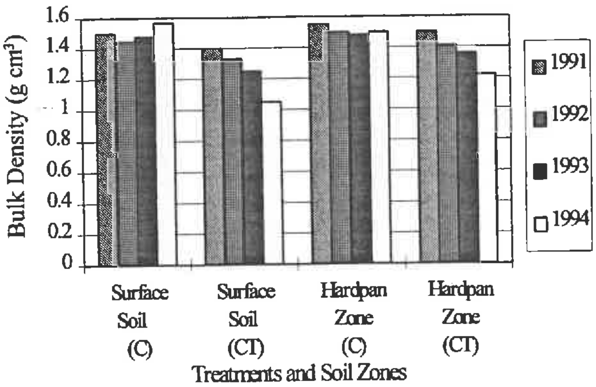

Figure 4: Soil Bulk Density from 1991 to 1994 in surface (0-50 mm) and hardpan (50-100 mm) zones. Results support penetrometer experiments.

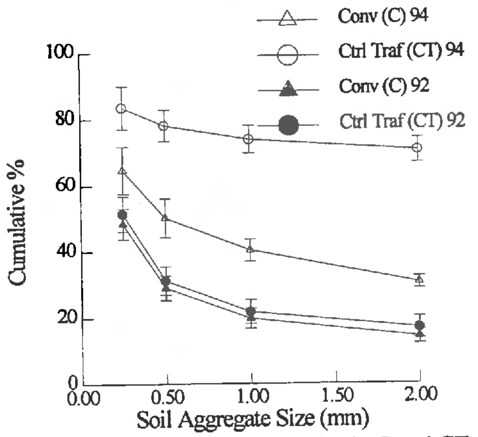

Figure 5: Surface soil aggregate stability in C and CT.

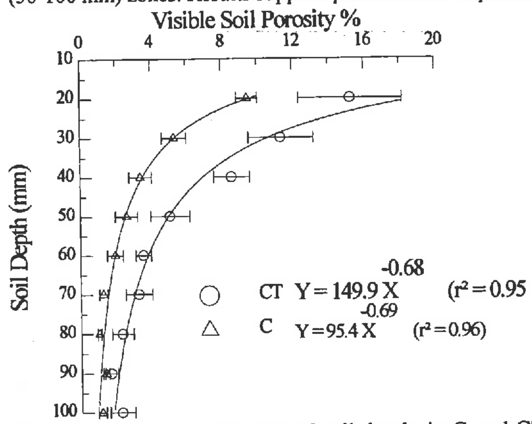

Figure 6: Soil porosity in top 100 mm of soil depth, in C and CT treatments.

6. Hydrological Characteristics of Soil:

6.a) Sorptivity as an index to assess the effect of wheel traffic on soil:

Sorptivity depends on the very early stages of infiltration of water into the soil (Philip, 1957). The hydraulic characteristics of the soil, particularly the top few millimetres, are critical (Sauer, et al, 1989) and related to presence of macropores. Wheel traffic can affect surface soil pore geometry and destroy, or block macropores to water entry. Sorptivity has been used as an index to assess the effect of wheel traffic on soil (Sedaghatpour and Ellis, 1994). Fig 7 shows that the value of sorptivity for CT is almost double of the value for C and sorptivity proved to be higher on CT in the last two years of controlled traffic when experiments were fully established.

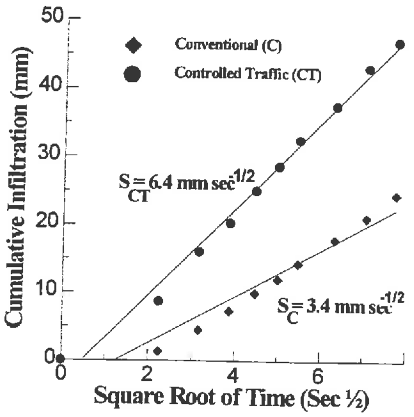

Figure 7: Sorptivity in C and CT. Lines fitted to the linear part of infiltration data to calculate sorptivity.

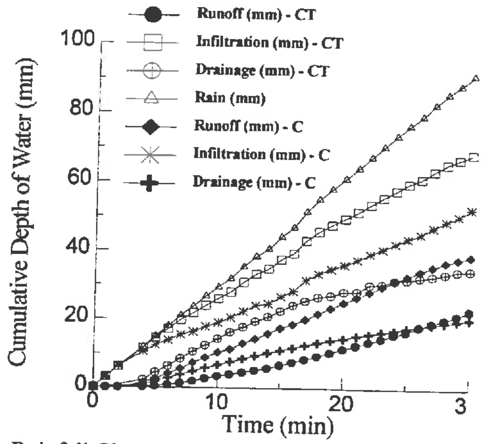

Figure 8: Rainfall Characteristic Curves for Conventional and Controlled Traffic treatments (wheat crop).

6.b) Rain, Infiltration, Runoff, and Drainage:

Other hydrological behaviour of soil under CT and C was studied (Sedaghatpour, et al, 1993, 1994), a month after harvest when sheep finished grazing, using an indoor rainfall simulator. Fig 8 shows significantly different results ($p<0.05$), in favour of CT comparing with C, for water infiltration, runoff and drainage under a rainfall energy of 8 $Jm^{-2}mm^{-1}$. The differences between treatments were observed 10 minutes after simulated rainfall commenced. The higher rate of water entry into CT soil could be because of its lower bulk density and higher porosity than C.

Discussion:

After 6 years of CT at Roseworthy, controlled traffic resulted in higher grain yields of wheat, barley and faba bean crops and higher herbage and seed production from medic pasture, compared to conventional (C) farming systems. This plant growth advantage was associated with improvement in a range of soil parameters including; bulk density, penetration resistance, soil porosity, increased sorptivity and water infiltration into the soil profile, higher cumulative percentage of water stable aggregates (WSA), longer and more lateral roots, higher rooting density, greater above ground plant production, better development of other components associated with yield, higher biological activities in soil (earthworm numbers - twice number in CT than in C, Sedaghatpour and Ellis, 1994) as well as greater effectiveness of direct drilling. These changes appear to be principally a result of the action of roots, macro fauna and wetting and drying cycles and have led to improvements in soil condition and crop yields. It was found that exclusion of wheel traffic without deep ripping can allow natural processes for improving soil structure. Such a method has the potential to be more cost effective and long lasting than mechanical or chemical methods of soil amelioration.

The effect of soil compaction on crop growth and yield can depend on the amount and temporal distribution of rainfall throughout the growing season (Boone 1988). A dense soil may give a yield advantage over a less dense soil in a "dry" year but the less dense soil may give a higher yield in a "wet" year (McKyes et al. 1979). Generally though, soil compaction by wheel traffic has a determinal affect on crop yield (Hakansson, 1987). Decrease in crop yield brings up the economic consequences to which ecological consequences could be added (Lhotsky, et al. 1991). Therefore, soil compaction is an urgent problem and a **practical preventive method** should be sought and used in fields.

Acknowledgments:

The authors thank the Grains Research Development Corporation for financially supporting the Roseworthy Controlled Traffic Cropping Project of which the above work is part.

References:

1. Boone, F.R. (1988) "*Weather and other environmental factors influencing crop responses to tillage and traffic*", Soil and Tillage Research, 2, 283-24.
2. Ellis, T.W., Sedaghatpour, S. and Thomas, J.B. (1992) "*Three years controlled traffic cropping at Roseworthy*", Conf. on Eng in Agric., I.E.Aust. National Conf. Publ No. 92/11. Pages 109 - 114.

3. Hakansson, I. (1987) "*Long-term effects of vehicles with high axle loads on subsoil compaction and crop response*", In Proc. Int. Soil Till. Res. Org. 9th Int. Conference. Osijek, Yougoslavia, PP 213-18.
4. Lhotsky, J., Beran, P., Paris, P. and Valigurska, L. (1991) "*Degradation of soil by increasing compression*", Soil and Tillage Research, 19, 287-295.
5. McKyes, E., Negi, S., Douglas, E., Taylor, F., Raghavan, V. (1979) "*The effect of machinery traffic and tillage operations on physical properties of a clay and on the yield of silage corn.*" J. of Agri.Eng. Research, 24, PP 143-48
6. Passioura, J.B. (1991) "*Soil structure and plant growth*" Aus. J. Soil Res., 29, 1991, pp. 1-10.
7. Philip, J.R. (1957) "*The theory of infiltration: 4. Sorptivity and algebraic infiltration equations*", Soil Sci. Soc. Am 84:257-264
8. Sauer, T.J.; Clothier, B.E. and Daniel, T.C. (1989),"*Surface measurements of the hydraulic properties of a tilled and untilled soil*", Soil and Tillage Research, 15:359-369.
9. Sedaghatpour, S. and Ellis, T.W. (1994) "*Sorptivity as an index to assess wheel traffic effects on a red brown earth*", CRC for Soil and Land Management, Annual workshop on tillage, The University of Adelaide, March 24 and 25.
10. Sedaghatpour, S., Hignett, C.T. and Ellis, T.W. (1993) "*The effect of controlled traffic and deep ripping on soil aggregate stability*", Annual workshop on tillage, soil, and other practices in SA and Vic., Uni of Adelaide, March 25.
11. Sedaghatpour, S., Bellotti, W.D. and Ellis, T.W. (1995) "*Growth of medic pasture in a controlled traffic cropping system on a red brown earth*", CRC for Soils, Annual tillage workshop,Uni of Adelaide, March 25 and 26, PP 10 - 11.
12. Spoor, G. (1988) "*Soil punishment or protection?* ", Conf. on Agric. Eng., I.E. Aust. Publ. No. 88/12. Pages 1-3.
13. Voohees, W.B., Senst, C.G. and Nelson, W.W. (1978) "*Compaction and soil structure modification by wheel traffic in the northern corn belt*", Soil Sci. Soc. Am. J., 42(2), PP 344-49.
14. Weaver, H.A. and Jamison, V.C.(1951) "*Effects of moisture on tractor tyre compaction of soil*",J.of Soil Sci.71,15-23.
15. Wischmeier, W.H. (1969) "*Relation of soil properties to its erodibility*". Soil Sci. Soc. Am. Proc. 33:131-13.

EFFECTS OF COMPACTION ON CROP ESTABLISHMENT, GROWTH AND YIELD ON AN ALLUVIAL SOIL IN CENTRAL QUEENSLAND

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ABSTRACT

Header wheels were used to compact moist alluvial soil in order to determine the effects of a defined compaction pressure on establishment, growth and yield of 2 wheat crops and a sorghum crop. This compaction treatment reduced establishment of all 3 crops and sometimes reduced early crop growth but had no effect on grain yield.

INTRODUCTION

Structure degradation was found in various forms and extents on all farms in all soils in south-east and central Queensland during a survey by McGarry (1990). The principal causes of degradation were wheels, tillage tools and animal hoofs.

Wheel traffic in fields has been recognised as a major source of forces causing undesired soil compaction (Schafer *et al.* 1992). For example, the compactive energy input of a tractor tyre (about 5 kJ/m^2), which is absorbed in plastic deformation of the soil, is of the same order as the energy input of a chisel plough, which is mostly used to decompact the soil (Tullberg 1990). It is difficult to envisage more than a small percentage of the energy input of a chisel plough going into soil compaction beneath the tines. It follows that most of the compaction damage from current farming practices is caused by tyres.

The first pass of a wheel causes a major portion of the total soil compaction (Burger *et al.* 1983; Koger *et al.* 1983; Pollock *et al.* 1984). Wheel damage is exacerbated by (a) increased weight on the wheel; (b) high soil water content because wet soil has reduced strength (Kirby and Kirchhoff 1990); (c) wheel slip (Soane *et al.* 1981), due to shear processes in the soil (smearing), which occur particularly at high soil water contents (Kirby and Kirchhoff 1990); and (d) high tyre inflation pressures (Soane *et al.* 1981; Rickman and Chanasyk 1988).

A large percentage of the area of a field is covered by random wheel tracks during a cropping cycle. Tullberg (1990) estimated that the trafficked area exceeds 100% in conventional tillage practice, 60% in minimum tillage and 30% in zero tillage.

It is not clear what effect random wheel compaction has on crop growth and yield. So (1990) estimated that soil compaction reduces annual productivity of Australian field crops by 300 to 850 million $. A difficulty in estimating yield losses is the uneven distribution of compacted and uncompacted areas in a field. This means that plants are using both compacted and uncompacted soil. These plants may wholly or partially compensate in terms of yield per unit area of ground. In order to assess the effects of compacted soil on crop performance, we compacted entire plots (which is not unrealistic) with a single wheel pass at certain times and avoided subsequent random wheel traffic by setting up controlled traffic beds.

MATERIALS AND METHODS

Site

The experimental site is located at Biloela Research Station (24° 22` S, 150° 31` E, altitude 173 m). Slope is 0.2%. The soil is a black cracking clay developed on an alluvium, and has been classified as a Tognolini (Shields 1989) or Vertisol (Soil Survey Staff 1975). The soil had minimal loss of structure and fabric before the experiment (P.G. Muller, pers. comm.). The long-term mean annual rainfall is 698 mm, and the long-term mean annual evaporation from a Class A pan is 1870 mm.

Treatments

The experiment commenced in April 1993 when all treatments except the control (C_0) were compacted with header tyres on wet soil. The mass on each front tyre was 4.9 t and on each rear tyre 1.0 t. Inflation pressures were high: 235 kPa (front tyres) and 205 kPa (rear tyres). Wheel slip was negligible.

Treatments C_1 - C_5 are compaction/repair treatments in which compaction is re-applied or different management regimes are used to "repair" the compaction damage. C_1 - C_3 are recompacted each fallow to simulate wheel traffic during the fallow: C_1 with header tyres on wet soil, C_2 with tractor tyres on wet soil, and C_3 with tractor tyres on dry soil. Tillage regimes are traditional tillage (C_1, C_2), reduced tillage (C_0, C_3) (tillage only at soil water contents below the plastic limit in the tilled layer), and zero tillage (C_4, C_5). C_5 was deep-ripped with a chisel plough (narrow points) after the 1993 wheat crop had dried the profile (this is a current recommendation to growers).

Brief descriptions of the 6 compaction/repair treatments are:

C_0: Control (uncompacted)
C_1: Extreme compaction
C_2: Traditional tillage
C_3: Reduced tillage
C_4: Zero tillage
C_5: Current best advice

The compaction treatments were investigated with and without fertiliser (50 kg N/ha at sowing and one spray of 1% zinc sulphate heptahydrate 59 days after sowing in 1994).

All treatments were investigated with and without supplementary irrigation (75 mm of spray irrigation at or just before anthesis).

Design

The experimental design comprises 2 replications of 2 main plot treatments (irrigation) split into 12 subplot treatments (2 fertiliser x 6 compaction treatments).

Experimental details

Crops grown after the April 1993 compaction treatment were wheat (June-March 1993), wheat (June - November 1994) and sorghum (January - June 1995). The cultivars used were Hartog (1993, 1994) and MR 31 (1995). The number of seeds sown/m^2 was 192 (1993), 74 (1994) and 12 (1995). The wheat was sown in 275 mm rows with a zero till planter equipped with smooth coulters, spearpoint openers, rigid tines and press wheels. The sorghum was sown in 750 mm rows through precision seeding units with narrow (35 mm wide) sowing points, rigid tines and press wheels providing individual depth control. Plots measured 30 x 9 m, and each plot contained 3 beds each 3 m wide.

Measurements

Crop establishment: Percentage establishment of seed sown was determined by calibrating the seeder and taking counts of emerged seedlings at 14 days for wheat and 8 days for sorghum. Counts were taken in 10 m (1993), 15 m (1994) and 50 m (1995) of row per plot.

Aboveground dry matter: Plant tops were sampled at anthesis from bed areas of 1m^2 in the wheat plots and 3 m^2 in the sorghum plots. Sorghum plant tops were also sampled from 3 m^2 bed areas at 35 days after sowing. The plant material was oven-dried at 80°C to constant weight. The sorghum plants were counted for determination of dry weight per plant.

Grain yield: Wheat grain was harvested mechanically (with a small-plot header) and sorghum grain by hand. Datum areas were 30 x 1.9 m (wheat) and 10 x 3 m (sorghum). Grain moisture content was determined by moisture meter (wheat) and gravimetrically (sorghum), and yield data were standardised to 12% moisture content.

RESULTS

Crop establishment

In 1993, the compaction treatment with the header reduced wheat establishment from 93 to 73%. A rotary hoeing operation 4 weeks after compaction shattered the compacted soil but failed to improve establishment.

In 1994, the C_1 treatment had lower establishment than the other treatments (Table 1) after compaction with the header on wet soil 5 months before sowing.

In 1995, C_1 again had the lowest establishment (Table 2) after compaction with tractor tyres immediately before sowing and with header tyres on wet soil 2 months before. The compacted soil in C_1 reduced penetration of the sowing points, resulting in too shallow placement of the seed.

Table 1. Effect of controlled compaction on wheat establishment, growth and yield in 1994

Treatment	Wheel traffic (surface soil moisture at trafficking)	Tillage operations during fallow (chisel plough, scarifier)	Establishment	Plant dry matter at anthesis (88 days)		Grain yield
			(%)	(t/ha)	(g/plant)	(t/ha)
C_0	Nil	2	76	5.21	9.6	2.55
C_1	Header (wet)	4	59	4.67	11.4	2.40
C_2	Tractor (wet)	4	73	4.77	9.2	2.41
C_3	Tractor (dry)	2	82	5.48	9.2	2.61
C_4	Nil	0	67	4.60	9.5	2.35
C_5	Nil	2	76	5.49	9.9	2.52
	lsd, $P = 0.05$:		11	0.66	ns	ns

Table 2. Effect of controlled compaction on sorghum establishment, growth and yield in 1995

Treatment	Wheel traffic (surface soil moisture at trafficking)	Tillage operations during fallow (chisel plough)	Establish-ment	Plant dry matter				Grain yield
				35 days		55 days (anthesis)		
			(%)	(t/ha)	(g/plant)	(t/ha)	(g/plant)	(t/ha)
C_0	Nil	1	35	1.19	19.9	3.54	67.6	2.56
C_1	Header, tractor (wet)	1	22	0.54	17.0	2.49	82.5	2.53
C_2	Tractor (wet)	1	39	0.84	15.4	2.88	52.6	1.99
C_3	Tractor (dry)	1	39	1.27	21.1	4.11	79.9	2.97
C_4	Nil	0	41	1.30	20.8	4.33	78.3	3.43
C_5	Nil	0	46	1.23	19.3	4.52	68.9	3.09
	lsd, $P = 0.05$:		8	0.26	2.5	0.65	13.6	0.67

Aboveground dry matter

The initial compaction treatment with the header on wet soil had no effect on plant dry matter per ha at anthesis in 1993 (data not shown), but in 1994 and 1995 the treatments which had been recompacted while wet (C_1, C_2) reduced anthesis dry matter per ha in comparison with the control (C_0) treatment (Tables 1 and 2). In C_1, this was due, at least in part, to significantly lower plant populations because of reduced establishment. In C_2, plant populations were similar to the control in both 1994 and 1995, and reductions in anthesis dry matter in C_2 indicate growth retardation, the effects of which lasted to anthesis.

Despite a reduced plant population (which increases dry weight per plant) in the C_1 treatment in 1995, C_1 had a lower dry weight per plant than C_0 at 35 days in 1995 (Table 2). This indicates that compaction also retarded early plant growth in C_1.

The compaction treatment with the tractor tyres on dry soil (C_3) had no effect on aboveground dry matter in comparison with the uncompacted control (C_0).

Grain yield

Applied compaction had no statistically significant (*P*>0.05) effects on grain yield, despite reduced early growth in 1994 and 1995 (Tables 2 and 3). In 1995, zero tillage (C_4) outyielded the control treatment (C_0).

DISCUSSION

Our results indicate that compaction affects crops adversely in their early growth stages but these effects do not persist long enough to reduce grain yield.

The compaction treatment with the header each year (C_1) reduced establishment in all three crops at this site. Reduced establishment can be attributed in part to reduced seedbed tilth caused by the compaction treatment. This results in poor soil-seed contact and poor coverage of the seed with soil, both of which limit the amount of water available to the seed. The tight, compacted seedbed would have caused even greater problems if traditional sowing machinery had been used, for example a combine with duckfeet openers and spring-loaded tines. However, with the state-of-the-art sowing machinery in use, no dramatic reductions in establishment occurred.

The annual compaction treatments on wet soil (C_1, C_2) also reduced aboveground dry matter in comparison with the control (C_0) treatment in 1994 and 1995. This was due in part to suboptimal plant population densities as a result of the reduced establishment. The lowest wheat population in 1994 was 44 plants/m^2 (in C_1), which is below the recommended range of 50-150/m^2 (Colwell 1963). The lowest sorghum population in 1995 was 2.6 plants/m^2 (also in C_1), which is below the recommended range of 5-10/m^2 (Thomas *et al.* 1981). Reductions in dry matter production can also be attributed to impeded root growth in the compacted soil surface.

The absence of grain yield reductions in response to our applied compaction indicates that the crops compensated for low plant populations and early retardation of growth. We hypothesise that such compaction could conceivably result in positive effects of compaction on grain yield. Firstly, the slow early root growth in compacted soil could delay soil water use and leave more stored soil water available at critical growth stages such as anthesis or grain filling. Secondly, the reduced establishment in compacted soil could lead to lower but more optimal plant populations under harsh environmental conditions.

It may be that the two crop species investigated (wheat and sorghum) are not particularly susceptible to the effects of compaction by heavy wheel traffic. It can also be speculated that both species were effective in repairing compaction damage to the soil or the soil quickly repaired itself through shrinking and swelling processes.. Investigation of other crop species and assessment of soil properties are being carried out to determine whether the mechanism is one of tolerance to, or repair of, compaction damage.

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REFERENCES

Burger, J.A., Perumpral, J.V., Torbert, J.L., Kreh, R.E. and Minaei, S. (1983). The effect of track and rubber-tired vehicles on soil compaction. Paper No. 83-1621, ASAE, St Joseph, Michigan 49085.

Colwell, J.D (1963). The effect of sowing rate on the yield and compostion of wheat grown in soils of high fertility in southern New South Wales. Australian Journal of Experimental Agriculture and Animal Husbandry 3:114-118.

Kirby, J.M. and Kirchhoff, G. (1990). The compaction process and factors affecting soil compactibility. Proceedings of Queensland Department of Primary Industries Soil Compaction Workshop, Toowoomba, 1990 (Eds. M.N. Hunter, C.J. Paull and G.D. Smith).

Koger, J.L., Burt, E.C. and Trouse, A.C. Jr. (1983). Multiple pass effects of skidder tires on soil compaction in soil bins. Paper No. 83-1919, ASAE, St Joseph, Michigan 49085.

McGarry, D. (1990). Soil structure degradation: extent, nature and significance in south east and central Queensland. Proceedings of Queensland Department of Primary Industries Soil Compaction Workshop, Toowoomba, 1990 (Eds. M.N. Hunter, C.J. Paull and G.D. Smith).

Northcote, K.H. (1977). A Factual Key for the Recognition of Australian Soils. Rellim Technical Publications, Glenside, South Australia.

Pollock, D. Jr., Perumpral, J.V. and Kuppusamy, T. (1984). Multipass effects of vehicles on soil compaction. Paper No. 84-1054, ASAE, St Joseph, Michigan 49085.

Rickman, J.F. and Chanasyk, D.S. (1988). Traction effects on soil compaction. Proceedings of Agricultural Engineering Conference, Hawkesbury, NSW, 25-28 September 1988.

Schafer, R.L., Johnson, C.E., Koolen, A.J., Gupta, S.C. and Horn, R. (1992). Future research needs in soil compaction. Transactions of the ASAE 35: 1761-1770.

Shields, P.G. (1989). Soils of the Biloela Research Station, Queensland. Queensland Department of Primary Industries Research Establishments Publication QR89001. Department of Primary Industries, Queensland Government, Brisbane 1989.

So, H.B. (1990). The extent and significance of compaction in Vertisols. Proceedings of Queensland Department of Primary Industries Soil Compaction Workshop, Toowoomba, 1990 (Eds. M.N. Hunter, C.J. Paull and G.D. Smith).

Soil Survey Staff. (1975). Soil Taxonomy - A Basic System of Soil Classification for Making and Interpreting Soil Surveys. USDA Agricultural Handbook No. 436. US Government Printer, Washington DC.

Soane, B.D., Blackwell, P.S., Dickson, J.W. and Painter, D.J. (1981). Compaction by agricultural vehicles: a review. II. Compaction under tyres and other running gear. Soil and Tillage Research 1: 373-400.

Thomas, G.A., Myers, R.J.K., Foale, M.A., French, A.V., Hall, B., Ladewig, J.H., Dove, A.A., Taylor, G.K., Lefroy, E., Wylie, P. and Stirling, G.D. (1981). Evaluation of row spacing and population density effects on grain sorghum over a range of northern Australian environments. Australian Journal of Experimental Agriculture and Animal Husbandry 21, 210-17.

Tullberg, J.N. (1990). Why control field traffic? Proceedings of Queensland Department of Primary Industries Soil Compaction Workshop, Toowoomba, 1990 (Eds. M.N. Hunter, C.J. Paull and G.D. Smith).

SOIL AND CROP RESPONSES TO COMPACTION BY RUBBER TYRES ON A CRACKING CLAY IN CENTRAL QUEENSLAND

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ABSTRACT

One pass of a bald tractor tyre was used to compact a moist, shallow cracking clay. The effects on soil physical properties and sorghum growth were measured. The average surface depression was 35 mm. Compaction significantly increased bulk density to a depth of 150 mm and penetration resistance to 195 mm, and decreased hydraulic conductivity by 91% at the soil surface and 72% at 100 mm depth. Compaction significantly reduced crop establishment, plant height, water extraction front advance rate from 43 mm day^{-1} to 30 mm day^{-1} and dry matter at anthesis. There was no effect on dry matter at harvest or grain yield (mean 1700 kg ha^{-1}). In this season better early growth in the uncompacted soil was no advantage as water stress at and after anthesis dominated grain yield. Treatments with zero-tillage after compaction performed well indicating the effectiveness of compaction repair by cracking and self-mulching.

INTRODUCTION

Compaction may be broadly defined as the act of moving soil particles closer together by force. Degradation by wheels, tillage implements and animal hooves are the principle causes of compaction. It has been estimated that soil compaction reduces annual productivity of field crops in Australia by $300-850 million (So, 1990).

Traffic-induced compaction directly affects soil physical, chemical and biological properties and processes, and indirectly influences plant root growth. Physical properties affected include bulk density and porosity, pore size and continuity, temperature, aeration, soil-water relationships and permeability, and penetration resistance (Panayiotopoulos *et al.*, 1994). Root elongation is reduced, while root diameter and branching usually increase (Tardieu, 1994). In general, a soil penetrometer resistance of approximately 1100 kPa will reduce root elongation by 40-50% (Bennie, 1991, cited by Volkmar, 1994).

Tullberg and Lahey (1990) showed that tractor wheelings always cover at least 15%, but more commonly 20-25%, of the tillage implement width. The energy requirement of sweeps working in wheel tracks varied from 1.1-2.9 times that of sweeps in unwheeled soil.

One method of limiting soil compaction induced by wheels is a controlled traffic system. Such a system can potentially (Tullberg, 1986) :-

- reduce the energy required for crop establishment by at least 50%;
- reduce the requirement for tractor power by at least 30%;
- maintain yield without the necessity for deep-tillage operations; and
- increase rainfall infiltration, thereby reducing runoff and erosion in some circumstances.

MATERIALS AND METHODS

Site

The experimental plots are located at the Emerald Research Station (23°29`S, 148°09`E, 190m a.s.l.). Slope is 1.0%. The soil is a shallow open downs cracking clay, developed from weathered basalt. The principle profile form (Northcote, 1977) is Ug5.12. Long-term mean annual rainfall and evaporation are 639 mm and 2265 mm, respectively.

Treatments

The experiment commenced on 13 September, 1994, when all compacted treatments received one wheel pass with a John Deere 4430 tractor. The whole plot was compacted in a series of passes, each beside the previous pass. Bald tyres were used to give uniform compaction and thereby simplify sampling. The site had been sprinkler irrigated four days prior to compaction. Average mass on the front axle was 1070 kg (11.00-16 tyres), and the rear axle 7470 kg (18.4-38 tyres).

Four treatments study the "repair" of initial compaction damage:

T_1: Control - nil compaction, mechanical and chemical weed control
T_2: Extreme compaction - heavy compaction each year when wet, mechanical weed control
T_3: Current Best Advice - initial compaction, deep rip when dry
T_4: Zero-tillage - initial compaction, chemical weed control, optional double cropping
T_5: Traditional practice - light compaction each year when wet, mechanical weed control

There are three replications and treatments are split for three fertiliser rates (nil, 40 kg ha^{-1} MAP, MAP+additional 50 kg N ha^{-1}) applied at sowing. Sub-plots receive supplementary flood irrigation at anthesis.

Experimental Details

Treatments T_2 and T_5 received a shallow cultivation on 23 September to create a seedbed, the experiment was irrigated (35 mm) on 26 September and sorghum (var. MR31) sown on 3 October at 290000 seeds ha^{-1}. The sorghum was planted in 600 mm rows with a zero-till planter equipped with narrow sowing points, parallelogram tynes and press wheels. A further 20 mm irrigation was applied on 5 October to ensure emergence during hot, dry weather.

Plots measure 12 x 5.4 m, and each plot contains three beds 1.8 m wide. After compaction, all traffic is restricted to permanent wheel tracks.

Measurements

Soil

a) Bulk Density - (i) soil sampling using 100 mm diameter core, with depth increments of 50 mm to 200 mm, and 100 mm to 500 mm.
(ii) twin probe gamma ray density meter (Campbell Pacific Nuclear Model MC-24S Stratigauge) in 50 mm increments to 500 mm.
b) Soil Water Content - gravimetric determination in association with core bulk density. In-crop soil water measurements are taken using a neutron moisture meter (Campbell Pacific Nuclear Model 503).
c) Surface Profiles - a Rimik Profilemeter with 15 mm spaced pins was used to determine heave and surface depression after each wheel pass.

d) Cone Penetrometer Index - a Rimik CP10 Recording Cone Penetrometer was used to measure force per unit base area in increments of 15 mm to 450 mm depth. The penetrometer was fitted with a standard 30° circular stainless steel cone of 12.83 mm diameter with a 9.83 mm shaft (ASAE Standards, 1992).
e) Hydraulic Conductivity - disc permeameters (Perroux and White, 1988) were used at supply tensions of -1, -2, -3 and -4 cm H_2O, and depths of 0 (surface) and 100 mm to calculate hydraulic conductivity and macropore density.

Crop
a) Establishment - percentage of seed sown was determined by calibrating the planter and taking counts of emerged seedlings at 15 days after sowing (DAS).
b) Early crop growth - 20 plants were measured for height (soil surface to extended leaf tip) from the centre row in each fertiliser sub-plot 24 DAS.
c) Aboveground dry matter - plant tops were sampled at anthesis (60 DAS) and harvest (116 DAS) from an area of 1.8 m^2 in each fertiliser sub-plot. All samples were taken from the centre bed. Plant material was dried at 80°C to constant weight.
d) Grain Yield - grain was hand-harvested in conjunction with the harvest dry matter samples, and dried with the plant material. Final yields were standardised to 12.0% moisture content.

RESULTS

Soil Properties

Table 1 summarises the effect of one tractor wheel pass on selected soil properties.

Average gravimetric soil water content at compaction was 0.4 g g^{-1} at 50-100 mm, decreasing to 0.35 g g^{-1} at 300 mm, and remaining uniform at depth.

The compaction caused by the tractor tyres depressed the soil surface by 40-50 mm. Heave outside the wheel was 10-15 mm. Average compaction across the bed was 35 mm. A significant increase in core bulk density was evident to a depth of 150 mm. At 100-150 mm, compaction increased bulk density from 1.15 to 1.30 g cm^{-3}.

Penetration resistance was significantly increased by compaction to a depth of 195 mm. Maximum resistance occurred at a depth of 30 mm below the new soil surface. This depth below the new compacted soil surface (65 mm below original soil surface) is where crop seeds are sown.

Compaction caused a 91% reduction in hydraulic conductivity at the soil surface, and a 72% reduction at 100 mm depth. Similar reductions in macropore density were measured.

Table 1. Effect of applied compaction on selected soil properties.

Soil Property			Pre-Compaction	Post-compaction
Bulk Density (g cm^{-3})	0-100 mm		1.09	1.21
Penetration Resistance (kPa)	30 mm		267	1738
Hydraulic Conductivity (mm hr^{-1})	Surface		803	70
	100 mm		115	32
Macropore Density (no. m^{-2})	Surface	1.0 mm dia.	168.9	15.0
		1.6 mm dia.	30.0	3.6
		3.0 mm dia.	4.2	0.4
	100 mm	1.0 mm dia.	23.4	4.7
		1.6 mm dia.	4.7	1.4
		3.0 mm dia.	0.6	0.2

Crop Growth

Table 2 summarises the effect of one wheel pass on the subsequent growth of a sorghum crop.

Establishment of sorghum was significantly reduced by compaction in T_2 and T_4. There was a non-significant decrease in T_3 and T_5. Cultivation prior to planting (T_2 and T_5) had no effect on establishment compared to other compacted treatments (T_3 and T_4).

By 24 days after sowing, plants in the control plots were significantly taller than those in the compacted plots (520 mm compared to 370 mm). A positive correlation existed between establishment percentage and plant height at 24 days. The reduction in plant height due to compaction could be associated with slower root growth down the profile. The extraction front advance rate was reduced from 43 mm day^{-1} in T_1, to 30 mm day^{-1} in compacted treatments. These rates are comparable with work undertaken by Robertson *et al.* (1993).

Aboveground dry matter at anthesis was significantly reduced by compaction, except in T_5. The observed effect of compaction on sorghum growth was less evident after anthesis. No significant response to compaction was evident in dry matter at harvest, or grain yield (except in T_2).

Table 2. Effect of applied compaction on dryland sorghum establishment, growth and yield

Treatment	Establishment (%)	Plant Height (mm)	Dry Matter at Anthesis (kg ha^{-1})	Dry Matter at Harvest (kg ha^{-1})	Grain Yield (kg ha^{-1})
T_1	73	523	5573	7220	1879
T_2	58	350	3559	4728	997
T_3	68	393	4533	6523	1913
T_4	61	367	4426	6238	1702
T_5	66	374	4586	6427	1984
lsd (P=0.05):	8	22	1039	1286	722

DISCUSSION

All soil physical properties measured showed significant changes to similar depths (150-200 mm). The most dramatic response to compaction was the 91% reduction in surface hydraulic conductivity, and similar reductions in macropore density. Non-significant changes were measured below 200 mm, but a small change does not necessarily imply soil structural degradation to a sufficient extent to inhibit the development of plant roots.

Compaction reduced establishment in most treatments. The reduction in establishment could be attributed to reduced seed-soil contact, and poor seed coverage with soil. The relatively good establishment in compacted treatments may be due to the zero-till planter used. We expect that traditional sowing equipment would result in greater reductions in establishment.

The reduction in aboveground dry matter at anthesis is attributed to reduced root development. The extraction front advance rate was reduced from 43 mm day^{-1} to 30 mm day^{-1} in compacted treatments. Although the advance rate was decreased, an increase in root diameter and branching may result. Tardieu (1994) reported that an increase in diameter could possibly avoid root buckling. This “biological drilling” has the potential to ameliorate subsoil in poor physical condition (Cresswell and Kirkegaard, 1995).

The absence of a reduction in grain yield due to compaction shows that the plants compensated for reduced establishment and reduced early growth. Slow root development delayed peak water use, and left more stored soil water for grain filling. Harvest index was higher in compacted treatments than the control. With more rainfall after sowing, higher dry matter at anthesis should produce higher grain yields. The irrigation treatment was applied late this season due to equipment problems. Mean yield in irrigated plots was 2660 kg ha^{-1} and the treatment responses were similar to dryland results (Table 2). Most of the yield response to irrigation was due to tillering.

The total mass of the tractor used for this experiment was 8540 kg. This would be considered a very small tractor for dryland farming in this region. Work undertaken by Blunden *et al.* (1994) used tractors with a mass in excess of 15000 kg. Had our tractor been of this magnitude, soil and crop responses may have been more dramatic.

The satisfactory performance of the zero tillage treatment shows that natural amelioration due to the cracking and self-mulching properties of this soil may be an important phenomenon in the compaction/repair process.

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REFERENCES

ASAE Standards (1992). American Society of Agricultural Engineers, St. Joseph, Michigan.

Blunden, B.G., McBride, R.A., Daniel, H., and Blackwell, P.S. (1994). Compaction of an earthy sand by rubber tracked and tyred vehicles. *Aust. J. Soil Res.* 32:1095-1108.

Cresswell. H.P. and Kirkegaard, J.A. (1995). Subsoil amelioration by plant roots - the process and the evidence. *Aust. J. Soil Res.* 33:221-239.

Northcote, K.H. (1977). A Factual Key for the Recognition of Australian Soils. Rellin Technical Publications, Glenside, South Australia.

Panayiotopoulos, K.P., Papadopoulou, C.P., and Hatjiioannidou, A. (1994). Compaction and penetration resistance of an Alfisol and Entisol and their influence on root growth of maize seedlings. *Soil and Tillage Research* 31:323-337.

Perroux, K.M. and White, I. (1988). Designs for disc permeameters. *Soil Science Society of America Journal* 52:1205-1215.

Robertson, M.J., Fukai, S., Ludlow, M.M., and Hammer, G.L. (1993). Water extraction by grain sorghum in a sub-humid environment. I. Analysis of the water extraction pattern. *Field Crops Research* 33:81-97.

So, H.B. (1990). The extent and significance of compaction in Vertisols. Proceedings of Queensland Department of Primary Industries Soil Compaction Workshop, Toowoomba, 1990 (eds. M.N. Hunter, C.J. Paull and G.D. Smith).

Tardieu, F. (1994). Growth and functioning of roots and of root systems subjected to soil compaction. Towards a system with multiple signalling? *Soil and Tillage Research* 30:217-243.

Tullberg, J.N. (1986). Controlled Traffic Tillage and Planting. Technical Report NERDDP EG 87/675. Dept. Prim. Ind. and Energy, Canberra.

Tullberg, J.N. and Lahey, G.V. (1990). Controlled traffic cropping. Technical Report NERDDP 1029. Dept. Prim. Ind. and Energy, Canberra.

Volkmar, K.M. (1994). Pre-germination effects on mechanically impeded root growth of barley (*Hordeum vulgare* L). *Plant and Soil* 163:197-202.

MEASURING THE VARIATION OF SOIL MECHANICAL PROPERTIES WITH TREATMENT AND TIME IN A COMPACTION CONTROL AND REPAIR EXPERIMENT.

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ABSTRACT

This paper investigates the use of critical state soil parameters measured in a simple shear box to characterise the state of two soils subject to different compaction control and repair regimes. It is shown that the compressibility and void ratio parameters are strong functions of the void ratio and degree of saturation at the critical stress, and can be used to distinguish between the different treatments.

1. INTRODUCTION

A large scale compaction control and repair experiment is being carried out in Central Queensland, with the main experimental work centred on two sites at Biloela and Emerald. Six different treatments are being imposed, consisting of varying degrees of initial compaction and subsequent repair practices. A multi-disciplinary team has measured a wide range of soil and crop parameters in order to assess various methods of investigating compaction, its effects and its repair.

The Biloela site is on the Biloela Research Station, and consists of a black cracking soil formed on an alluvium, and is classified as a Vertisol. The Emerald site is on the Emerald Research Station, and the soil type is clasified as a shallow basaltic black earth, and is the same as in the major cropping areas of the Central Highlands. The farming practices being used are as realistic as is possible on small sites.

This paper reports measurements of soil mechanical properties measured on samples taken principally from the Biloela site. Some of these parameters can differentiate between the uncompacted, compacted and current best advice treatments and show how the soils vary with time.

These measured properties are parameters defined within the framework of the Cambridge critical state theory, which was initially derived for saturated clays in the civil engineering environment. It is well established there, and offers a powerful conceptual framework which deals with the mechanical behaviour and volume change behaviour of such soils under generalised conditions of loading.

Its application to unsaturated soils in the agricultural context has been discussed by a number of authors. There have been, until very recently, very few measurements presented in the literature of the relevant parameters, and their dependence on the state of the soil (that is, moisture content, density, stress history). The work of Leeson and Campbell (1983) considered two Scottish soils, and demonstrated the effect of water content on the gradient of the virgin compression line, which is expressed in terms of void ratio and the logarithm of applied stress, and concluded that the critical state theory can be extended to unsaturated agricultural soils. Hettiaratchi (1987) considered a sand, a loam and a clay soil and investigated the influence of microstructure, volume change and moisture status on soil strength, and demonstrated that the relevant state boundary surfaces of critical state theory for unsaturated soils could be determined. Kirby (1989) measured yield surfaces and the critical state condition on four unsaturated agricultural soils and demonstrated that these soils displayed yield and deformation behaviour qualitatively consistent with the critical state concept. In a later paper, Kirby (1991) measured critical state parameters of undisturbed samples of several Vertisols and investigated the inter-relationships and variability among the various parameters, and the dependence of the parameters on the state of the soil. Also, Petersen (1993) investigated the variation of critical state parameters using two different loam soils. Current work by Bakker (1994) has been directed at establishing critical state parameters and yield surfaces for a Vertisol and to investigate their dependence on moisture content and stress history.

Apart from Kirby, all these authors have used a triaxial apparatus to make their measurements, and all have commented on the tedious and slow processes required. This apparatus has the advantage that the stress state within the sample is completely defined. Kirby (1989) showed that a soil sample stressed in a split shear box, which is a much simpler and easier apparatus to use, displayed a behaviour analogous to critical state behaviour. The state of stress in a split shear box is unknown, and so boundary stresses have to be used to construct the critical state space. Recent work by Bakker et al (1994) using a simple shear box, which imposes a more uniform and predictable stress field, has also demonstrated critical state like behaviour in terms of boundary stresses. The simple shear box is limited, in that because of the particular stress fields it creates it cannot impose general stress paths defined by possible and practical combinations of shear and normal stresses.

For the results presented here, the approach of Bakker is followed in which the state of stress of the soil is expressed in terms of total stresses applied at the boundaries viz the applied normal stress, σ, and the applied shear stress, τ, rather than the effective octahedral stresses. Also the compressibility is expressed in terms of the void ratio e as opposed to specific volume due to the reactive nature of the clay soils to be examined. This represents a transformation of the Cambridge critical state concept to a critical state space defined by the applied total boundary stresses. Therefore, the relevant parameters necessary to describe the behaviour of the soil are themselves an analogue of the Cambridge critical state parameters and will be presented next for reasons of clarity.

By analogy with the critical state concept, the yield behaviour of the soil can be represented in e-σ-τ space. This model can be more conveniently represented by 2-dimensional diagrams of the e-ln σ and the τ-σ relationships. These relationships are illustrated in Figures 1 and 2 along with the relevant parameters which define their geometry.

These parameters include state parameters (the current void ratio and stresses) and the current pre-consolidation stress, P_c. When soil is compressed there is a slight reduction in void ratio for stresses below P_c, but after P_c is exceeded void ratio decreases markedly (Figure 2). Therefore, P_c is related to the strength of the soil, and can be found at the intersection of the tangents of the elastic section and the plastic section of the NCL. P_c also describes the maximum past stresses to which the soil was subject and therefore is related to the stress history of the soil. The corresponding void ratio at this stress is defined as the critical void ratio, e_{pc} (Kirby, 1989).

Property parameters can also be defined, and these include the compression index, λ_{bs}, and the rebound index, K_{bs}. These two parameters describe the volume change characteristics and are defined in Figure 2. The NCL in Figure 2 is fully described by

$$e = N_{bs} - \lambda_{bs} \ln \sigma \qquad ......(1)$$

where N_{bs}(capital nu) is defined as the void ratio at $\sigma = 1$ kPa.

