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Controlled Traffic: Progress and Potential

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Introduction:

Concepts such as zone tillage and raised bed production have been applied to specific agricultural and horticultural systems since the middle ages, and gantry farming was first proposed in the 19th century. Controlled traffic was first investigated seriously in the 1960's, as a response to soil compaction problems, suggesting that random traffic had not previously been recognized as a significant problem in field crop production. That it was first applied in furrow- irrigated row cropping says something about the situation in which the problem is most obvious, and the conditions where controlled traffic is most easily applied.

Restriction of all heavy wheel traffic to permanent wheeltracks largely eliminates the dissipation of tractive energy in unnecessary soil deformation. This was the original motivation for controlled traffic research and adoption in Queensland, and this single step will substantially reduce energy requirement, soil degradation and the cost of crop production operations. Subsequent large-scale field application has demonstrated a range of other benefits, of equal significance to those originally envisaged. It is difficult to overstate the contribution of innovative farmers, and their advisers, to this process.

An improved level of precision in field operations is necessary in controlled traffic. Improved precision also provides significant opportunities for better crop management, some of which have already been realized by far-sighted farmers. The rapid improvement in field guidance systems occurring now will, however, provide the basis for even more significant innovations in cropping systems.

This paper provides an overview of the current situation in terms of the benefits originally expected from controlled traffic and the by-product 'system' benefits now being achieved. Some of these by-products turned out to be of great practical importance. The paper also considers the potential for future development of precision controlled traffic farming.

Australia already leads the world in on-farm applications of controlled traffic systems. The interaction of research, development and on-farm application has provided a farming system that is demonstrably more viable and sustainable. All the evidence suggests that the potential for further improvement is just as great, provided we accept the challenge to do things differently, on-farm and in research, and in maintaining communication between the two.

Original Objectives – Energy, Cost and Compaction Benefits

Energy. Most of the energy wasted in traffic and traction must be dissipated in soil deformation under tyres, and this effect is relatively easy to measure. Random traffic operation of equipment such as planters and chisel ploughs entails an energy input to the soil in the range of 20 – 50MJ/ha, most easily understood as an average tractor drawbar power requirement of 7.5 kW/m (3HP/ft)of implement width. In practice this means 10 kW/m(4HP/ft) power delivered to the axles, so approximately 2.5

kW/m(1HP/ft) is dissipated in soil deformation under the tyres. This is 75% tractive efficiency, where 25% of power has been wasted.

This level of efficiency looks reasonable, until you realize that the implement requires extra power to re-loosen wheeled soil. Our measurements demonstrate that wheeling by tractor or implement tyres roughly doubles the tillage power requirement for the wheeled area. In this situation, when tractor and implement tyres wheel 30% of implement width, implement power requirement increases in the same proportion.

Our 25% power wasted in traction is now compounded by the fact that the traction process has increased tillage power requirement by perhaps 30%, in the process of re- loosening soil within the tilled zone. The net effect of poor tractive efficiency is that total power requirements are almost doubled. More detail is given later in these proceedings, by Tullberg and Victor-Gordon.

Cost. Reducing the energy requirement of operations by 50% also reduces operating costs, and the tractor size required for a given operation, by the same proportion. Just as important, the improved trafficability of permanent wheeltracks allows operations to start or re-start one or two days earlier after rain. Farmers are sensibly cautious about reducing the margin of safety offered by a larger tractor, but many long-term controlled traffic farmers can demonstrate the economic benefits of reduced tractor size.

Soil compaction. It is interesting to note that we normally recognize 'soil compaction' as a phenomenon in soil beneath the tilled layer. We see it there only because tillage has destroyed most of the evidence of surface damage, although increased cloddiness is sometimes visible behind tractor wheels. The most intensive energy input to the creation and breakup of compaction must have clearly occurred within this tilled layer, even though we sometimes find it difficult to identify. Perhaps it is the absence of this damage, along with the reduction in tillage frequency and/or intensity which accounts for the references to improved soil structure under controlled traffic.

Assessment of soil compaction effects is difficult, and quantitative measurements often demonstrate smaller traffic effects than those provided by more qualitative, visual assessment (McHugh, these proceedings). Some part of this difficulty might be related to the fact that non-compacted (ie non-wheeled) soil is simply not available on most farms and research stations.

A variety of indices can be used to illustrate soil response to wheel traffic, but the most convincing data is that related to rainfall infiltration and crop performance. Evidence from a number of sites and experimental approaches indicates that wheel traffic can be expected to provide a substantial increase in runoff under most conditions. In recent work at Gatton, controlled traffic reduced runoff by 30% on average, and this effect was greater when the soil surface was protected by crop residue. Crop yield response to controlled traffic has reliably reflected the increase in soil water resulting from reduced runoff from non-wheeled plots. These trials have given no indication that the soil condition achieved in the absence of traffic and tillage is not optimal. Detailed results are provided later in these proceedings by Li, Ziebarth and Tullberg.

Indirect, System Benefits

The most important indirect benefit of controlled traffic is its comprehensive compatibility with zero till and other less intrusive crop production systems. Increased tractor tillage energy efficiency might be valuable, but it is of much greater significance that random traffic itself has often created the surface compaction (wheel ruts) or sub-surface compaction (hard layers) that generate the demand for tillage. The need for comparisons has ensured that our research has continued to compare controlled traffic effects in both conventional and zero tillage, but the majority of farmers adopting controlled traffic have also taken the opportunity to reduce tillage.

Controlled field traffic depends on permanent wheeltracks, or traffic lanes, which clearly require accurate installation. Installation guidance systems have included sophisticated GPS guidance systems, large conventional marker arms, and lengths of wire stretched between vehicles. Regardless of the system, accuracy is usually significantly improved by controlled traffic. In all cases overlap and 'misses' are reduced, and field efficiency increased, providing significant direct reductions in operating cost and consumables.

Readily visible, permanent wheeltracks are also a major advantage when spraying, improving guidance and allowing spray applications to occur at night, when conditions are often more favourable. Controlled traffic improves the reliability and timeliness of chemical application.

Because the tracks are usually at a different height to the non-wheeled field surface, they also have a major influence on overland flow of runoff water. Wheeltracks can be used as a disposal pathway for surface water to take it rapidly to contour channels on sloping land subject to high-intensity rainfall, or -in "raised beds" systems -- as a drainage system to of avoid waterlogging. These topics are dealt with from