The CSL in Figure 2 is described by,

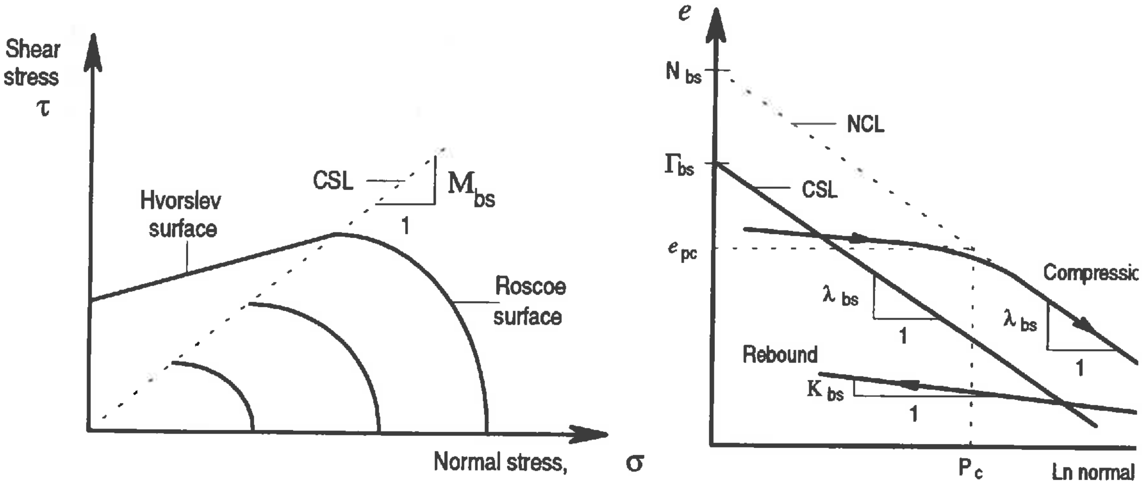
$$e = \Gamma_{bs} - \lambda_{bs} \ln \sigma \qquad \text{..........(2)}$$

where Γ_{bs} (capital gamma) is defined as the void ratio at $\sigma = 1$ kPa.

The slope of the critical state line in shear stress/normal stress space is described by

$$\tau = M_{bs} \sigma \qquad \text{..........(3)}$$

as shown in Figure 1.



FIGURES 1 and 2 Yield surface projection in σ - τ space and NCL and CSL projection in e - ln σ space

The subscript $_{bs}$ is used on all these parameters to emphasise that they have been derived using boundary stresses rather than the octahedral stresses on which critical state theory is based.

High values of λ_{bs} denote a soil which is compressible, because the increment of normal stress required to reduce void ratio by a given amount is decreased.

Higher values of N_{bs} imply that a soil is stronger, because it can support a stress of 1kPa at a higher void ratio, and because the volume of state space enclosed by the boundary surfaces extends to higher values of stress.

Higher values of Γ_{bs} similarly imply a stronger soil.

A number of authors including Leeson and Campbell (1983), Kirby (1989, 1991b) and Bakker (1994) have demonstrated that the above described parameters can be expected to vary according to the state (moisture content, degree of saturation) of an unsaturated soil while Hettiaratchi (1987) showed that the microstructural state and moisture content greatly influenced the behaviour of an unsaturated soil.

Soil behaviour in the present context refers to the mechanical behaviour as opposed to the electro-chemical behaviour. Hettiaratchi (1987) developed a simple model which dealt with those aspects of electro-chemical behaviour concerned with the micro-structure of a clay loam soil, and identified two extremes of microstructural state. These are "remoulded" and "cemented", and are identified respectively with soils as prepared in the laboratory, and field soils which have not been disturbed following saturation.

2. METHODS AND PROCEDURES

2.1 FIELD SAMPLING

Field (undisturbed or cemented) samples were collected for testing in the simple shear box to enable the relevant critical state parameters to be determined.

These samples were collected using thin walled sampling tubes, fabricated from sheet metal, 65 mm in breadth by 105 mm in length and 40 mm in height. The tubes were greased on the inside and then pushed into the soil and subsequently excavated and then sealed and wrapped to prevent moisture loss. They were then transported to Toowoomba for testing and when not required immediately, were stored in a refrigerator at 4^{O} C. For testing the sample was removed from the tube and then trimmed to the appropriate size. The samples were therefore tested at their field moisture contents.

2.2 REMOULDED SAMPLE PREPARATION

To provide information on the effect of microstructural state on soil strength, remoulded samples were prepared in the laboratory using loam soil from the Biloela experimental site and then shear and compression tested in the shear box.

Remoulded samples were prepared over a range of predetermined moisture contents (10 - 35 %) by adding a calculated amount of distilled water to a known mass of dry soil constituents. The resulting wet sample was placed in a polythene bag, sealed and then kneaded to distribute the moisture evenly. This disturbance constitutes the remoulding process and parallels that reported by Hettiaratchi (1987). The sample was then left to equilibrate for 48 hours and subsequently tested for moisture content.

2.3 MEASUREMENT OF CRITICAL STATE PARAMETERS

Undisturbed samples were tested for strength and compressibility at the field moisture contents. Eight samples were collected at each depth and this allowed four over-consolidation ratios to be sampled at both constant volume and constant load, thus eight tests were completed at each depth. After each test the samples were individually tested for moisture content by the oven drying method. Identical tests were performed on remoulded samples at each moisture content and each sample subsequently tested for moisture content.

2.4 UNI-AXIAL COMPRESSION TEST

Uni-axial compression was achieved by the application of only the normal stress prior to shearing. The shear box is stress controlled and the maximum allowable normal stress that could be applied to the sample was 300 kPa. For the field samples a maximum normal consolidation stress of 200 kPa was applied. This represented typical stress levels being applied to the soil by the compacting equipment. For remoulded samples a range of maximum normal consolidation stresses was applied, viz 100, 200 and 300 kPa.

Soil response in the compression test is measured by the void ratio, *e*. By plotting *e* as a function of the logarithm of applied stress, ln σ, values for λ_{bs}, K_{bs}, Γ_{bs}, N_{bs}, P_c and e_{pc} were determined.

3. RESULTS AND DISCUSSION

The results of these measurements can be grouped according to the site, the preparation, the time and the treatment, as follows:

Biloela

Remoulded Samples

Field Samples
June 1993, uncompacted and compacted (initial characterisation)
December 1993, uncompacted, compacted and current best advice
June 1994, uncompacted, compacted and current best advice

Emerald

Field Samples
March 1994, uncompacted and compacted (initial characterisation)

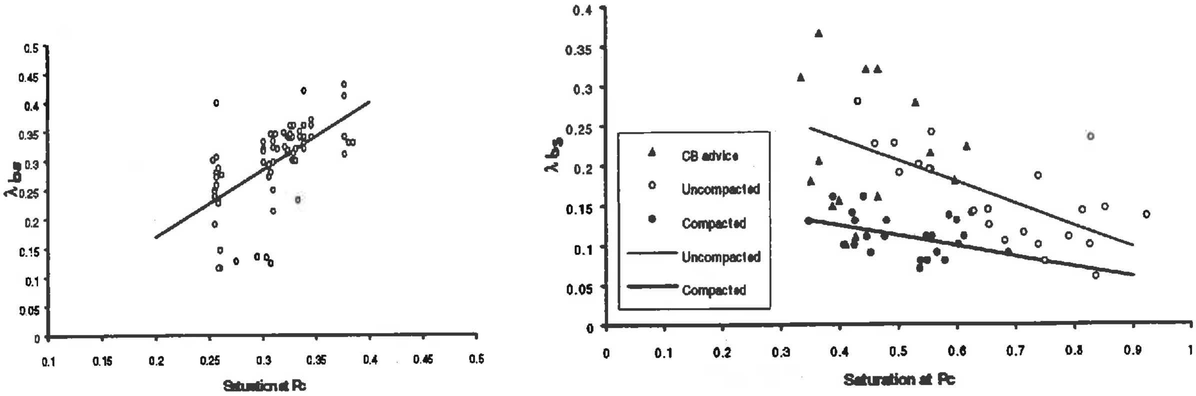
The total program of measurements has generated a large amount of data on the variation of the critical state parameters with soil type, microstructure, treatment, time and moisture content. The measurements of most interest here are those which reveal differences between treatments and with time.

3.1 BILOELA RESULTS

The two most significant independent variables were found to be the void ratio e_{pc} at the preconsolidation stress P_c, and the degree of saturation S_{epc} at the preconsolidation stress. The microstructural state of the soil was also found to have a significant effect on the variation of the parameters with e_{pc} and S_{epc}.

We have chosen therefore to present only a sample of the results which illustrate these variations. They are for the Biloela soil in its remoulded state, and as sampled in the field in December 1993.

Figures 3 and 4 show, respectively, the variation of λ_{bs} with S_{epc} for the remoulded and the field soil. It is obvious that the compressibility of the remoulded and cemented forms of this soil have opposite responses to the saturation at P_c. The remoulded soil becomes more compressible as the saturation increases, and its compressibility is always greater than that of the cemented soil. A highly saturated field soil has a low compressibility. This result is the same as that reported by Leeson and Campbell (1983) for loam soils, and by Kirby (1991b) for Vertisols. As expected, the compressibility of the uncompacted field soil is greater than that of the compacted soil. For both remoulded and cemented soils, other data (not given here) shows that the compressibility increases with e_{pc}. When the variation of λ_{bs} with S_{epc} and e_{pc} is considered, straight lines as defined below can be fitted to the data.



FIGURES 3 and 4 Compression index, λ_{bs}, versus saturation at the pre-consolidation stress .

For Figure 3, the remoulded soil

$$\lambda_{bs} = -0.566 + 0.437\, e_{pc} + 0.347\, S_{epc} \qquad (R^2=0.506)$$

For the field soil (December 1993) in Figure 4, which is
(a) uncompacted

$$\lambda_{bs} = 0.0871 + 0.120\, e_{pc} - 0.0946\, S_{epc} \qquad (R^2=0.478)$$

(b) compacted

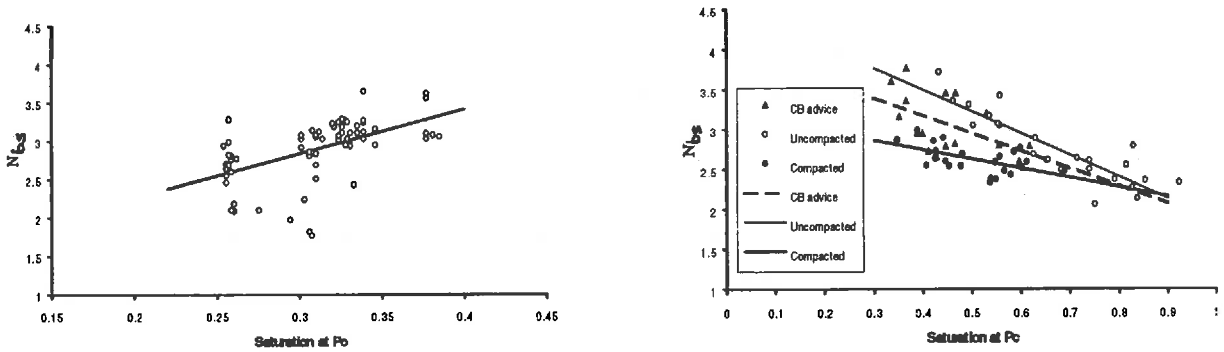
$$\lambda_{bs} = -0.172 + 0.245\, e_{pc} - 0.00071\, S_{epc} \qquad (R^2=0.608)$$

(c) current best advice

$$\lambda_{bs} = -1.24 + 0.70\, e_{pc} - 1.201\, S_{epc} \qquad (R^2=0.807)$$

Differences between the initial compacted and uncompacted treatments in June 1993 were minimal, with the uncompacted samples being slightly more compressible at higher void ratios. The December 1993 samples described above show substantial differences between the treatments.

Figure 5 and 6 show how N_{bs} varies with S_{epc} for the remoulded soil and the field soil respectively. Again, the variation of this parameter with S_{epc} is the opposite for the two microstructural states. At low saturations the field soil when uncompacted has a higher void ratio than the remoulded or compacted soil, which is as expected. N_{bs} was also found to be an increasing function of e_{pc} for both cemented and remoulded soils, and the lines of best fit to the data were as follows.



FIGURES 5 and 6 NCL void ratio at $\sigma = 1$ kPa, N_{bs}, versus saturation at the pre-consolidation stress

For Figure 5, the remoulded soil

$N_{bs} = -2.02 + 2.71\, e_{pc} + 0.801\, S_{epc}$ (R^2=0.499)

For Figure 6, the field soil in December 1993

(a) uncompacted

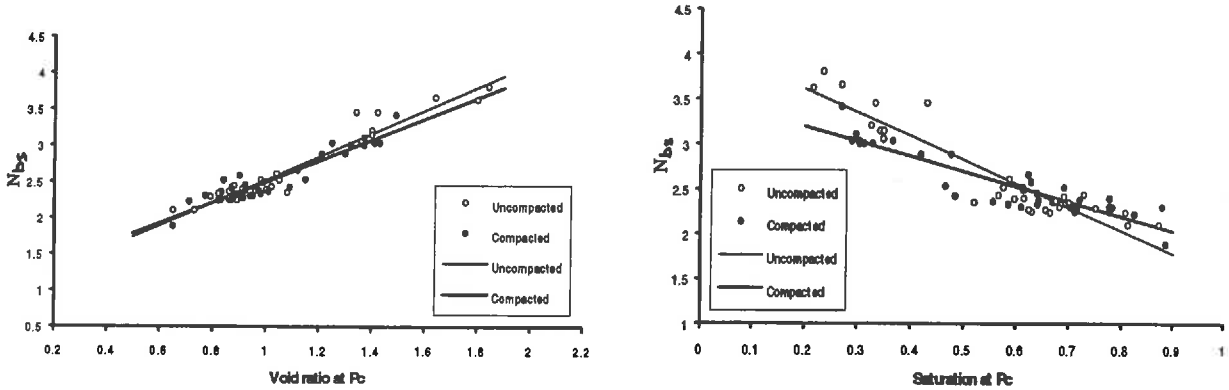
$N_{bs} = 1.67 + 1.38\, e_{pc} - 0.698\, S_{epc}$ (R^2=0.854)

(b) compacted

$N_{bs} = 0.368 + 2.01\, e_{pc} - 0.126\, S_{epc}$ (R^2=0.837)

(c) current best advice

$N_{bs} = 2.24 + 2.93\, e_{pc} - 3.32\, S_{epc}$ (R^2=0.784)



FIGURES 7 and 8 NCL void ratio at σ = 1 kPa, N_{bs}, versus void ratio and saturation at the pre-consolidation stress - June 1993.

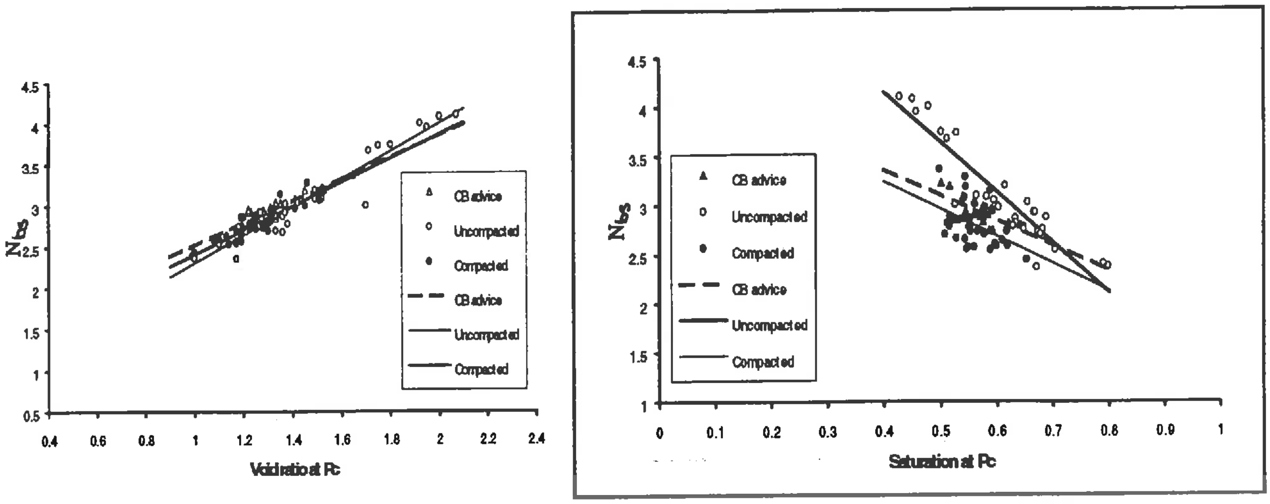
Figure 7 shows that there were no significant differences between the treatments in June 1993 when plotted as functions of e_{pc}. However, plotting against S_{epc} as shown in Figure 8 reveals differences, with the compacted soil becoming stronger at high saturations.

The two void ratio parameters Γ_{bs} and N_{bs} are highly correlated, with a typical R^2 in excess of 0.9. For instance, the uncompacted field soil in December 1993 yielded the following relationship between Γ_{bs} and N_{bs}.

$\Gamma_{bs} = 0.147 + 0.884\, N_{bs}$ (R^2=0.924)

The relationship for the other treatments was not statistically different from this, and a similar conclusion could be drawn across all times and treatments. N_{bs} is a reliable predictor of Γ_{bs}, and so the location of the critical state line is not an additional independent parameter useful for distinguishing between treatments. The slope of the critical state line, M_{bs}, did not show any consistent variation with treatment or time, and is therefore also not useful as a measurement of the degree of compaction.

The field samples taken in June 1994 were wetter than any of the previous samples, and moisture content was not adjusted before testing. However, the parameter S_{epc} can be used to correct for this uncontrolled moisture content because it is defined at a known point (P_c) and therefore depends on both the moisture content and stress history of the soil. Figures 9 and 10 show N_{bs} plotted as a function of e_{pc} and S_{epc} respectively for the samples taken in June 1994. Plotting against S_{epc} clearly reveals the differences between the treatments.



FIGURES 9 and 10 NCL void ratio at $\sigma = 1$ kPa, N_{bs}, versus void ratio and saturation at the pre-consolidation stress - June 1994.

3.2 FURTHER COMMENTS

The major changes in the parameters were measured after the first six months or between June 1993 and December 1993 with only a few slight changes measured in the following six months to June 1994. After the first six months, the soil had increased in strength and had decreased in compressibility over all treatments.

The uncompacted treatment was found to have a higher degree of variability in void ratio than both the current best advice and compacted treatments.

Differences between the uncompacted and compacted treatments at Emerald were found in all the parameters. These differences became more apparent when compared with the level of saturation. A significant difference in the parameters, P_c, λ_{bs}, N_{bs} and Γ_{bs} was found between the surface and the subsoil samples in the compacted treatment. This difference was not found in the parameter M_{bs} or in the separation of the intercepts N_{bs} and Γ_{bs}. The uncompacted samples were more compressible and more likely to compress when sheared and required a lower level of stress for failure. Therefore the uncompacted treatment is more susceptible to compaction. The surface of the compacted treatment was less compressible and had a higher strength than the subsoil and this could aid in preventing damage to the subsoil.

4. CONCLUSIONS

It is possible to use simply measured critical state parameters based on boundary stresses applied by a simple shear box to distinguish between compacted, uncompacted and current best advice treatments for the field soils investigated in this work.

For all treatments, the compressibility λ_{bs} and the normal compression parameter N_{bs} are highly correlated with the void ratio e_{pc} at the critical stress P_c, and the degree of saturation S_{epc} at this void ratio. S_{epc} depends on the stress history of the soil and its current moisture content, and was found to assist in differentiating between treatments for soils with high moisture contents.

In terms of these parameters, the behaviour of a remoulded soil is quite different from that of a field soil. λ_{bs} is found to increase with e_{pc} rather than decrease. The critical state parameter

Γ_{bs} is highly correlated with the normal compression parameter N_{bs}, and so it cannot be used as an additional soil parameter. The slope of the critical state line, M_{bs}, did not show any consistent variation with treatment or any of the independent variables.

5. REFERENCES

Bakker, D. M., 1994. Critical State Soil Mechanics Parameters for a Vertisol. Submitted to Soil and Tillage Research.

Hettiaratchi, D. R. P., 1987. A critical state soil mechanics model for agricultural soils. *Soil Use and Management*, **Vol 3**, No 3, 94 - 105.

Kirby, J. M., 1989. Measurements of the yield surfaces and critical state of some unsaturated agricultural soils. *Journal of Soil Science*, **40**, 167 - 182.

Kirby, J. M., 1991b. Critical state soil mechanics parameters and their variation for vertisols in eastern Australia. *Journal of Soil Science*, **42**, 417 - 500.

Leeson, J. J and Campbell, D. J., 1983. The variation of soil critical state parameters with water content and its relevance to the compaction of two agricultural soils. *Journal of Soil Science*, **34**, 33 - 44.

Petersen, C. T., 1993. The variation of critical-state parameters with water content for two agricultural soils. *Journal of Soil Science*, **44**, 397 - 410.

A comparison of the impact of 14 years of conventional and no-till cultivation on physical properties and crop yields of a loam soil at Grafton NSW.

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Abstract.

The impact of 14 years of continuous conventional (CT) or no-till (NT) cultivation on surface soil structure and crop yields were examined on a loam soil at Grafton in N.S.W. During the earlier years of the trial, soil porosity and crop yields were not greatly effected by the different tillage techniques. At the end of the trial, however, soil porosity, stability, and crop yields were greatest under NT.

Measured increases in soil macroporosity, and stability under long term NT were consistent with higher saturated hydraulic conductivity, plant available water, water use efficiency, and crop yields. The improvement in soil structure observed under NT is believed to have been the major contributor to the sustained improvement of crop yields.

Introduction.

Past research into the long term effects of cultivation upon soil physical properties, has yielded many apparently contradictory results (Lal et al 1989). Tillage effects on soil properties are usually site specific and depend upon the interaction of soil and climatic conditions, with soil and crop management practices.

Under non-limiting conditions, the availability of water to crops is largely determined by soil porosity. Tillage immediately increases the total porosity of soils (Hamblin 1984; Lindstrom and Onstad 1984) through the creation of a few strongly irregular macropores (Pagliai et al 1984). However, prolonged continuous conventional tillage (CT) reduces soil porosity through the mechanical obliteration and compaction of structure, and the gradual degradation and loss of the soil organic matter which stabilises soil aggregates against slaking, dispersion, and collapse. Significant tillage-induced structural degradation of loam soils can occur as early as 3 (Burch et al 1986) to 5 years (Hamblin 1984) after the commencement of cultivation, and is typically associated with reductions in crop yields.

By contrast, the prolonged use of continuous no-till (NT) has been shown to gradually improve the stability, macroporosity, and crop yields of loam soils over time (Hamblin 1984; Unger and Fulton 1990). Within a NT system soil porosity develops through the actions of the soil biota, which typically occur in higher densities under NT. For example, Chan and Heenan (1993) found a significant correlation between the increased macropore incidence and the greater earthworm population densities found in the soil under extended NT.

Methods.

An experimental field trial was conducted at a site in Grafton, NSW, which had previously been under pasture for at least 5 years. The soil at the site had weakly structured loam A horizons (0-30cm), which abruptly graded into more strongly structured clay loam (to medium heavy clay at depth) B horizons. These soils have been variously classified as red/yellow Podzolics (Stace et al 1968), Kurosols (Isbell 1992), or Ultisols (Soil Survey Staff 1975).

The experiment began in 1981, and consisted of two tillage treatments (CT and NT) within a summer soybean and winter cereal crop rotation. Each treatment was replicated 3 times and each replicate consisted of a field plot measuring 60m long x 20m wide. NT treatments were never disturbed apart from the sowing operation, whereas CT treatments were chisel ploughed to a depth of 20cm and disk harrowed between each crop. Superphosphate was applied at a rate of 400kg/ha four weeks prior to the sowing of the soybeans, and an additional 100kg/ha was applied at sowing. Potash was used in some years at rates of up to 100kg/ha, and Molybdenum was applied as a seed dressing. A four row direct drill planter was used on both treatments.

Soil samples were collected to a depth of 50cm to determine soil bulk density, and also structural stability using the wet sieving and percentage dispersible silt and clay techniques. Soil water potential data were obtained using the pressure plate technique and intact soil cores. Soil strength measurements were made in the laboratory using intact soil cores and a laboratory penetrometer, following a series of unsuccessful attempts at measuring strength in the field. Saturated and unsaturated (4cm suction) hydraulic conductivity were measured in the field using disc permeameters, and crop water use was determined using a neutron moisture meter.

A rainfall event with an intensity of 80mm/hr was simulated in the field to assess the infiltration and runoff characteristics of the soil. Soil cores were collected before and after the simulation to examine the redistribution of infiltrated water.

Results and Discussion.

Although some deeper measurements were made, the majority of the significant treatment effects were detected within the surface 20cm of the soil profile. Previous work at the site by Harte and Desborough (1985) and Thompson (1986) found that the soil bulk density was not greatly effected by tillage during the early years of the trial. However, recent data has shown that the NT surface soil has a significantly lower bulk density than the CT surface soil.

Table 1 : Soil physical properties in year1 (Y1) and year14 (Y14) of the cropping phase

Physical Property of the Soil		No Tillage	Conventional Cultivation	l.s.d.	Prob %
Bulk Density (g/cm^3)	Y1 0-10cm*	1.38	1.34	0.07^+	0.01
	Y14 0-10cm	1.13	1.37		
	Y1 10-20cm*	1.51	1.46		
	Y14 10-20cm	1.36	1.44		
	Y14 20-30cm	1.37	1.40	n.s.	
	Y14 30-40cm	1.31	1.36	n.s.	
	Y14 40-50cm	1.24	1.30	n.s.	
Percentage organic matter **	Y14 0-10cm	3.37	1.65	n.a.	
Dispersible silt and clay %	Y14 0-10cm	16.3	23.6	6.2	0.01
Dispersible clay %	Y14 0-10cm	0.6	1.9	0.9	0.01
Mean Weight Diameter (mm)	Y14 0-5cm	4.48	0.83	2.08	0.01
	Y14 5-10cm	2.73	1.10	1.37	0.05
Hydraulic Conductivity (mm/hr)	Y14 sat	189.4	28.0	75.5	0.01
(surface 10cm only)	Y14 unsaturated	2.3	10.8	7.8	0.05

* from data of D.Thompson (1986) ** from data of N.Dacquiado (1994) (Pers Comm)
+ l.s.d. for bulk density data are valid across time, depth, and treatments.

The bulk density of the CT surface soil did not change greatly over the 14 years of the experiment, whereas it has significantly decreased in the NT surface soil. This indicates that the dominant treatment effect was the development of porosity occurring under NT. The higher organic matter content of the NT surface soil (see Table 1) supports this conclusion, as it is typically associated greater biological activity.

Soil bulk density below a depth of 20cm was consistently greater under CT than under NT. Although not statistically significant, the consistency of the data suggests that sub-surface (below 20cm depth) compaction may have occurred under CT and not under NT.

The dispersible silt and clay, dispersible clay, and mean weight diameter data shown in Table1 indicate that the NT surface soil was more stable and aggregated than the CT soil. These differences in stability are consistent with differences in the soil organic matter contents under the different treatments. The collapse of the larger unstable aggregates, and the associated increase in the smaller aggregate sizes, as shown in Figure1, contribute to the lower porosity and greater bulk density of the CT surface soil.

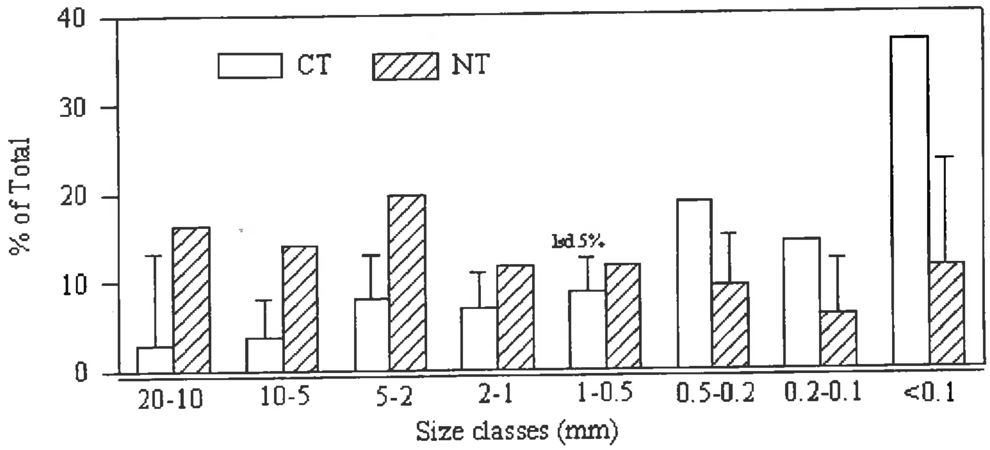

Figure1 : Proportion of total aggregates in each size class.

The NT surface soil had a significantly higher saturated hydraulic conductivity (K_{sat}) and a significantly lower unsaturated hydraulic conductivity (K_{unsat}) than the CT surface soil. The difference between K_{sat} and K_{unsat}, is due to the contribution of macropores with a diameter >0.8mm (transmission pores) to K_{sat}. The difference measured between K_{sat} and K_{unsat} was greatest for the NT soil, and is consistent with the data of Chan and Heenan (1993).

As a result of the observed effects on soil porosity, soil water release characteristics were also effected by tillage (see Table 2). The soil water content at wilting point (ψ_m=-1.5 MPa) was not significantly different between the two treatments. However, at field capacity (ψ_m = -0.01MPa) and at saturation (ψ_m = 0 MPa) NT had greater water contents.

Table 2 : Water potential data for the CT and NT soils (Y14) (cm^3/cm^3)

Matric potential (MPa)	**CT 0-5cm**	**NT 0-5cm**	**CT 5-10cm**	**NT 5-10cm**	**CT 10-20cm**	**NT 10-20cm**
0 (saturation)	0.40^a	0.61^b	0.47^a	0.50^a	0.53^a	0.51^a
-0.01 (field capacity)	0.27^c	0.36^d	0.37^b	0.42^b	0.42^b	0.40^b
-1.5 (wilting point)	0.06^e	0.11^e	0.21^c	0.22^c	0.24^c	0.23^c
0-0.01 (drainage) (mm)	6.5	12.5	5.0	4.0	11.0	9.0
0.01-1.5 (available water) (mm)	10.5	12.5	8.0	10.0	18.0	17.0

($^{a b c d e}$ are significantly different at P<0.05 within each depth interval)

The greater number of macropores within the surface of the NT soil resulted in a significantly greater amount of water between the matric potentials of 0MPa and -0.01MPa, and also -0.01 MPa and -1.5 MPa. This is consistent with the higher hydraulic conductivity of the NT soil, and suggests that water infiltration and redistribution characteristics of NT surface soil are superior to those of the CT surface soil. As a result the ability of NT surface soil to readily transmit water, the overall potential of the NT profile to store and provide water for crops was superior to that of CT profile.

Soil strengths above 2000kPa are thought to impede root extension and the data in Table 3 show that at a matric potential of -1.5 Mpa the overall strength of the CT surface soil was greater than that of the NT soil, and that it also exceeded 2000kPa. The combination of lower plant available water holding capacity and greater soil strength suggests that root extension may have been inhibited to a significantly greater extent under CT. Unfortunately root sampling was not conducted.

No significant differences in soil strength were detected between the treatments at matric potentials of 0 MPa (saturation) or 0.01MPa (field capacity)

Table 3 : Soil strength (kPa) under CT and NT at a matric potential of -1.5Mpa (Y14)

Depth	CT	NT	Avg
0-5cm	1874^{a}	1236^{a}	$1555^{a''}$
5-10cm	2898^{a}	1927^{a}	$2413^{b''}$
10-20cm	3709^{a}	2234^{a}	$2972^{c''}$
Avg	$2827^{a'}$	$1799^{b'}$	

($^{a\ b}$ are significantly different at $P<0.05$)

Under simulated rainfall, the steady state infiltration rates of CT plots were significantly lower than those of NT plots (5mm/h and 25mm/hr respectively). These infiltration rates were consistent with the redistribution data, which found that, after the simulation, the water contents of the NT and CT soil profiles had increased by 27mm and 13mm respectively. A reduction in infiltration typically results in greater runoff and soil loss and the calculated soil losses during the simulation were equivalent to 12.1t/ha and 2.6t/ha under CT and NT respectively.

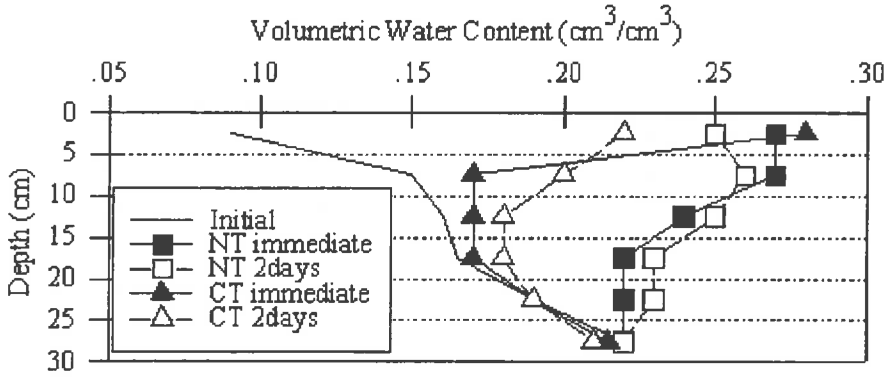

Figure 2 : Distribution of water in the profile before and after rain.

Immediately prior to the simulation, the initial soil profile water contents of the two treatments were not significantly different, and were plotted as a single line (see Figure 2). Immediately after the simulation, water had penetrated to depths of 25cm and 15cm for the NT and CT treatments respectively. Two days later infiltrated water had moved further into the profiles of both treatments.

Surface sealing was observed on CT soil under rapid wetting. The associated reduction in surface soil porosity would have contributed to reduced infiltration and increased soil loss of the CT soil. Similar results have been reported by Chan and Mead (1988), and Burch et al (1986).

A blanket of decaying plant residues, fungi, mosses, and lichens covered the NT soil, whereas the CT soil was sealed with a bare hardsetting erosional crust. Seedling counts of 14 plants/m^2 under CT, and 36 plants/m^2 under NT were taken during the establishment of the soybean crop, these differences are consistent with the greater strength of the CT surface soil when dry.

The relationship between crop yields and tillage practices has changed over time. As shown in Figure 3, the annual soybean yields of the NT treatments between 1981 and 1985 were consistently less than or equal to those resulting from CT (averages of 2.46t/ha and 2.82t/ha respectively). CT was unable to sustain these higher yields indefinitely, and from 1987 onwards the yields of the NT treatments were typically greater than those of the CT (averages of 2.14t/ha and 1.67t/ha respectively).

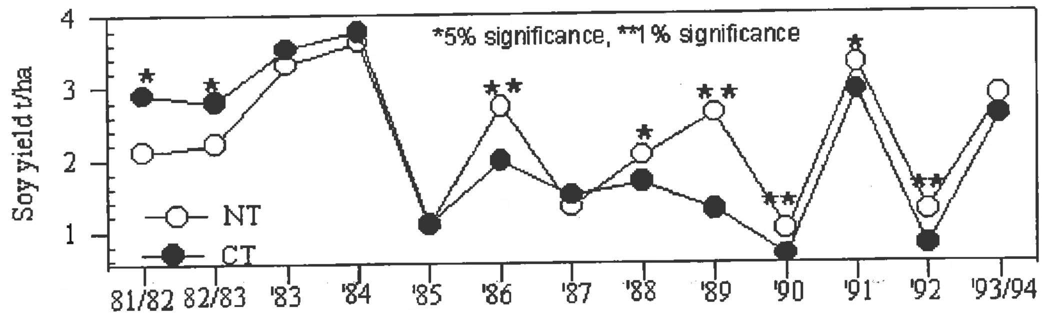

Figure 3 : Soybean yield during trial history

During the final cropping cycle of the trial, apparent total water use (the difference between the total profile water content at beginning and end of crop, plus total rainfall) and crop yield were examined. The dry matter yield, grain yield and the associated apparent water use efficiencies (WUE) of the winter oats crop were greatest under NT (see Table 4). Similar results were obtained from dry matter sampling during the following soybean crop, however, low rainfall and extensive pest damage during the growth of the soybean crop confounded the final yield data for both treatments.

The large differences between the calculated WUE of the treatments suggests that water is being lost from the CT system due to factors other than crop uptake.

Table 4 : Crop water use, and yield data for the soybean and oats crops

Crop and Treatment		Dry Matter @ 8o days t/ha	Total Water use mm	Water use efficiency kg/ha/mm	Grain Yield kg/ha	Total Water use mm	Water use efficiency kg/ha/mm
Oats	**NT**	5.72	97.2	**58.8**	661	97.2	**5.2**
	CT	4.45	97.1	**45.8**	290	97.1	**2.2**
Soy	**NT**	2.61	121.7	**21.4**	-	-	-
	CT	1.74	125.3	**13.9**	-	-	-

During the last soybean crop, areas of the field plots were intentionally cleared to measure the infiltration and evaporation of rainfall under the prevailing field conditions. Water use data taken from these areas indicated that reduced infiltration and increased evaporation contributed to the greater apparent water use of the CT treatments. Over 22 days in March 1994 a total of 68.9mm of rain fell at the experimental site in low intensity storms, and the cumulative evaporation was 67.7mm. At the end of this period, 20% of the total rainfall was accounted for by the measured increase in the profile water content of the bare NT soil, whereas there was no measured increase in the profile water content of the bare CT soil. Assuming that the net intake of rainfall was the same under the adjacent cropped areas, a significant correlation (r^2=0.8; n=5) was found between the actual measured water use, and the associated soybean dry matter yield increase during this period. These data show that the evaporative loss of water under a CT system, where the depth of water penetration is limited, is greater than that occurring within the NT system.

The result of long term NT has been an improvement in the stability and macroporosity of the surface soil and hence, a greater potential for the uptake and storage of water by the entire soil profile. In this way it is the structural improvement of the surface 10-15cm of the soil, through the use of long-term NT, which has led to the sustainable improvement of crop yields on these fragile soils.

Acknowledgments.

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References.

- Burch, G.W., Mason, I.B., Fischer, A.B., and Moore, I.D. (1986) Tillage effects on soils: physical and hydraulic responses to direct drilling at Lockhart, New South Wales. *Aust. J. Soil. Research.* **24**, 377-391
- Chan, K.Y., and Heenan, D.P. (1993) Surface hydraulic properties of a red earth under continuous cropping with different management practices. *Aust. J. Soil Res.* **31**, 13-34.
- Chan, K.Y., and Mead, J.A. (1988) Surface properties of a sandy loam soil under different tillage practices. *Aust. J. Soil Res.* **26**, 549-559..
- Hamblin, A.P. (1984) The effect of tillage on soil surface properties and the water balance of a xeralficalfisol. *Soil and Tillage Research.* **4**, 543-559.
- Harte, A.J., and Desborough, P.J. (1985) Internal Report, NSW Soil Conservation Service
- Isbell, R (1992) A Classification System for Australian soils. *CSIRO Div. of soils, Tech. Report*
- Lal, R., Logan,T.J., and Fausey, N.R. (1989) Long term tillage and wheel traffic effects on a poorly drained mollic ochraqualf in nothwest Ohio. 1. Soil physical properties, root distribution, and grain yield of corn and soybean. *Soil & Tillage Research* **14**, 341-358.
- Lindstrom, M.J., and Onstad,C.A. (1984) Influence of tillage systems on soil physical parameters and infiltration after planting. *J. Soil & Water Consv.* March-April 1984, 149-152
- Pagliai, M., La Marca, M., Lucamante, G., and Genovese, L. (1984) Effects of zero and conventional tillage on the length and irregularity of elongated pores in a clay loam soil under viticulture. *Soil & Tillage Research.* **4**, 433-444.
- Soil Survey Staff (1975) Soil taxonomy : a basic system of soil classification for making and interpreting soil surveys. *Handbk. US Dept. Agric.*
- Stace, H., Hubble, G., Brewer, R., Northcote, K.,Sleeman, J., Mulcahy, M.,and Hallsworth, E. (1968) A handbook of Australian soils. (Relim Tech. Publ.: Glenside, south Australia.
- Thompson, D. (1986) Soil structure investigations in conservation tillage for crop and pasture production on the north coast of NSW. <u>In</u> Cole, B.E., Desborough, P.J. (eds) (1986) Project team meeting, Grafton, NSW, august 1986.
- Unger, P.W. and Fulton, L.J. (1990) Conventional and no-tillage effects on upper root zone soil conditions *Soil & Tillage Research.* **16**, 337-344.

Wheeltrack Compaction Effects on Runoff ,Infiltration and Crop Yield

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1. INTRODUCTION

In Queensland, conservation tillage practices have been widely used in an attempt to optimise sustainable rainfed grain production in an environment where soil degradation is a problem, and moisture is limiting.

Conservation cropping with reduced tillage and maintainance of surface mulch has beem shown to reduce runoff and erosion. However, under zero tillage some of the positive effects of conservation practices have, to some extent been negated by the harmful effects of compaction caused by random wheel traffic. In traditional cropping systems, these effects are removed in the surface layers by regular tillage. This is not the case in many conservation tillage systems.

A recent major review of soil compaction in crop production concluded that amongst soil properties affected by soil compaction and related tillage, perhaps least is known about soil hydraulic properties(Horton et al. 1994). Young and Voohees(1982)demonstrated that wheel traffic influenced a number of soil properties which in turn affect runoff and erosion. Tullberg and Lahey(1990)provided some evidence of controlled traffic effects on infiltration, and the results of a pilot trial by Tullberg and Ziebarth(1994), demonstrated that traffic had a major effect on infiltration and runoff rates under irrigation.

The object of this trial was to investigate the effect of wheel traffic on runoff, infiltration and crop yields in a rainfed grain production system with different tillage and trash management practices.

2. MATERIALS AND METHODS.

Statistical design included four complete randomised plots of three tillage/residue treatments (zero till, mechanical minimum till and conventional or stubble mulch tillage) each split into compacted and controlled traffic plots. All plots were worked with a tractor (J.D. 4040) modified to give a track width of 3m, so providing a non compacted 2.5m 'bed'and a highly compacted 0.5m 'wheeltrack'. Furrowers positioned behind the tractor front wheels were used to move soil out of the wheeltrack, and ensure these were depressed 100mm below the level of the beds.

Plots were 30m long, positioned diagonally across a 10% slope so that the runoff from each plot was channelled via the depressed wheel track to 6L tipping bucket runoff gauges(Ciesiolka and Coughlan 1995).

The soil was black earth, a self -mulching Lawes series clay overlying a friable B horizon with sand lenses at 1.2-1.5m. Before installation the plot area was ripped to a depth of 0.45m. Compaction treatments were applied four days after the application of 50mm of irrigation in June 1994.

Compaction was carried out by three runs of a working 100 kW tractor with a rear axle mass of 60kN on single 18.4 x 42 tyres at 100 kP pressure. 'Work' was a drawbar load of 25kN provided by the 3m tractor travelling in the wheel tracks. This operation served to simulate the normal and shear loads applied to the soil by a working medium weight tractor, so the complete 'bed' area of each compacted plot (approximately 2.5m wide) experienced compaction treatment by a 30kN wheel applying a 12kN horizontal force . This appears to be more uniform, but otherwise similar treatment applied to fields in stubble mulch opportunity cropping system, where an area exceeding that of the crop is trafficed by tractors after rain ,each year.

Simular treatments were applied to all plots to allow planting of the initial winter crop. Planting was carried out using a 2.4m 'agroplough' tine planter for winter crops. Summer crops were direct planted into zero till plots with an experimental planter using 'Jahnke' knife tines. The same planter was used in other plots after the minimum mechanical till plots received one tillage treatment with a spring tine scarifier, and stubble mulch plots received three such treatments.

Wheat was planted in July 94 and harvested in November, strategic irrigation only being used to ensure establishment in very dry condition. No further compaction treatments were undertaken before sorghum was planted in January 1995, again after irrigation to allow planting. At this stage wheat residue levels were approximately 2t/ha in zero till plots and 1t/ha in mechanical till plots. Sorghum was harvested in June. The runoff measuring system was installed by October 94 on all plots. Neutron probe tubes were installed prior to the sorghum being planted and were read on a weekly basis until after harvest.

3. RESULTS AND DISCUSSION

a) Runoff and Infiltration

No natural runoff events occurred between September 1994 and February 1995, when sorghum was planted in the plots after the completion of tillage treatments, and a light irrigation of 20mm was applied. In the absence of natural rainfall, irrigation was applied on the 9th February to simulate rainfall and produce a runoff event. A number of natural runoff events occurred between 12 February and 9 March, providing a range of rainfall intensities on the plots at different levels of soil moisture content. These results are summarised in Table 1.

The same information is illustrated in Figure 1 ,but the tabulated data includes corrections made for a number of errors in the original data, occurring as either blockages to tipping bucket units, or overland flow breaking through the diversion bank at the top of one set of plots during one high intensity event. Figure 1 illustrates one instance of this where the runoff from the compacted MT treatment with (1T/ha of residue) was 20% greater than any other treatment.

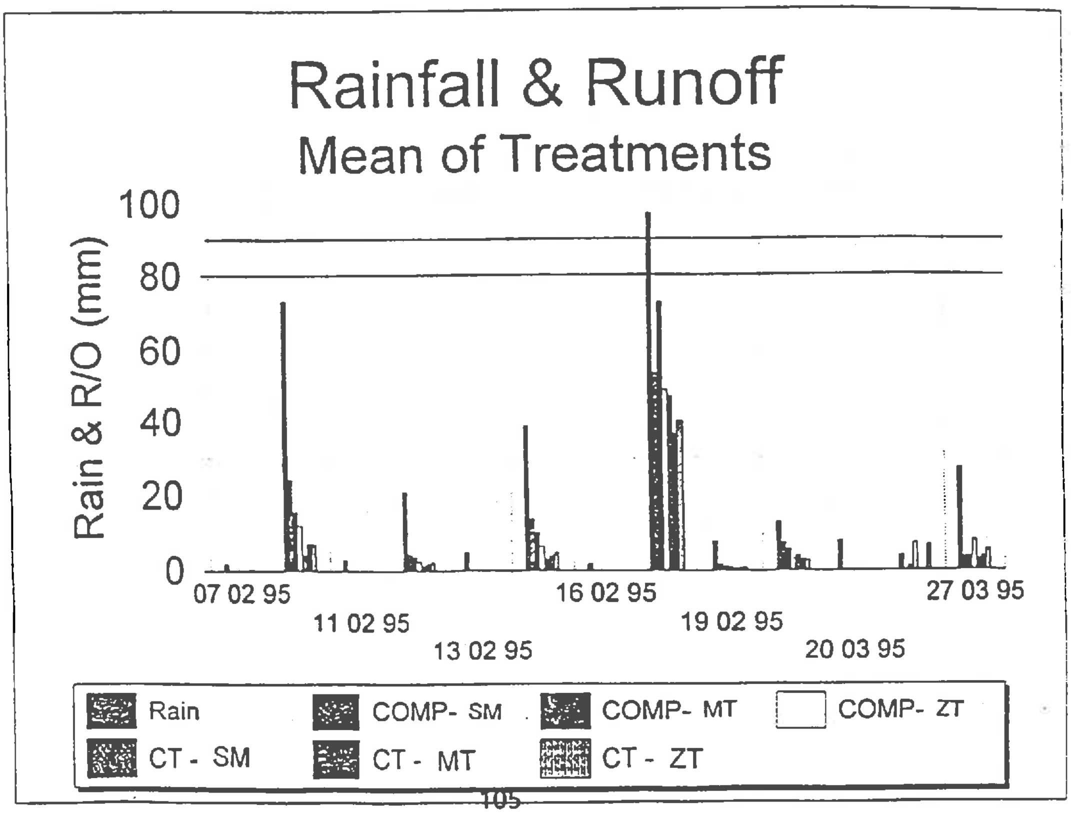
Table 1 **Rainfall and runoff on compacted and controlled traffic plots under different tillage systems (corrected figures) SM - Stubble Mulch MT - Minimum Tillage ZT - Zero Tillage**

Date	Rainfall		Runoff in mm													
			Compacted Plots						Controlled Traffic Plots					
			SM		MT		ZT		SM		MT		ZT	
	Event	Total	Event	Total	Event	Total	Event	Total	Event	Total	Event	Total	Event	Total
7/2	2	2	0	0	0	0	0	0	0	0	0	0	0	0
9/2	73	75	19	19	21	21	12	12	4	4	10	10	7	7
11/2	3	78	0	19	0	21	0	12	0	4	0	10	0	7
12/2	21	99	5	24	4	25	3	15	1	5	2	12	2	9
13/2	5	104	0	24	0	25	0	15	0	5	0	12	0	9
15/	39	143	14	38	10	35	7	22	3	8	5	17	5	14
16/2	2	145	0	38	0	35	0	22	0	8	0	17	0	14
17/2	97	242	67	115	65	100	55	77	47	55	37	54	33	47
18/2	8	250	2	117	1	101	1	78	0	55	1	55	1	48
19/2	13	263	8	125	6	107	3	81	4	59	3	58	3	51
9/3	8	271	0	125	0	107	0	81	0	59	0	58	0	51
Total Infiltration			146 mm		164 mm		190 mm		212 mm		213 mm		220 mm	

All totals are cumulative

The data in Table 1 demonstrates clearly that the wheel traffic treatment imposed on these plots had a very large effect on runoff, and the traffic effect was substantially greater than the tillage treatment effect . the effect might be illustrated by the cumulative mean runoff of 104 mm from the wheeled treatments whereas 56mm ranoff from the controlled traffic treatments. In other words, out of the total precipitation of 271mm, an additional 48mm infiltrated into the controlled traffic plots

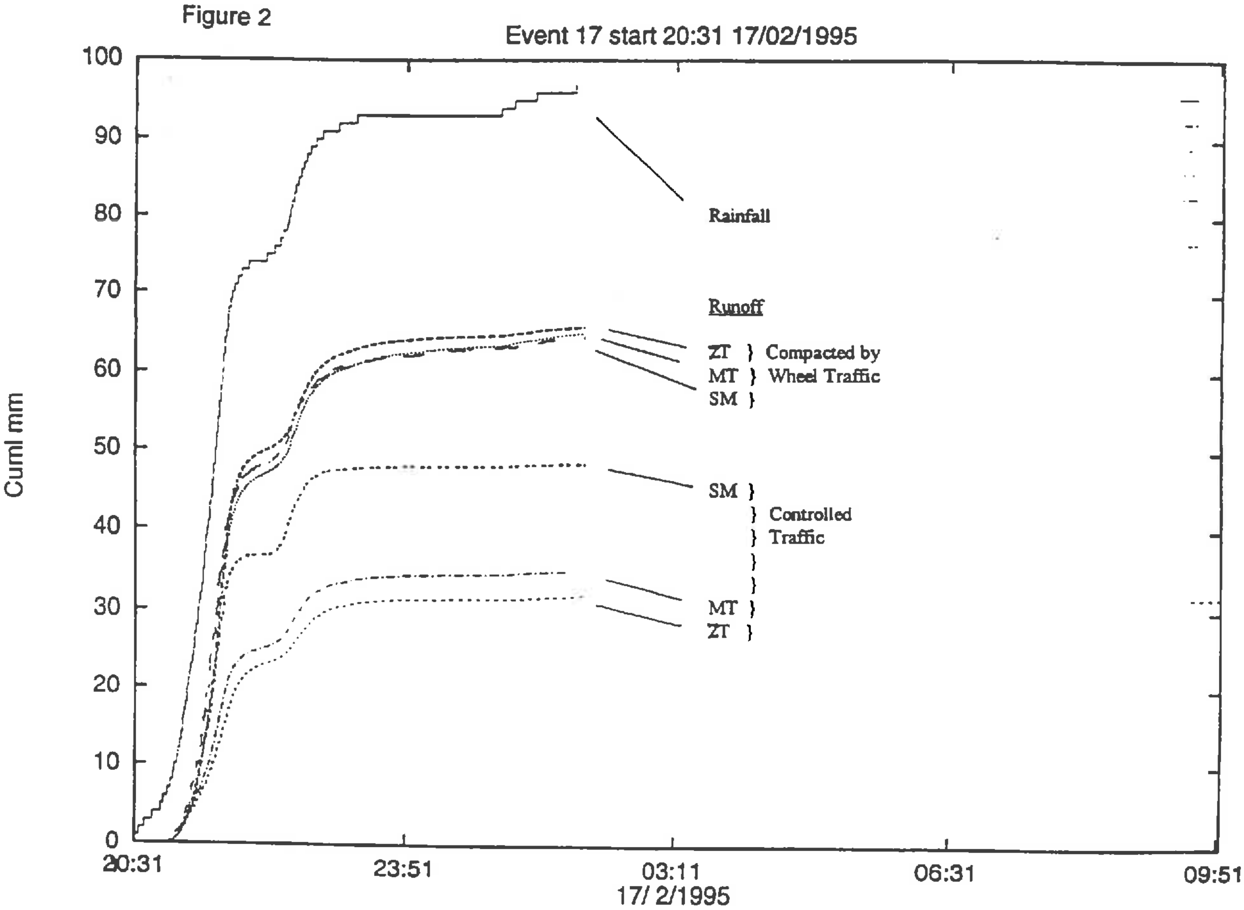
Figure 1



Tillage treatments had the expected effect, with gross mean runoff from zero till being 66mm, from minimal mechanical till 83mm and from stubble mulching 92 mm. Zero tillage thus provided an increase in infiltration of 26 mm.

Statical analysis of these results is not complete, however the quality of the data can be illustrated with reference to figure 2, which shows the cumulative runoff from block 1 during the high intensity rainfall event that began on the 17 February. The corresponding hydrograph demonstrates that maximum short term rainfall intensities exceeded 100 mm an hour on two occasions during that event. Under this high intensity rainfall, the difference between different tillage systems was almost negligible when soil was compacted, but the tillage treatments had a large effect on the controlled traffic plots. this is consistent with the notion of a compaction 'throttle' to infiltration.

Figure 2



b) Crop Performance

Yield was assessed using 3 quadrats taken from the middle of each bed - thus avoiding edge effects. Total plot yield was subsequently recorded after harvesting with a modified Harvester front and using a stationary thresher. Results are presented in Table 2.

Although the mean population was substantially greater in controlled traffic plots, this difference was not significant at the 5% level. According to Keys and Younger (1988), and Colwell(1963) wheat yield is relatively insensitive to plant population over a range from .5 million to 2 million plants per ha, so population appears unlikely to be affecting yield in this case.

Table 2. Wheat Yield

		C	CT	
Plant population	M/ha^{-1}	.79	.95	NS
Tiller length	mm	459	503	*
Tillers/plant		3.54	3.18	**
Grain yield	t/ha	2.23	2.44	**
Total biomass	t/ha	7.33	8.19	**
Whole plot (corrected yields)	t/ha	1.37	1.68	**

Grain yield as assessed by quadrats was approximately 10% greater in controlled traffic plots, at 2.44 t/ha, and simular ratios apply to total biomass. Whole plot yield on the other hand , was greater by 22% in controlled traffic. The difference between these two must be due to a greater edge row effect in controlled traffic plots.

Preliminary quadrat data from the 1995 grain sorghum crop showed a slightly greater mean yield of controlled traffic sorghum but did not prove to be statistically significant. Following the hand harvesting of the whole plots ,controlled traffic treatments proved to have significantly higher yields, and these results are presented in Table 3.

Table 3 . Sorghum Yield. t/ha.

Tillage treatment	Wheeled	Controlled Traffic	
stubble mulched	5.38	6.57	**
minimum mechanical	5.13	5.56	*
zero till	5.17	5.46	*
Average	5.22	5.86	**

The 1994 wheat crop was grown on limited moisture, with a strategic irrigation of less than 40mm to establish the crop , followed by a total of less than 120mm during it's growing period. It appears likely the yield of this crop was limited by moisture availability, particularly towards the later stages of growth.In these conditions the greater soil volume potentially available to control traffic wheat could account for the greater yield

The sorghum crop on the other hand, was well supplied with water. A preplant irrigation, was followed by the rainfall events reported in Table1, providing a total of more than 330 mm. The crop appeared water stressed only briefly in late March at which point infra-red temperature measurements indicated that the mean leaf temperature of sorghum growing in compacted soil was 1.5 degrees greater than that of controlled traffic sorghum at noon when relative humidity was 25%. This indicates greater water stress in the contacted plots despite the greater neutron probe readings at the time showing the compacted plots had approximately a 10% greater water content than the controlled treatments. It is evident that water in the compacted plots was being held at tensions that made it unavailable to the crop. Unfortunately 25 mm of rain fell 2 days after this observation preventing any longer term measurements. Subsequent disc-permeameter increase in very small pores in the compacted plots.Soil strength and bulk-density measurements were also higher in the compacted plots

4. CONCLUSION

This work has demonstrated

1. A large consistent and important difference in runoff due to wheel traffic effects under a range of natural rainfall and irrigation intensities.

2. These differences occurred almost 9 months after the compaction treatment was installed using a relatively light tractor, subject to normal drawbar loads.

3. Compaction treatments had a significant effect on the yield of a wheat crop grown under moisture limiting conditions. This effect was repeated in a sorghum crop where the conditions were more liberal and water supply less limiting

5. REFERENCES

Ciesiolka, C. and Coughlan, K.G. 1995 (in press). Field methods for erosion research. ACIAR Research series.

Colwell, J.D. 1963. Effect of sowing rate......Aust. J. Exp. Ag. and Husb. 3 314-318

Horton, R., Aukeng, M.D. and Allamaras, R.R. 1994. in Soane, B.D. (ed). Soil Compaction in Crop Production. Elsever.

Keys, P.J. and Younger, D.R. 1988. Plant population for central Queensland. AGDEX 112/22

Tullberg, J.N. and Lahey, G. 1990. Controlled Traffic Cropping. (Unpubl. report to NERDDC)Gatton College.

Tullberg, J.N. and Ziebarth, P.D. 1994. Wheel Traffic Effects on Runoff. Proc. Ag Eng. Conf. Lincon, Christchurch, NZ.

Young, R.A. and Voorhees, W.B. 1992. Soil erosion..... as influenced by tractor wheel traffic. Trans. ASAE 25 708-712.

The Economics of Controlled Traffic : South Burnett Case Study

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Introduction

The majority of crops grown in the Burnett are rain-grown. For these crops the major limiting factor is soil moisture. However, the viability of cropping in the Burnett is being questioned following a run of "dry" seasons. The problem of dry seasons has been compounded by the destruction in the soil physical properties which has reduced the soil's ability to take in water and store it so that it is available to the crops.

Research into the current cropping system suggests that it's not sustainable and changes are required if cropping is to continue. The option being considered here is controlled traffic. As most of the crops are grown as row crops they are, to a limited extent, in a controlled traffic system from the time they are planted through to harvest. The next step is to extend the controlled traffic from one crop to the following crop by maintaining permanent laneways.

For this technology to be adopted by landholders they must have the confidence that they will be no worse of in the short term but better off in the long-term..

This paper describes the results of an analysis on a property in the South Burnett. The objective was to determine whether or not controlled traffic and zero tillage would contribute to both short and long term profitability without jeopardising the ability to revert back to the current system if the changes do not work .

Description of the Case Study property - Current System (CS)

The property is located in the South Burnett. It is operated by the owner and one permanent farm hand and they plant between 500 and 600 ha of rain-grown crops per year. A typical crop rotation on this property would be, Soybeans; Wheat; Maize; Maize; Millet; Soybeans; Sorghum; Soybeans. Up to 40% of the crops are grown on a share-farming basis where 25% of the gross income of the crop is paid to the land owner. The crops grown over the past year were:

Maize	189ha	Millet	26ha
Soybeans	170ha	Wheat	100ha
Sorghum	63ha		

Four tractors (100, 90, 70, 45 kW PTO power) perform the tillage, planting and spraying operations. Summer grains and legumes are the dominant crops and winter cereals are planted as an opportunity crops. The landholder has a specialist summer crop planter and a tractor mounted air-seeder to apply fertiliser prior to planting and to plant winter cereal and narrow row soybean crops. Both planters can be used as zero tillage planters. A contractor is used to harvest all crops.

Up to half the crops in any one year are grown under zero tillage conditions. This is decided by seasonal and paddock condition at the time of planting. The choice of crop and tillage system are chosen to maximise profits, while minimising the soil erosion potential. Where possible a winter cereal crop is planted after a summer legume to provide erosion protection for the following summer crops.

Options considered and assumptions

PADCOST (an Excel spreadsheet) was used to analyse the current cropping system on the property. This was compared with three alternative systems and the impact on labour requirements, costs and profitability was measured and compared. The options considered were.

1. controlled traffic without changing the current cropping system.
2. changing completely to zero tillage.
3. changing to a combined system of complete zero tillage and controlled traffic.

To incorporate seasonal variations in yields and prices a beta distribution was used to estimate expected yields and prices. The beta distribution uses the landholders estimate of the best, worst and most likely yield and price for each crop. The mean yield and price used in the calculations were calculated using the following equation.

$$Mean; Yield / \Pr ice = \left(\frac{best + (4 \times most\_likely) + worst}{6} \right)$$

1. Current system + Controlled traffic (CT)

In this analysis it was assumed that controlled traffic would be introduced with minimal changes to the current system. The largest tractor (100kW PTO) would be replaced with a 70kW PTO tractor and there would be no chisel plough or offset disk operations. As the tractors would be driving on permanent wheel tracks it is assumed that their overall fuel consumption would be reduced by 30% (Tullberg, 1994). No tractors or implements would be sold and their costs would be included in the overall costs of production.

It was assumed that in the worst seasons yields would improve by 40%, the most likely change would be an increase of 10% and in the best seasons there would be no change in yield. Fertiliser rates were increased to take account of the higher nutrient removal.

2. Zero tillage (ZT)

It would be possible to grow every crop currently produced on this property Under a zero tillage system. In a zero tillage system we have assumed that only planting, slashing and boom-spray operations would be retained. No machinery would be sold and more fallow and in-crop herbicides would be included to control weeds. The area of winter crop would be increased to match the soybean area.

In most seasons there would be no change in yield. However, in the worst seasons it was assumed that yield would increase by 10% and in the best seasons yields may decline by 10%.

3. Controlled traffic + Zero tillage (CT & ZT)

This combines the previous two options. The assumptions are:

- replace 100kW tractor with 70kW tractor (PTO)
- retain only planting, slashing and boom-spray operations
- replace mechanical weed control with chemical weed control
- reduce all tractors fuel consumption by 30%
- increase winter crop area from 100ha to 150ha
- Yields
  - in the worst seasons +40%
  - most likely season +10%
  - in the best season no change
- increase fertiliser rates to take account of increased nutrient removal
- no machinery would be sold and the cost of all machinery would be included in total production costs.

Changes in Labour requirements

PADCOST calculates the labour inputs based on the number of operations in a paddock and the expected work rate for each operation. The labour input is calculated on a paddock basis and these are added together to give a total labour requirement for current system and the alternatives considered (Figure 1). By implementing controlled traffic with the current system the labour requirement decreased by 28%. However, by changing to complete zero tillage the labour requirement for this property was almost halved.

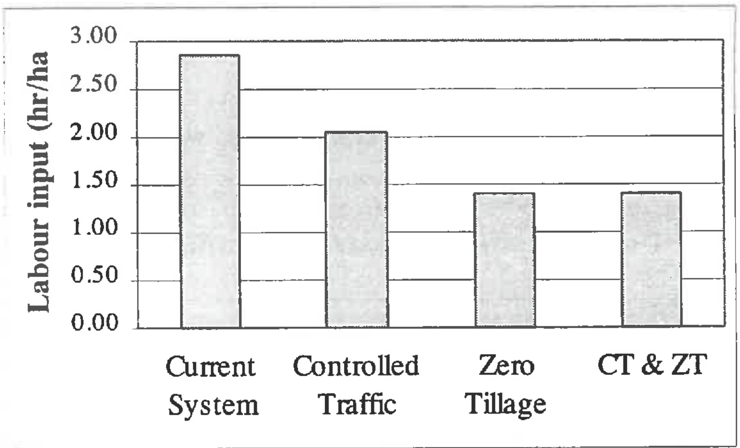

Figure 1 Labour inputs under four tillage systems.

Changes in Costs

Costs have been calculated on a paddock basis, then summed for the whole property and divided by the cropping area (figure 2). Variable costs decreased when the current system changed to controlled traffic. This is mainly due to less tillage operations. However, variable costs increased in the zero tillage and the combined zero tillage and controlled traffic because there was more wheat grown and the cost of controlling weeds by chemicals was higher than mechanical weed control.

Ownership costs are the costs that are incurred whether the machinery is used or not. They include interest, depreciation, insurance and shelter (Anon, 1985).

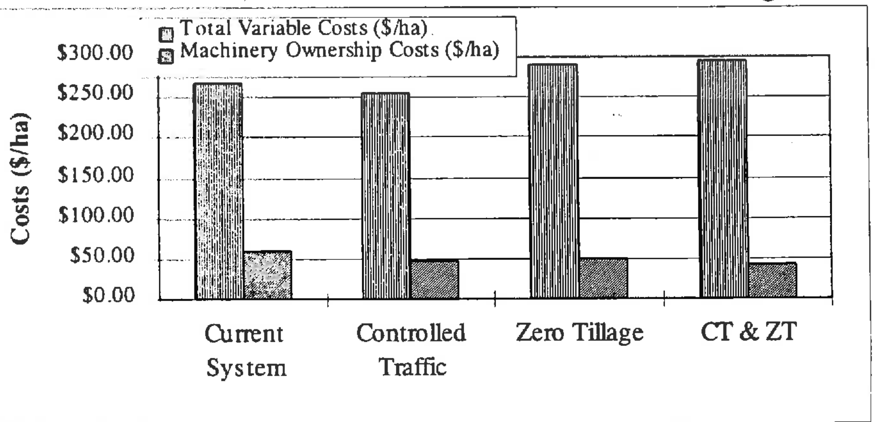

Figure 2 Variable and fixed costs for the case study property under four tillage systems.

Ownership costs are calculated for each operation and are allocated to each paddock. Machinery ownership costs are the lowest in the combined controlled traffic and zero tillage option, but because we assumed that no machinery would be sold (even if it was not used) they are not significantly less than the current system.

Changes in Profit

The total farm gross margin has been calculated by subtracting the variable costs from the gross income. The net margin is the gross margin less the fixed machinery costs. The highest net margin was achieved with the combination of controlled traffic and zero tillage. By implementing controlled traffic with the current system the landholder could expect a significant increase in returns.

These returns do not take into account other increases in production that could be expected with improved timeliness. This could be through planting crops closer to the optimum time or more opportunities for double cropping (McPhee, et.al., 1995). In many seasons planting operations are restricted because of planting into hard soil or are delayed due to wet soil. If hard soil was confined to the wheel tracks more and extended planting opportunities would be available.

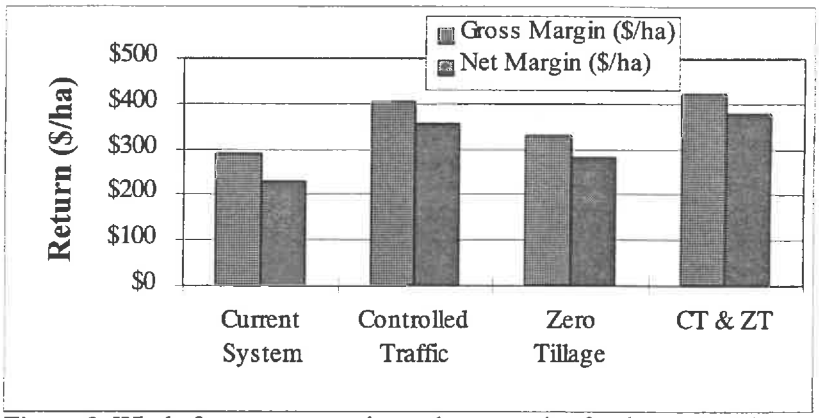

Figure 3 Whole farm gross margins and net margins for the case study property under four tillage systems.

Changes in the machinery investment

Investment in machinery is the current replacement value (in the case of tractors this is the new value) for the machinery used in each cropping system (Figure 4). This graph shows the long-term benefit of changing from the current system. On this property reducing the size of one tractor had a larger impact than not using any tillage equipment. The greatest reduction in capital required for working machinery was achieved when both the size of the tractor was reduced and the tillage equipment was not used. This occurred in the combined controlled traffic and zero tillage option.

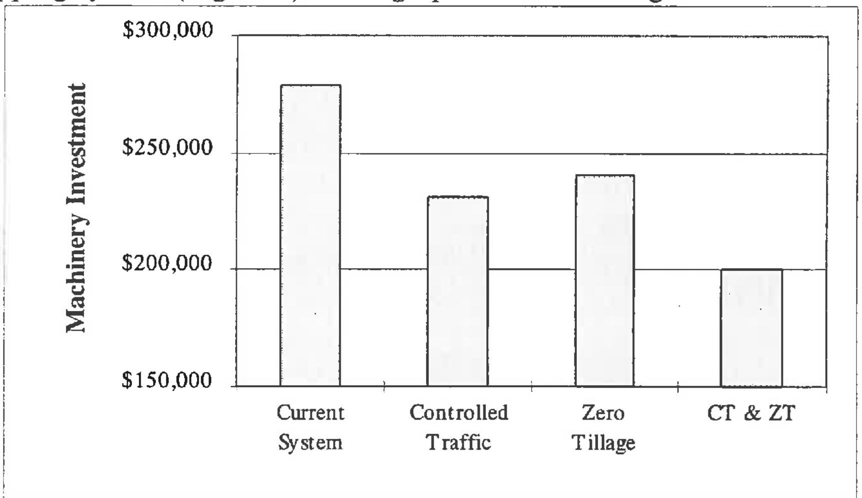

Figure 4 The value of the machinery used under the different cropping systems.

Discussion

Controlled traffic should be viewed as a further refinement for the conservation farming systems promoted to landholders over the past 20 years. Unfortunately, until now, only some elements of the recommended conservation farming system has been adopted (reduction in the number of cultivations, retention of stubble and the use of tined rather than disked implements). Failure to widely adopt these elements suggest that producers are not convinced they will be better off even though there are significant benefits for the soil resource. The change to conservation cropping is perceived by landholders as being too complex, too costly, too difficult to implement and for some landholders there is an underlying fear of chemicals (Glanville, Day, 1994).

In light of the low adoption rate of the conservation farming system, it would seem a change in approach is required before the "average" landholder will implement more sustainable practices. Controlled traffic may be the link between what the current farming practices are and the conservation farming approach. Controlled traffic allows the landholder to gradually change from the current system to a tillage system that reduces energy and labour requirements, increases infiltration rates (Ziebarth and Tullberg, 1995), and improves timeliness and the chance of double cropping. Many benefits can be obtained with minimal change to the current cropping system. In time, it would be envisaged that under a controlled traffic system the reason for tillage would change from one of creating a deep seedbed to that of digging out weeds in situations where chemical control is not suitable.

This case study shows that there are strong financial and labour reasons why the combination of controlled traffic and zero tillage should be adopted as standard management practice in the South Burnett. Although this should be the medium term aim of landholders, there are immediate benefits to be gained from changing to controlled traffic using the current tillage system. Under the most sustainable system of controlled traffic and zero tillage, labour requirements will almost halve (Figure 1), variable costs will increase (Figure 2) and profitability (both gross and net margin) will increase by more than $100/ha or around 30%. Added to this the total capital tied up in machinery will fall by $78 000. On properties that had higher investment in machinery the savings would be even greater.

Some questions that remain are:

1. Is the increase in profitability reported here achievable?
2. Is the increase in profitability, when combined with the soil benefits and increased sustainability of the cropping system a compelling reason to change?
3. Is the increase in profit and flexibility, combined with the reduction in capital invested in machinery enough to compensate landholders for the increase in the complexity of the controlled traffic / zero-tillage system?

It is unlikely that landholders will read this paper and make a simple decision to either ignore or adopt controlled traffic or zero tillage technology. However, this case study, and the spreadsheet (PADCOST) developed for the evaluations will allow landholders to explore these questions for their own situation. As a result, they may be encouraged to explore other options in addition to controlled traffic and or zero tillage. These other option can also be evaluated with PADCOST and compared with their current cropping system. In the medium-term improvements on individual properties will collectively add to the international competitiveness of Australian agriculture and also contribute to the continued prosperity of rural communities.

References

Anon (1985). A guide for calculating farm machinery costs. Information Series QI82004 (Queensland Dept. Primary Industries : Brisbane).

Bridge B.J. and Bell M.J. (1994). Effect of Cropping of the Physical Fertility of Krasnozems. Australian Journal of Soil Research., **32** 1253 - 73.

Glanville, T. and Day, J. (1994). Project report for Constraints to the adoption of conservation cropping in the extensive cropping areas of the South, Central and North Burnett. Unpublished paper

McPhee, J.E., Braunack, M.V., Garside, A.L., Reid, D.J. and Hilton D.J. (1995) Controlled traffic for I irrigated double cropping in a semi-arid tropical environment: Part 3, Timeliness and trafficability. Journal of Agricultural Engineering Research.. **60**, 191-199.

Tullberg, J.N. (1994) The cost of soil compaction. Unpublished paper

Ziebarth, P.D. and Tullberg, J.N. (1995). Evaluation of traffic effects in conservation tillage. Gatton ACIAR experiment. (Preliminary report).

CONTROLLED TRAFFIC DEVELOPMENT ON DRYLAND BROADACRE FARMS IN CENTRAL QUEENSLAND.

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INTRODUCTION

The Queensland British Food Corporation (QBFC) pioneered large scale cropping (26000 ha) in Central Queensland from 1948 till 1952 when operations ceased due to financial losses. QBFC land was broken up, balloted and many successful applicants were experienced farmers from southern Queensland and New South Wales. They facilitated the commencement of successful grain production in the Central Highlands (Spackman and Garside 1995, Gillies 1978). In the adjoining Dawson-Callide area development occurred during the Fitzroy Basin Land Development Scheme (Brigalow Scheme) in the 1960s. Across Central Queensland the area cultivated has increased dramatically from 350 000 ha in 1970 to more than 800 000 ha in 1990. Major expansions during the 1950's and 1970's were associated with decades of generally above average rainfall and the collapse in beef prices during the 1970's. In 1995, crops are grown on 510 000 ha in the Central Highlands and 124 000 ha in the Dawson-Callide. The main planting windows and principal crops are December to March for sorghum, sunflowers and mung beans, and March to June for wheat and chickpeas. Dryland cotton is planted October to December. Spring planted grain and fodder crops are generally unreliable due to high temperatures at flowering and low probability of in-crop rain.

The region receives an average of 600-700 mm of predominantly summer rainfall, but falls greater than 75 mm have been recorded in every month. There is a high degree of variability, within and between seasons (Willcocks 1993). Sixty percent of daily rainfall occurs in falls under 10 mm, while annual pan evaporation is 2.5 times the annual rainfall (Willcocks 1993). Pan evaporation exceeds rainfall in all months and averages 4 mm/day in winter and 8 mm/day in summer. Soil water storage efficiency during fallows is typically less than 20% (Carroll *et al.* 1994). Soil evaporation is the dominant loss mechanism and can account for 70% of rainfall in a normal year. During a 9 month fallow in 1991, 299 mm of rain was received and 267 mm lost as soil evaporation. Runoff can be significant (up to 15% of annual rainfall) and in wet periods, usually associated with cyclonic influences, drainage losses can also be as high as 10% (Carroll *et al.* 1994).

The major threat to long term sustainability is soil erosion from the sloping (up to 3%), highly erodible, cracking clay soils. Contour banks have been installed on 60% of the erosion prone cultivation in the Central Highlands (G. Bourne pers. comm.), but inter bank erosion is still high. Peak rainfall intensities (I_5) up to 170 mm/hr have been recorded within storms (K. Rohde pers. comm.), but the average intensity (I_{60}) is 35 mm/hr. 1 in 10 storms reach 75 mm/hr (Willcocks, 1993). Residue retention (>30% cover) and a reduction in tillage will reduce runoff and , more particularly, erosion (Carroll *et al.* 1994). Runoff reduction can be important at planting time when, due to surface sealing, runoff can occur from finely mulched soils without fully wetting the seedbed. Judicious use of fallow herbicides is the key to effective soil management. However, efficient herbicide application has been limited on large areas by ineffective marker systems.

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CENTRAL QUEENSLAND FARMING SYSTEMS

Broadacre grain farmers in Central Queensland have traditionally conducted machinery operations within contour bays. However, parallel runs, generally across the slope, are now more popular following the development of broad based contour banks which can be traversed at any angle with contour-flexing machinery up to 20m wide. This practice improves the efficiency of operations with large machinery. Where herbicides are commonly used, "tram-lines" for subsequent spraying operations are made using unplanted wheel tracks or missed rows.

Minimum tillage practices of chemical weed control with blade and chisel plough cultivation are typical. Some farmers are loathe to use chemical fallow due to concern about chemicals, limited knowledge of herbicides, higher cost than cultivation, increased requirements for specialised equipment and marking difficulties. Treatments at planting range from full cultivation to zero tillage. The only set rule for these systems is their flexibility. The decision to spray or cultivate is usually made on the basis of soil water stored, the cost of spraying, density of weeds and time of year.

Tractors used in the Central Highlands range from 230 to 460 kW for 4WD, and 150 to 300 kW for tracked type machines. Typically these machines weigh 14000 kg to 28000 kg for 4WD, and 14000 to 36500 kg for tracked machines. Common tyres are dual 30.5 X 32 loggers. Area under cultivation varies between farms, with 2500 hectares or more, common.

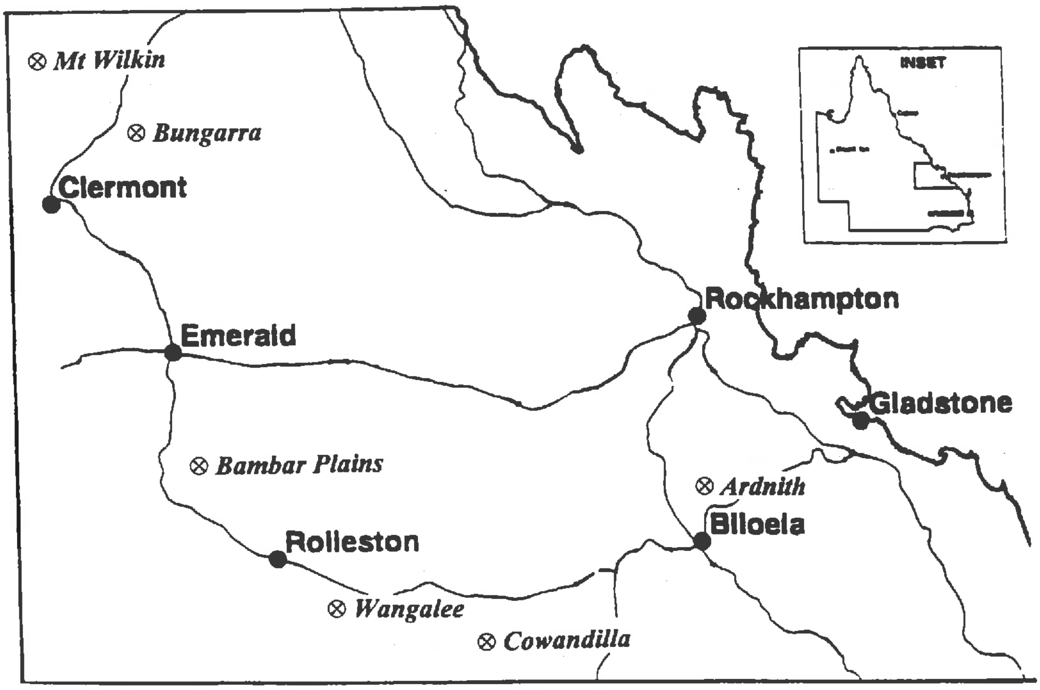
Throughout the Central Highlands, soil compaction is commonly observed in soil pits, and obvious crop effects include "right angle disease" and poor germination in tractor wheel tracks. One farmer has observed that "Tractor tracks from the last two workings are visible from the air, even months later." D. McGarry (pers. comm.) found that compaction was worse in dryland cultivation compared to irrigated land in the Emerald Irrigation Area.

DEVELOPMENT OF CONTROLLED TRAFFIC SYSTEMS ON-FARM

Our on-farm project recognised that to control soil compaction, the only available technique was controlled traffic (CT), and therefore we set out to study the development of CT layouts for broadacre farms. In early 1993, workshops and growers meetings were held and five farmer co-operators "volunteered" to experiment with our concepts. These were Rod Birch, "Mt Wilkin", Kilcummin; Lyall Swaffer, "Bungarra", Clermont; Ian Buss, "Bambar Plains", Orion; Murray Jones, "Wangalee", Rolleston; and Charles McDonald, "Cowandilla", Bauhinia (Figure 1). Our meetings also identified growers who had been developing their own CT approaches, in particular Bob Mathieson, "Ardnith", Biloela. These co-operators are distributed over a distance of over 500 km, from Kilcummin in the north, to Bauhinia Downs in the south, and east to Biloela. Their farming methods, soil types, land forms and machinery cover the spectrum of CQ farms. Our goals are to measure the benefits achieved on-farm (tractor and farm efficiencies, ease of operations, etc), to identify practical problems that would constrain adoption and to research new innovations made possible with CT. The controlled traffic project also aims to apply the findings of the soil compaction research discussed by Bruce Radford, Ken Rohde, Harry Harris and Jahangir Alam (these proceedings).

Our co-operators were attracted to CT for compaction control, ease of herbicide application (facilitating moves to zero till), and aiding dryland cotton production. Initially, grower's concerns included suitability and compatibility of tractors and implements, direction of permanent wheeltracks, and runoff and soil erosion. Direction of permanent wheeltracks has implications for visibility of operations due to sun glare, and impact of prevailing winds on spraying operations and harvesting of lodged crops. A soil erosion research program was established (Rohde and Yule, these proceedings). In practice, direction of layout has been determined more by runoff control considerations than by wind or sun direction. By September, 1995 CT has been established on 4 farms: Mt Wilkin (2 000 ha, rubber track tractor), Bungarra (100 ha, 4WD tractor), Wangalee (325 ha, steel track tractor) and Bob Mathieson's (170 ha, 2WD tractor). A planned layout on Cowandilla (both 4WD and steel track tractors) was unsuccessful due to tracking problems which saw the planter up to 2 m off line, and CT will be established on Bambar Plains (4WD tractor) as soon as a new planter is on site. The oldest sites are at Bob Mathieson's with 4 crops under CT and Lyall Swaffer established his block in 1992 as dryland cotton. Despite our extended drought since 1991, all co-operators have remained firmly committed to CT and have been encouraged by their experiences so far. With increased publicity associated with this Conference, many enquiries from growers have been received and all believe the system will enable greater accuracy when spraying and assist management of zero-tillage, reduce capital expenditure in the long run, confine soil compaction and improve soil structure.

Figure 1. Distribution of farms within the controlled traffic project



We have recommended farm layouts to minimise erosion risk by applying two basic rules:

- crop rows and permanent wheeltracks must drain to a safe disposal area (water way or contour bank) without reverse slopes or flat spots; and
- the furrows and ridges must contain all the runoff generated within the microcatchment. This distributes runoff across the area and prevents crossflows, which concentrate runoff and create rills and gullies with high erosion rates.

In the field these rules are hard to apply due to uneven slopes. However, Rod Birch has shown that it is possible to change the direction of layout in the second year with only limited problems of crop establishment in the previous wheeltracks. The co-operators use straight runs and plant over any contour banks. The exception is Bob Mathieson, who has developed a parallel contour bank system with narrow based contour banks and six passes of his implement between banks. However, Bob's layout also follows our runoff rules.

ON-FARM BENEFITS OF CONTROLLED TRAFFIC

All co-operators report benefits gained from the adoption of CT. These are described as follows:-

Accuracy of operation. The accuracy possible with CT impacts on all farming operations. Because of this, Rod Birch believes his CT farming system gives him more options. Last summer Rod demonstrated the potential of late fallow furrowing. This technique is useful where soil evaporation has dried the seedbed to 10 or 15 cm depth and the sub-soil is wet. Rewetting the seedbed requires 40-60 mm rain, so falls of 20-30 mm evaporate without providing a planting opportunity. A shallow furrow reduces the depth of dry soil to 5 cm or less, so that a 20 mm rainfall will link up with subsoil moisture in the furrow and any runoff is concentrated in the furrow. CT allows a planting opportunity by planting in the furrows.

Spraying. Bob Mathieson has found night spraying much easier, enabling spraying to be conducted in either more ideal or over a wider range of conditions. This can lead to improved efficacy on weeds in a crop or fallow spraying program, and on nocturnal insect pests.

Co-operators find spraying operations are easier and much less fatiguing without spray markers. Foam markers used in fallow spraying operations are often troublesome, and foam life is short in hot conditions. Foam markers have been rendered obsolete by CT. Overlaps are eliminated, which have substantially reduced spraying costs. For example, a 5% overlap when spraying 1L Roundup/ha costs approximately $500 over a 1000 hectare area, plus additional application costs. Spraying operations are conducted more easily and at higher speeds on more trafficable permanent wheeltracks, and they are trafficable sooner after rain than non-compacted soil. These benefits might enable reduced spraying charges to be negotiated with spraying contractors.

Efficient band spraying is possible with CT, due to the improved precision of machinery operations. Murray Jones, Rod Birch and Lyall Swaffer applied insecticides to young dryland cotton in a 30% band over the rows using ground rigs. The saving in chemicals greatly lowered costs. CT will also enable herbicides to be band-applied either over or between planted rows to reduce costs, and residual herbicides to be band-applied with subsequent planting of sensitive crops between the herbicide bands.

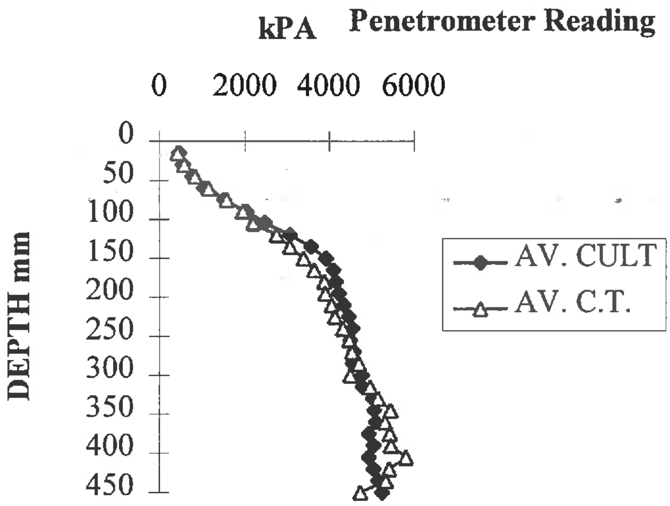
Environmental considerations will increasingly impact on agricultural practice. Limiting the amount of herbicide and insecticide used in dryland agriculture by targeting specific areas such as row spaces for weed control, or crop foliage for insect control, has environmental and sociological benefits in addition to agronomic and economic advantages.

Fertiliser application. Last season, nitrogen was side-dressed to sorghum when rain occurred after planting. Dry matter production, 125 days post planting, doubled for one site, however grain response at that time was not as pronounced. Yield increases between 10%-30% were recorded at harvest from the application of the equivalent of 20 units Nitrogen/ha at some reps. Although encouraging, variation across treatments and the limited nature of the trial indicate further work is needed. We expect side-dressing of crops with nitrogen will be beneficial when seasonal conditions improve during early crop growth, or following waterlogged conditions. Currently growers are unable to side-dress fertiliser due to lack of implements, inaccuracy of placement and interference from stubble. CT will also facilitate banded application of phosphorus and trace elements, such as zinc. CT will improve precision in fertiliser placement and timing of application, even in crops with comparatively narrow row spacings. The offset hitch Bob Mathieson developed allows him to side-dress fertiliser into 30 cm rows.

Tillage and planting. CT facilitates accurate tillage operations including selective tillage to help maintain stubble cover. Rod Birch considered sorghum stubble that was too stressed to consider spraying could be selectively cultivated without cultivating the inter-row areas. He will also interrow cultivate at times for weed control. Bob Mathieson has planted mung beans in rows that are offset to previous wheat rows, thereby improving establishment and stubble handling at planting. With 30 cm tyne spacings, the Gyral T226 can comfortably handle 3.6 t/ha wheat stubble and 1 t/ha mung bean stubble.

Soil compaction. Preliminary penetrometer results at Lyall Swaffer's (Figure 2) indicate decreased resistance to 30 cm in the crop zone. The higher readings for the CT area deeper in the profile probably reflect increased number of readings at depth for the CT paddock, as realistic results to 450 mm were difficult to record from the non-CT paddock. Growers expect the development of better structured soil in the crop zone to improve crop establishment, yield and uniformity. CT will also help to minimise harvest traffic effects on the paddock in wet harvest conditions, if trucks and chaser bins travel the compacted wheeltracks. We have not yet measured these responses.

Figure 2. Average penetrometer readings across two adjoining paddocks on "Bungarra", one with normal cultivation and one with controlled traffic.



Reduced costs. Fuel savings contribute directly to profit and Bob Mathieson has cut his fuel use at planting from 8 L/ha to 2.3 L/ha. Lyall Swaffer reported tillage operations were much easier to perform in his trial area than elsewhere on the farm. In future, fuel flow meters will allow us to quantify these benefits in the field. Farmers with wide machinery report that working within contour bays can reduce efficiency by as much as 20-30% due to overlaps in irregularly-shaped bays. Controlled traffic eliminates unnecessary overlap, either by farming within parallel banks as Bob Mathieson does, or by farming over banks. This avoids increased fuel, seed, chemical and fertiliser input costs, and maximises yields by avoiding double planting.

Improved cropping. Following this year's sorghum harvest, Brendon Swaffer felt that in the CT plot it took less time to fill the grain bin during harvest, indicating a probable higher yield. Most benefits will probably come from increased planting opportunities. Bob Mathieson believes it was the combination of zero-tillage and CT which allowed him to harvest a crop when most crops in his district failed. Even during the drought, Bob is preparing to harvest his sixth crop in three years. Ian Buss has said that "in his area, one spray can be the difference between getting a crop and not getting one."

ON-FARM PROBLEMS WITH CONTROLLED TRAFFIC

The on-farm testing program has highlighted several problems, both expected and unexpected.

Machinery Modifications. Some tillage equipment proved to be more adaptable than others. Lyall Swaffer's scariseeder with welded tyne mounts makes it difficult for him to manage both traditional and CT cultivation with the one machine. Consequently, the permanent pathways are cultivated at planting, although the bolt on tynes on his chisel plough are removed from behind the tractor wheels for primary workings. The matching of primary and secondary tillage equipment has not been a major impediment.

Harvester - Tractor Incompatibility. We have not included harvesting in our layout planning at this stage. Fortunately, wet harvests have not been a problem during the drought, and our co-operators have preferred to develop the CT system and react to any problems generated at harvest. The incompatible wheel spacings and differences in operating widths has been put in the "too hard basket" at this time. As grower's demands increase, we hope that machinery manufacturers will address this problem. Possibly this Conference will be the catalyst.

Installation Techniques and Marking. Row cropping marker arms have been successfully used to install permanent wheeltracks during planting operations by Bob and Rod, although they are looking forward to an easy to use and effective alternative. Lyall Swaffer tried installing pegs to guide for one run and then working visually from that run. This did not give accurate guess rows as tractor position was difficult to gauge in relation to the last pass. The resulting overlap or underlap reduced the fundamental advantage of CT. Guess row variation was minimised by Murray Jones who measured every track across a relatively flat 325 ha paddock. Each track was marked with a furrow and the tractor was driven directly over the furrow during the planting operation. This enabled dryland cotton to be inter-row cultivated over the past two seasons, with a 18.4m trailing cultivator. Drawbacks to the system are the length of time required to set up a paddock and, in common with marker arms, the high level of skill required to drive the tractor down a pre-defined mark. Straight driving is particularly difficult with articulated 4WD tractors.

In the short term, marker arms seem to be the best way to install the permanent wheeltracks. To date this has been done at planting, in anticipation of the tracks being defined by the lack of stubble in the wheeltracks in subsequent seasons. Bob Mathieson has found this a satisfactory solution, although the ability to see the position of the front wheel of his 2WD tractor relative to the wheeltrack, may be a contributing factor. Lyall Swaffer has increased the number of summer crop rows planted beneath the tractor compared to the rest of the planter. This has allowed easier identification of wheeltracks following harvest. Both Murray Jones and Rod Birch use a "gun sight" on the tractor to assist the driver to drive straight. We need a system to layout a paddock quickly and accurately, preferably vehicle-mounted and capable of covering at least 500 ha in a day.

Operator Skills. All co-operators have found it difficult to follow a marker furrow, and drive accurately on permanent wheeltracks while monitoring implement performance. This causes variable guess rows and subsequently inter-row cultivation is much more difficult. Weeds can grow unchecked in gaps. Accurate guess rows are essential in CT layouts to reduce overlap inefficiencies, and maximise opportunities. Although marker arms are working, they only provide a mark for the tractor operator to follow, they do not steer the tractor. Marker units suitable for large (18+m) equipment are heavy and require additional operator skills to operate. All co-operators agree the development of automated guidance systems are essential for effective operation of CT systems. We are collaborating with the University of Southern Queensland to develop systems for both tractor and implements.

Wheel Tracks. Finding the permanent wheeltracks following harvest has become an issue. Without matched harvester and tractor tracks, harvest operations leave extra wheel tracks in the field. This is compounded by the self mulching nature of many CQ soils which tends to remove surface distinctions during a growing season. Consequently, wheeltracks become blurred and header tracks cause confusion.

Herbicide effectiveness has been reduced on the wheeltracks probably due to dust interference and stressed weeds. Bob Mathieson has fitted extra nozzles over the wheel tracks to increase the chemical application rate, and increased his spray boom width to twice the implement width. Wheeltracks are trafficked alternately. It is unlikely this will be a viable solution on larger areas. Rod Birch is considering using high rates of residual herbicide on the wheeltrack area. Murray Jones has slashed the wheeltrack area which was not planted for dryland cotton. Mechanical control (scrapers, etc.) works well in experimental plots at Emerald and Gatton. Perennial woody weeds are already a problem for Bob Mathieson and he uses a blade plough when necessary.

CONCLUSION

On-farm development work is progressing well. Layout design and future recommendations are being tested commercially in a collaborative approach which links research and industry needs with extension and adoption. Preliminary feedback from growers is extremely encouraging. Controlled traffic appears to allow much easier adoption of existing research and extension objectives (maintenance of cover, etc.). As the project progresses, other effects are expected to emerge. Positive interactions with soil structure, soil water and soil fertility are expected. However, many of the benefits of CT described will only be achieved with a strong farmer commitment, and with achievement of the high level of precision in farming operations offered by the CT system. There are undoubtedly practical and technical issues yet to be resolved. While some farmers will be able to modify existing equipment to suit a CT system in the short term, there will be a need for additional capital investment on many farms to satisfactorily implement a CT system. For instance, many farmers will need to upgrade certain items of farm machinery by the fitting of marker arms, etc, with some farmers likely to opt for three-point linkage equipment in the long term. Much of the machinery in Central Queensland is reaching the end of its working life. This should aid the adoption of this technology as farmers will have an opportunity to replace existing plant with CT compatible equipment. Some farmers will need to re-shape contour banks to facilitate farming operations and traffic across them, and in some cases to alter soil conservation and fencing layouts for efficient farming operations and runoff control.

Many grain farmers integrate a livestock enterprise into their farming program. How this will affect management of a CT system is being assessed at Rod Birch's this season.

CT farming systems have many benefits to offer grain farmers. It is likely that CT systems will play a major role in improved soil water management and improved crop performance, by facilitating more convenient and efficient minimum tillage practices.

ACKNOWLEDGMENTS

We wish to thank our co-operators for their help and acknowledge the support of NLP, LWRRDC and GRDC for this project.

REFERENCES

Carroll, C., Yule, D., Halpin, M., and Burger, P. (1994). I have got the rain in, why do I lose it. In: Huf, S. and Agnew J. (Eds). *RAIN to GRAIN* QDPI Information Series Q194039: 22- 31.

Gillies, C. (1978). An overview of the development of agriculture in the Central Highlands. QDPI Report, Emerald, Qld.

Spackman, G.B. and Garside, A.L. (1995). Major factors affecting grain production in Central Queensland and their implications for sustainable grain farming systems. *A Review prepared for GRDC.*

Willcocks, J. (1993). The resource. 1. Climate. In: Garside, A.L., Radford, B.J. and Carr, A.J. (Eds). *Farming systems for Downs and Brigalow soils in Central Queensland.*, QDPI, 2-30.

TRAFFIC AND COST REDUCTIONS UNDER BROADACRE CONTROLLED TRAFFIC

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ABSTRACT

Two dryland farming systems, using reduced tillage and zero tillage practices, were examined to determine the potential benefits of broadacre controlled traffic. Wheel-track locations were calculated using computer simulations of the existing machinery and cropping practices.

Wheel-tracks accounted for 28% of the paddock area under large scale zero tillage and 40% under the smaller cropping system. Even at these low levels, potential benefit exist in converting to controlled traffic. Practical difficulties, particularly with respect to harvesting, do exist but the economic analysis indicates controlled traffic to be a viable option.

INTRODUCTION

Controlled traffic is a farming method that aims to separate the wheeled areas and the root-beds. This can lead to benefits in soil conditions for moisture storage and crop growth within the root-beds as well as for traction and trafficability within the wheeled areas (Marchenko, 1989). This paper looks at the potential benefits of controlled traffic in the context of two existing farming systems on farms on the Darling Downs and in Central Queensland in Northern Australia.

The benefits of controlled traffic that are of most importance to the farmers are the potential yield increases where compaction is eliminated and the possible reduction in energy and machinery costs when tyres consistently work on prepared traffic lanes.

Researchers have generally found yield increases when compaction due to wheel traffic has been eliminated. In reviewing research on crop yields under controlled traffic, Murray (1993) concluded from recent research that crop yield increases under controlled traffic were more than sufficient to compensate for loss of root-bed area to permanent wheel-tracks. Yield increases of between 0-10% could be expected under controlled traffic systems.

When compared to random traffic systems, researchers have consistently reported reduced implement draft. In summarising European controlled traffic research, Chamen et al (1992) reported implement draft reductions in all experiments. Tullberg (1988) reported reduced draft for tillage tools in soil that had not been wheeled compared to those working in wheel-tracks. Draft reduction ranged from 15% for firm soil to 55% for soft (previously tilled) soil conditions. He also reported chisel plough and cultivator draft reductions averaging 27% for replicated trials. Tullberg and Lahey (1990) reported reductions in machine draft averaging 40%. They also noted that greater draft savings were possible because it was not necessary to till so deeply in the controlled traffic plots.

The reduction in implement draft in controlled traffic systems is accompanied by an improvement in tractive performance for tractors operating on the compacted wheel-tracks. Murray and Tullberg (1988) and Lamers et al (1986) reported 8% and 13% improvement in tractive efficiency respectively when comparing tractors working on rolled traffic lanes to random traffic systems.

A third aspect of confining the wheel traffic to designated traffic lanes is a possible reduction in the frequency and depth of tillage required. Walsh (1994) showed evidence of disturbance and reduced porosity to a depth of approximately 500 mm below the existing soil surface for a single pass of a loaded grain harvester tyre. This work was conducted at soil moistures near the plastic limit for an alluvial silt loam, not unlike the conditions that may be encountered during a wet harvest in the Northern grain areas. It is readily apparent that such compaction is below the depth where it would be alleviated by ploughing under normal tillage operations. Additional tillage passes at increased depths may be the only alternative to accepting the deleterious effect of such wheelings on subsequent crops.

For the two example farms, this paper aims to clarify the potential benefits of controlled traffic by :-

- Identifying the machinery configuration and sequence of operations for example crops.

- Quantifying the wheel traffic involved in terms of numbers and locations of passes as well as the tyre pressures involved.

An attempt to quantify the possible benefits and costs involved in moving to a full controlled traffic system was undertaken for Farm One. Farm machinery was accurately measured and tyre sizes recorded. Tyre inflation pressures were recorded in an attempt to quantify ground pressures. Some inflation pressures recorded were considered excessive causing the tyres to be overly rigid. This information should be considered with the work of Smith et al (1994) where soil-tyre interface pressures many time the inflation pressure of rubber tyres were recorded. This notwithstanding, documentation of tyre inflation pressures allows some comparison of the relative ground pressure of the different machinery.

Implement width overlap was assumed to be 10% for the slasher and the harvester. Overlap of other machinery was reduced depending on the width and use of markers and guidance aids.

CURRENT FARMING SYSTEMS

It is important to note that the example farms and crops chosen for this exercise were not selected to be representative of farming systems and machinery currently in use. The selected farmers are considered leaders in adopting improved farming systems and machinery. The two farming systems have independently evolved to zero tillage or reduced tillage operation. The Central Queensland operation has a history of high initial energy usage, including a 391 kW four wheel drive tractor, but now both tractor size and operating hours per year have reduced. The Darling Downs farm was initially based around smaller machinery. The adoption of zero tillage and the benefit of increased cropping frequency have resulted in the original tractors being able to satisfy current cropping requirements.

The potential benefits of a full controlled traffic system may not be large for these farmers as, it can be argued, they have already progressed a considerable way towards this goal. However, and more importantly, it will be farmers such as these who are most likely to move to controlled traffic systems. Therefore it is important to quantify the potential benefits and problems which will drive and hinder this process.

Farm One

Tables 1 and 2 contain a broad summary of the cropping systems and the machinery employed for the two example crops on Farm One.

Table 1 Details of Farm One

Location	Central Queensland
Crop Area (Ha)	2000
Crop Type	Wheat
Preceding Crop	Wheat
Operation Sequence 1 (Reduced till)*	Spray -18m boom on truck
	Cultivate -16m cultivator (Steiger ST350)
	Cultivate
	Spray
	Plant 16.6m planter (D8 crawler)
	Harvest
Operation Sequence 2 (Zero till)	Spray -18m boom on truck
	Spray
	Spray
	Spray
	Plant 16.6m planter (D8 crawler)
	Harvest

* For this example crop only: the fallow was a very dry period and the number of cultivations and sprays during the fallow was reduced compared to "normal" conditions

Table 2 Farm machinery details for Farm One

IMPLEMENT	WIDTH	TRACTOR	TYRE SIZE	PRESSURE (kPa) for tyres or track
Heavy cultivator	16m	Steiger ST350	40x14 Compactor	200
Boomspray	18m	Truck mounted	9.00x20 Truck	350
Planter	16.6m	Cat D8	10.00x20 Truck	300
-	-	Steiger ST350	30.5LR32 Singles	105
-	-	Cat D8	Tracks 559mm wide	87 (Average)
Harvester			30.5x32	

Figure 1 Wheel-track pattern for Farm One, reduced tillage

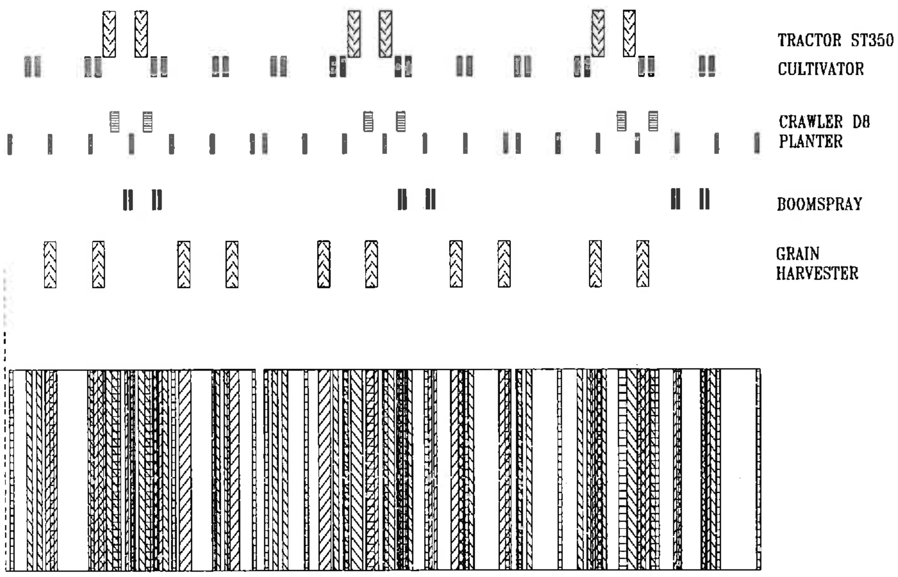
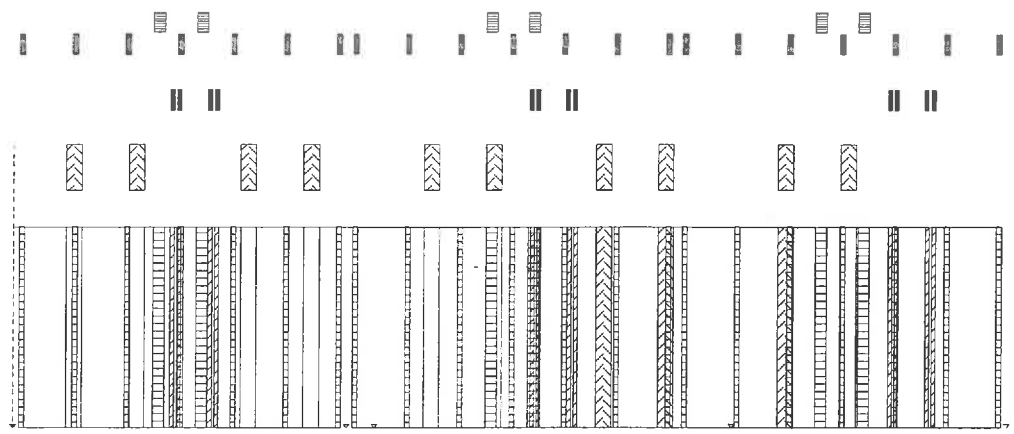


Figure 2 Wheel-track pattern for Farm One, zero tillage



Farm Two

The property is situated near Chinchilla on a brigalow cracking clay loam. The current owners moved onto the property in 1978 and were concerned with the high level of soil erosion. Strip cropping was introduced in 1984 and parallel contour banks introduced to control excess water flows. Zero tillage trialed in 1989 and the whole farm was converted to a zero tillage system two years later.

Table 3 Details of Farm Two

Location	Darling Downs
Crop Area (ha)	340
Crop Types	Wheat, sorghum or dryland cotton
Preceding Crop	Cotton
Operation Sequence (wheat)	Slash - after cotton only, 2 passes Plant - Multi-planter Spray - post-emergent herbicide 2 passes Harvest - New Holland 8080 harvester
Operation Sequence (cotton)	Plant - 3 point linkage, twin disk planter Spray - herbicide 2 passes (spray rig 1) Spray - insecticide 7 to 10 passes (spray rig 2) Harvest - 2-row International Harvester cotton harvester
Operation Sequence (sorghum)	Spray - herbicide 2 passes Plant - Multi-planter Harvest - New Holland 8080 harvester

A front wheel assisted tractor, John Deere 4450 (Tractor 1), is used for tillage and slashing operations. A small two wheel drive tractor, Fiat 750 (Tractor 2), is used for all spraying operations. Both tractors use similar width tyres at the same spacing. Current tractor usage is approximately 120 hours per year for the larger tractor and 220 hours per year for the smaller tractor..

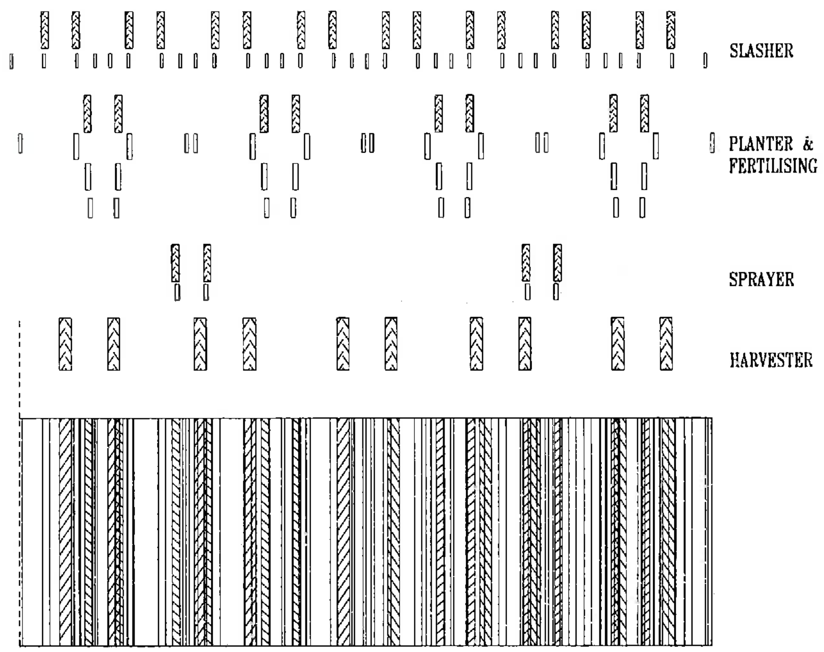
TABLE 4 Farm machinery details Farm Two

IMPLEMENT	WIDTH (m)	TRACTOR	TYRE SIZE	PRESSURE (kPa)
Planter	10.6	FWA	12.00R20 (inner)	275
			7.50x16 (outer)	200
Airseeder			12.4x24	200
AA Trailer			10.00x16	310
Slasher	6.1	FWA	6.95x14	210
Spray rig (1)	8.5	2WD	7.60x15	180
Spray rig (2)	21.2	2WD	10R15	200
Tractor (1)		FWA	18.4x38	100
Tractor (2)		2 WD	18.4x32	100
Harvester (grain)	9.14		30.5x32	180
Harvester (cotton)	2 row		18.4x38	200

The wheat and sorghum planting system has evolved into a one pass operation which places seed and the full fertiliser requirements of the crop. The planter comprises of the planter frame with planting tines and presswheels, a trailed seed and solid fertiliser airseeder and a one tonne trailed anhydrous ammonia (AA) tank. The N-jector tine developed by Robotham (1994) and Strong enables fertiliser placement during sowing occur without causing seedling mortality.

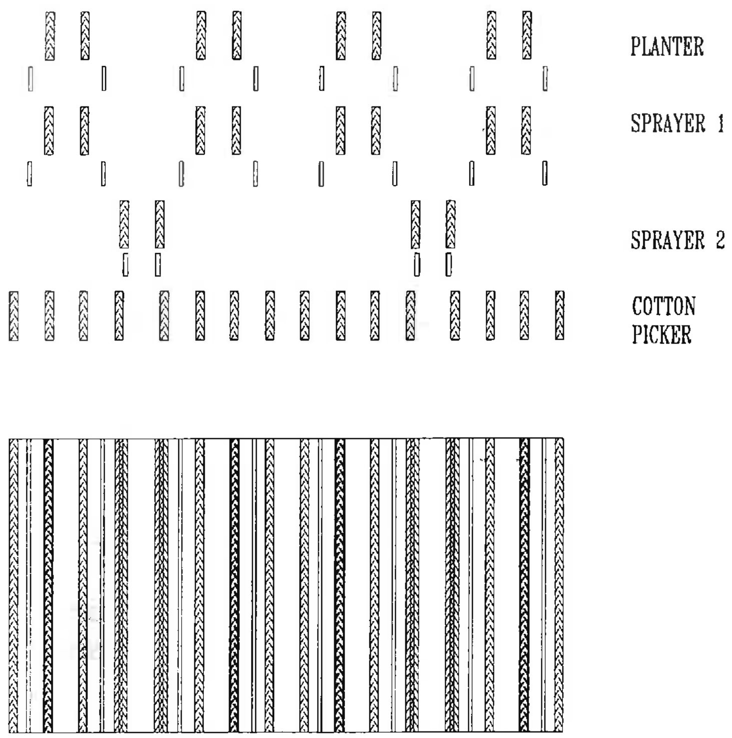
As sorghum is planted with the same planter configuration as wheat, only the wheat wheel-track pattern is shown. The wheel-tracks of the slasher could be deducted to determine the area wheeled during the sorghum crop.

Figure 3 Wheel-track pattern for Farm Two, zero tillage wheat



The cotton crop was grown under a twin row skip configuration with two rows of cotton being separated by a one metre gap. Each paired row is separated by a three metre gap enabling the insecticide rig to clear the fully grown crop. Cotton crop wheel-tracks, Figure 4, has been included to contrast the broadacre wheat cropping systems with a intensive but zero tillage row crop.

Figure 4 Wheel-track pattern for Farm Two, zero tillage cotton



RESULTS

Farm One

For farm one the two farming systems resulted in 55% of the area wheeled for reduced till and 28% for zero till. This assumed a consistent 5% overlap for all operations, as well as a single set of wheel-tracks for repeat operations such as spraying, and is therefore a conservative estimate of the area covered by wheel-tracks. By comparison, the controlled traffic system considered most achievable is based on wheel-tracks at 4 m centres. It would reduce wheeled area to 11.8% for the same sequence of operations for reduced till and for zero till. It is notable that the zero till wheelings are identical to the reduced till system in terms of the percent of the area wheeled for the example crop. Although the reduced till would have more passes on the wheel-tracks, the actual area of wheel-tracks would be the same.

A preliminary economic analysis of the long term benefit of a controlled traffic system for continuous wheat production on farm one was undertaken. The analysis used a spreadsheet based technique developed by Page and Walsh (1991). This analysis estimated cash flows to develop and set up a new system and produced yearly cash flows over the life of the project. Return or cost of the project is summarised as the Net Present Value (NPV) or the Internal Rate of Return (IRR) of the project. Straight line depreciation was used to estimate the cost of machine ownership.

Assumptions used in the economic analysis were as follows :-

1. The average (35%) of the estimates for draft reduction provided by Tullberg (1988) and Tullberg and Lahey (1990) can be achieved. The added possibility of shallower working should make this conservative.
2. Tractive performance will be improved by 10% or the average of the available estimates.
3. This will allow the Steiger tractor to pull a 32 m cultivator and planter as opposed to the current 18 m.
4. A 12 m grain harvester could be employed.
5. This wheel spacing could be matched to a 32 m boom spray, cultivator and planter, such that all wheeling were at 4 m centres.
6. Accurate marking out and tracking could be achieved.

The analysis indicated that cost of ownership and operation of machinery would be reduced by $19 per hectare for each crop. This only accounts for the reduced implement draft and improved tractive efficiency assumed above. No account is taken of the potential to increase yield due to reduced area compacted or other benefits of improved precision in controlled traffic systems.

For the 1 000 ha of wheat cropped on the example farm, the potential benefits translates to a Net Present Value of around $100 000 over ten years. Such a benefit would only be realised if the machinery required could be purchased as part of the normal machinery replacement program on the farm. Where this expenditure was required to be brought forward to the first year to initiate the controlled traffic program, the analysis indicates that the break-even point for such expenditure could be as high as $100 000. In other words, for 1 000 ha of wheat in Central Queensland, expenditure of $100 000 to convert to controlled traffic would be returned within ten years due to savings in reduced implement draft and improved traction only.

A similar analysis for the zero till area showed reductions in cost of around $7 per hectare due mainly to the use of a wider planter with the same tractor. This translates to a Net Present Value of $35 000 for 1 000 ha of wheat over ten years, based on machinery replacement as part of the normal on farm replacement system.

Farm Two

The wheat cropping system resulted in 51% of the paddock surface being wheeled. If the 6.1 m slasher, used twice to reduce the cotton trash, was not required the wheeled area would have reduced to 40%. Under cotton, 32% of the ground was wheeled. Cotton planting was the first and only tillage operation, therefore no tillage of wheel tracks was undertaken. Only 17.5% of the wheeled area was trafficked once and the wheel-tracks used for insecticide spraying received multiple passes plus one pass of the harvester. There is potential to better match the tyre spacings of the insecticide spray rig and tractor and the harvester.

The grower is quite happy with his current cropping system. Both the 10.6 metre planter and Spray Rig (2) were purchased in the last 12 months. With this purchase has come the potential for income through limited contract sowing and spraying. Purchase of a cotton mulcher would save one machine operation compared to the current slasher but a mulcher is considered an item which cannot be economically justified. The grower concedes that the planter and new spray rig are not compatible in terms of wheel-tracks but questions the cost and mechanical reliability of a 31.8 metre spray boom. As all crops are harvested by contractors, the grower has little input into harvester width, tyre sizes and wheel spacing. He believes the harvester to be the weak link in his cropping systems but sees no real solution in the foreseeable future. The grower did not consider the use of a gantry as probable solution for his farm.

CONCLUSIONS

The two example farms illustrate the importance of using realistic situations when comparing controlled traffic systems to current farming practices. The methodology used has enabled the potential benefits of broadacre controlled traffic systems to be identified and a dollar value placed on these gains. Because the data is based on real farm situation, further economic evaluation may assist farmers and researchers to develop economically viable controlled traffic systems.

The importance of using realistic cropping system data is clearly indicated by the crop rotation currently practiced on farm two. The common usage of planter and spray rig indicates a wheat and sorghum rotation would assist in the development of a controlled traffic system. But as the current returns of an average cotton crop are approximately four times that of a sorghum crop, economics determine that a row crop and a swath crop are often grown in rotation.

The use of low cost computer-aid-drafting (CAD) packages enables growers and researchers to examine wheel-tracks in real cropping situations and superimpose many what-if scenarios in a clear visible manner. Different levels of implement overlap or poor tracking of implement passes can be easily simulated. An additional examination of the cropping systems used on these two farms in 5 to 10 years time may show significant advancement towards the appropriate broadacre controlled traffic systems.

REFERENCES

Chamen, W.C.T., Vermeulen, D.J., Campbell, D.J. and Sommer, C. (1992). Reduction of traffic-induced soil compaction : A Synthesis. Soil and Tillage Research, 24 (1992) 303-318.

Lamer, J.G., Derdok, U.P., Lumkes, L.M. and Dlooster, J.J. (1986). Controlled traffic farming systems in the Netherlands. Soil and Tillage Research, 8 (1986) 65-76.

Marchenko, O.S., 1989. Optimising soil cultivation and seedbed parameters referring to soil conditions. In 'Land and Water Use'. Vol. 3. Agricultural Mechanisation. Edited by V.A. Dodd and P.M. Grace. Balkema Rotterdam pp 1507-1516.

Murray, J.R. (1994). Controlled traffic; a sustainable approach to agricultural land management. Dept. of Management Studies Research Series. Vol. 2 No. 1. University of Queensland, Gatton College.

Page, J.R. and Walsh, P.A. (1991). The economic evaluation of crop research proposals. Proc. Conf. Australian Economics Society, Armidale.

Robotham, B.G. (1994). Placement of Nitrogen Fertiliser at Sowing for Reduced Tillage Cropping nin Northern Australia. Masters Thesis, University of Southern Queensland.

Smith, B.E., Burcham, T.N., To, F.S., VanDevender K.W. and Matthes R.K. (1994). Mobile Soil-Tyre Interface Measurement System. Trans of ASAE, Vol 37(5)

Tullberg, J.N. (1988). Controlled traffic in sub-tropical grain production. Proceedings 11th Conference International Society Soil Tillage Research Organisation, Germany.

Tullberg, J.N. and Lahey, G.V. (1990). Controlled Traffic Cropping. Final Report to The National Energy Research, Development and Demonstration Program

Walsh, P.A. (1994). An Improved Soil Displacement Assessment System for Compaction Studies. Proceedings of the Conference on Engineering in Agriculture, Christchurch, Paper No. SEAg 94/050.

LAND MANAGEMENT SYSTEMS INCLUDING CONTROLLED TRAFFIC, EROSION CONTROL AND CROP ROTATIONS FOR DRYLAND COTTON

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BACKGROUND

A research project is currently being undertaken in Central Queensland in association with the dryland cotton industry. The work is focussing on sloping country (where soil erosion is a major concern), on cracking clay soils (to develop soil management principles based on an understanding of their specific properties and responses) and a range of crops. Dryland cotton cannot be a monoculture, but must be integrated into a broad cropping program.

Aims of the project are:

(i) to optimise cotton production by maximising infiltration (stubble retention and reduced tillage) and crop water use (opportunity planting);

(ii) to minimise soil structural degradation by controlled traffic and *permanent wheel tracks*; and

(iii) to minimise soil erosion by controlling runoff.

The *challenge* is to incorporate runoff control on sloping country into controlled traffic permanent wheel track layouts. This creates the problem that with controlled traffic, runoff will be directed by wheel tracks, crop rows and tillage furrows. Runoff could be concentrated in low undulations in the paddock where this water flows with high velocity and energy, producing rills and gullies.

One *solution* is to prevent this concentration by confining the runoff to closely spaced furrows, which may or may not be wheel tracks. Each furrow must carry all the runoff from its catchment or contributing area. If the furrows are 2m apart, the catchment area is small (for example, 0.1 ha for a 500m long furrow), the volume of runoff is small and a layout can be designed to prevent erosive flow velocities being developed. Furrows must not overtop, and they must drain through (no low spots). Consequently, furrows will in general go down the slope.

These concepts have many *secondary benefits* for dryland cropping, including:

(i) Controlled traffic provides tramlines for herbicide spraying so that markers are not needed. Once the layout is in place, markers are not needed for any operation. Many of the difficulties with reduced or zero tillage are reduced.

(ii) The ability to position the current operation relative to previous operations allows all forms of directed spraying, accurate inter-row cultivation, planting between rows of stubble etc.

(iii) The drained wheel tracks will increase trafficability. Typically, it is the wet, low spot in the paddock that dictates when any operation can begin.

(iv) The system may allow a degree of crack management. If large cracks form in the wheel tracks and furrows, and the system directs runoff to these cracks, high infiltration rates can be expected. With common broadacre farming, cracks rarely function as high infiltration zones. Increased infiltration increases production potential and decreases runoff and erosion.

MATERIALS AND METHODS

This experiment is based on an 8 m wide commercial system with 550 m long plots on a 1.5% slope. The plots go generally down the slope. Several rotations are used to provide a range of antecedent conditions (cover, soil water content, furrow condition) when runoff-producing rainfall occurs. Crop production, soil parameters, runoff and erosion are measured, and a comparison made of 1 m and 2 m beds, and wheeled and non-wheeled furrows.

Site

The experimental site is located on Elsden Farms, Tyson Road, Emerald (10 km west of the township of Emerald). The soil is a shallow open downs cracking clay, developed from weathered basalt. Long-term mean annual rainfall and evaporation for Emerald Research Station are 639 mm and 2265 mm, respectively.

Experimental Details

The experiment commenced in September 1993, with the installation of controlled traffic lanes. Planting opportunities and crop rotations (Table 1) have been restricted by rainfall. Wheat rotations were planned, but lack of winter rainfall has restricted this option. Total rainfall for 1994 was 523 mm (289 mm in March), and January-July 1995, 242 mm.

Table 1. Crop rotations

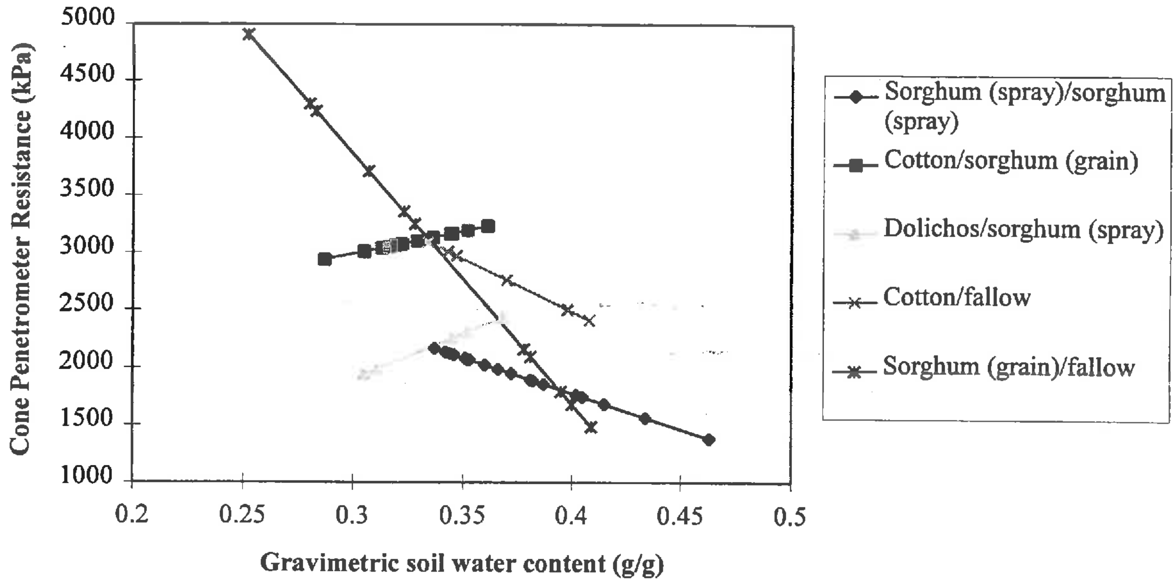
Treatment	1993		1994		1995	1996
(bed size)	Spring	Summer	Winter	Summer	Winter	Summer
T1 (1m)	S(sp)			S(sp)		C(lp)
T2 (1m)		C	D	S(gr)	D	C(lp)
T3 (2m)	S(sp)		R	S(sp)	R	C(lp)
T4 (2m)		C	O	S(gr)	O	C(lp)
T5 (2m)		S(gr)	U	fallow	U	C(ep)
T6 (2m)		S(gr)	G	fallow	G	C(ep)
T7 (2m)		C	H	fallow	H	fallow
T8 (2m)	S(sp)		T	S(sp)	T	C(ep)
T9 (2m)	D(sp)			S(sp)		C(ep)
Dates:						
Planting	S 7/9; D 13/9	C 19/11; S 10/2		S (21/2)		
Spray-out	S 18/11; D 15/3			S (5/4)		
Harvest		C 25/4; S 21/6		S (10/7)		

S = sorghum; D = dolichos; C = cotton.
sp = sprayed out; gr = grain; lp = late plant; ep = early plant.

Measurements

a) **Soil water content** - sampled gravimetrically using 37 mm diameter cores, with depth increments of 100 mm down the profile. Samples are taken at planting and harvest, and at anthesis for grain sorghum. In-crop measurements for cotton are taken using a neutron moisture meter (Campbell Pacific Nuclear Model 503) at identical depth increments.

Figure 1. Relationship between soil water content and penetration resistance (at 300-400 mm depth) for various crop rotations (sampled on 25/7/94 and 4/4/95)



Measurements were made of furrow cross sections during the 1993/94 cotton season on three occasions. The furrow cross-sectional areas are given in Table 5.

Table 5. Effect of rainfall runoff and refurrowing on furrow cross-sectional area (cm^2) for three treatments.

		T5 (2m bed)	T4 (2m bed)	T2 (1m bed)
Date	**Condition**	**Fallow**	**Cotton**	**Cotton**
7/12/93	after runoff	372	325	397
6/1/94	after furrowing	507	386	560
25/1/94	after runoff	406	429	505

Furrowing tended to increase furrow capacity, which was subsequently reduced by a small amount following a runoff event. There was a larger decrease in furrow capacity in fallow plots than those with a cotton crop. The furrow shape changed from deep and narrow (V shape) after furrowing, to broad and shallow (U shape) after runoff. Furrow capacity at the top of the slope varied little after runoff compared to the bottom of the slope. These results suggest that most of the observed silt deposition in furrows was due to furrow slumping, but some movement toward the bottom of the furrow was also observed. Observations during 1994/5 suggest that the furrows were more stable than the previous season. This could be attributed to increased stubble cover and natural consolidation. Soft edges of newly formed furrows and beds are very susceptible to erosion.

Runoff and soil loss measurements were recorded for events on the 4th and 7th February, 1995 (Table 6). Rainfall on the 7th February occurred in three events, which have been reported separately.

The runoff and soil loss data showed consistent patterns. The highest runoff and soil loss occurred from T4 and T7 (ex. cotton) during all events. Additional cover in T1, T3 and T8 reduced runoff by 42%, and soil loss by 38%. T5 and T6 provided the highest cover levels which reduced runoff by 72%, and soil loss by 89% (compared to bare plots). The highest runoff from each treatment (as a percentage of rainfall) was during the second event on 7/2/95 when the soil surface had been wet by the previous storm. The height recorder in T8 non-wheel track malfunctioned during these events.

The amounts of soil loss are small when compared to expected amounts from bare, cultivated soils. Total sediment concentrations were generally low (1.0-3.0g L^{-1}) with the lowest concentrations coming from plots with high stubble cover. These preliminary results indicate the possible benefits from controlled traffic layouts.

Table 6. Runoff and soil loss data from the experimental site, February 1995 (WT = wheel track)

a) 4th February - total rainfall 39 mm, I_5= 82.6 mm hr^{-1}.

Treatment		Runoff (mm)	Max. Runoff Rate (mm hr^{-1})	Soil Loss (t ha^{-1})
T1 WT	Sorghum sprayed 11/93	8.8	20.2	0.02
T1 non-WT	Sorghum sprayed 11/93	11.2	23.7	0.42
T3 WT	Sorghum sprayed 11/93	2.2	5.2	0.04
T4 WT	Cotton picked 4/94	15.6	26.6	0.34
T4 non-WT	Cotton picked 4/94	29.9	40.6	0.13
T5 WT	Sorghum harvested 6/94	10.9	19.7	0.01
T6 WT	Sorghum harvested 6/94	0.0	0.0	0.0
T7 WT	Cotton picked 4/94	26.4	59.9	0.15
T8 WT	Sorghum sprayed 11/93	2.8	7.0	0.02
T8 non-WT	Sorghum sprayed 11/93	?	?	0.07

b)7th February - total rainfall 54.4 mm

	Rain=22 mm I_5=45.6 mm hr^{-1}		Rain=25.6 mm I_5=79.2 mm hr^{-1}		Rain=6.8 mm I_5=19.2 mm hr^{-1}		Total	Soil
	Runoff	Rate	Runoff	Rate	Runoff	Rate	Runoff (mm)	Loss (t ha^{-1})
T1 WT	8.9	30.5	12.2	22.2	4.5	5.9	25.6	0.53
T1 non-WT	3.7	15.1	14.2	32.7	4.7	13.7	22.6	1.05
T3 WT	1.6	8.1	16.4	32.0	0.8	1.2	18.8	0.85
T4 WT	4.6	12.2	13.3	24.6	4.4	9.3	22.3	1.30
T4 non-WT	7.0	18.4	12.5	18.4	6.6	11.4	26.1	1.10
T5 WT	2.2	12.0	15.8	22.3	0.7	2.9	18.7	0.05
T6 WT	2.4	13.0	6.2	16.2	1.7	3.2	10.3	0.24
T7 WT	4.3	25.3	23.7	40.9	3.2	9.3	31.2	1.15
T8 WT	0.2	3.3	25.6	67.3	1.9	3.7	27.7	0.60
T8 non-WT	?		?		?		?	0.44

ACKNOWLEDGMENTS

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REFERENCES

ASAE Standards (1992). American Society of Agricultural Engineers, St. Joseph, Michigan.

McIntyre, G., Marshall, J., Rickman, J., and Lucy, M. (1992). Dryland Cotton Production Guide. Queensland Department of Primary Industries Publication Series SQA92011.

Tractor wheel compaction effects on infiltration and erosion under rain.

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Introduction

Controlled traffic is expected to increase infiltration in non-traffic areas, presumably leading to reduced soil loss. However, actual measurements of these effects for Australian conditions are rare. Field studies of runoff and erosion effects of controlled traffic have only recently begun in Australia (D.Yule, QDPI; J. Tullberg, UQ, pers.comm). Controlled traffic or 'permanent' beds are now reasonably common in irrigated cotton farming. Differences in infiltration and runoff behaviour between traffic and non-traffic furrows are observed by irrigators, and were evident during our studies of runoff and erosion in irrigated cotton fields. Thus, furrows used in our studies were selected according to prior traffic status so that differences between other experimental treatments could be determined. Data from these studies relating to effects of prior wheel traffic on runoff and erosion are presented here. Also, data for stubble retention are presented to show the relative benefits, and the interaction, of the two methods of management.

A related issue is that of effects of surface compaction, for instance due to recent wheel traffic on moist soil, on runoff and erosion. Most studies of erosion are carried out on loose, fine-tilled soil, as this is seen to be a worst case erosion status. Compaction of the soil surface could potentially reduce erosion, by increasing soil strength, or increase erosion, by reducing infiltration and increasing runoff. In swelling/self-mulching soils any positive benefits of compaction may be short lived. Compaction of furrow bottoms by machines has given variable results in controlling erosion during furrow irrigation, including reduced erosion (Voorhees et al., 1979), no effect (Dickey et al., 1984) and increased erosion (Young and Voorhees, 1982). There has been some discussion of the potential for use of tractor wheel compaction to reduce erosion in dryland cotton in central Queensland (S. Cannon, QDPI, pers. comm.). This issue is addressed using experimental data and an analysis of erosion processes.

Methods

Two forms of tractor wheel compaction were studied:-

a) short term surface compaction,
b) long term compaction related to wheel tracks in controlled traffic farming systems.

Data are taken from a number of studies of erosion from furrows where compaction was included as a treatment (short term surface compaction - at Gatton and Kingsthorpe) or occurred due to the nature of prior farming operations (long term compaction - at Emerald and Warren). At Gatton, erosion was studied soon (3 days) after compaction. At Kingsthorpe, erosion was measured several months after compaction, during a summer crop. A rainfall simulator was used to apply rain at high intensities (95-110 mm/hr) as large intense storms cause the majority of long-term total soil loss (Wockner and Freebairn, 1991). The rainfall simulator uses a line of oscillating Veejet 80100 nozzles (Loch, 1989) and can apply rain to 2 m wide plots (2 furrows) of 2 to 12 m length. Runoff rates and sediment concentrations were measured every 1-2 minutes from each of the two furrows under the simulator. General information for each study (site, soil, plot size, intensity, duration and furrow width and range of furrow slopes) is given in Table 1; site specific details are given below.

Short Term Surface Compaction Studies

Compaction was applied with 0, 1, 2 or 5 passes of a tractor wheel in the furrow bottoms, or 1 pass each on the sides and bottom of the furrow. Furrows were 0.75 m wide (top to top), bare, freshly tilled, with ~50 % sideslopes and a 100 mm wide (roughly) flat section in the bottom, before compaction. Furrows were moistened and allowed to drain for 3 days, to about field capacity, prior to compaction. No attempt was made to alleviate prior compaction. The tractors used at Gatton and Kingsthorpe had rear wheels 0.46 m and 0.38 m wide, and rear axle weights of 2930 kg and 2830 kg, respectively.

Gatton. The simulator plots were run two days after compaction. Compaction treatments are compared with data from furrows with no additional compaction, run as part of another study at the site. Two furrows were rained on for each compaction treatment. No plots were run for the 2 wheel pass treatment.

Kingsthorpe. The aim of this study was to see if effects of compaction persisted over a summer crop period. Treatments, furrows and methods were the same as used at Gatton, except that a) compaction was performed in early December after sprinkler irrigation, cotton was planted the same day and rainfall simulations were carried out in mid-March, 95 days after compaction, and b) a wheat cover crop treatment was included; wheat was grown on the hills and furrows before cotton was planted, giving 24 % cover of anchored stubble under the cotton in March. Natural rainfall was below average in the period between planting and simulation studies - 22mm (Dec), 32mm (Jan), 93mm (Feb), 16 mm (Mar). By March the surface soil (0-100mm) was dried to about wilting point by the cotton and some cracks had formed in the subsoil. Cotton plants were removed before rain was applied. The furrow hills had slumped somewhat.

Table 1 - General information about the rainfall simulator studies

Site	Soil		Rainfall Simulator			Furrow	
	Great soil group/Type	Texture	Plot Length (m)	Intensity (mm/hr)	Duration of Rain (min)	Width (m)	Channel Slope (%)
Short term surface compaction							
Gatton QLD (University of Queensland Farm)	Prairie soil, Alluvial (Lockyer)	clay loam /clay	1.8	95	40	0.75	0.25 - 6
Kingsthorpe QLD (QDPI Research Station)	Black earth, (Craigmore)	clay	1.8	107	30	0.75	0.6 - 4
Long term controlled traffic							
Emerald irrigation area (left bank EIA)	Black earth	clay	12	105	40	1.0	0.75
Warren NSW (Auscott Field 23)	Grey clay	clay	12	100	40	1.0	0.5

Long Term Compaction and Controlled Traffic

Emerald. This study was carried out soon after planting of irrigated cotton on 'permanent' 1 m wide beds. Runoff and erosion was measured separately from two furrows for each simulator run, one being a wheel track and one a non-wheel track. Surface cover of none (bare), or two levels each of wheat stubble or cotton trash, were studied. Cover was mainly in the furrow bottom.

Warren. This study was carried out several weeks after cotton planting on `permanent' 1 m beds. Treatments included:- bare, cotton trash (in furrow bottom, about 40 % cover overall), and wheat cover crop. The wheat cover crop was grown on the beds over winter, sprayed out in spring and cotton planted without extra tillage or hilling-up. All plots were on non-wheel track furrows, except the cotton trash treatment where non-wheel track and wheel track furrows were studied.

Results and Discussion

Short Term Surface Compaction Studies - Gatton and Kingsthope

Runoff was 23-44 % greater for the compacted furrows than for the bare non-compacted furrows at Gatton (Table 2). Increasing the severity of compaction in the furrow (5 passes) or proportion of area compacted (sides&bottom) maximised runoff and reduced infiltration to 13-16 % of rain applied (Table 2). A cover of 2 t/ha wheat stubble caused a large reduction in runoff compared with the bare and compacted furrows. At Kingsthorpe, runoff was only slightly greater for all compacted treatments except the 5 pass treatment (Table 2), indicating that surface effects of these treatments had been ameliorated by wetting, drying and self-mulching during the summer crop. Five wheel passes gave 35 % more runoff and halved the total infiltration. The wheat cover crop significantly increased infiltration, even though it gave only 24 % cover.

Table 2 - Runoff and infiltration for furrows with various compaction treatments, at Gatton 2 days after compaction (65mm rain in 40 min) and at Kingsthorpe 95 days after compaction (54mm rain in 30 min).

	Number of Plots	Runoff [mm]	Infiltration [mm]	Infiltration [% of rain]
Gatton				
Bare non - compacted	22	39	25	39
1 wheel pass in furrow	2	48	16	24
5 wheel passes in furrow	2	54	11	16
1 wheel on sides & bottom	2	56	8	13
Covered non - compacted	4	13	50	79
Kingsthorpe				
Bare non - compacted	2	31	23	42
1 wheel pass in furrow	2	33	20	38
2 wheel passes in furrow	4	34	20	37
5 wheel passes in furrow	2	44	10	18
1 wheel on sides & bottom	2	32	21	39
Covered non - compacted	2	10	43	81

As soil loss is highly influenced by slope, and slope of each furrow could not be controlled precisely, soil loss data from the compaction treatments are compared in terms of their deviation from the erosion-slope response derived for non-compacted furrows. At Gatton, soil losses for all compaction treatments equalled or exceeded those from furrows receiving no additional compaction (Figure 1). Compaction with one wheel pass caused little or no additional soil loss, however soil loss was almost doubled for one each of the furrows given five passes and side&bottom compaction. Evidently, surface compaction did little to reduce the soil available for erosion. At Kingsthorpe, no major differences are apparent between bare non-compacted and compacted treatments (Figure 2), with all soil losses in a band of about +/- 2 t/ha around the general trend of increasing soil loss with increasing furrow slope. Effects of compaction on soil loss appear to have been ameliorated during the summer crop. The greater runoff for the 5 wheel pass treatment did not result in greater soil losses, indicating a reduction in sediment concentration

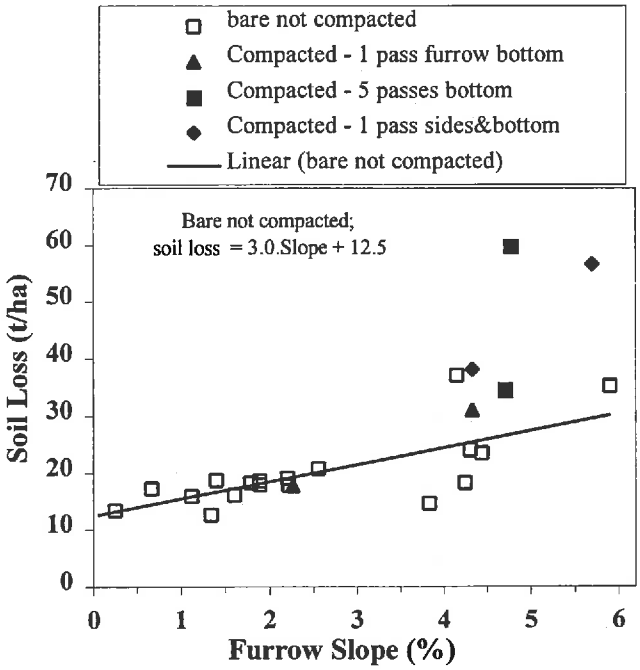

Figure 1 - Soil loss from for bare furrows, with and without short term surface compaction, at Gatton on a clay loam (40 min of rain).

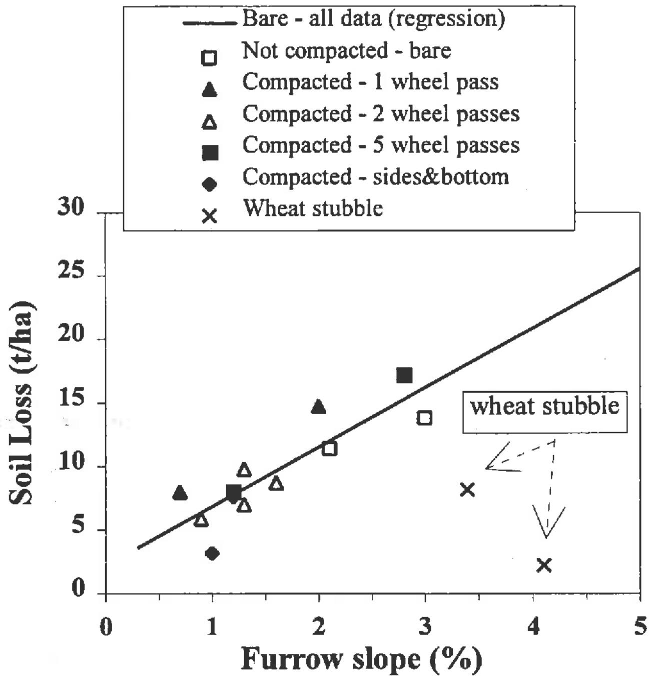

Figure 2 - Soil loss from furrows, bare with and without compaction, and with standing stubble; black earth at Kingsthorpe (30 min of rain).

possibly related to some residual effects of the compaction treatment. The 24 % wheat cover reduced soil loss by 55-90 % compared to soil losses expected for bare furrows of the same slopes (Figure 2).

Long Term Compaction and Controlled Traffic

Emerald. Total runoff decreased with increasing cover (Figure 3), with wheel track furrows giving more runoff than non-wheel track furrows at all covers. This difference was small for bare furrows and increased with greater cover. Surface sealing restricts infiltration on bare furrows, overriding the improved infiltration potential of subsoil in non-wheel track furrows. On partially covered furrows the proportion of the plot that is sealed (and therefore the runoff) is reduced but on wheel track furrows the compacted subsoil restricts infiltration, reducing the effects of cover. Soil losses are reduced by an order of magnitude when cover is > 40% (Figure 4), compared with 17 % lower soil loss from no wheel traffic on bare furrows. The combination of retaining cover and controlled traffic gave the least runoff and soil loss. However, of the two practices retaining cover had the greater effect. Controlled traffic alone is of limited benefit for increasing infiltration and reducing runoff and soil loss from storms on this soil.

Warren. The combination of cotton mulch in non-traffic furrows gave much less runoff (7mm) than cotton mulch in wheel track furrows (25mm) (Figure 5). Runoff from furrows with cotton mulch and traffic was similar to runoff from bare non-traffic furrows (27mm). Reduced infiltration in the traffic furrows eliminated most of the benefits of cover. However, soil loss was still reduced in the cotton mulch traffic furrows (1.7 t/ha) compared with the bare non-traffic furrows (3.3 t/ha), due to trapping of sediment in the mulch. Soil loss from the cotton mulch non-traffic furrow was 0.5 t/ha. Wheat stubble cover gave the least runoff (5.4 mm) and soil loss (0.1 t/ha). This treatment had cover on both the hills and furrows, and had non-traffic furrows, reducing runoff from both areas.

Erosion Processes in Hill-Furrow Systems

The geometry of hill-furrow systems has a large effect on erosion processes and whether or not compaction affects erosion. In a hill-furrow system, the hill (or bed) is subject to net erosion and is a lateral source of sediment to the furrow. The furrow can be a net sink (deposition site) or source of

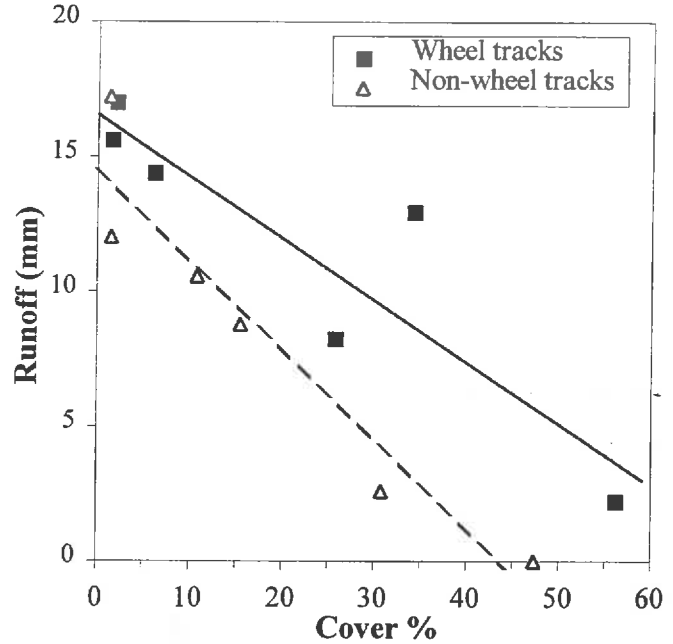

Figure 3 - Runoff from a 40 min storm as affected by cover and wheel traffic (Black Earth-Emerald).

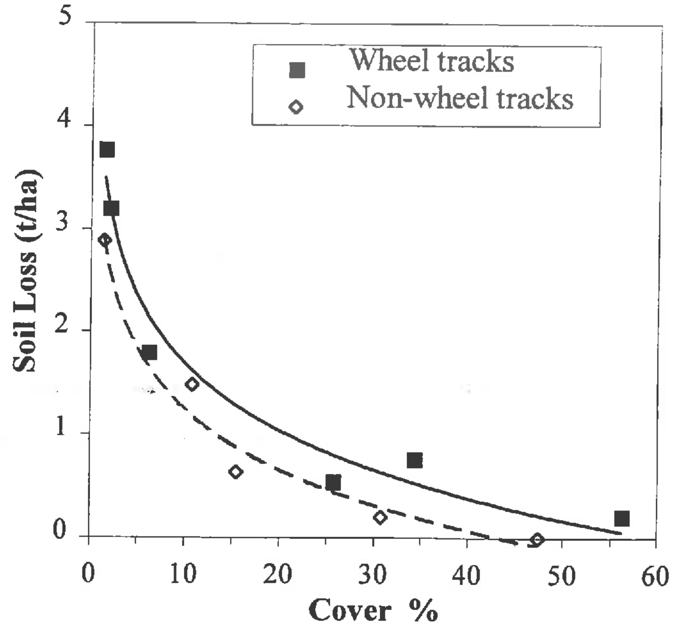

Figure 4 - Soil loss from a 40 min storm as affected by cover and wheel traffic (Black Earth -Emerald).

sediment (scour site), depending on the furrow slope, hydraulic conditions and runoff rate. Looking at each component in turn, the hill is typically a short but steep (eg. 50 %) slope or a nominally flat bed with steep slope into the furrow. Laboratory studies (Silburn and Mitchell, unpub. data) of bare short steep slopes (0.55-0.35 m long, 50 % slope) gave erosion rates of 20-50 t/ha (depending on soil type) for a 40 min 100 mm/hr storm (similar to the storms applied in the field). Erosion rates were similar when half of the slope was made nearly level and the rest 50 % slope. At the furrow scale, soil losses for bare soil (eg. at Gatton) were 12-35 t/ha (Figure 1) while lateral supply from hills on this soil was 38 t/ha, ie. flow in the furrow was not capable of removing all soil supplied by erosion on the hills. Only at furrow slopes >6% would the flow in the furrow be able to remove all sediment supplied and begin to erode the furrow bottom on these plots. Until this happens, soil strength in the furrow bottom can have no effect in reducing erosion.

Furrow discharge, and related variables such as velocity and depth, increases with length of furrow under rainfall. Thus, the critical conditions for initiation of net erosion in furrows (rather than net deposition) would be defined by a combination of slope and length. Soil strength in the furrow bottom (eg. from compaction) can have no effect in reducing erosion from furrows at low slopes and shorter lengths (ie. where deposition rather than erosion occurs), and may increase erosion if it is also related to decreased porosity and infiltration rates. For furrows on steep slopes and longer lengths, or where lateral sediment supply from the hill is reduced (eg. by cover), greater soil strength in the furrow bottom will reduce erosion (see also Titmarsh et al., this proceedings).

Conclusion

Surface compaction from tractor wheel traffic on moist soil (clay loam) resulted in reduced infiltration, and increased runoff and soil loss compared with non-compacted furrows, when intense rain was applied two days after compaction. These effects were largest where the severity (number of wheel passes) or proportion of area compacted were greater. When intense rain was applied 95 days after compaction on a swelling clay where cotton was grown, infiltration, runoff and soil loss were similar for non-compacted furrows and furrows compacted by one and two wheel passes. Reduced infiltration was still evident on furrows that received five wheel passes. Otherwise effects of wheel traffic were largely ameliorated by wetting, drying and self-mulching during the summer crop. On both the clay loam and clay, surface compaction was not effective in controlling soil loss. Cover from cereal crop residues gave large reductions in runoff and soil loss on both soils.

On controlled traffic furrows in irrigated cotton, wheel track furrows gave more runoff and soil loss than non-wheel track furrows across a range of cover levels. The difference was small for bare furrows and increased with increasing cover. The combination of retaining cover and controlled traffic gave the least runoff and soil loss. However, of the two practices, retaining cover had the greater effect. Controlled traffic without retained cover gave little or no increase in infiltration and reduction in runoff and soil loss from storms, as surface sealing restricts infiltration on bare furrows.

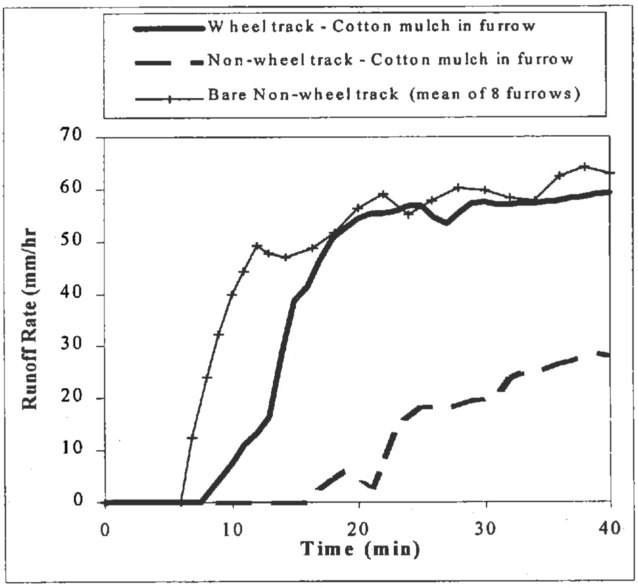

Figure 5- Runoff from furrows with cotton mulch, with and without wheel traffic, during a 40 minute storm on grey clay, Warren.

In hill-furrow systems where the furrow bottom is subject to sediment deposition rather than scour (ie. furrows with lower slopes or shorter lengths), compacting the furrow bottom will not be effective in controlling erosion and may increase it. In steep furrows, where the furrow is subject to erosion rather than deposition, compaction may decrease erosion, but only by the amount of scour occurring in the furrow itself and large soil losses will occur if no other management practices are used.

Acknowledgments

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References

Dickey, E.C., Eisenhauer, D.E. and Jasa, P.J. (1984). Tillage influences on erosion during furrow irrigation. Trans. ASAE 27: 1468-1474.

Loch, R.J. (1989). Aggregate breakdown under rain: its measurement and interpretation. Unpublished Phd Thesis, University of New England, Armidale.

Titmarsh, G.W., Silburn, D.M., and Jukes, P. (this proceedings). Compaction and crop residue effects on furrow flow erosion. Nat. Controlled Traffic Conf., 13-14 Sept. 1995, Rockhampton, Australia.

Voorhees, W.B., Young, R.A. and Lyles. L. (1979). Wheel traffic considerations in erosion research. Trans. ASAE 25: 786-790.

Wockner, G.H. and Freebairn, D.M. (1991). Water balance and erosion study on the eastern Darling Downs - an update. Aust. J. Soil and Water Conservation, 4:41-47.

Young, R.A. and Voorhees, W.B. (1982). Soil erosion and runoff from planting to canopy development as influenced by tractor wheel-traffic. Trans. ASAE 25: 708-712.

Making Controlled Traffic Work In Non-Parallel Contour Banks.

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Introduction

Permanent wide-bed systems are now common in the major cotton areas of the Darling Downs and Northern NSW (Lucy, 1993). This cropping area is well suited to permanent beds as the crops are grown on low sloping flood plains and in straight rows for flood irrigation. However, large areas of rain-grown crops are planted on sloping land where non-parallel contour banks have been constructed to control run-off water. The established benefits of permanent beds / controlled traffic in the irrigated cotton areas could also be true in other cropping areas if there was a system of managing parallel permanent wheel tracks in non-parallel contour bank layouts.

In the Burnett region of Southern Queensland, row crops have been grown within non-parallel contour banks for the past fifty years. Crops are planted in multiples of 4, 6 or 8 rows (3.6m, 5.4m, 7.2m) then managed until harvest in this same pattern. The introduction of single-spaced contour banks (this means on slopes greater than 6% there is a contour bank every 30m) produced some problems for producers who once prided themselves on straight rows. However, producers in the Burnett now successfully grow row-crop in non-parallel contour bank layouts using modified row layouts as explained later. A logical development for cropping in the Burnett is to leave permanent wheel tracks in multiples of 4, 6 or 8 rows as part of a controlled traffic program.

Row layouts are usually based on one of the following three layouts.

*1. **Traditional method.*** Up until the last ten years this was the standard technique of row cropping with non-parallel contour banks was to plant parallel to the top contour bank for most of the bay. It is then finished by planting parallel to the bottom bank. As the banks are not parallel there will be a number of short rows (or point rows) in the middle of the bay. The aim is to have most of the machinery turning above the contour bay channel so the tractors do not become bogged in wet periods (Figure 1).

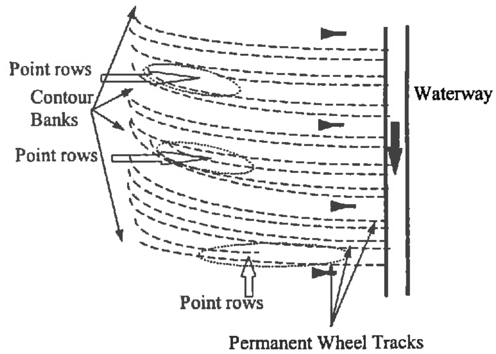

Figure 1 Traditional method of managing row crops in non-parallel contour banks.

In paddocks with steep slopes (greater than 6%) where there are narrow based contour banks this is the only option to plant a row crop. This layout has the disadvantages that up to 30 percent of the area is taken up with point rows. Weed control in the point rows is difficult and these areas act as a weed seed source for the following crop. When there is a run-off event the furrows tend to run in both directions and discharge at a low spot (which is often a rill from previous run-off).

2. Plant parallel to a paddock boundary ignoring the non-parallel contour banks. This method is only suitable on lower slopes where broad-based contour banks are constructed. The aim is to maximise row length and eliminate point rows. Row direction is determined by a paddock boundary and the contour banks are ignored and crossed at any angle.

This system has the major disadvantages of high contour bank maintenance (tillage machinery drags the contour banks down), and there is minimal surface detention as the furrows discharge directly to a contour bank channel. Modifications to machinery are required to allow adequate depth control of planting and tillage equipment and it may not be possible to direct harvest low growing crops, such as soybeans and navy beans because of the angle the rows cross the contour banks. There is also a risk in this system of high harvest losses in some years as the wet channel may delay planting or harvesting operations.

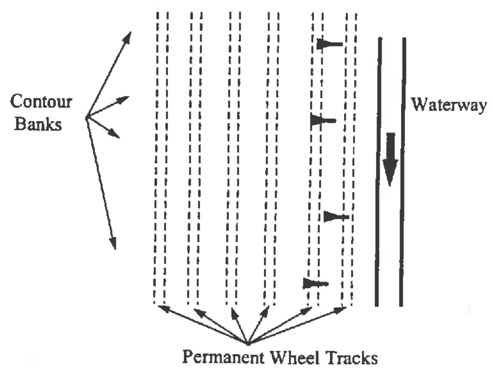

Figure 2 Choosing the longest row and planting the paddock parallel to this ignoring the contour banks.

*3. **Parallel furrows.*** In this system a key furrow is chosen across the slope so that it discharges directly to a contour bank channel or waterway. The paddock is planted parallel to the key furrow. The aim is to minimise the grade on the furrows but ensure they all discharge to the same end. The direction of water flow in the furrow may be the reverse of the flow direction in the contour bank and the furrows may be either straight or curved depending on the topography of the paddock. This has the advantage over the traditional method in that furrows have a continuous fall to contour banks and discharge into waterways. Similar to the previous system this parallel furrows system requires extensive machinery modifications, and restricts the harvesting of some crops. There is also a higher contour bank maintenance requirement but it eliminates point rows.

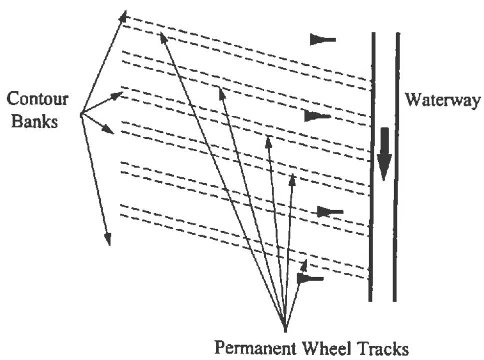

Figure 3 The rows and wheel tracks are designed to discharge directly to a contour bank channel or waterway.

Implementing controlled traffic using the three possible layouts

To maintain permanent wheel tracks through a fallow period and minimise the compacted area, sunken wheel tracks appear to be the most suitable solution. There is some concern that these sunken, compacted wheel tracks will channel water and lead to an increase in run-off and soil erosion.

This paper will look at the estimated run-off and soil movement from the three layout types for a range of land slopes, furrow gradients and furrow lengths.

Methodology

The effects of the three layouts on run-off and soil loss were simulated for a range of furrow length and gradients. Run-off was estimated using KINCON, a kinematic wave type model (Connolly et al., 1988). Soil loss was estimated using results from studies on a similar soil.(Sallaway et al. ,1994).

Furrow shapes and dimensions differed between random and controlled traffic (Figure 4). For the traditional layout (Figure 1) furrow gradient was set at 0.3% (the same as contour banks) and furrow lengths used ranged from 30 to 150m. For second layout (Figure 2) furrow gradients are the same as the land slope. Here the furrow length is determined by land slope. Furrow gradient

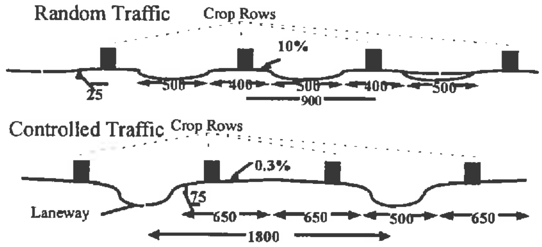

Figure 4 Cross-section and dimensions (mm) of beds in the traditional and controlled traffic systems.

used were: 1%, 2%, 60m; 4% 40m; and 6%,30m. In the parallel furrow layout (Figure 3) furrow gradients ranged from 0.3% to 6% and furrow lengths from 30 to 150m. A range of land slopes up to 6% were also considered.

KINCON is suitable for evaluating the effect of alternative surface conditions on design of soil conservation structures. In the model different surface conditions can be allowed for in two ways: firstly, by alteration of infiltration properties; and secondly, by modifying flow retardance. Here only infiltration properties were obtained for the different conditions- a bare smooth surface was used in all cases (Manning retardance co-efficient of 0.035). The rainfall loss model used is based on a three layer Green and Ampt infiltration model (Brakensiek and Rawls, 1983; Moore and Larson, 1980). Some values of the parameters used in the simulations were obtained from Bridge and Bell, (1994) and are in Table 1.

Table 1. Parameters used in Green and Ampt Equation.

Parameter	Treatments		
	Conventional	CT furrow	CT bed
Ki	100	30	100
Kf	5	1	20
Za	150	150	1000
Ma	0.1	0.05	0.1
Mb	0.1	0.05	0.1
Md	0.1	0.05	0.1
B	0.95	0.95	0.95
Sa	250	100	200
Sb	100	100	200
RR	0.5	0.5	1
EO	250	750	750

In all cases the 1 in 10 storm of 25 minutes duration and 37mm was used. Stream power (units of Kg/s^3) was calculated from KINCON output on a minute by minute basis. Sediment generation rates for each minute were calculated using equations 1 or 2 as appropriate and summed to give a total sediment moved of the storm.

Random Traffic

$$\text{Sediment Transport Rate (g/s)} = 5.37 * \text{Stream power}^{1.66} \quad (1)$$

Controlled Traffic

$$\text{Sediment Transport Rate (g/s)} = 1.35 * \text{Stream power}^{1.86} \quad (2)$$

Results

Traditional and Parallel Furrow Layouts

Total Run-off. KINCON predicted only small differences in total run-off for the parallel furrow layouts (Figure 5). Furrow gradients had minimal impact on the amount of run-off above approximately 1%. There was a noticeable increase in run-off as furrow gradient increased from the lowest value (0.3%) to 1% for the longest rows. Generally, the controlled traffic (CT) treatments yielded less run-off. This was despite the wheel track area shedding 90% of the rainfall occurring on it. However this high run-off rate was compensated for by the higher infiltration(84%) in the bed area, which comprised the larger part of the field. If there was less area of compacted tracks throughout the

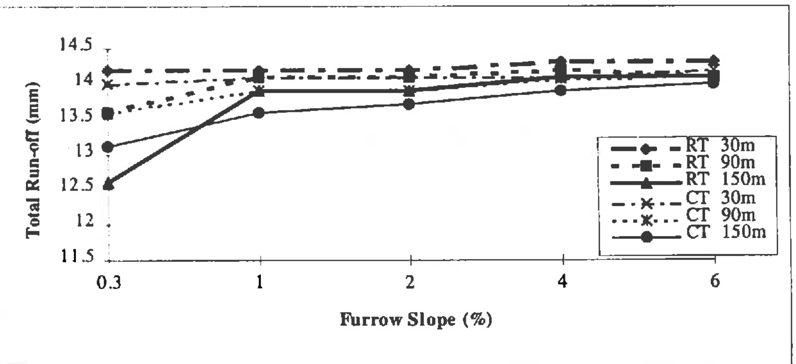

Figure 5 Simulated total discharge from furrows following a rainfall event of 37mm in 25 minutes.

paddock compared to bed area through wider wheel spacing there would have been less run-off from the controlled traffic treatments. The effect of row length is minimal for all furrow gradients above 1%.

Soil Loss As furrow gradient increased the amount of soil loss increased (Figure 6). The lowest soil loss was achieved when all furrows had a gradient of 0.3% (the traditional method). There was a higher rate of soil loss in the random traffic treatments at all furrow gradients and lengths. The length of the furrow also impacted on the estimated soil loss as the longer the furrow the greater the soil loss.

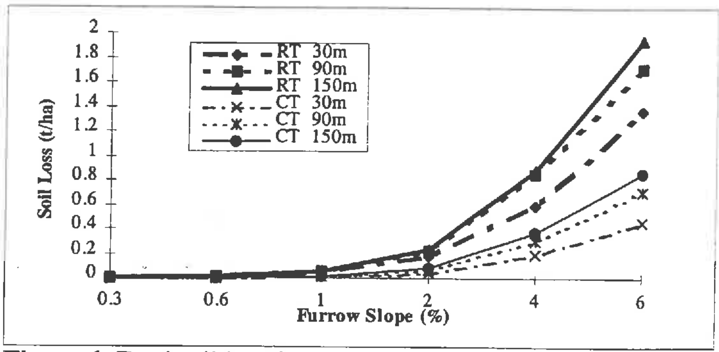

Figure 6 Total soil loss from a range of furrow gradients and lengths under random traffic(RT) and controlled traffic treatments (CT).

For furrows above 2% there is a rapid increase in the rate of soil loss from both the controlled traffic and random traffic treatments.

When Furrows run Parallel to Boundary Layouts.

If the furrows were positioned at right-angles to the contour bank (Figure 2) the furrow gradient is controlled by the land slope and the furrow length by the predetermined bank spacing. For both farming systems, as the slope of the furrow and the corresponding land surface increased the amount of run-off and soil loss also increased (Figure 7). This occurs despite the length of the furrow decreasing. as the slope increases. However for both run-off and soil loss the increase was less under controlled traffic situations than for random tillage.

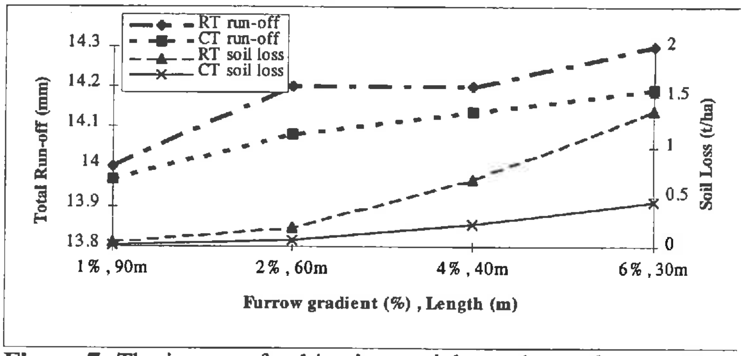

Figure 7 The impact of cultivating at right-angles to the contour bank in terms of run-off and soil loss.

Discussion

It is possible to implement controlled traffic using the layouts described in Figures 1, 2 and 3. The simulations show run-off and soil erosion would be minimised if all furrows had a gradient the same as contour banks at 0.3%. Reconstructing the contour banks to a parallel layout is an unacceptable cost to many producers and in many cases is not possible due to the topography of the land surface. Therefore they must use one of the 3 options and realise the limitations of each.

The case for CT using the traditional row-cropping layout

There is little option but to use this method on slopes greater than 6% or where contour banks are constructed in such a way that they can not be crossed with tractors and machinery. This system requires the least change to the current method of growing crops. By implementing controlled traffic the point rows will be identified before the crops is planted. The results from the simulations show that there will be less soil erosion (Figure 7) and run-off will not be increased (Figure 6) over the current system.

The limitation of this system is there is still the problem of furrows over-topping before they reach a safe disposal area (contour bank channel or waterway). This occurs because of reverse grades caused by previous wash lines, and changes in topography between contour banks. In most cases, the furrows themselves have sufficient capacity. On the red soils in the Burnett this appears to be the major cause of soil movement between contour banks. This may be improved by land leveling between contour banks or changing the gradient on the furrow so there are no reverse grades.

The case for crossing contour banks parallel to a paddock boundary.

This is the simplest method of implementing parallel furrows within non-parallel contour banks. As long as the cultivating and planting equipment have some flotation ability and the contour banks are large enough to have no steep batters it appears possible to "climb" over the contour banks.

The problems with this approach is that all though furrows may begin by crossing at right-angles at some part of the paddock the furrows are going to cross at an angle other than at a right angle. This poses problems for harvesting low crops such as soybeans and requires more complex depth control on the machinery.

Of more concern is that by adopting this type of layout there is an increase in run-off and soil loss (Figure 7). On lower sloping land (less than 2%) this system may be considered an acceptable compromise. However, in dry years yields may be reduced through less stored water. In the long-term concern of higher soil erosion under this layout which leads to a decline in productivity and higher contour bank maintenance. On the land slopes considered in this series of simulations controlled traffic again provided a significant reduction in soil loss and total run-off.

The case for parallel furrows

The concept of parallel furrows within non-parallel contour banks is not new. It was suggested in the 1950's as a method of reducing erosion in paddocks where the construction of contour banks would make row-cropping too difficult to manage. However, it was only recommended on land slopes less than 5% and where the soil had moderate to high permeability (Jones et al, 1959). Dickenson and Faulkner (1988) showed that parallel furrows could reduce soil erosion in a random traffic system. This study shows how controlled traffic combined with parallel furrows would reduce the soil loss even further.

Figure 7 shows a significant increase in the rate of soil loss as the furrow gradient exceeded 2%. At this slope furrow length had minimal impact on the rate of soil loss but as the slope increased the length became more important. In all cases the furrow gradient controlled the rate of soil loss rather than the land slope. This suggests that furrow gradients of less than two percent on paddocks with a land slope of 6% would provide an acceptable compromise between a parallel system of laneways within a non-parallel contour banks. If these furrows drain directly to the contour bank channel or a waterway there is potential to reduce soil erosion over the current traditional point rows. However, to achieve this planning is required to ensure the furrow gradients do not exceed 2% and there are no reverse grades within the furrow.

The system of parallel furrows requires more machinery adaptations to allow constant depth while crossing contour banks at an angle. In the Burnett there are no harvesting fronts that will allow the harvesting of low growing crops such as soybeans in the system.

Further work.

In all simulations it was assumed there was a bare fallow. The next step would be to examine the impact of cover on run-off and soil loss. In the controlled traffic layout used here it was assumed that there was a permanent wheel track/furrow at a maximum spacing of 1.8m. The results suggest that if there were less wheel tracks there would be less overall run-off but the furrow size may have to increase in capacity to safely convey the larger area contributing to the furrow. The shape of furrow may also impact on the rate of run-off and the total soil loss.

References

1. Brakensiek, D and Rawls, W, 1983, Agricultural management effects on soil water processes, Part 11: Green and Ampt parameters for crusting soils, Trans. American Soc. Agric. Engrs., Vol 26, pp 1753 - 1757.

2. Bridge, B.J. and Bell, M.J., 1994. Effect of cropping on the physical Fertility of Kraznozems. Aust . J Soil Res. 32, 1253 - 73.

3. Connolly, R.D., Ruffini, J.L. and Smith, R.J., 1988. Design of structural soil conservation measures using kinematic wave theory, Conf. on Agric. Eng, Inst. Engrs, Aust., Natl. Conf. Publ. No. 88/12, pp 178 - 181.

4. Dickenson, J.P and Faulkner, G.B. 1988. Parallel furrows in non-parallel soil conservation layouts of the South Burnett. Internal Discussion Paper : QDPI.

5. Jones, B.A., Burwell, R.E., Atkison, H.B., Hay, R.C. and Van Doren, C.A. 1959. Effect of farming across terraces in straight-row field operations. Trans. American Soc. Agric. Engrs., pp 115-119.

6. Lucy, M.J. 1993. Permanent wide beds - a controlled traffic system for irrigated vertisols. Information Series QI93051 DPI : Brisbane.

7. Moore, I. and Larson, C., 1980. An infiltration model for cultivated soils, Trans. American Soc. Civil Engrs., Vol 23, pp 1460 - 1467.

8. Sallaway, M.M., Titmarsh, G.W., Sullivan, T., Scarborough, T., Lamb, C., and Glanville, T., 1994. Methodology for determination of design specifications for interrow furrows. Int. Conf. on Hydraulics in Civil Engineering. Inst. Engr. Aust. Natl. Conf. Publ. No. 94/1, pp 19-23.

9. Titmarsh, G.W., Sallaway, M.M., and Jukes, P., 1994. Farming systems and design specifications of interrow furrows. Int. Conf. on Hydraulics in Civil Engineering. Inst. Engr. Aust. Natl. Conf. Publ. No. 94/1, pp 19-23.

Parallel Strip Cropping between Nonparallel Contour Banks

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In broadacre cultivated areas most contour bank systems are not parallel. This creates difficulties for farmers wishing to adopt practices such as controlled traffic farming or inter row cultivation. Figure 1 provides an example of a non parallel contour bank layout in a broad acre farming area.

Mason et al (1995) in another paper presented at this conference describe a system of growing crops in parallel furrows in paddocks with non parallel contour banks. This paper describes yet another approach which could be taken.

In southern Queensland and northern New South Wales, strip cropping is a well accepted erosion control practice on floodplains subject to erosive flooding. The practice has rarely been used as an erosion control measure on upland areas. Figure 1 shows how strips of crop could be grown parallel to contour banks. The contour bank would be in the middle of each cropping strip.

Ideally a summer / winter crop rotation would be used so that at any time half the contour bay would be protected from erosion by a growing crop. Better use of rainfall could occur when runoff from the top strip in a contour bay may be absorbed by the bottom strip in the bay. This situation could arise when the top strip was under fallow and the bottom strip was under crop.

How to use the irregular areas that do not fit into the parallel pattern requires some innovative thinking. They could be used for growing some type of speciality crop. An alternative use for these areas would be for growing grass or to incorporate them into one of the strips above or below them. This would mean that only every second strip would then be parallel. Another option would be to use wide machinery to cultivate the parallel strips with a smaller unit used to "mop up" the irregular areas.

Potential problems associated with the use of the proposed system are as follows:

- difficulties associated with precisely following the alignment of rows around sharp bends
- chemical application where different crops are grown in adjacent strips

There may be opportunities to modify some layouts at minimal cost to improve their workability. eg the sharp bends where contour banks cross drainage lines in figure 1 could be minimised by altering the alignment of the contour banks crossing the drainage lines. Such action would require careful attention to levels and would require an alteration to the specifications of the contour banks to be modified.

The proposed system would provide farmers with an opportunity to adopt controlled traffic farming practices, to achieve an increased level of erosion protection and to make better use of rainfall.

References

Mason, R.M., Titmarsh, G.W. and Sallaway, M.M. (1995). Making controlled traffic work in non parallel contour banks. *A paper presented to the National Controlled Traffic Conference, 13-14 September 1995, Capricorn International Resort, Rockhampton.*

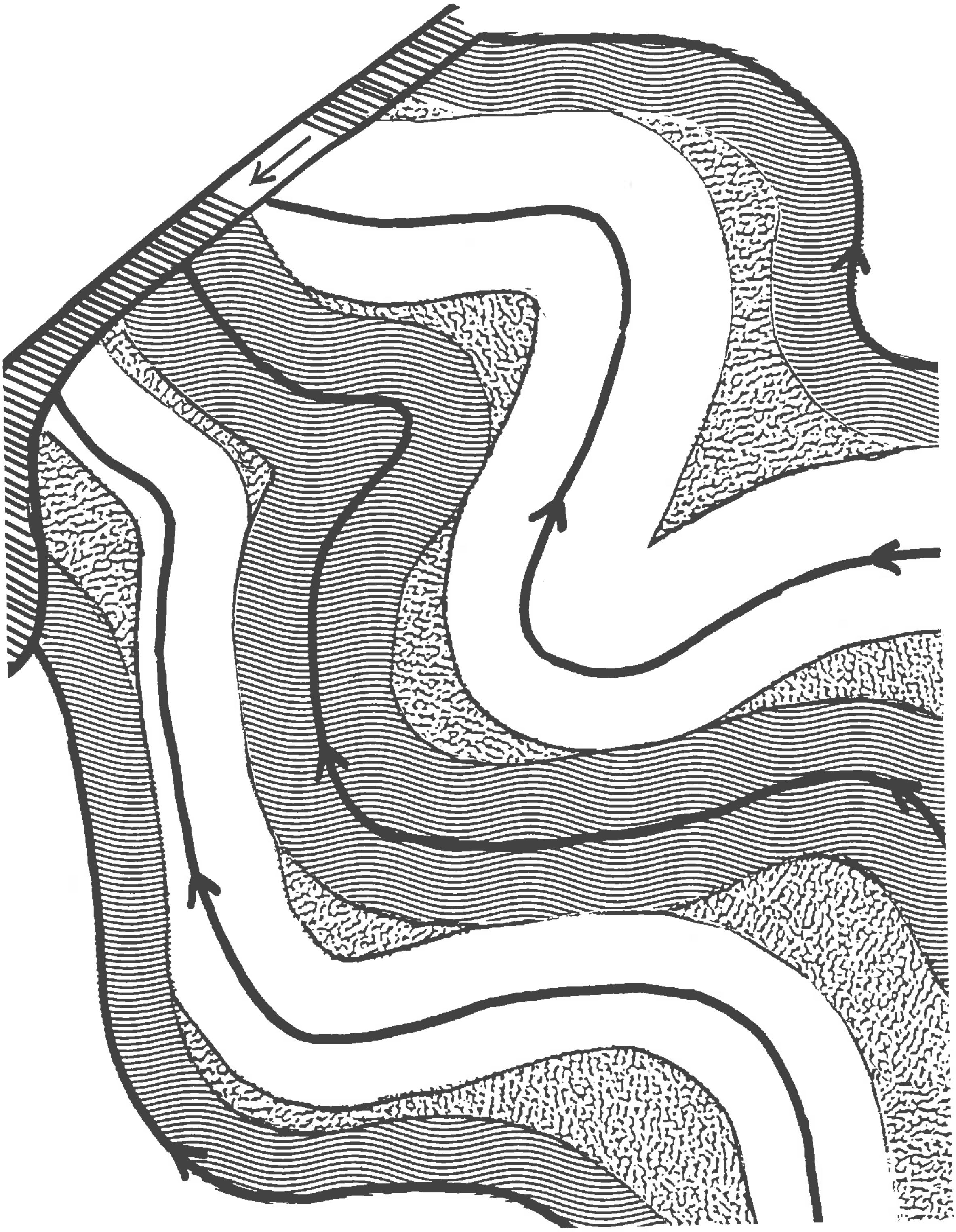

Figure 1 Parallel strip cropping between non parallel contour banks

ON-FARM CONTROLLED TRAFFIC SYSTEMS FOR IMPROVING BENEFITS OF DEEP TILLAGE WITH BROADACRE CROPPING IN WA;
WITH COMMENTS ON CHOICE OF TRACTION SYSTEMS AND APPLICATION TO NO-TILLAGE

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INTRODUCTION

There has been no deliberate research of controlled traffic in WA broadacre cropping before 1990. On-farm investigations have come from the inventiveness of two innovative farmers in the Northern Wheatbelt (Boyle, 1991). Vic Vlahov, of Yuna, had noticed crop growth patterns in his sand paddocks which corresponded to the tractor tracks at seeding. He then adjusted his spray width to match the spray tracks with the seeding tracks and invent his own controlled traffic system in a wheat/blue lupin pasture rotation. I began research on his farm four years after he began the method, especially to improve the long term benefits of deep ripping the compact layers of the sand.

Graeme Malcolm is chairman of the very active Koolanooka-Bowgada Landcare group south of Morawa. On hearing of Vic's system at landcare meetings he decided to try it for his sandy loam soil to improve any long term benefits of breaking up traffic pans. Compaction layers are found in both soils at about 20-30 cm depth. Deep ripping is expensive, but has usually provided yield benefits in the sand, though not so reliably in the heavier textured soils (Perry and Hillman, 1991). Avoidance of recompaction by controlled traffic and direct drilling seemed a sensible strategy to improve the benefits of deep ripping.

With little more than fuel costs, the use of a penetrometer and a weighing trailer, much on-farm collaboration and regular hospitality we have been able to establish that broadacre controlled traffic is practical, can help benefits of deep ripping last at least three years for improved production from the sand, as well as improved structure of the sandy loam. Fitting these systems into the timeliness pressure of the northern wheatbelt is difficult, as well as maintaining convenient matching of machinery.

Interest in the work from the University of Western Australia and CSIRO Division of soils also helped to understand the magnitude of stresses beneath rubber tyred or tracked tractors for the seeding operation. No-till farming is being rapidly adopted in WA, this may increase the risk of accumulated compaction and encourage more rapid development of controlled traffic systems for no-till cropping. There are many interesting possibilities for technical development in this area, especially in relation to compatibility with timeliness; the R&D future looks very stimulating.

METHODS

locations, landscapes and soils; Vic's farm is NE of Yuna, mainly sand, with about 300mm annual rainfall on the eastern, dissected edge of the Victoria sandplain, overlooking the broad Irwin and Greenough valley system. Wind erosion and compaction are the principle land degradation problems. Graeme's farm, south of Morawa, is mainly loam soil and has about 350mm annual rainfall. It lies among the lower valley systems which drain into chains of salt lakes; salinisation, water erosion and compaction are the main land degradation problems.

Methods, Equipment & Techniques.

Vic has the larger farm, larger paddocks and larger seeding equipment. We used a 21m wide seeding bar with 'Thomas' tines for seeding depth control, and a 500HP Steiger Tiger tractor at the time of the research (1990-1993). Graeme has many smaller paddocks and contour banks to negotiate, thus a smaller, 14m wide seeder and a 350 HP Steiger Panther tractor. The sand at Yuna was deep ripped in the winter of 1990, while in pasture, while the loam at Morawa was deep ripped in autumn 1991, before seeding. Extra ripping was also done at Yuna in 1991, before seeding. Crop was sown in the unwheeled and wheeled zones behind the tractor used at seeding. The system formed a more compact traffic lane about 5m wide in every seeding run. Both farms had spray booms that matched or could be adjusted to match the seeding width. Graeme's modification of the sprayer was most inventive. Two 20c coins and multigrip pliers closed off the excess nozzles at one end of the boom. Guidelines for the spraying were by a missing central crop row at Yuna, or the central ridge left by the pairs of prickle chains at Morawa. Parts of or half of paddocks were ripped to 30cm with deep rippers in 1990 and 1991 at Yuna and Morawa respectively. Table 1 is a brief cropping history.

Table 1. Summary of the cropping history at both sites during the research.

	Yuna (ripped 1990)		Morawa (ripped 1991)	
year	rainfall, mm	crop	rainfall, mm	crop
1990	334	pasture	-	-
1991	324	wheat	249	wheat
1992	429	pasture	449	wheat
1993	314	wheat	321	peas

Measurements of soil penetration resistance and water content were made each winter to document gross structure in the unripped, ripped unwheeled and ripped wheeled areas. Yield was measured with weighing trailers and small headers in the unripped, ripped unwheeled and ripped wheeltrack zones in 1991 and 1993 at Yuna and in 1991 and 1992 at Morawa.

RESULTS

Strength responses and their persistence.

Soil strength during drained periods of the winter showed the usual clear effects of ripping the hardpan on the sand. Measurements in 1993 at Yuna (Figure 1) revealed these effects has persisted over 3 years, where wheeling had been avoided. The benefits of lower soil strength from ripping had been removed by wheeling.

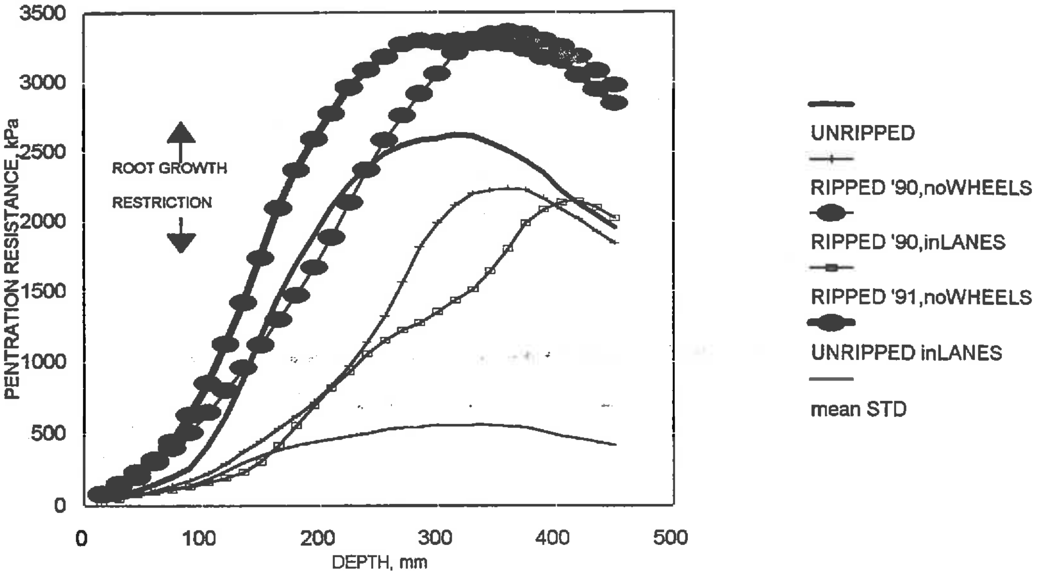
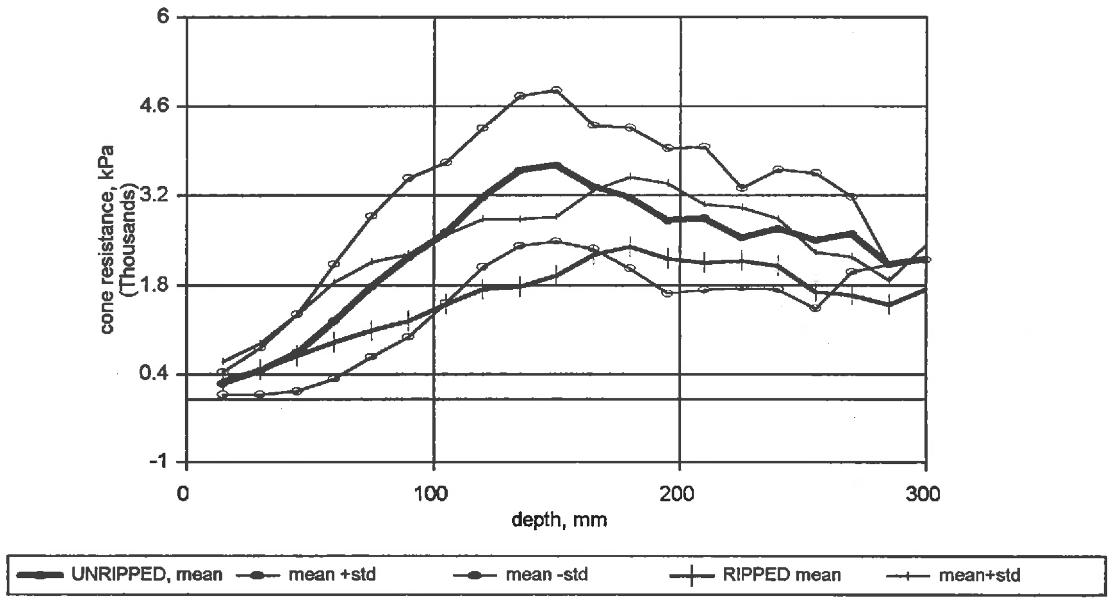


Figure 1. Soil Penetration resistance in winter 1993 at Yuna.

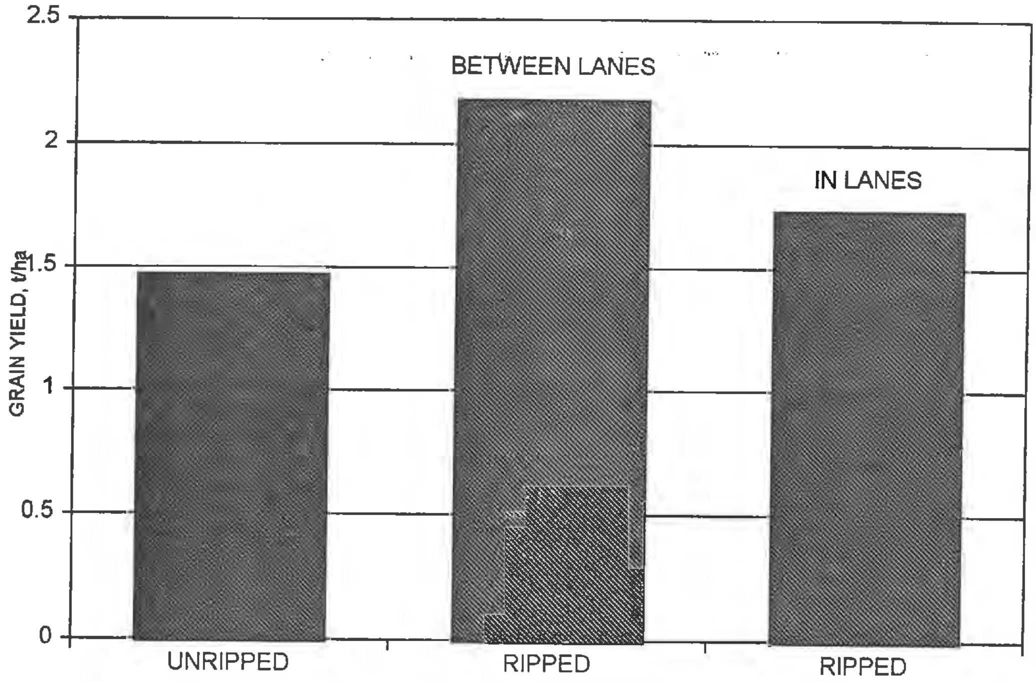
At Morawa the effects on ripping on soil strength of the loam where not so large as for the sand at Yuna. There was also much more variance in the soil strength measurements (Figure 2). The variance corresponded with the more structured soil with peds from remanent fragments of the ripped soil. The benefits to soil strength could be seen after two years, but not confidently after three years. However there was still visible evidence, in 1994, of a better, more permeable structure, of the loam four years after ripping.

Figure 2. Penetration resistance in unwheeled soil ripped or unripped at Morawa in 1993. The soil was ripped in 1991.



Yield responses and their persistence.
The initial yield response to ripping without wheeling the sand at Yuna was large, approximately 700kg/ha (Figure 3). Yield benefits of unwheeled ripping persisted from 1991 to 1993 at Yuna (Figure 4), but were not as large as in earlier seasons, or from later ripping. Wheeling would obviously reduced these benefits had it not been controlled to regular 'lanes' because most recompaction comes from the first wheeling by such heavy tractors on ripped soil.

Figure 3. The yield response at Yuna in 1991 in the first year after ripping.



Crop ripening was also slower in the wheeltracks, but produced a useful yield and better weed control than would have happened with bare wheel tracks. However, the main constraint to sandplain farming in low rainfall areas is timeliness of seeding. Any new systems such as controlled traffic must be very easy to use and not slow down the rate of a seeding program once suitable conditions prevail.

Yield improvements at Morawa were smaller than at Yuna and less consistent. There was a maximum yield benefit of about 200kg/ha in the first season.
Traction on the loam soil at Morawa was markedly improved for spraying the ripped soil, both pre or post seeding. Any major deviation from the traffic lanes resulted in considerable wheel sinkage and almost immobilisation.

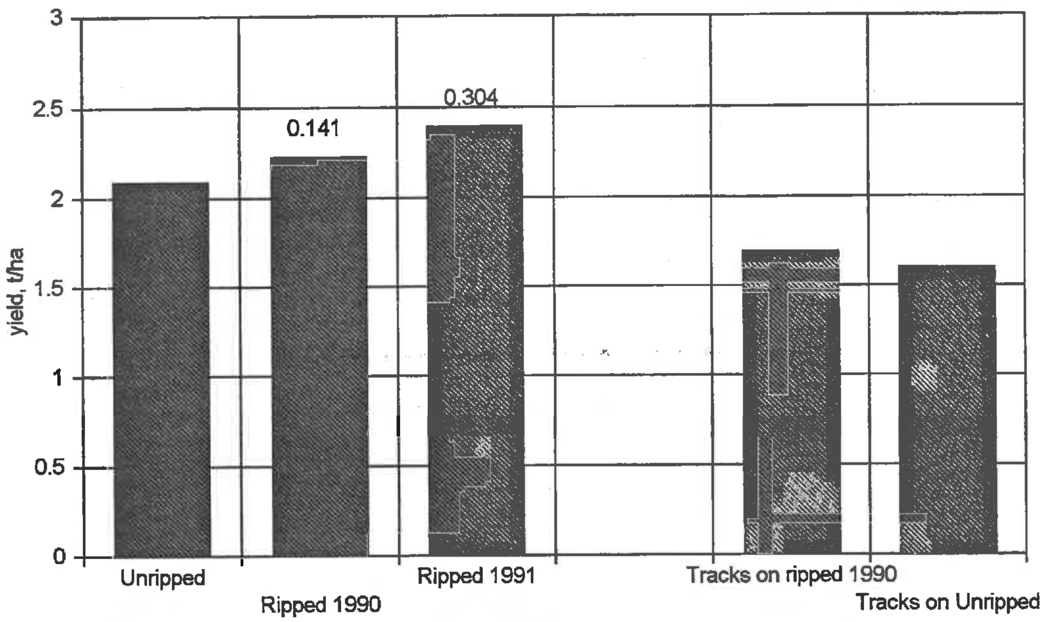


Figure 4. Yield responses at Yuna in 1993, three years after ripping.

DISCUSSION and CONCLUSIONS

Yield benefits from ripping sandplain soil could persist at least 3 years with these on-farm controlled traffic systems. More research and development is needed to make these systems even more practical and acceptable for sandplain farming in low rainfall areas. The yield benefits of controlled traffic on the heavier texture soils of the low rainfall wheatbelt of WA are smaller than for the sand. However there are obvious benefits for improved traction and maintaining structure for better infiltration and drainage.

TRACTION SYSTEMS.

Part of the research at Yuna and Morawa looked at the difference between wheels (dual tyres) or rubber tracks for the seeding tractor. Observations on-farm mainly found the tracks had an advantage of a smaller controlled traffic track width. Further studies of soil stresses beneath the same vehicles used at Yuna (Blunden et al., 1994) showed benefits to tracks for reducing vertical soil stresses, but shear stresses may be increased. This helps to explain why compaction beneath dual tyres and tracks, for the same tractor mass, is often similar in the subsoil. Thus the main benefits of tracks over tyres for controlled traffic is in reduced width of compaction.

NO-TILL

Reduced soil disturbance for erosion protection, with sufficient disturbance for crop production, is being developed in new No-Till systems in WA. These may increase the opportunities for subsoil compaction and Controlled Traffic with No-Till may be the better system design. This needs more research to clarify such ideas more confidently.

ACKNOWLEDGMENTS

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REFERENCES

Blunden B.G., McBride, R.A., Daniel, H. and Blackwell, P.S. 1994. Compaction of an earthy sand by rubber tracked and tyred vehicles. AJSR 32; 1095-1108.

Boyle, S. 1991. Green Light for Controlled Traffic. Kondinin Group Talk.

Perry, M and Hillman B. 1991. The Wheat Book, Technical Bulletin 4196, Western Australian Department of Agriculture.

CONTROLLING THE RESEARCH TRAFFIC

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Introduction

The Land and Water Resources Research & Development Corporation is concerned with improving the long-term productive capacity, sustainable use, management and conservation of Australia's land, water and vegetation resources. This charter is very similar to that of many organisations dealing with agriculture and natural resources, reflecting a generally accepted view about the importance of managing our productive resources in a sustainable way. It also reflects that there is a complex web of many organisations and institutions dealing with common issues and resources, albeit from different perspective, and suggests the need for coordination and cooperation so as not to waste limited resources. Unfortunately, the environment under which all these organisations and institutions operate is constantly changing. While this is a constant source of frustration for researchers and advisory staff, it is an unavoidable consequence of the broader debate about what constitutes private and public benefit in relation to resource management. It will be some time before this debate is through, but in the meantime some important directions are emerging which will impact on the place of agricultural research, including controlled traffic research, and extension in future.

Sustainability Context

Sustainable agriculture is defined by the Standing Committee on Agriculture (Hamblin, 1991) as the use of farming practices which maintain or improve the economic viability of agricultural production, the natural resource base and the environment influenced by agricultural activities. The biophysical, economic and policy environment of Australian agriculture means that neglect of any one aspect of the three dimensions of sustainability (economic, resource base and off-site environment) is done so at one's peril.

In a recent study undertaken by ACIL *et al* (1994), it was found that for many producers preoccupied with financial viability, sustainability is not relevant. The general perception was that anything to do with sustainability inevitably costs money which they do not have. This perception, while missing the point about sustainability, is understandable given the long-term cost/price squeeze and the declining returns from agriculture faced by most producers. Indeed, Australian agriculture and its producers have largely managed to survive through the increased productivity resulting from research and development activities. However, there are many examples of where neglect of the resource base has ultimately resulted in financial ruin. Fortunately, though, there are many examples of where investment in new technologies and farming systems has increased financial profitability while at the same time maintaining, and even improving, the resource base. I would classify controlled traffic technologies as having potentially the same benefits.

Elsewhere in the Wylie study it was noted that producers have mixed perceptions about landcare and its place in sustainable agriculture. Some producers were said to view landcare as basically a "greenie" movement concerned with little more than revegetation, particularly tree-planting, and resulting in little more than a warm, inner glow. Others, however, are said to be concerned that landcare is being used as a disguised vehicle for traditional extension activities and that sustainability is often only given lip service. My view is that these mixed perceptions arise from the confusion due to the changes in the way that information is now managed and disseminated. Much of this confusion arises from fundamental changes in the focus of publicly-funded extension programs and the role government sees for itself in the future provision of extension services. Moreover, reductions in government budgets have required new and different forms of extension mechanisms to be utilised, and it has taken some time for these new mechanisms to cope with the complex information story that is sustainable agriculture. At the same time, debate on the private versus public benefits of maintaining agriculture's resource base is demanding a rethink on who pays and who plays in the funding, research, development, management and dissemination of information leading to its maintenance.

Issues about sustainable agriculture in Australia, what is meant by it, how it is measured and who is responsible for what, won't disappear overnight. On the contrary, as governments increase their focus on holistic resource management at the catchment and regional scales, and place greater responsibility in the hands of community groups for managing their wider environment, the nature of agricultural systems in the context of alternative land use practices and impact on common goods, such as water systems, will come under greater scrutiny. At the same time, forecasts for food requirements of a exponentially growing world population will place added pressure on food producing nations to increase their output from land already heavily utilised for agriculture.

For these reasons, the role of research, development and extension will continue to be essential to ensure that the push for increased production efficiency doesn't come at the cost of a decline in the long-term productive capacity of the resource base. There is nothing new in any of this, of course, and for the past decade we have all witnessed a change to the way that these activities are funded and carried out. Most notable is the emphasis placed on final outcomes, interdisciplinary approaches, inter-organisational collaboration and end user involvement. Essentially the management of research has changed and it will continue to change.

Managing Research

Many researchers still have a deep-seated suspicion of people who are interested in managing research (Price, P 1994). These researchers hold the view that research is a creative activity that cannot be managed if it is not to be constrained. However, history shows that because curiosity itself is not free of values, research will always be constrained, or motivated, by a driving force of one desire or another. History also demonstrates that there are very few examples where curiosity-motivated research leads primarily on its own, and through the force of the ideas generated, to practical outcomes and applications. This has particularly been the case in agricultural research where, for example, in the pioneering years of early Australian settlement, producers themselves became the major innovators as they were left alone to cope with the exigencies imposed by the harsh environment. This is not to advocate that researchers should be made redundant and that we go back to the old days of producer as sole innovator, but it does suggest that the trend towards increased involvement of producers in setting the directions for research and development, and indeed aiding in the undertaking of R&D side-by-side with researchers, is an appropriate one. Particularly worthy of applause is where the research is undertaken on-farm rather than on experimental stations, where frequently the conditions are not representative (either in reality, or in the minds of producers) of the wider agricultural resource base.

It is not enough, however, for researchers and producers alone to work together. This is very much becoming recognised by the various R&D corporations, most of which consider R&D funding in the context of an investment in but one part of a complex innovation process. This view is promoted by evidence which suggests that increased investment in R&D is futile if other components of the innovation process, such as marketing, processing, production, etc., are not also present and interact with the research (Price, P 1994). This has important implications for the way in which research should be undertaken and eventually developed and extended. The most obvious implication is that an investment at the research point in the innovation process needs to be preceded by properly identifying the market opportunity and then defining the product or service that the customer or client wants. Failure to address this issue has often been a major problem with government-funded research and extension problems in the past.

From a funding perspective, the investment approach by the R&D corporations has been refocussed towards achieving outcomes and has had a considerable impact on how they operate. As a result of focusing upon solutions to problems in a context of sustainable agriculture, research funders are looking more holistically at issues and are, therefore, increasingly directing their R&D investments towards multi-disciplinary, multi-organisational efforts aimed at holistic solutions. This has resulted in a greater level of investment by most of the corporations in fewer, but larger, projects and in programs of diverse, but related, R&D activities. While most research organisations are willing to participate in complex, multi-organisational ventures, problems inevitably arise. In some cases, traditional research methods and values become an impediment to sharing knowledge and skills, while in other cases, institutional and managerial barriers arise. Intellectual property rights is a major, and ongoing, concern.

For the researcher, this will mean having to consider their area of expertise as not being the most critical to address certain problems, but rather as one critical skill within a host of critical skills required to resolve these problems. It will become increasingly difficult for researchers to find support for their projects if they do not form partnerships with economists, engineers, other fields of biophysical sciences, producers and other community interests. For many researchers working in areas which have been well supported in the past, their project proposals may be overlooked in future as other components of the innovation process are backed in an endeavour to redress past imbalances. For example, in a number of areas of soil management, questions are being asked about whether the real issues lie with lack of knowledge about the physical processes involved, or whether there is sufficient understanding of these and that the problems lie in the development, dissemination and uptake of existing knowledge. This process of re-examination will become more common in future, and its impact will be greater particularly as organisations become increasingly reliant on external sources of support.

R&D corporations are not alone in going down this track. There is an almost universal trend towards developing appropriate institutional structures to handle multi-disciplinary research, including Cooperative Research Centres and various government and university research institutes.

Controlled traffic research lends itself to this approach and researchers with an interest in this field need to take advantage of it. A perfect example of this is a project jointly funded by the LWRRDC and the Grains R&D Corporation (GRDC), and carried out under the leadership of Drs Radford and Yule in central Queensland. It involves half a dozen organisations and around thirty researchers, including agronomists, soil physicists, plant physiologists, engineers, economists and extension experts. Most importantly, it involves research being undertaken on farms, and involves the producers themselves. While this is not a cheap venture, it is most unlikely that either LWRRDC or GRDC would have invested in any the individual components of this project.

Managing Extension

As with research, the trend in extension has been towards taking a more systemic approach. This is particularly reflected in some of the initiatives falling under the landcare umbrella, such as the property management planning (PMP) program. While this approach is ideally suited as a vehicle for disseminating information regarding sustainable agriculture, the approach as it stands at present has some inherent problems which act as barriers to achieving actual adoption of research results. For example, the PMP process may be perceived in two ways: the first and narrower view is that of being a government-conceived initiative intended to provide a means of raising producer skills in holistic farm management and perhaps to a lesser extent to provide an avenue for the extension of research results and information on best management practice. As such, the PMP process is made tangible and from the position of a producer becomes just one of many options for obtaining information and receiving training. This view is reinforced by the dominant role of government agricultural and resource management agencies in the implementation and operation of the program. The second view is that PMP is a philosophy intended to change the landholders' paradigm of operation towards holistic farm management. Within this paradigm, the producer rather than the institution, is the director of information flows. Although this is a preferred aspiration, it is not one easily accomplished. It requires not only attitudinal and behavioural change, but also a change to many producers' central values and beliefs.

The former of these views is fraught with the problems faced by many extension initiatives; ie. how can participation rates and, more pertinently, adoption rates be increased? The latter view, on the other hand, is fraught with the problems of ideology and ethics as well as with the problems of managing complex, intangible systems. These problems raise questions about how emerging extension programs should be delivered.

It is becoming recognised (Price, R 1995) that if we are to pursue holistic approaches as a means of marrying important economic and environmental goals in the context of sustainable agriculture, then this will require an effort targeted at more than just the producers themselves. In essence, the target audience for such extension programs should involve all those in the innovation process, including marketing authorities, R&D organisations, agro-political institutions, and rural service and support industries, as well as the landholders themselves.

Addressing the interface between the holistic-based extension programs and the many information sources in a way that generates demand and subsequently increases adoption is critical. To date these interfaces have been very weak; not only with the difficult areas of economics and marketing for example, but also with the traditional areas of research and development. Some may argue that these linkages are weak primarily because traditional extension programs have been handled by government, but it can also be argued that it is more related to the lack of recognition by the non-government sector as to its potential role in extension, at least until recently.

In this regard, a very significant trend is occurring which is likely to have a profound impact in future extension of research results. This is the increasing move by industries to adopt sector wide benchmarking processes which build quality assurance and best management practice into every tier of industry. An example of this philosophy is for an industry to develop measurable targets for the quality of its export products, use these to define the quality targets for the processing methods, which in turn define the quality targets for the farm product, which define targets for the production practice and ultimately for the resource base condition.

At present, many rural industries are beginning to develop best management practice and self-accreditation programs to help deliver the quality and consistency of their products, and to monitor environmental sustainability; the pig and cotton industries are examples. These programs are commendable, and indeed it is the view of the LWRRDC that such programs should eventually make resource-based organisations such as the LWRRDC redundant. Effectively managed, these programs should ensure that it is not only the producers themselves who are concerned with sustainability, but rather that the entire industry is concerned with this issue. This should result in far more resources being made available across industries to develop and support new technologies which will eventually lead to achieving the dual objectives of profitability and sustainability. It is within this context that those concerned with controlled traffic technology, research, development and extension should direct their attention.

Conclusions

While this paper reflects some visions for the future environment of research, development and extension management, it also embodies within it some truths about the directions that these areas are taking. More and more R&D is being directed by industry needs and driven by industry participation. Most research organisations would have found by now that this has resulted in fewer but larger research programs and has demanded a greater element of on-farm research involving the participation of farmers, graziers and other producers. While this trend is often frustrating for some researchers, it should be considered as a worthwhile and necessary challenge; for indeed as government funding of R&D is further eroded in future, the input by industry will increase. Chasing the dollar will become a more common and difficult task, but it should be more rewarding to researchers when they see an increased level of adoption of the results of their efforts.

From an extension point of view, the writing is just about on the wall. Already the role of the private sector, and in particular the farm adviser, in extension has been increasing at an exponential rate. It is not inconceivable that this private sector role will also start spreading into the facilitation of group activities such as landcare in a way which it has already with the traditional production oriented producer groups. If, as suggested, industries take up the challenge to develop industry-wide benchmarking processes based on best management practices at every tier, then we will see a whole new paradigm for extension delivery in future.

Those involved in controlled traffic research, development and extension are well-placed to fit in with these new directions, particularly as their field wholeheartedly embraces the objectives of sustainable agriculture.

REFERENCES

ACIL Economics and Policy Pty Ltd, Agriculture and Environment Consulting, Fievez P, Patterson R and Wylie P (1994) *A program of R&D in Indicators of Sustainable Crop Production Sytems: Report of a Consultancy*, LWRRDC Occasional Paper 02/94, Canberra

Hamblin, A (1991) *Sustainability: Physical and Biological Considerations for Australian Environments*, BRR, Canberra

Price, P (1994) "Managing Research: Is it Possible" in S. Field (ed), *Reviewing the Reviews: Agriculture Under the Microscope*, Conference Proceedings, AIAS, Melbourne

Price, R (1995) *Property management Planning: A Submission to the Prime Minister's Land Management Taskforce*, LWRRDC, Canberra

Controlled traffic for irrigated row crops in the semi-arid tropics

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Summary Research was undertaken to investigate the use of controlled traffic for irrigated row cropping in a semi-arid tropical environment. The research was carried out on a cracking clay soil, in a region where the climate and availability of irrigation water provide the potential to grow two crops per year. Controlled traffic, combined with stubble retention and direct drilling, improved the timeliness of field operations, thereby improving the probability of successful double cropping. Energy use was reduced, crop emergence and yield were unaffected, and there were slight trends of improvement in soil structure over the three year duration of the research.

1. Introduction

Research in the 1960's identified benefits for crop growth by using controlled traffic to isolate the compaction effects of wheel traffic from the crop growth zone (Cooper *et. al.*, 1969). Controlled traffic has since been studied as a strategy for improving soil structure and infiltration (Tisdall and Adem, 1988) and the management of soil compaction (Taylor, 1986).

Reduced energy use and improved timeliness have emerged as additional benefits arising from the use of controlled traffic. Energy use savings ranging from 19% to 48% have been reported by a number of researches (Voorhees, 1979; Murray and Tullberg, 1986; Lamers *et. al.*, 1986). Most reports conclude that reduced tillage draft, brought about by not cultivating the compacted traffic lanes, is the major reason for decreased energy use. Compacted traffic lanes may also offer benefits of earlier access for field operations (Burt *et. al.*, 1986; Spoor *et. al.*, 1988), which may be important in some cropping systems.

The research reported in this paper was undertaken to investigate the use of controlled traffic to improve the management of for irrigated row crops in a semi-arid tropical environment. Specifically, the aims were to improve the reliability of double cropping, reduce energy inputs, and arrest soil structural decline resulting from intensive and frequent tillage in a furrow irrigated cropping system.

2. Background to Burdekin River Irrigation Area

The research was undertaken at Millaroo in the Burdekin River Irrigation Area (BRIA) (19°35'S, 147°24'E) in north Queensland, Australia, between 1988 and 1991. The climate of the region is dry monsoonal, with 75% of rain falling in summer, often in high intensity storms. Soils are extremely variable, ranging from sodic duplex through to cracking clay. This research was conducted on a cracking clay soil, classified as a Ug5.29 (Northcote, 1979) or Entic Chromustert (Soil Survey Staff, 1975). This soil is locally regarded as difficult to manage, since there is a narrow range of water content at which tillage will produce a desirable tilth.

Sugar cane, grown under furrow irrigation, is the main crop of the region, with rice, soybeans, sorghum and maize grown in smaller quantities. Although the climate and water supply is suited to double cropping, it is often possible to produce only one grain crop each year due to timeliness constraints, particularly during summer crop planting. Double cropping can provide many benefits such as improved profitability, protection of soil from erosion by either stubble or a growing crop for most of the year, and reduced weed competition (Smith and McShane, 1981).

Conventional tillage operations, undertaken to incorporate stubble, loosen subsoil compaction, and prepare a seedbed, may require from one week to three months to complete, depending on weather conditions. This period must be reduced to improve the reliability of double cropping. It was considered that controlled traffic, in conjunction with direct drilling, would be able to achieve this aim.

3. The Research

Three treatments were studied: i) controlled traffic with direct drilling into permanent beds (CTDD); ii) controlled traffic with conventional tillage on the top of a permanent bed (CTC); iii) conventional tillage with random traffic and crops grown in ridges formed at planting time (CONV).

The controlled traffic system used raised beds with 1.5 m between furrows to suit existing row crop machinery. The beds were formed using a laser controlled bedformer, similar to that developed by Adem and Tisdall (1986). This allowed accurate grading of the irrigation furrows. A laser controlled furrow cleaner, with two hydraulically driven rotors, was built to allow silt deposits and stubble to be cleaned from furrows after harvest.

Two tractors were instrumented to measure fuel flow, engine speed, ground speed and wheel slip. PTO dynamometer test data were used to establish equations for estimating power use in the field (Harris and Pearce, 1990). Dates of tillage operations was recorded to allow comparisons of timeliness.

Soil physical parameters were measured to quantify seedbed conditions in relation to emergence and crop establishment. Properties measured included gravimetric soil water content, aggregate size distribution and bulk density in the sowing line at the time of sowing. Soil temperature and water content were measured during the time leading up to full emergence, and cone index was recorded in the sowing line and wheel track at selected times during the season.

4. Results and Discussion

4.1 Timeliness

The combination of controlled traffic and direct drilling gave a marked improvement in timeliness of field operations, particularly planting. The number of days between harvest and planting of the subsequent crop for each of the treatments are shown in Table 1.

Table 1. Days from harvest to planting the next crop.

SEASON	CTDD	CTC	CONV
1988/89 wet	3	70	105*
1989 dry	18	31	59
1989/90 wet	2	3	6
1990 dry	2	14	77
1990/91 wet	4	74*	74*

* Seedbed preparation not completed due to weather conditions.

Even when conditions were favourable for seedbed preparation using conventional techniques, the combination of controlled traffic and direct drilling gave a timeliness advantage of four days. This advantage was much greater when rainfall interrupted seedbed preparation on the cultivated treatments.

Improvements in timeliness have important implications for the reliability of double cropping, as conventional seedbed preparation is often interrupted by rainfall in the tropical environment.

4.2 Energy

Energy use in the CTDD treatment was 28-34% of the CONV treatment, and 39-59% of the CTC treatment (Table 2). Seedbed preparation with conventional cultivation required at least three, and sometimes up to seven, operations. However, cleaning silt and stubble from the furrows between the beds was often the only pre-planting operation needed in the CTDD treatment. Energy use in the CTC treatment was high because the furrow cleaning operation was used between most tillage operations to remove loose soil to allow adequate drainage from the furrow. This was particularly important during wet season operations. The results for the CTDD treatment have major implications for lowering capital and operating costs.

Table 2. Seasonal energy use, MJ/ha, for each treatment in three seasons

SEASON	CTDD	CTC	CONV
1988/89 wet	252	424	132 [a]
1989 dry	259	586	936
1989/90 wet	b	b	b
1990 dry	358	923	1040

[a] seedbed preparation was not completed due to wet weather, so energy use was recorded for only some operations.

[b] no data were recorded due to logger failure.

4.2.1 Peak energy demand

As well as differences in overall energy use between treatments, there were differences in peak energy demand (*ie*. the energy required for the most energy intensive operation). The peak energy demand is important in that it influences the level of capital investment required in tractor power. The first furrow cleaning operation after harvest had the highest energy demand in the controlled traffic treatments (CTDD and CTC). The highest demand recorded was in CTC in the 1990 dry season (444 MJ/ha). This was associated with slumping of the beds during the growing season, resulting in substantial silt accumulation in the furrows. In contrast, the same operation in the CTDD treatment required 250 MJ/ha in the same season, due to the direct drilled beds becoming more stable and less prone to slumping. There was little difference between treatments in energy demand for subsequent furrow cleaning operations (eg. 55 MJ/ha for CTDD compared with 59 MJ/ha for CTC in the 1990 dry season).

The indications are that energy demand in CTDD may decline over time due to the bed system becoming more stable. However, this is not a possibility in a conventional tillage system. Seasonal peak energy demand in the CONV treatment always occurred with rotary hoeing. The energy input to rotary hoeing ranged from 165 to 339 MJ/ha across the seasons for which data were recorded.

4.3 Seedbed Properties

Aggregate size distribution is an important soil property with respect to crop emergence and establishment, as it influences seed-soil contact. Glasshouse experiments with soil from the project site suggest that emergence of maize and soybeans was most reliable with aggregate sizes in the range of 1-2, and 2-5 mm. (Braunack, 1995). Rathore *et. al.* (1983) reported similar results for soybeans. Aggregate size distributions in the planting zone are presented in Table 3.

There were no consistent statistically significant effects of treatment on aggregate size distribution. This lack of consistency makes it difficult to draw conclusions regarding soil structure, but this in itself indicates that seedbed condition was no worse with CTDD and CTC than under the CONV treatment. Trends suggested that soil condition was probably improving under CTDD, but the rate of change was too slow, and the results too variable, for this to be confirmed in this research.

Table 3. Sowing line aggregate size distribution (%) at 0 - 50 mm depth for all treatments.

		AGGREGATE SIZE DISTRIBUTION (% in mm size ranges)				
SEASON	**TREATMENT**	**<1**	**1-2**	**2-5**	**5-15**	**>15**
1988-89 wet (soybeans)	CTDD	3.1	1.3	5.2	28.9	61.4
	CTC	5.0	3.3	12.5	43.2	36.0
	CONV			not planted		
1989 dry (maize)	CTDD	9.0	6.3	13.8	21.3	49.6
	CTC	7.6	5.9	15.3	26.2	45.0
	CONV	8.9	7.5	16.2	25.4	42.1
1989-90 wet (soybeans)	CTDD	16.5	16.4	19.2	14.4	33.5
	CTC	14.4	14.6	19.7	15.9	35.4
	CONV	11.9	11.6	11.4	10.9	54.3
1990 dry (maize)	CTDD	5.8	5.5	17.8	18.7	52.2
	CTC	4.5	3.5	11.1	15.1	65.7
	CONV	2.7	1.3	3.1	4.3	88.6

4.4 Crop Factors

Crop establishment and yield were not significantly effected by the different treatments. Only on one occasion did differences in yield approach levels of statistical significance, when the yields for the controlled traffic treatments were marginally greater (P=0.097) than the CONV treatment. More importantly, there was no indication of any adverse affect on grain yield due to controlled traffic.

5. Economic considerations

The energy use differences between controlled traffic and conventional farming systems have major economic implications for two reasons. Lower seasonal energy use naturally leads to a reduction in operating costs in crop production. Further, the reduced peak energy demand and change in tillage practices due to controlled traffic, particularly in conjunction with direct drilling, could lead to substantial reductions in the capital investment in tractors and equipment.

An economic analysis was conducted to indicate the relative differences in capital investment and operating costs per crop. It was based on details of this research, including equipment used, the average number of operations required, average fuel consumption, and the number of crops grown. Crop yield was not considered, as there were so few differences in treatment yields over the duration of the project. Other aspects of crop production costs, such as fertiliser, weed control etc. were not included in the analysis, as these were common across all treatments in the context of this research.

It should be noted that the selection of equipment was not necessarily optimal for the work loads encountered in this research. No attempt was made to optimise tractor performance through techniques such as implement matching and selection of gears and throttle settings for optimal engine loading. Further savings would likely be possible in all treatments if these factors were taken into account. Capital costs were based on new prices for the selection of equipment used in the research. The results of the economic analysis are shown in Table 4.

Table 4. Costs for three tillage systems

	CTDD	CTC	CONV
Capital cost [a]	38,000	56,400	121,500
Operating cost [b]	28	62	97
Total cost [c]	80	199	292

[a] Capital cost of machinery required for each system, ($A)

[b] Operating costs include repairs and maintenance, fuel and oil, but not labour, ($A/ha per crop)

[c] Total costs include, in addition to operating costs, depreciation on capital over the estimated life of the machinery, shelter, insurance and interest on the capital, all distributed over the area cultivated annually, ($A/ha per crop)

The large difference in capital cost between CTDD and CONV is primarily due to the size of tractor required. The operating costs per crop for the CONV are higher than would be expected in a commercial farming situation. (A. Bourne, unpub. data). Apart from implement selection and optimisation issues, this higher cost was influenced by two important factors: i) costs are allocated across fewer crops as this treatment was not planted in the 1988-89 summer, even though some cultivation costs were incurred early in the season; ii) unseasonal rainfall in the 1990 dry season increased the number of operations required to prepare a seedbed, and this increased the average number of operations per crop.

6. Conclusion

The foregoing results indicate that controlled traffic, as used under these particular environmental and soil conditions, offers considerable benefits in improving timeliness and energy use. Effects on soil structure and crop production were minor over the period of the research, although trends suggested that improvements may be gained in the long term.

Timeliness was the most important short term benefit. The ability to rapidly move from the harvest of one crop to the planting of the next is all important in a double cropping system, and particularly so in the tropics. The success of direct drilling, in a soil which is considered to be difficult to manage, was a major factor in providing the timeliness advantage.

7. References

Adem, H. H. and J. M. Tisdall, (1986) Automatic laser-levelling and tractor guidance for the Tatura permanent bed system of cropping. Proc. of Conference on Agricultural Engineering, Institution of Engineers, Australia, National Conference Publication No. 86/9:1-7.

Braunack, M. V., (1995) Effect of aggregate size and soil water content on emergence of soybean (*Glycine max*, L. Merr.) and maize (*Zea mays*, L.). Soil and Tillage Research, 33:149-161.

Burt, E. C., J. H. Taylor and L. G. Wells. (1986) Traction characteristics of prepared traffic lanes. Transactions American Society of Agricultural Engineers, 29(2):393-397, 401.

Cooper, A. W., A. C. Trouse Jr. and W. T. Dumas. (1969) Controlled traffic in row crop production. Proc. 7th International Congress on Agricultural Engineering (C.I.G.R.), Baden-Baden, Germany, Sect. III, Theme I:1-6.

Harris, H. D. and F. Pearce. (1990) A universal mathematical model of diesel engine performance. Journal of Agricultural Engineering Research, 47:165-176.

Lamers, J. G., U. D. Perdok, L. M. Lumkes and J. J. Klooster. (1986) Controlled traffic farming systems in the Netherlands. Soil and Tillage Research, 8:65-76.

Murray, S. T. and J. N. Tullberg. (1986) Controlled traffic cropping system. Proc. of Conference on Agricultural Engineering, Institution of Engineers, Australia, National Conference Publication No. 86/9:234-238.

Northcote, K. H. (1979) A factual key for the recognition of Australian soils. 4th Ed. Rellim Technical Publications, Glenside, South Australia. 123pp.

Rathore, T. R., B. P. Ghildyal and R. S. Sachan. (1983) Effect of surface crusting on emergence of soybean (*Glycine max,* L. Merr) seedlings. I. Influence of aggregate size in the seedbed. Soil and Tillage Research, 3:111-121.

Smith, G. D. and T. J. McShane. (1981) Modification and management of irrigated soils in the lower Burdekin Valley, Queensland. Agricultural Chemistry Branch Technical Report No. 17, Queensland Department of Primary Industries, 56pp.

Soil Survey Staff. (1975) Soil Taxonomy: A basic system of soil classification for making and interpreting soil surveys. USDA Agric. Handbook No. 436. Gov. Printer, Washington, D.C.

Spoor, G., S. M. Miller and H. T. Breay, (1988) Timeliness and machine performance benefits from controlled traffic systems in sugar beet. Proc. of 11th Conference of the International Soil and Tillage Research Organisation, Scotland: 317-322.

Taylor, J. H. (1986) Controlled traffic: a soil compaction management concept. Society of Automotive Engineers, Technical paper 860731, 9 pp.

Tisdall, J. M. and H. H. Adem. (1988) An example of custom prescribed tillage in south-eastern Australia. Journal of Agricultural Engineering Research, 40:23-32.

Voorhees, W. B. (1979) Energy aspects of controlled wheel traffic in the northern corn belt of the United States. Proc. of 8th Conference of the International Soil and Tillage Research Organisation, Bundesrepublik, Deutschland:333-338.

Controlled Traffic: An Integral part of a New Rice Cropping System for the Dry Tropics.

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Until 1992, rice was a major irrigated crop grown on the clay soils in the Burdekin River and the Mareeba-Dimbulah irrigation areas of north Queensland. The crop was grown using the traditional paddy culture, similar to that used for mechanised rice systems in southern Australia and labour intensive systems throughout the tropics. The rice crop was grown in either the wet or dry season and generally produced good yield and quality, however, because the soil was fallow for the six month period between rice crops, the rice cropping system was not as productive nor as profitable as the competing perennial crop sugarcane.

Cereal or legume crops could be grown instead of the fallow, however, few farmers were successful with the practice of rotating their rice crops with other field crops. A major problem with these rotations was that rainfall often delayed the rice harvest or interrupted the cultivation practices needed to change the soil culture from a paddy to a raised ridge or bed system. The problem occurred most often when farmers tried to harvest a dry-season rice crop during December and plant a wet-season soybean or maize crop during January.

For rice farmers to remain viable, rice production practices had to change. In this paper, a new cropping system for rice that allows year round cropping of rice and soybean is described. Recent research work comparing the growth of a rice crop in either a paddy or the new watertable system is discussed.

Components of the Rice Cropping System

Research components of the new rice-based cropping system that would promote the continuous production of rice and soybean crops in rotation were outlined by Garside *et al.* (1992). The new system involved growing crops on permanent, raised beds with either continuous or intermittent irrigation in the furrows between the beds. Potentially, the new system would increase the opportunity for cropping, increase yield, reduce water use, improve nitrogen use and reduce energy use.

Since the components were developed separately in previous research projects, they needed to be combined into a single crop production system. The system could then be assessed on-farm with the general purposes: (a) to confirm that the system was relevant to farming in the tropics; (b) to ascertain what changes in farming culture were required; and (c) to encourage farmers to consider and use the new technologies to promote a better farming system.

Commercial Application of the Rice System

When the new system was trialed on a farm each of the new technologies was applied in a different way, and with different constraints, to how it was tested during the research phase. Some interesting technical problems were encountered. What soil type? We used a Barratta Clay (2Ug). What size block should be used? What slope? We used a 3 ha field with 300 m long irrigation runs and a slope of 0.47%. Farmers considered this to be the minimum irrigation row length for easy management. What size should the soil beds be? Bed size was determined by the size of our gear and was 1.5 m wide and 0.2 m high. In practice, the bed size will be determined by the hydraulic conductivity of the soil because it is essential to form a watertable. Would a water table form? Yes. Should rice be grown in the furrows? Yes, but it grows with different nitrogen fertility. How should nitrogen be applied to the rice crop? Don't know but nitrogen movement in the irrigation water and rainfall will probably influence the transport, forms, uses and loses of N. How much water needed to be recycled? Not much, since the flow rate in each furrow could be controlled to minimise tail water. Could weeds be controlled. Yes and no. Some weeds like phasey bean were well adapted to the new system. Would establishing soybeans in the rice residue be a problem? No, but mulching the rice residue probably helped. Would rice be a weed in the soybean crop? No, rice growth seemed to be limited by N stress.

Benefits of the Rice System

The trial produced a successful rice crop yielding a mean of 6.7 t ha^{-1} (8.0 t ha^{-1} on the bed and 6.1 t ha^{-1} in the furrow) and a successful soybean crop yielding 3.2 t ha^{-1}. These yields were equivalent to the best commercial yields for the district.

Other benefits were more difficult to quantify but are worthy of mention. Birdlife did not affect the establishment phase of the rice crop in the new system, however, in the paddy system birds frequently puddle the soil and cause the loss of many seedlings. The laser graded furrows provided good irrigation water flow and drainage. For example, when the trial was drained at rice maturity, there was no surface water left after four days and after eight days the trial was harvested and the rice residue was mulched. Within a week a large rainfall event flooded the site. The soybean crop was subsequently planted into stored soil moisture, whereas the harvest of an adjacent commercial rice crop was still delayed due to the wet weather.

Rice Growth and Yield on a Watertable

Probably the most important question that was raised by the trial was whether rice growth and yield was limited, unchanged or promoted by the watertable system compared with the flooded paddy system. To provide some replicated data on this comparison, an experiment was conducted at Walkamin Research Station on the Atherton Tablelands during the dry season of 1994. The soil type was a grey clay (Ug5.22) with a slope of 1.5%.

The experiment compared the growth, nitrogen fertility and yield of five contrasting lines of rice grown with either a paddy or watertable irrigation system. The data presented are for treatments that received a total of 28 g N m^{-2} applied as urea in four split applications. The urea was either cultivated into the soil before planting, applied onto the soil surface and watered in, or applied into the floodwater.

The grain biomass at maturity and the whole grain millout was similar for the paddy and watertable systems (Table 1). In both treatments the line J26 produced more grain than the other varieties although the percentage of whole grains for this line was smaller. J26 was a very interesting line because in both irrigation treatments it exhibited visual symptoms of leaf rolling usually associated with water stress.

Table 1. Grain biomass and wholegrain millout of rice lines grown either in a paddy or with a watertable system.

	Grain biomass (g m^{-2})		Wholegrain millout (%)	
Rice lines	Paddy	Watertable	Paddy	Watertable
Starbonnet	998	856	-	67
Lemont	1043	848	61	63
Amaroo	993	904	59	63
YL39	912	1190	62	65
J26	1248	1368	-	50
s.e. mean	52	122	-	3
l.s.d. (P=0.05)	205	351ns	-	9

The growth of the variety Lemont varied between the paddy and watertable systems before and after anthesis (Table 2). The time to anthesis was longer and there was more leaf area and vegetative growth for the watertable treatment, however, the grain biomass was bigger in the paddy. Kernel biomass was much greater for the paddy treatment and resulted in a bigger harvest index. The N fertility of the two systems may have been different with more N taken up after anthesis by the rice crop in the paddy. Reduced growth before anthesis in the paddy treatment may also be due to an attack of Rice Leaf Miner when the paddy was permanently flooded. The rice seedlings in the watertable treatment were not affected.

The total N content of the rice crop in each treatment was 27 g m^{-2}. It is unlikely that this amount of crop N was limiting to yield since in the Burdekin River Irrigation Area paddy rice crops yielding 1000 g grain m^{-2} have contained less than 25 g N m^{-2} (Ockerby 1994).

In general, the experiment found no evidence of differences in the growth of rice on a watertable compared with the traditional paddy culture that could be directly attributable to the irrigation system.

Table 2. Effects of paddy and watertable irrigation systems on the growth of Lemont.

Components of rice growth	Data for Lemont (mean and s.e.)	
	Paddy	Watertable
Time to anthesis (d)	105 (1.0)	111 (3.0)
LAI at anthesis	4.7 (0.3)	8.6 (1.1)
Tiller number at anthesis	555 (24)	938 (103)
Grain biomass (g m^{-2})	1043 (52)	848 (122)
Kernel biomass (mg)	24 (0.3)	20 (0.6)
Harvest index	0.51 (0.02)	0.39 (0.03)
N content at anthesis (g m^{-2})	23.7 (3.2)	25.3 (1.5)
N content at maturity (g m^{-2})	27.2 (3.4)	27.1 (0.4)

The work with the watertable system of rice production is still in its infancy. The indications at his time are that rice will produce a good yield and quality when grown on permanent beds using continuous furrow irrigation to form a watertable about 0.2 m below the soil surface. The benefits of the new culture to the cropping system are large since it allows rice to be grown in rotation with other irrigated field crops and, as such, promotes the efficient use of irrigated environments in north Queensland where year-round crop production is possible.

References

Garside, A.L., Borrell, A.K., Ockerby, S.E., Dowling, A.J., McPhee, J.E., and Braunack, M.V. (1992). An irrigated rice-based cropping system for tropical Australia. *Proc 6th Aust. Agron. Conf.*, Armidale, NSW. pp. 259-261.

Ockerby, S.E. (1994). The uptake and use of soil, residue and inorganic nitrogen by a rice crop in the tropics. Masters of Agricultural Science Thesis. The University of Queensland.

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SOILpak - a Decision Support System for Extending Controlled Traffic Information to Irrigated Cotton Growers

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Introduction

Soil compaction can greatly reduce cotton lint yield on intensively cropped Vertisols (McGarry 1990; McKenzie *et al.* 1990). Crop managers with a soil compaction problem have several options (Vomocil and Flocker 1961):

- techniques for avoiding excessive compaction in the future;
- procedures for reducing excessive compactness (e.g. use of rotation crops to create numerous vertical cracks; shattering of dry soil with deep ripping tines), preferably in a more than temporary manner, and;
- management strategies for the upcoming crop, in cases where prevention or amelioration of compaction is uneconomic.

The phrase 'Custom Prescribed Tillage' (CPT) has been coined by Johnson *et al.* (1982) to describe an approach which encompasses this philosophy. CPT encourages the selection of tillage systems, sometimes in conjunction with the development of improved tillage equipment, that match the soil conditions at a specific location. Combined with CPT is a need to define the ideal levels of soil physical properties for each land use (Tisdall and Adem 1988).

'Controlled Traffic - Reduced Tillage' (CT-RT) has become a popular soil management option for Australian cotton farmers. Most of these growers produce their crops on furrow-irrigated Vertisols. CT-RT restricts compaction to narrow laneways. It usually is a less expensive and more flexible option than the alternative land preparation techniques such as regular deep tillage. CT-RT will become easier to use once improvements such as tractor guidance systems (Schoenfisch and Billingsley 1994), and the standardisation of wheel spacings of all farm machinery used in cotton farming systems, are introduced throughout the industry.

However, CT-RT cannot be expected to provide good results all of the time. For example, crop growth may be restricted when farming tools or tractor tyres have created compaction under the plant rows, or where there has been a failure to prevent the movement of ridges or beds onto previous wheel-tracks. The continued separation and maintenance of cropping and traffic zones is critical in CT-RT systems. If soil beneath the plant lines is compacted, CT-RT should be preceded by biological and/or mechanical loosening of the soil.

Numerous scientific papers have been written about sub-sections of the topic of soil structure management for irrigated cotton. However, none thoroughly and clearly integrate all of the available information into a form which can be used routinely by farm managers, and which can account for risk, particularly in relation to the weather, and economic constraints (Arkin and Taylor 1981). The ideal tool for farm managers would be an accurate model which quantitatively describes the relationships between soil, plant, weather and management inputs in all cotton growing districts. Unfortunately, complexity of the farming system has delayed progress towards this goal.

Farmers using 'best practice' soil management techniques cannot wait for the development of a flawless computer-based model, and need an interim decision support system. Letey (1991) therefore expressed the hope that, through 'practical wisdom', soil structure information and knowledge can be coordinated and systemised so that the knowledge may have real value.

This paper describes a successful attempt to develop such a system within the Australian cotton industry.

The SOILpak System

The SOILpak decision support system (Daniells and Larsen 1991) has been developed to encourage Australian cotton growers to assess the physical condition of their soil before making a choice about tillage, gypsum application, etc.. It was based on results from problem-oriented soil structure research in the Macquarie Valley of NSW, but eventually included much information from experiments in the nearby Namoi Valley, and from scientific literature published elsewhere.

SOILpak evolved through a cooperative and practical process that involved cotton farmers, researchers and advisory staff. In the 1980s, growers generally believed that soil-related research information was poorly collated, and directed at research publications rather than at production people. It was thought that a central working manual for the industry would provide an important link between research projects and field problems. Cotton producers, aware of the complexity of the problems that needed to be addressed, believed that such a manual would be the catalyst for better coordination and focus of the soil management investigations that they were supporting.

The main aims of SOILpak are to:

1. Provide an easily accessible and clearly presented `central repository' for research results, and expert opinion, to assist with the objective measurement and management of soil structure;

2. Assist research administrators by highlighting research gaps; this process also reduces the risk of repeating work that has already been done;

3. Allow a group of widely situated soil experts to deliver their skills to on-farm decision makers through industry information networks;

4. Encourage everyone associated with soil management in the cotton industry to develop a holistic view of their work that considers both the short-term financial viability of growers and long-term sustainability of the natural resource base;

5. Present soil management information in a form that can quickly adapt to the latest available information-delivery technology.

The structural assessment procedure recommended by SOILpak is usually based upon the assessment of soil profiles in backhoe pits. The key measurement is the SOILpak score, which is a semi-objective measure of the ability of a soil to allow unimpeded root growth and function. Improved soil structure assessment methods are being developed (Greenhalgh 1994).

Although the knowledge base for SOILpak is far from complete, it provides useful "best-bet" land management options for growers and their advisers, based on the results of the structural assessment procedure. No attempt is made to enforce a particular option; the landholder makes the final decision.

Surveys of SOILpak users have indicated that they are happy to receive information which reflects the latest thinking about soil management, but which does not neccessarily have detailed answers for all of the relevant scientific questions. The loose-leaf format of the manual allows the management recommendations to be updated easily when new information becomes available. Surveys of potential users showed that a manual is preferred to computer-based packages such as the SIRATAC pest management system described by Hearn (1987). Despite having reduced pesticide use by the entire Australian cotton industry, SIRATAC failed to be directly adopted by most growers in the early 1980s because of perceived problems that included excessive complexity (Macadam *et al.* 1990).

SOILpak will be updated in the near future, and is likely to be accompanied by extra manuals such as MACHINEpak (which would contain detailed information about land preparation equipment options), and NUTRIpak (a detailed outline of techniques for dealing with cotton nutrition problems). New information about controlled traffic farming has become available since production of the second edition of SOILpak in 1991, and will be included in the next version. CD-ROM versions will be produced if there is sufficient demand.

Controlled Traffic Research Data Used in SOILpak

The CT-RT recommendations in SOILpak are based upon the data of Hulme (1987) (obtained under commercial conditions) and Constable *et al.* (1992). They proved the financial viability of CT-RT farming systems. Grower trials in several districts confirmed these results.

However, CT-RT has not been tested under all possible combinations of irrigation frequency, climatic conditions and raised bed architecture - there is a role here for modelling, in conjunction with the establishment of some new, well-monitored, tillage/raised bed experiments.

Impact of SOILpak on Farm Productivity

SOILpak has allowed cotton farmers to become more aware of soil management issues, and has boosted the confidence of those changing from traditional tillage systems to CT-RT. Since the widespread introduction of CT-RT to the Australian cotton industry in the late-1980s, land preparation costs have decreased. Large regional lint yield losses no longer occur after wet harvests.

Controlled Traffic Information Needs for the Next Version of SOILpak

Intensity of tillage of the topsoil is likely to increase in some areas due to the introduction of transgenic cotton varieties. This is because the insect resistance strategy required to ensure long-term viability of the genetically engineered cotton will not succeed unless the overwintering *Heliothis* pupae that burrow into the soil are disturbed by tillage. Soil issues associated with the new *Heliothis* management strategy will be presented in the next version of SOILpak.

Several other soil management issues need to be emphasised:

- "Moderate" compaction under CT-RT systems may lead to poor efficiency of use of applied N, even though lint yields are acceptable, so the nitrogen management strategies need to be refined;

- Once serious compaction problems have been controlled by the use of CT-RT, other soil-related factors such as sodicity may have to be dealt with. In fields where the severity of sodicity is not uniform, site specific farming procedures can be used to deliver the appropriate amounts of a treatment to different parts of a field via variable-input row-crop equipment (Robert 1989; McBratney and Whelan 1995);

- The implications of CT-RT on deep leaching and salt movement of Australian cotton soil have not been documented. Research currently being supported by the Cotton CRC into the hydrology of various wheel track and raised bed configurations is likely to provide solutions to any problems that may exist. However, we need to learn more about the interaction of these factors with other management variables such as slope, irrigation water application rate and quality, and severity of soil compaction;

- Contrasting land preparation techniques need to be evaluated in terms of their ability to maximise water use efficiency.

Conclusions

- Compaction can be a major problem when growing irrigated cotton on Vertisols;

- 'Controlled traffic - reduced tillage' (CT-RT) has become a popular technique for minimising compaction within the Australian cotton industry;

- Because CT-RT often is preceded by profile modification, procedures have had to be developed for assessing soil physical condition prior to the selection of a soil management option;

- The SOILpak decision support system was developed to organise available facts and opinions about soil profile assessment and management technique selection. It has helped growers to reduce their land preparation costs through the introduction of CT-RT, and has prevented major lint yield declines in the seasons following wet harvests;

- An improved version of SOILpak is planned, and research is continuing within the cotton industry to refine the CT-RT recommendations.

References

Arkin, G.F. & Taylor, H.M. 1981. Root zone modification: systems considerations and constraints. In: *Modifying the Root Environment to Reduce Crop Stress* (eds. G.F. Arkin & H.M. Taylor), pp. 393-401. American Society of Agricultural Engineers, St Joseph, MI.

Constable, G. A., Rochester, I.J. & Daniells, I.G. 1992. Cotton yield and nitrogen requirement is modified by crop rotation and tillage method. *Soil & Tillage Research*, **23**, 41-59.

Daniells, I.G. & Larsen, D. (eds.) 1991. *SOILpak$_b$: A Soil Management Package for Cotton Production on Cracking Clays.* NSW Agriculture, Narrabri.

Greenhalgh, S.E. 1994. *An evaluation of field soil structural assessment techniques for grey cracking clays under irrigated cotton production.* M. Rur. Sci. thesis, University of New England, Armidale.

Hearn, A.B. 1987. SIRATAC: a decision support system for cotton management. *Review of Marketing and Agricultural Economics*, **55**, 170-173.

Hulme, P.J. 1987. *An evaluation of seedbed preparation methods for growing irrigated cotton in grey clays.* PhD thesis, University of New England, Armidale.

Johnson, C.E., Schafer, R.L. & Elkins, C.B. 1982. Prescribed tillage for clay soils. *Tropical Agriculture (Trinidad)*, **59**, 92-96.

Letey, J. 1991. The study of soil structure: science or art? *Australian Journal of Soil Research*, **29**, 699-707.

Macadam, R., Britton, I., Russell, D., Potts, W., Baillie, B. & Shaw, A. 1990. The use of soft systems methodology to improve the adoption by Australian cotton growers of the Siratac computer-based crop management system. *Agricultural Systems*, **34**, 1-14.

McBratney, A.B. & Whelan, B.M. 1995. *The Potential for Site-Specific Management of Cotton Farming Systems.* Cooperative Research Centre for Sustainable Cotton Production, Narrabri.

McGarry, D. 1990. Soil compaction and cotton growth on a Vertisol. *Australian Journal of Soil Research*, **28**, 869-877.

McKenzie, D.C., Abbott, T.S., Anthony, D.T.W., Hulme, P.J., MacLeod, D.A. & Higginson, F.R. 1990. Management of subsoil degradation in an Australian Vertisol used for irrigated cotton production. *Transactions of 14th International Congress of Soil Science, Kyoto.* Vol. VI, pp. 176-181.

Robert, P.C. 1989. Land evaluation at farm level using soil survey information systems. In: *Land qualities in Space and Time* (eds. J. Bouma & A.K. Bregt), pp. 299-311. Pudoc, Wageningen.

Schoenfisch, M. and Billingsley, J. 1994. Automatic guidance for farming tractors. In: *Proceedings of 7th Australian Cotton Conference, Broadbeach, Qld.*, pp. 303-308. Australian Cotton Growers Research Association, Wee Waa.

Tisdall, J.M. & Adem, H.H. 1988. An example of Custom Prescribed Tillage in south-eastern Australia. *Journal of Agricultural Engineering Research*, **40**, 23-32.

Vomocil, J.A. & Flocker, W.J. 1961. Effect of soil compaction on storage and movement of soil air and water. *Transactions of the American Society of Agricultural Engineering*, **4**, 242-246.

COMPACTION: SEIZING THE PROBLEM

Dave Anthony[1]

Farming the land using tractors and implements results in some soil compaction, the degree often depends on the moisture content of the soil and the diligence of the tractor operator to control where they run their machinery wheels. Where the wheel tracks are strictly controlled so that a minimum of field area is traversed by the tyres for the entire cropping season and beyond, the compaction caused can become an ally of the farmer. It is important that farmers and scientists become fully aware of the advantages and opportunities that can arise from these controlled traffic lane ways particularly in irrigated agriculture.

To gain the greatest advantage from controlled traffic the first step is to ensure precise tracking of the tractor wheels with each pass of the tractor. The second step is to ensure that in subsequent cropping years the beds or hills are maintained in exactly the same position.

If tractor wheels are allowed to wander laterally then a greater area of the field will be compacted and the opportunities of controlled traffic will be lost. A common rule of thumb to work by is that a tyre will compact a zone roughly twice the width of the tyre. The commonly used 18.4 * 38 tractor tyre has a nominal width of 47 cm and will consolidate a zone approximately 94 cm wide. Within that zone there will be a range of applied pressures to the soil with the greatest pressures under tyre lugs and directly under the wheel. If on each subsequent pass of the tractor the operator allows the tractor wheel to move sideways by say 15 cm from the original tyre pass a further 30 cm width of the soil may be compacted.

The high axle weights (5-9 tonnes) of tractors used in modern cropping programs create considerable weight loadings on the grey and brown-grey clays of the Australian cotton belt especially when moisture contents exceed the plastic limit. During a cropping phase the soil rarely reaches a moisture content below the plastic limit and so compaction during a tractor pass in inevitable. Unless the tractor is passing over already firmed soil considerable machine sinking resulting in wheel ruts can occur.

Farmers are aware that the first pass of a machine causes the majority of the compaction. Provided the subsequent passes of the tractor wheel follow exactly in the same track no further significant compaction damage to the soil will result. This provides an opportunity for a "road way" without undue affects on crop productivity. It provides a supportive base, with a "bottom line" compaction level for equipment.

Studies on wetting and drying cycles in Australian cotton belt clays have shown that these soils have a strong ability to "self-repair". This characteristics has meant that traditional cultivation and deep tillage is often not needed provided sound management and suitable rotation systems are used. Coupled to this, the cotton industry through equipment supply companies and innovative farmers has developed minimum tillage machines which allow manipulation of cotton stubble from

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one crop to the next. The result is a suitable seed bed created without major disturbance or moving of the beds or hills.

Cotton farmers were moving steadily towards controlled traffic, permanent beds and minimum tillage systems through the late 1980's. The very wet winters of 1989, 1990 and 1991 in the Australian cotton belt accelerated the rapid adoption of permanent beds across the industry. The subsequent cotton crops which followed produced good yields of cotton and this helped cement confidence and a favourable acceptance of permanent bed and controlled traffic systems. Growers could see that a reasonably consolidated wheel track would produce a firm support for tractor operations without the tractors sinking into wet soils. As well the wheel tracks seemed to prevent compaction spreading sideways provided each tractor pass was positioned reasonable well. By not overly working the beds due to the wet soil conditions the soil remained friable and produced much better seed beds than had been generally experienced under traditional back to back cropping systems.

Timeliness of farming operations improved as well. Cotton harvesting during wet seasons on traditionally chiselled or ripped soil often resulted in harvesters sinking and becoming bogged. The controlled traffic lane-ways of the permanent bed system however supported machines and allowed the cotton crop to be harvested earlier than would otherwise have occurred. Similarly with planting, traditionally worked soils often presented problems with planter tractors sinking and causing problems with hills and furrows.

Today the cotton industry has seized the opportunity that compaction from wheel tracks can offer. It has developed a system for land preparation that combines and utilises:

A) The benefits of wetting and drying cycles to ameliorate soil structure problems

B) The benefits of a supportive lane way for carrying tractors and equipment.

C) The knowledge that the seed bed should stay in the same position for each succeeding crop and the knowledge that the traffic lane way must be maintained in the same position.

D) The technology for the minimum working of seed beds and crop residue from one crop to the next.

To better utilise the opportunities that compaction brings there are still a few issues which need to be resolved:

A) The tractors need to track accurately so that with each pass the tyres are precisely in the same position as the previous pass. Work on tractor guidance systems by the Cotton R & D corporation and the University of South Queensland is proceeding to solve this problem. Commercially there are many very effective guidance systems for implements but nothing for guiding and controlling the tractor which is the most important contributor to field compaction.

B)The width of the tyres used on tractors needs to be reduced and if possible a longer "foot print" created. This would help reduce the width of compaction. With controlled traffic and permanent beds larger flotation tyres are not necessary due to the firmness of the soil to support the tractor. Narrower tyres can be substituted for wider ones. Several tractor manufacturers have commenced commercial release of rubber tracked tractors for inter-row cropping. It is too early to make many judgements on these machines however tractor costs and weight balance issues will need to be addressed. It is possible that tracks much narrower than current tyres could be available for large inter-row tractors in the future.

C) Continued efforts in minimum tillage equipment for handling cotton stalks and stubble are needed so that a more trouble free and flexible system can be developed. Trash clearance is a key issue.

D)A simple and quick system of assessing soil structure which relates to crop productivity would be useful. In any minimum tillage system a management monitoring program for soil structure condition would be an important management tool. Confidence in the life of permanent beds could be greatly enhanced or any potential problems quickly identified if such a tool were available. SOILpak currently provides valuable assistance through its rating system but needs further refining. The Solicon Soil Image Analysis systems and Crackscan also offer exciting opportunities to be combined with SOILpak for profile assessment.

In conclusion, compaction if controlled can provide a useful support base or lane-way for a highly productive and stable land management system. Further developments in technology will allow farmers to seize on more of the opportunities provided by permanent beds and controlled traffic.

Mathematical Modelling of Soil Characteristics and Changes Effected by Compaction

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Abstract

Mathematical models have been used for quantitative representation of changes in soil characteristics due to compactive forces. Due to highly complex nature of the problem and difficulties in making accurate observations, only limited success has been reported so far. Very basic, regression type models, are currently available on the relationship between compactive forces and soil bulk density. However, analytical models are available on hydraulic conductivity of soils. Hydraulic conductivity is related to the macropores in soils, which in turn are related to the bulk density. This paper examines the possibility of incorporating the effects of compaction into an analytical model on soil moisture movement.

Introduction

Mathematical models are quantitative representations of physical processes. When an input is fed into a physical system, the components of the system manipulates the input and produces an output. Mathematical models mimic the physical system by a set of equations such that the input values produce the same output values as the physical system when the equations are solved. For example, if we consider a catchment to be a physical system with rainfall as the input and streamflow out of the catchment as the output, a mathematical model of the catchment should be able to manipulate rainfall data with a set of equations and come up with streamflow values which match actual observations within acceptable errors. Since the real world is extremely complex, and our knowledge and our capacity to observe the real world phenomena are limited, mathematical models are essentially simplified versions of actual state of affairs. Some mathematical models seek to find a regression type relationship between input and output ignoring the mechanism which goes on within the system. Such mathematical models are called black box models. An example in the context of catchment modelling is the unit hydrograph. By contrast, white box models or analytical models are attempts to describe the physics of each component of the physical system and find a rationale for the systems behaviour as it does. An analytical catchment model applies the laws of physics to raindrops describing their dispersion under given ambient atmospheric conditions, soil moisture state and infiltration capacity, ground topography, and gravitational forces. The rainwater is traced and its movement described by the laws of physics until the water reaches the outflow point. Considering the variability and heterogeneity of ground surface, soil, and atmospheric conditions some sort of averaging of basin and rainfall characteristics are essential for a realizable situation. SHE model is such an analytical model. The data requirements for an analytical model are enormous, and the costs associated with operation can be colossal. Half-way between the black box and white box models are the grey box or conceptual models. Conceptual models endeavour to describe the physics of the system but introduces fictitious elements to simplify the real world. Tank models are conceptual models for catchments. While the real world does not have a series of tanks containing surface water, subsurface water, and groundwater, but the actual catchment behaves similarly as a series of tanks in terms of output when excited by similar inputs.

Any mathematical model requires data on system characteristics in order to predict output from a given input. For example, to predict runoff from a given rainfall we need information on ground slope, soil porosity, atmospheric humidity, and similar data which are called parameters. Sometimes parameters are measurable and can be measured from the field, but often they cannot be measured because either satisfactory methods of measurements do not exist or any measurement scheme is prohibitively expensive. To find values of parameters which cannot be measured, a procedure called model calibration and verfication is used. The model calibration procedure consists of starting with the plausible values of the parameters and compare model outputs with actual outputs for a given series of inputs; then by a system of trial and error modify the values of the parameters until a good match between observed and model outputs are achieved. To test that the calibrated model continues to perform beyond the input-output data used for calibration, a new set of input-output values are used to assess the performance of the model. The latter process is called model verification. A mathematical model is considered acceptable when its performance at verification stage is similar to that at calibration stage. International standard is that three-fourths of available data be used for calibration and one-fourth for verification. The length of data required for model calibration and verification depends on the complexity of the model, but it should be at least several hundred values.

Mathematical Models for Soil Compaction

Analytical models between degree of soil compaction and compactive forces caused by agricultural machinery do not exist. A conceptual model has been proposed by Arvidsson and Hakansson (1991). They defined ultimate compaction as that achieved by standardized uniaxial compaction of 200 kPa. The ratio of bulk densities before and after ultimate compaction is the degree of compactness. Their model for the degree of compactness (D) is:

$$D = 68.2 + 2.37(\text{soil moisture class}) - 7.82(\text{soil moisture class})^2 + 0.002(\text{axle load in kg}) + 4.8\log(\text{inflation pressure in kPa}) - 0.055(\text{tyre width in cm}) \qquad (1)$$

They gave additional formulations for increased number of passes and crop yield losses, but they did not really give a convincing rationale for using the variables in the way they are used in equation (1). McBride (1989) gave the following quasi-theoretical relationship:

$$\ln(\rho) = \ln(\rho_o) - (A + B\sigma)[1 - \exp(C\sigma)] \qquad (2)$$

where ρ is post-compression dry bulk density; ρ_o is pre-compression dry bulk density; σ is total normal stress applied; A,B, and C are parameter coefficients. McBride's formulation does not include soil moisture content, but it has been shown by many investigators (e.g., Voorhees, 1987) that mositure content has a profound influence on the degree of compaction. Larson et al. (1980) gave the following formulation at a given degree of water saturation, S_1, under applied normal stress, σ_a:

$$\rho = [\rho_k + S_T(S_1 - S_k)] + C_\rho \log (\sigma_a/\sigma_k) \qquad (3)$$

Where ρ_k is dry bulk density at known applied stress σ_k and degree of water saturation S_k; S_T is the slope of ρ versus the degree of water saturation at a standard stress of 100 kPa; C_ρ is the compression index.

Compressive forces reduce the macropores in soils. This in turn reduces the hydraulic conductivity of soils affecting the nutrient uptake capability of plants. Fortunately analytical models for hydraulic conductivity of soils have been developed. Combining mass balance equation for incompressible fluid with Darcy's law for flow through porous medium, we get the Richards' equation. The necessary and sufficient conditions for use of this equation in non-swelling soils are that both the hydraulic conductivity, K, and water potential, ψ, are well-defined macroscopic average functions of the volumetric water content θ. Richards' equation is nonlinear partial differential equation and cannot be solved directly except for very simple boundary conditions. The available computer software SWIM solves the Richards' equation by numerical methods, and in the following section we describe the SWIM model and how we can incorporate the effects of compaction in the model.

The SWIM model

The SWIM model solves the following partial differential equation by a fixed grid implicit numerical scheme (Ross, 1990):

$$\frac{\partial\theta}{\partial t} = \frac{\partial}{\partial x}K\left(\frac{\partial\psi}{\partial x} + \frac{\partial z}{\partial x}\right) + s \qquad (4)$$

where θ is volumetric water content, t is time, s is source strength, ψ is matric potential, z is gravitational potential, and x is the direction of water movement or hydraulic gradient. For computational efficiency SWIM assumes horizontal homogeneity, negligible vapour flow in soil, no temperature changes, and no hysteresis in soil moisture curves. The model uses a very simple power law for overland flow, and simply the product of potential evaporation and surface matric potential to estimate evapotranspiration. Evidently, the model is very crude in terms of overland flow and evapotranspiration, but those are not the important components of the model and major errors are not expected when those elements are not significant. The important component of the model is infiltration and deep drainage. The input requirements of the model are the following variables:

i) simulation time
ii) vegetation characteristics (xylem potential, root development, transpiration)
iii) soil moisture characteristics (matric potential, air entry potential, moisture content)
iv) unsaturated hydraulic conductivity function
v) surface conductance and rainfall distribution
vi) runoff coefficients
vii) cumulative rainfall and
viii) cumulative evaporation

The printed outputs from the model contain the following variables:

i) potential evaporation (eps) for the soil
ii) potential transpiration (tp) for the vegetation
iii) actual evaporation (eas) for the soil
iv) actual transpiration (ta) for the vegetation
v) water potentials (psi) for the soil depths
vi) cumulative rainfall (cr)
vii) cumulative runoff (cro)
viii) cumulative drainage (cd)
ix) cumulative evapotranspiration [ce(cev + cevs)]
x) surface water (surf)
xi) total water present in the soil profiles (pres)

Incorporation of Compaction Effect into SWIM model:

In hydraulic properties function, the following equation is used to calculate the water content

$$\theta/\theta_s = (\varphi/\varphi_e)^{-1/b} \qquad (5)$$

where φ_e is the air entry water potential (potential at which the largest water filled pores just drain), and b is the slope. In order to incorporate the effect of tillage or compaction on hydraulic properties, and to take account of density effects on moisture retention, the effect of bulk density (ρ_b) can be specified on the parameters in equation (5). Hall et al (1977, cited by Campbell, 1985) gave an empirical relation as

$$\varphi_e = \varphi_{es}(\rho_b/1.3)^{0.67b} \qquad (6)$$

where φ_{es} is the air entry potential and it is for a standard bulk density of 1.3 Mg/m^3 and can be calculated from the equation

$$\varphi_{es} = -0.5 d_g^{-1/2} \qquad (7)$$

and b can be calculated from the relation given below

$$b = -2\ \varphi_{es} + 0.2\ \sigma_g \qquad (8)$$

where d_g in equation (7) is the geometrical particle diameter and σ_g in equation (8) is the geometrical standard deviation both of those can be calculated from

$$d_g = \exp(\alpha)$$
$$\sigma_g = \exp(\beta)$$

where $$\alpha = \Sigma m_i \, ln \, (d_i)$$
$$\beta = \sum m_i \, \ell n^2 (d_i) - \alpha^2]^{1/2}$$

m_i is the mass fraction of textural class i and d_i is the arithmetic mean diameter of class i.

Results and Discussion

Ongoing field studies are expected to provide adequate data to test the significance of compaction on hydraulic characteristics of soil mass, and the results will be reported elsewhere. To give a feel as to how hydraulic characteristics may change due to application of compactive forces on soil mass, the original and modified SWIM models were fed with different bulk density and saturated hydraulic conductivity values as observed in the field and the results are summarised in Table 1. All the values show significant effect due to model change. The greatest effect being in case of low bulk densities. This difference may be due to the fact that the original model uses air entry potential value from soil moisture retention curve, whereas the modified model calculates the same from bulk density. Since the soil moisture retention curve used is hypothetical, a conclusive statement regarding model performances cannot be made.

References

Arvidsson, J. and Hakansson, I. (1991), "A model for estimating crop yield losses caused by soil compaction." *Soil & Tillage Research*. Vol. 20, pp. 319-332.

Campbell, G.S. (1985), *Soil Physics with Basic. Transport Models for Soil-Plant Systems*. Elsevier, New York

Larson, W.E., Gupta, S.C., and Useche, R.A. (1980), "Compression of agricultural soils from eight soil orders." *Soil Science Society of America Journal*. Vol. 44, pp. 450-457.

McBride, R.A. (1989), "Estimation of density-moisture-stress functions from uniaxial compression of unsaturated, structural soils." *Soil & Tillage Research*. Vol. 13, pp. 383-397.

Ross, P.J. (1990), "SWIM - A simulation model for soil water infiltration and movement." Reference Manual. CSIRO Division of Soils, Townsville, Queensland.

Voorhees, W.B. (1987), "Assessment of soil susceptibility to compaction using soil and climatic data bases." *Soil & Tillage Research*. Vol. 10, pp. 29-38.

Table 1. Comparsion of SWIM and modified SWIM outputs

Model used	Bulk density, gm/cc		K_s,cm/h		Rainfall cm	Runoff cm	Infiltration cm	Drainage cm	ET cm	Profile water, cm
	Surface	15 cm depth	Surface	15cm Depth						
SWIM	1.09	1.16	48.93	15.52	30.00	0.00	30.00	7.61	22.44	1.75
Modified	1.09	1.16	48.93	15.52	30.00	0.00	30.00	7.34	22.65	1.37
SWIM	1.38	1.35	1.57	0.88	30.00	0.00	30.00	6.73	23.40	1.67
Modified	1.38	1.35	1.57	0.88	30.00	0.00	30.00	6.66	23.66	1.66
SWIM	1.40	1.36	1.17	0.78	30.00	0.00	30.00	6.68	23.46	1.66
Modified	1.40	1.36	1.17	0.78	30.00	0.00	30.00	6.62	23.52	1.67

Measuring Soil Stresses and Deformations during Sugar Cane Harvesting

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Introduction

In recent years there has been an increase in research activity into the compaction consequences of cane growing, focusing on the major traffic occurrences during harvesting operations. Nominal row spacing for growing sugar cane is 1.5m, whereas most harvesting equipment has a wheeltrack of approx 1.85m. Due to this anomaly, under normal circumstances, wheeltracks on harvesting equipment pass close to, if not on top of, the cane stool. Combined with the fact that each row receives a minimum of two passes of a harvester and two of a haulout it would seem that this application of controlled traffic has the potential for some significant compaction consequences.

Sugar cane is grown in rows over several years. With a statewide average of 3.9 ratoons, sugar cane is somewhat different to other controlled traffic crops in that the beds and wheeltracks are in some cases permanent for 5 years. With the increase in green cane trash blanketing, which utilises minimum or zero tillage, and given the high number of passes each row receives during harvesting it is evident that this application of controlled traffic farming has a special set of circumstances.

The work described in this paper was undertaken as part of a wider project setup by the BSES and the USQ to investigate the linkages between machine traffic, soil conditions and productivity in the sugar industry. Two key USQ objectives in meeting the projects aims were to :-

- quantify the stresses that occur within a soil under a range of cane machinery

- establish the extent to which the soil stresses spread from the machinery path under the crop rows with a range of soil types and conditions.

To carry out these objectives I have set out to obtain field measurements of stress and deformations that occur within the soil under a range of traffic and soil conditions.

Methodology

The stress measurements were made at 2 depths (approx 150 and 250 mm) in two trial plots at Tully and one at Ingham. During the '94 harvest the first plot at Tully was at 2nd ratoon stage while the second plot was being harvested for the first time. The plot at Ingham was 1st ratoon. The same plots were used again during the '95 harvest. Harvesting equipment at Tully consisted of an Austoft harvester and high flotation haulouts , while the equipment used at Ingham included a full track harvester and a combination of conventional and high flotation haulout bins. Soil deformation measurements were made in the same locations as the stress measurements.

The soil type at Tully is a yellow silty clay while there is a self mulching black clay soil at the Ingham site.

Other data obtained include tyre sizes and inflation pressures as well as soil moisture and density.

A Soil Stress Transducer (SST) has been developed and used by researchers from the USQ over several of years under several different conditions, mainly in the cotton industry. This SST is based on a set of six miniature pressure sensors mounted on an approximate sphere of 40 mm dia. (Harris & Bakker 1994). When combined with a high speed data acquisition unit and laptop computer, the SST allows pressures transmitted through the soil body by surface loadings to be recorded. The six pressure sensors are aligned in different directions so that the total state of stress at a point can be mathematically computed.

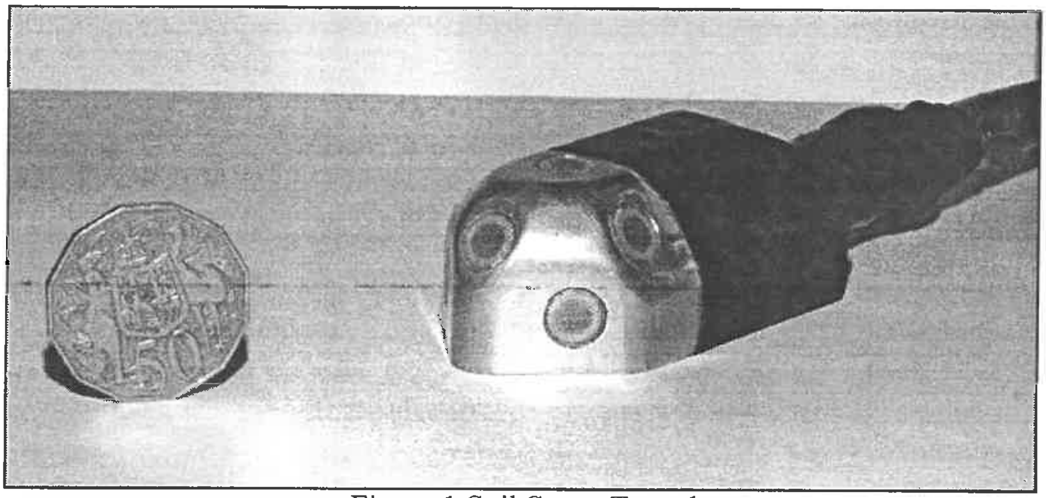

Figure 1 Soil Stress Transducer

During the harvest, the measurements are made as follows:-
(i) The SST is installed by digging a trench at right angles to the row. A core is taken from the end of the trench to leave a tunnel under the row. This is then reamed out apart from the end 10cm.
(ii) The SST is placed inside a soil plug in an open ended perspex cylinder. This plug of soil, containing the SST, is then inserted into the tunnel and pushed into the unreamed end section thereby ensuring good contact. The perspex cylinder is then withdrawn and the trench backfilled.
(iii) The data acquisition system and operator initially record the first pass of the harvester from two rows away, in uncut cane. On the return pass the harvester is only one row away as the SST is passed over for the second time. The equipment is then relocated to the cut cane side of the harvester as the haulout impact is recorded as it passes over the SST.
(iv) After the data has been downloaded, the SST is excavated for relocation to a new pit and the process repeated at a different installation depth.

The method adopted to measure soil deformation from cane traffic is the point grid method developed by Derk Bakker. It involves excavating a narrow pit across the row. The dimensions of the pit are 1.2m in length, 0.5m deep and 0.2m wide. The pit is kept as narrow as possible to minimise any influence on the actual stresses. A perspex board with holes drilled on a 50mm grid is used to insert displacement pins two longest sides. Wooden pegs are placed in the corners of the pit as a reference and to allow the board to be levelled. After installation of the matches the board is taken away and a plastic sheet stretched over a metal frame is located in its place. The position of the match heads are then mapped onto this sheet using permanent marker pens. The original ground surface is also marked onto the plastic. The pit is then carefully backfilled, trying to get the soil close to its original density.

After harvesting the pit is re excavated, the plastic sheet put back into place and the new position of the pins recorded.

Two pits were used in both the of plots. One was for a single pass and the other pit for multiple passes. Bulk density samples were taken across the pit at several different depths before and after trafficking to quantify the bulk density changes that might have occurred.

Horizontal and vertical displacements for each match are determined by placing the plastic sheet over the perspex board used to insert the matched and the before and after positions measured relative to each grid point.

Results

The results from the SST are converted to pressures through laboratory calibration. This involved placing the SST inside a plug of soil which was then placed inside a steel chamber. Air pressure was then applied and the sensors read for a number of different pressure levels.

The results are initially displayed in terms of the pressure recorded by each sensor. They can then be used to calculate the stress path in terms of the octahedral shear stress q and the normal stress p. This provides information on the relationship between the applied loading and the soil response.

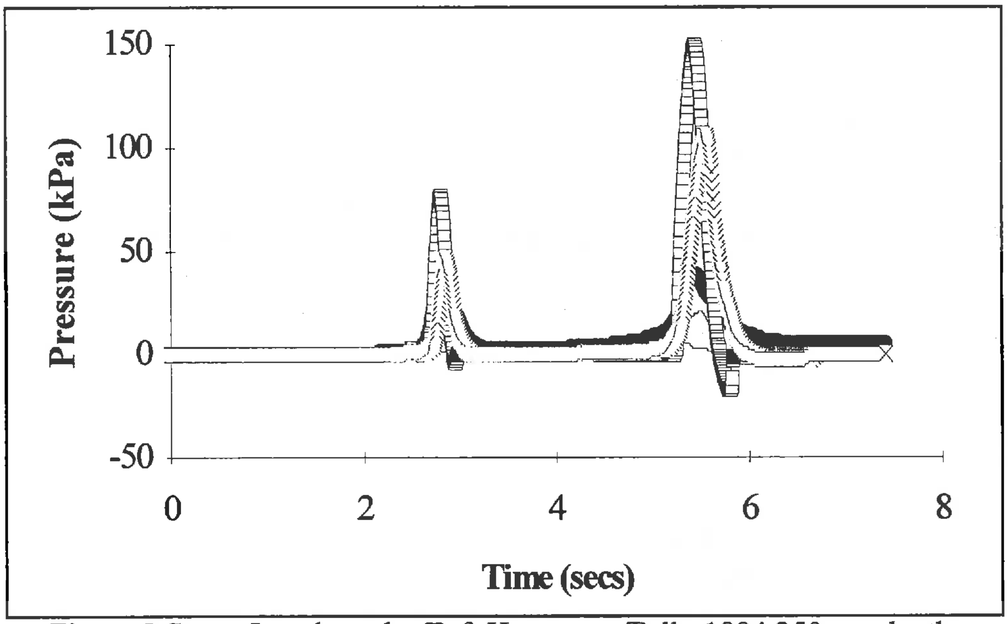

Figure 2 Stress Levels under Toft Harvester. Tully 1994 250mm depth.

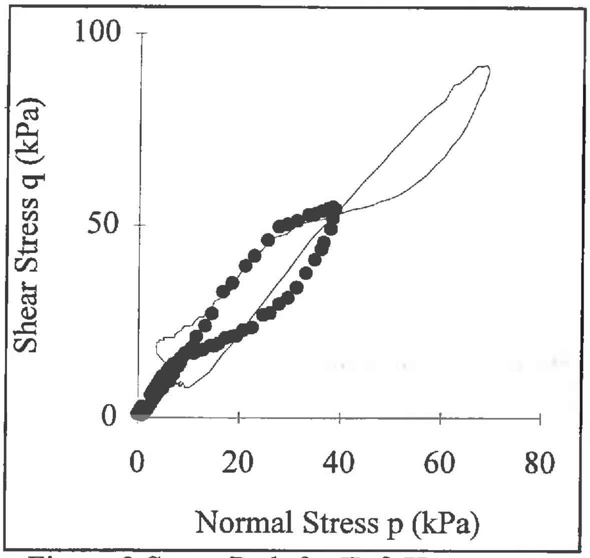

Figure 3 Stress Path for Toft Harvester
(•) Front tyre (——) Back tyre

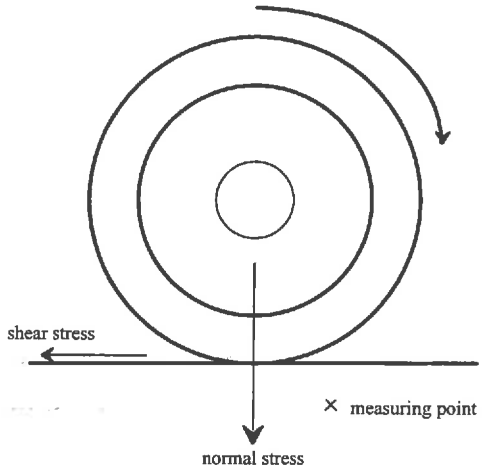

Figure 4 Schematic of process

The pin displacement results can be plotted to show the relative movement of each point on the pit face. Clearly the largest movement is expected to be directly under the tyre centre line close to the soil surface but the displacements at depth and also the sideways provide us with useful information. The point displacements can also be converted to bulk density changes by analysing the change in area of each square region of the grid. This can be compared to those changes found using the bulk density samples.

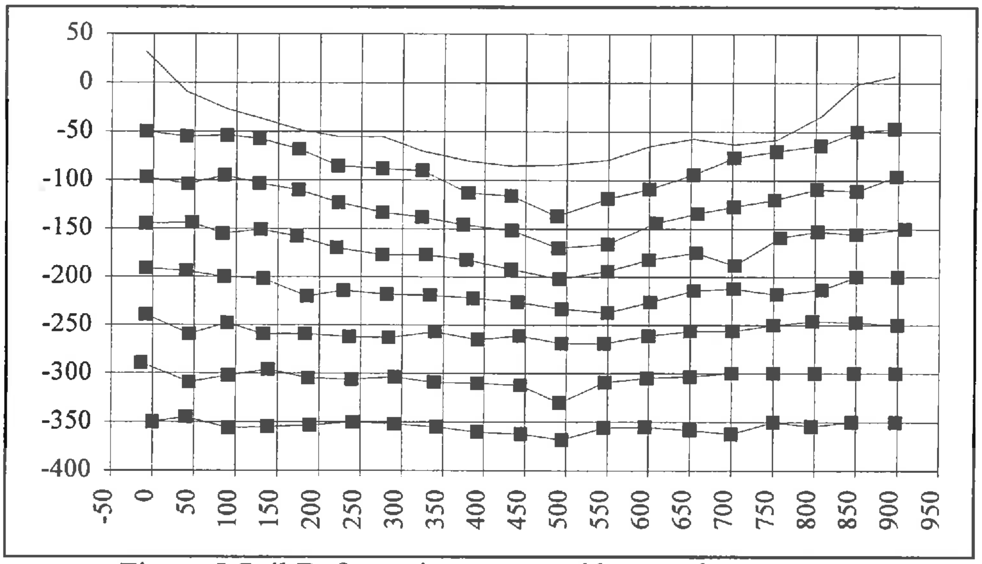

Figure 5 Soil Deformation measured by match movement
Caused by Single Pass of Toft Harvester, Plant Crop

Discussion

The SST has provided some much needed data on the levels of stress transmitted by cane harvesting equipment. The equipment is reasonably robust and reliable considering the unfriendly environment. Some initial problems were encountered with installation of the SST but these were overcome as experience was gained with the procedure. The soil deformation measurements , while involving a considerable amount of time and effort have provided some valuable data, as illustrated in Fig 6.

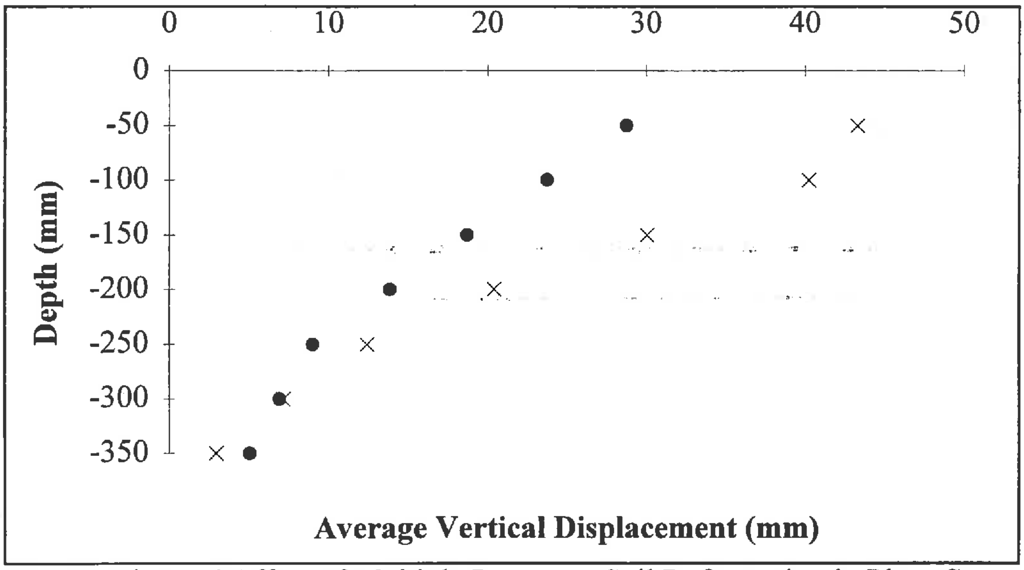

Figure 6 Affect of Multiple Passes on Soil Deformation in Plant Crop
(•) Single Pass (1 x Harvester) (×) Multiple Passes (2 x Harvester, 4 x Haulout)

At present this data is being used in the calibration and verification of a computer model that can be used to simulate a number of traffic inputs and determine their effects upon the soil. If this model is successful it will then be able to be applied to a range of soil type harvesting conditions etc.

By combining these data with the yield and other relevant data the BSES are collecting from the trial plots, a practical insight into the compaction consequences of controlled traffic in the sugar cane industry will be gained.

References

Harris H.D and Bakker,D.M 1994 A soil stress transducer for measuring in situ soil stresses. Soil & Tillage Research 29:35-48.

Compaction on Vertisols: Can it be predicted?

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Abstract

A simple laboratory method was developed to assess compactibility of clay soils using a Uni-Axial Compaction apparatus. Models were derived to predict maximum bulk density and optimum soil water content for compaction and the bulk density at water contents below maximum compaction at a range of pressures and clay contents. Amongst texture dependant soil properties, such as liquid limit, permanent wilting point or cation exchange capacity, the lower plastic limit was best suited to assess compactibility for maximum compaction as well as compaction occurring before maximum compaction was reached. The models can potentially be used as a decision making tool to reduce compaction on clay soil.

Introduction

Soil compaction is generally accepted as a major limiting factor to crop productivity. Its effect and magnitude depends on soil type, climatic conditions and crop type. Despite the large body of information and its effects, the information available on compaction of clay soil with vertic properties, *i.e.* vertisols, is inadequate. These soils have high yield potential and are used intensively for crop production in Australia and other countries. Their high clay content and likely high soil water content during field preparation makes them intrinsically sensitive to compaction. Compaction on vertisols may be reduced by the potential of the soils to self-ameliorate during wetting and drying cycles. This could happen during a single cropping cycle and may contribute to contrasting reports on crop performance. It is unlikely that all soils within the order of vertisols respond to compaction in the same manner, as vertisols can be quite different in soil structure and their response to compactive forces may therefore vary (So and Cull 1984).

This paper briefly describes a simple method to assess the compactibility of Vertisols, how it can be predicted and the potential implications on plant growth.

Materials and Methods

The determination of soil compactibility was made using a Uni-Axial Compaction test(UACT). It was considered appropriate to simulate soil compaction resulting from pressures applied to the soil by agricultural machinery (Koolen 1974). Although this type of test is commonly used by engineers to measure compactibility, no appropriate procedure is available for use in agricultural compaction studies.

The design of the simple apparatus used in this study is shown in Figure 1. A movable beam was fitted with a piston which was positioned at a distance (x) from the pivot point, to ensure the application of a perpendicular load with very little resistance to movement. The counter weight (A) was used to compensate for the weight of the beam and internal friction of the apparatus. Weight (B), located on the same side as the piston at a known multiplier to the unit distance x, was used to apply a force through the piston onto the soil. The force applied is equal to the product of weight and the multiplier factor for the distance from the pivot point. The compactive pressure applied to the soil is the force at the pressure arm divided by the surface area of the piston. It could be altered by varying the weights and distances from the pivot point. The apparatus could be used to obtain a maximum uni-axial pressure of up to 590KPa on a soil sample placed into a brass ring with 5 cm diameter.

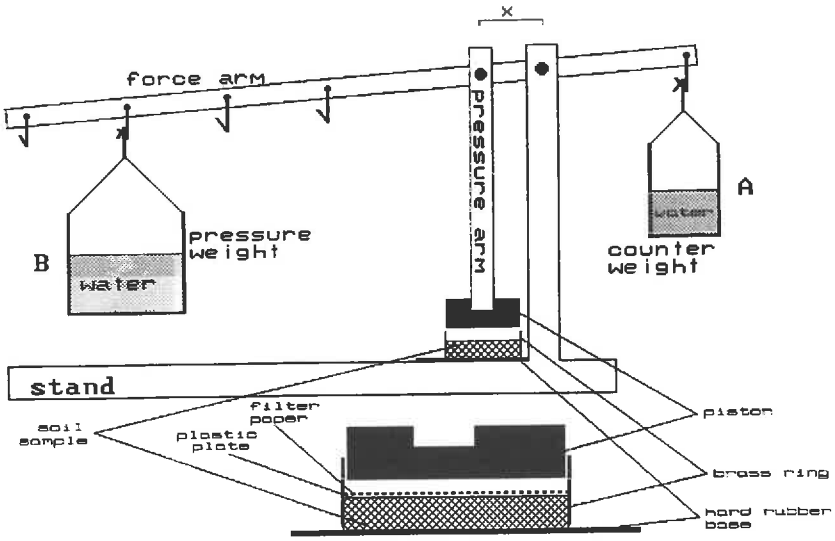

Figure 1. The Uni-axial Compaction apparatus.

Preliminary investigations were conducted into the effect of period of load application, depth to height ratio of the samples and the effect of repeated application of load. A standard procedure was then adopted to study the response of soils to compaction.

The standard procedure in using the uni axial compaction test was as follows. Soil samples (<2 mm) were prewetted to a water content at approximately permanent wilting point using a spray gun. 25g of prewetted soil was transferred into the ring (5 cm diameter, 2.5 cm height) and water added using a pipette to further increase the water content. Initial wetting by spraying was found necessary to increase the rate of wetting of the air dry soil and accelerate the equilibration process. The soil filled ring was then left for two days to equilibrate before the soil was compacted.

For the compaction process, the ring with the moist soil was placed onto a hard rubber base to prevent water extrusion during loading through the lower boundary (Figure 1). A plastic plate (4.9 cm diameter) was put on top of the soil to prevent adhesion between piston and soil. For samples where compaction was expected to be on the wet side of the compaction curve, a filter paper (4.95 cm diameter) was placed between plastic plate and piston and the amount of water that may be extruded through the upper boundary was measured by weighing the filter paper before and after loading the soil. The prepared samples were loaded for 3 seconds.

On those cores where compaction occurred at the wet side of the optimum, bulk density was calculated assuming water was not extruded. The volume of water absorbed by the filter paper was added to the volume of soil. This procedure was considered valid in these cases because the bulk density/gravimetric water content relationship follows the saturation line and in the water would not be lost during compaction.

The test was used to determine 90 compaction curves from 37 different soils collected from a range of locations including South-Eastern Darling Down, Lockyer Valley and Emerald Irrigation Area. Pressures used were 20 to 590 KPa, with the majority of pressures to correspond to those under vehicular tyres, *i.e.* 50 and 150 KPa. Clay contents of the soils ranged from 30 to 73%.

Results and Discussion

A wide range of compaction curves was obtained from the uni-axial compaction test. Figure 2 shows the effect of compaction on a range of soil types at 50 KPa load.. The compaction curve tended to be 'flatter' with the peak shifted toward higher water contents as clay content and organic carbon contents increased. These changes were associated with lower matric potential at the same water contents for soils with higher clay contents. Therefore, aggregate strength would have been greater resulting in lower bulk densities. This suggested that the compaction curves for different soils would be similar if expressed as bulk density against matric potential rather than water content. However, unlike soil water content, the matric potential of the soil may be altered during compaction and therefore the use of matric potential in lieu of water content would not be practical. In addition it was not possible to measure the change in matric potential with the compaction apparatus used in this study.

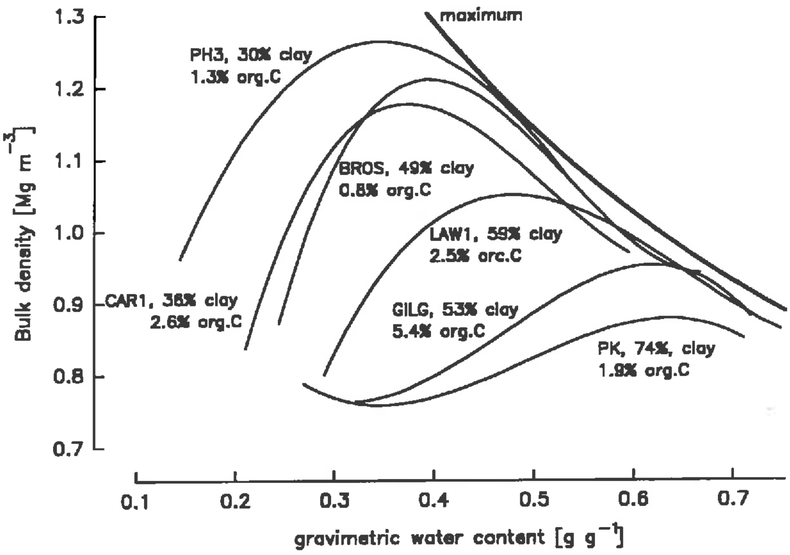

Figure 2. Uni-axial compaction curves at 50 KPa for a range of clay and organic matter contents.

For analysis the uni-axial compaction curves were divided into three sections: (i) the compaction curve before maximum bulk density, i.e. the dry side of the optimum water content, (ii) the point of maximum bulk density at the optimum water content for compaction and (iii) the compaction curve after maximum bulk density, i.e. the wet side of the optimum water content. Third degree polynomial equations as well as broken linear regressions (Greenhalgh *et al.* 1987) were fitted to the data. The maximum bulk density was obtained (i) as the common point of the two linear regression equation and (ii) by differentiating the 3rd degree polynomial equations. The maximum bulk densities derived from the two procedures were almost identical and highly correlated. However, the procedure using a broken linear regression required that sufficient observations were available to obtain linear equations for both the wet and dry side of the optimum. The use of a 3rd degree polynomial expression made it possible to extrapolate to a maximum and beyond in such cases. The latter was therefore regarded as a more versatile method to obtain the points of maximum bulk density.

When the maximum bulk density and the optimum water content for maximum compaction were plotted, the points followed the saturation line at 90-95% of maximum possible bulk density (Figure 3). A quadratic regression through these data points was parallel to the saturation line within the water contents observed. Maximum compaction could therefore be considered relatively constant at an average value of 0.08 m^3m^{-3} air filled porosity, or 92% potential maximum compaction.

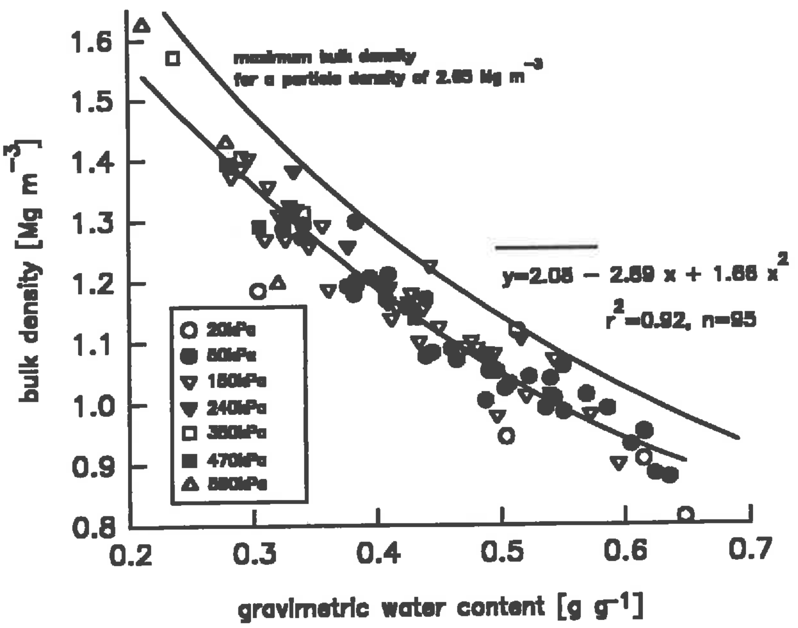

Figure 3. The position of points for maximum uni-axial position in relation to absolute maximum compaction.

For each compaction pressure, the maximum bulk densities and optimum water contents were closely related to *texture dependant properties* other than CEC and could be predicted from these properties. Prediction was improved if the organic matter content was included. It tended to reduce the maximum bulk density (and increase the optimum water content). This was consistent with the observations of Soane (1990) who attributed the effects of organic matter to a dilution effect, increased aggregate strength due to organic bondings and increased shear resistance. Table 1 shows the relevant equations.

The models to predict maximum bulk density (Table 1) was derived using data associated with a wide range of clay soils and should therefore be applicable to other Vertisols. Its validity was verified for 4 other clay soils which were used in the study by Cook (1988). For this purpose, the maximum bulk density was calculated from the equations which used (i) clay content and organic carbon or (ii) the plastic limit. The soils were then wetted to a water content approximately 3% greater than that corresponding to the optimum water content to account for water lost by evaporation during sample mixing and equilibration. The uni-axial compaction test was then performed using 2 replicates and 3 different pressures (50, 100 and 150kPa). Since the samples were not at optimum water content, the bulk densities were corrected to the predicted optimum water content assuming normal shrinkage. The experimentally derived maximum bulk densities shown were in very close agreement to the predicted values (Figure 4).

Similar to the point of maximum compaction, bulk densities at water contents lower than those for maximum compaction could be predicted using texture related properties. These models are potentially useful for soil management techniques that aim to reduce soil compaction by predicting resulting bulk density (ρ [Mg m^{-3}]) from soil water content (θ_g [g g^{-1}]) and applied load [KPa] if, for example clay content [in g g^{-1}] of the soil is known:

$$\rho = 1.425 - 0.986\,clay + 0.144\,Ln(p) + 0.530\theta_g$$

$$n = 507, \quad r^2 = 0.71$$

Table 1. Equations to predict maximum bulk density, minimum void ratio and optimum water content from textural properties, pressure P, with and without organic carbon content. Type of function used: y = a + bx + c ln(p) + d orgC.

y = maximum bulk density [Mgm^{-3}]					
x*	a	b	c**	d***	r^2
plastic limit	1.595	-1.333	0.105	-	0.907
	1.609	-1.243	0.111	-0.0222	0.931
liquid limit	1.596	-0.678	0.106	-	0.866
	1.604	-0.629	0.111	-0.0200	0.885
clay content	1.585	-0.776	0.099	-	0.803
θ_{pwp}***	1.629	-1.747	0.111	-	0.853
y = optimum water content [gg^{-1}]					
plastic limit	0.136	0.889	-0.066	-	0.830
liquid limit	0.142	0.446	-0.067	-	0.781
clay content	0.128	0.542	-0.061	-	0.738
θ_{pwp}***	0.141	1.250	-0.058	-	0.802

* units of the textural properties are in [gg^{-1}]
** pressure in [100KPa] (the factor c is the compression index)
*** organic carbon content in [%]
**** water content at permanent wilting point (-1.5MPa water content) in [gg^{-1}]

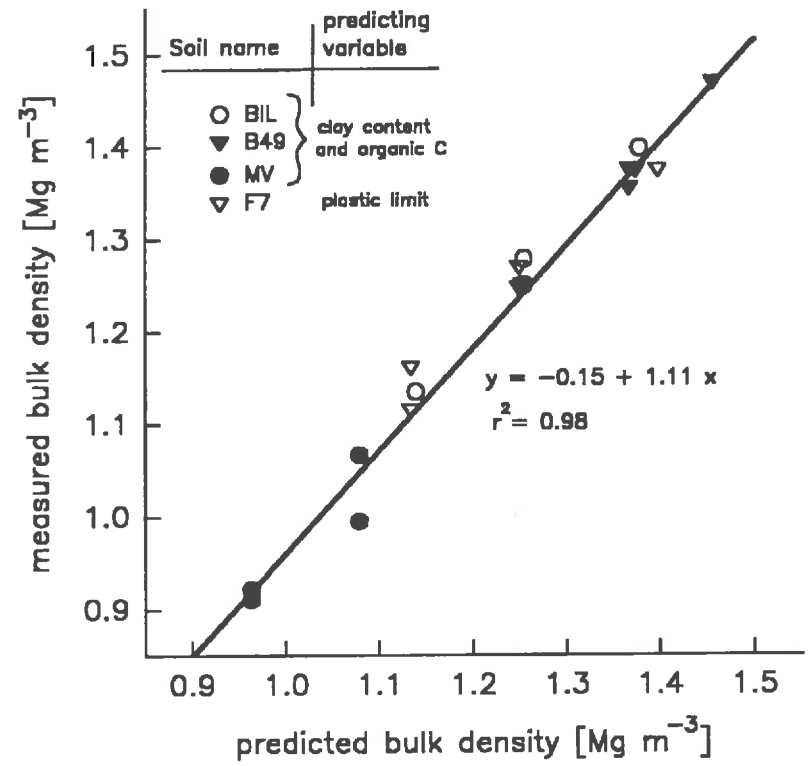

Figure 4. Comparison of predicted and measured points of maximum bulk density.

Conclusion

A simple uni-axial compaction test was found to be a convenient and reliable method to determine the compactibility of soils and to derive their compaction curves. The point of maximum compaction derived from the uni-axial compaction test could be predicted with high precision ($r^2 > 0.80$) from the soil's clay content, organic carbon content and uni-axial pressure. Similarly, the optimum water content to achieve maximum bulk density can be predicted using the same parameters. Compaction to bulk densities lower than maximum bulk density could be predicted from clay content, applied pressure and soil water contents. Refinement of these models and adaptation to cloddier field soils will be a potentially valuable tool to minimise soil compaction.

References

Cook G. (1988). Degradation of soil structure under continuous cultivation on the Darling Downs, Queensland. PhD-Thesis, University of Queensland.

Greenhalgh M.C., Horton I.F. and Basford K.E. (1987). MicroQuasp. Department of Agriculture, Uni.of Qld., St.Lucia, Australia.

Koolen A.J. (1974). A method for soil compaction determination. Journal of Agricultural Engineering Research, 19, 271-278.

So H.B. and Cull P. (1984). Effect of soil compaction on cotton growth in the Emerald Irrigation Area. The Australian Cotton Grower. May-July, 52-57.

Soane B.D. (1990). The role of organic matter in soil compactibility: A review of some practical aspects. Soil and Tillage Research. 16, 179-201.

Controlled Traffic for Sugarcane

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Introduction

Loss of productivity through soil structural degradation and soil compaction is of increasing agricultural concern. This can occur through excessive cultivation (Adem *et al* 1984) and high axle load traffic at inappropriate soil water contents (Voohees *et al* 1986). Controlled traffic has been instigated to reduce soil structural decline (Tisdall & Adem 1988) and to restrict the spread of soil compaction (Taylor 1986). Much of this work has been undertaken in the temperate regions of the world (Campbell *et al* 1986; Murray & Tullberg 1986; Perdok & Lamers 1985; Taylor 1986). In some instances there was little or no yield response due to controlled traffic (Braunack *et al* 1995; Gerik *et al* 1987; Williford 1985). However, in other instances significant yield increases have resulted from the adoption of controlled traffic (Hadas *et al* 1990; Perdok & Lamers 1985).
This paper presents early data from a project investigating the effect of matching crop row spacing with equipment track widths on soil properties and ratoon performance of sugarcane.

Materials & methods

Field trials have been established on Tully Sugar Experiment Station (Tully) and a cooperators property at Ingham (Ingham). The soil types are classified as Uf6.34 and Ug3.2 for the Tully and Ingham sites, respectively. Some physical and chemical properties for the surface soil are given in Table 1.

Table 1. Selected soil properties at each site

Site	Depth	Clay	Silt	Sand	pH	Ca	Mg	K	PL
	cm		%				mg/Kg		%
Tully	0-10	45.5	24.5	30.8	5.6	2.63	0.76	0.2	26
Ingham	0-25	44.8	25.5	27.3	4.65	4.24	3.19	0.46	32.5

PL= Plastic Limit

The Tully soil is rigid whereas the Ingham soil has a slight self-mulching tendency (it cracks when dry).

Trial details

Trials were planted at Tully and Ingham in 1993 and 1992, respectively. Treatments consist of planting single rows 1.5m apart (current practice) compared with dual rows (0.3m apart) at 1.8m spacing. Both treatments are fertilised at the same rate (based on area). Plots at Tully consist of 7 rows by 17m long with four replicates, while those at Ingham are 4 rows by 30m long with five replicates. The experimental layout is a randomised block design with results being analysed by ANOVA. Two cane varieties are grown at each site, namely Q117 and Q138 at Tully and Q115 and Q124 at Ingham.

Soil properties

Undisturbed soil cores (7.5cm dia, 5cm high) were collected to a depth of 30cm from the row and from a near-row position before and then after each harvest. The near-row position was approximately 10cm and 30cm from the row for the 1.5m and 1.8m spacing, respectively. These cores were used to determine bulk density (BD) and saturated hydraulic conductivity (Ks). Soil cone resistance was also measured before and then after each harvest.

Crop parameters

Crop response was determined by stalk counts and height measurements at regular intervals through the season. Crop yield was measured by weighing the two central rows in each plot at harvest.

Results

The crop is currently second ratoon at Tully and Ingham, with the second ratoon at Ingham to be harvested in the near future.

Soil properties

Data for the most recent harvest is presented, and all measurements pertain to the row position only. At the time of measurement there was no significant difference in soil bulk density between the 1.5m and 1.8m systems at both Tully and Ingham, although it tended to be higher at the 1.5m spacing. There were, however, significant differences with depth, with the shallow layers (0-5, 5-10cm) having lower densities compared with those at depth (15-30cm)(Fig 1).

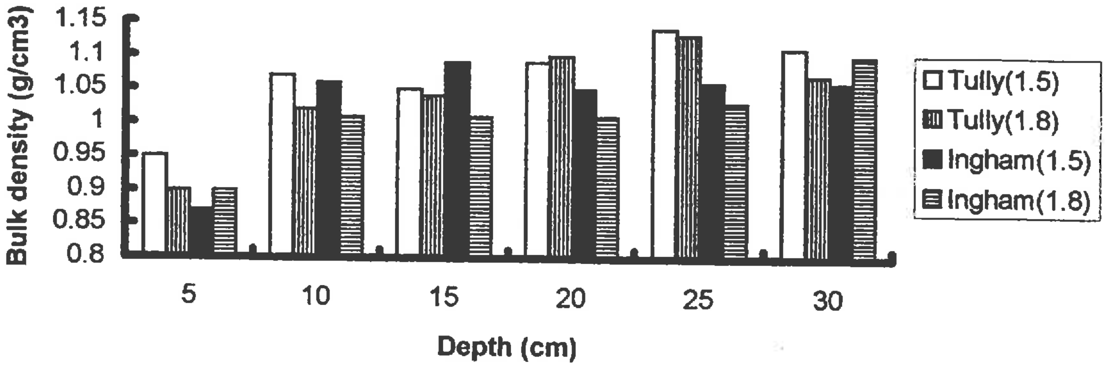

Figure 1. Bulk density in the row under different management

The saturated hydraulic conductivity was higher at the shallow depths compared with the deeper layers, and tended to be higher under the 1.8m system than the 1.5m system at both sites (Fig. 2).

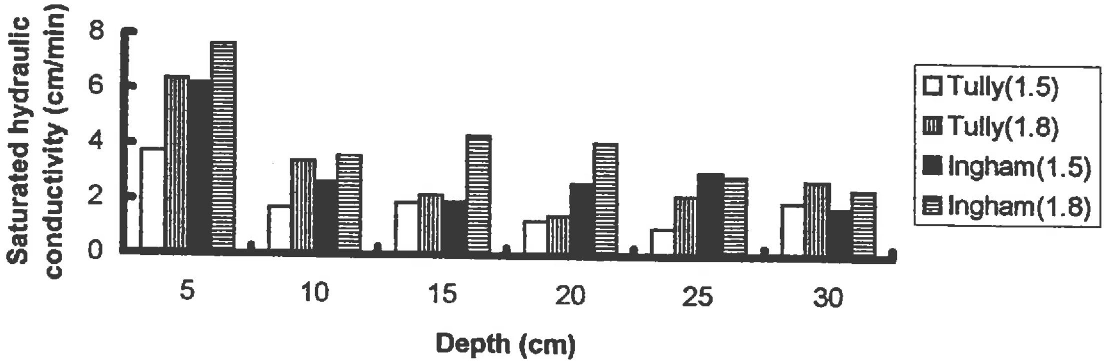

Figure 2. Saturated hydraulic conductivity under different management

Soil cone resistance tended to be more variable with no distinct trend evident (Fig. 3).
The cone resistance for the 1.5m system tended to be slightly greater at Tully and lower at Ingham. There were several depths where the cone resistances crossed over (Fig. 3). At Tully a zone of high strength (6000 kPa) occurred at a depth of approximately 46cm under the row with 1.8m rows compared with 50cm under the 1.5m rows (Fig. 3).Soil resistance at Ingham tended to increase with depth, with no peak values being evident.

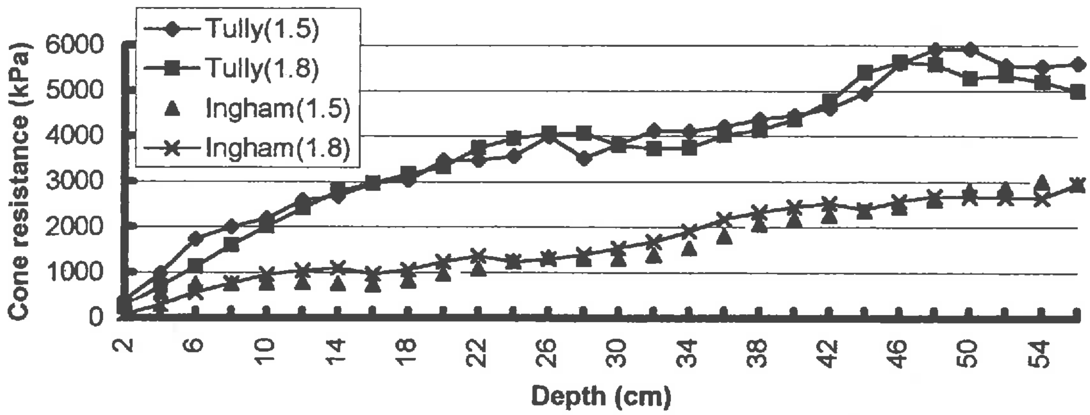

Figure 3. Cone resistance in the row under different management

Crop response

Since the crop response was similar at both sites only data for Tully is presented for illustrative purposes. Stalk counts show that for the plant crop the 1.8m rows contained a slightly greater stalk population than the 1.5m rows. However, the reverse was the case for the first ratoon (Fig. 4).

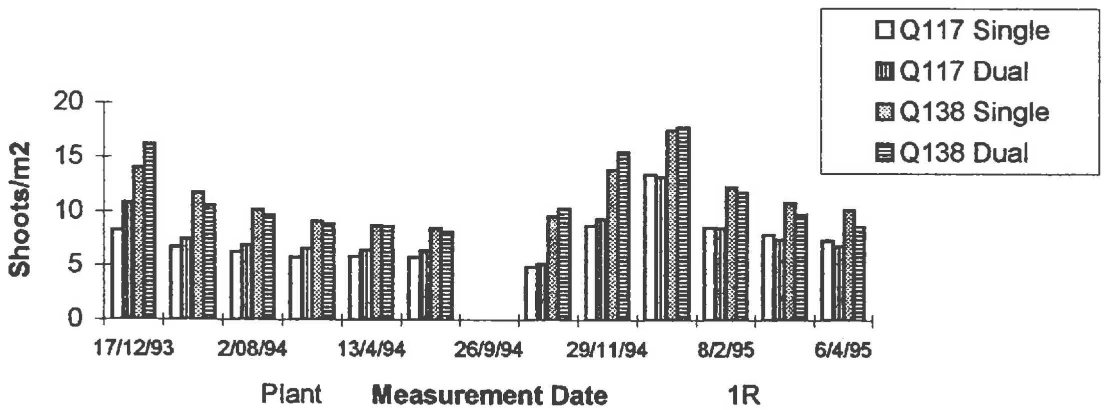

Figure 4. Effect of management on stalk numbers at Tully

A similar result was observed at Ingham (data not shown). Stalk heights at maturity were slightly higher in the 1.5m rows than the 1.8m rows, but there was some variation during early growth (Fig. 5).

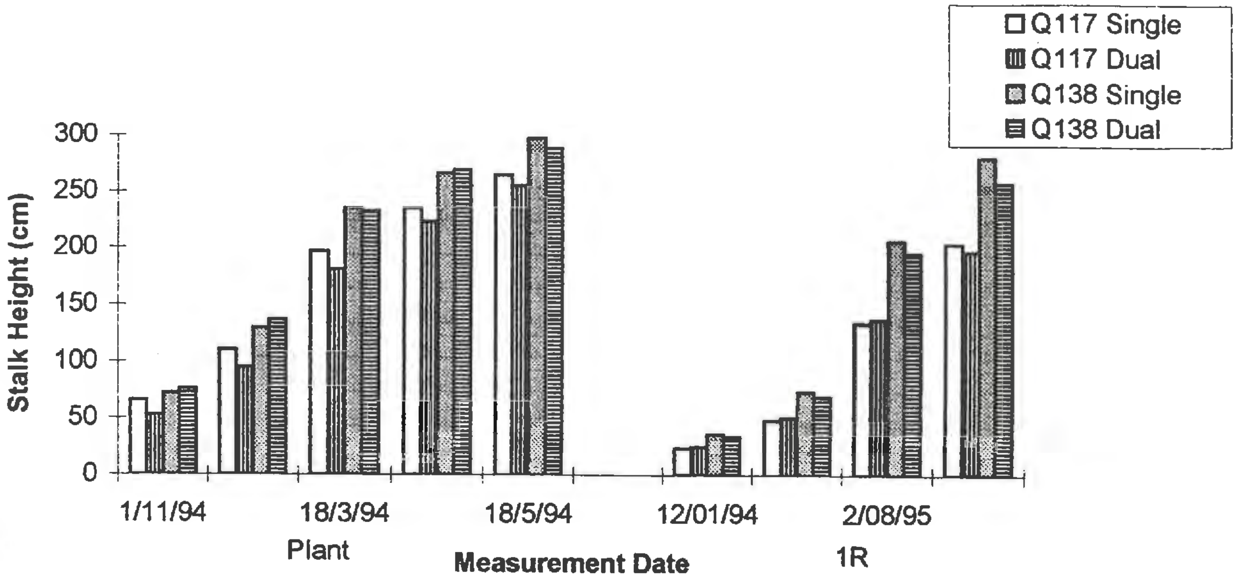

Figure 5. Effect of management on stalk height at Tully

Yield response to management system varied between sites with the 1.8m rows yielding less than the 1.5m rows at Tully, but the reverse occurred at Ingham (Fig. 6).

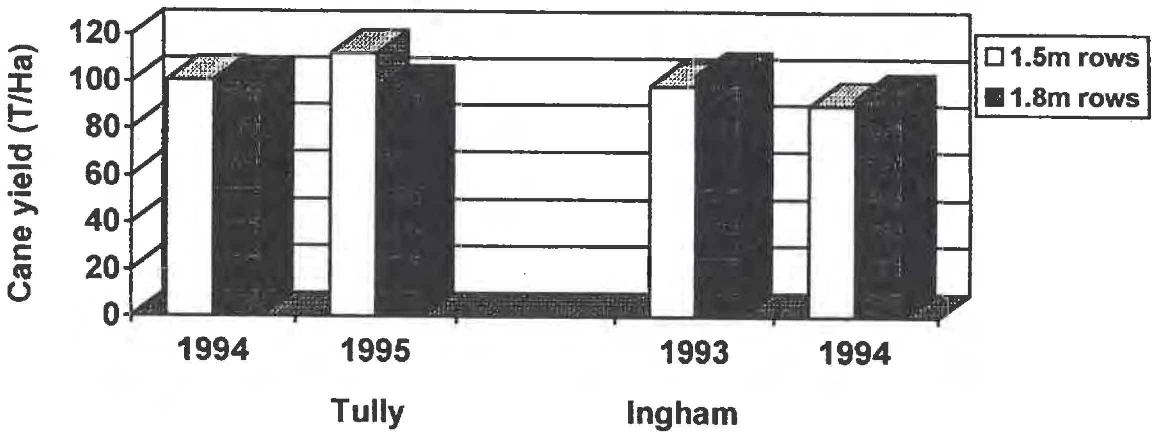

Figure 6. Effect of management on yield

Discussion

There is some indication that BD increases more under the row with 1.5m rows than it does with 1.8m rows. This is due to the proximity of traffic to the row in the narrow system compared with the wider system. The Ks measurements also reflect this result. Soil cone resistance measurements suggest that a zone of high strength may be developed at a shallower depth under the 1.5m rows compared with the 1.8m rows. This would restrict root growth and reduce profile exploitation by roots. Depending on the season this may result in water stress and possible yield reduction. It is speculated that in time the plant growth zone will be reduced to a greater extent under 1.5m rows than under 1.8m rows.

Crop response varied between sites, which may be a response to soil type and environment. It is essential to continue the trial for sufficient time to enable reliable yield data to be collected.

There is a greater chance for direct impact of the stool to occur at harvest under 1.5m spacing than under 1.8m spacing. However, there is the problem of elevator length to be resolved with current harvesters when harvesting 1.8m rows. Visibility may be improved at the wider spacings, thus allowing more accurate tracking at harvest. At this stage there is little evidence to suggest that changing to a controlled traffic system will be beneficial to crop growth, but this may change with time. By restricting soil compaction, soil degradation will be reduced and more favourable plant growth zones may develop with time, especially if used in conjunction with reduced tillage techniques.

References

Adem, H.H., Tisdall, J.M. & Willoughby, P. 1984 Tillage management changes size distribution of aggregates and macro-structure of soils used for irrigated row crops. Soil & Tillage Res.,4:561-566.

Braunack, M.V., McPhee, J.E. & Reid, D.J. 1995 Controlled traffic to increase productivity of irrigated row crops in the semi-arid tropics. Aust. J. Exp. Agric., (In Press)

Campbell, D.J., Dickson, J.W., Ball, B.C. & Hunter,R. 1986 Controlled seedbed traffic after ploughing or direct drilling under winter barley in Scotland. Soil & Tillage Res., 8:3-28.

Gerik, T.J., Morrison, J.E.Jr., & Chichester, F.W. 1987 Effects of controlled traffic on soil physical properties and crop rooting. Agron. J., 79:434-438.

Hadas, A., Schmulevich, I. Hadas, O. & Wolf, D. 1990 Forage wheat yields as affected by compaction and conventional vs wide frame tractor traffic patterns. Trans. Agric., 33:79-85.

Murray, S.T. & Tullberg, J.N. 1986 Controlled traffic cropping system. Proc. Conf. Agric. Engng. p234-238. Inst. Engrs. Aust. Publ. 88/9.

Perdok, U.D. & Lamers, J.G. 1985 Studies of controlled agricultural traffic in the Netherlands. Proc. Int. Conf. Soil Dynamics. 5:1070-1085, Auburn, Alabama,USA.

Taylor, J.H. 1986 Controlled traffic: a soil compaction management concept. Soc. Auto. Engrs. Tech. Paper 860731, 9pp.

Tisdall, J.M. & Adem, H.H. 1988 An example of custom prescribed tillage in South-eastern Australia. J. agric. Engng. Res., 40:23-32.

Voorhees, W.B., Nelson, W.W. & Randall, G.W. 1986 Extent and persistence of subsoil compaction caused by heavy axle loads. Soil Sci. Soc. Am. J., 50:428-433.

Williford, J.R. 1985 A controlled traffic cropping system for the Mississippi Delta. Proc. Int. Conf. Soil Dynamics. 5:1132-1138

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LOW COST CONTROLLED TRAFFIC FOR PROTECTION OF SOIL STRUCTURE WITH CURRENT FARM EQUIPMENT

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Collaboration between a research officer and farmers from the Chapman Valley and Kooloonooka / Bowgada Landcare groups.

SUMMARY

Farmer innovation has provided a cheap and convenient system to restrict wheel traffic to "lanes" within a paddock. Improvements to soil structure can be conserved and spraying operations made more efficient. Some crop yield benefits have been found in the first seasons. Opportunities to modify structure with biopores are provided. The farm trials will continue to follow the fate of soil structure and crop yield.

CONTROL TRAFFIC WORKS!

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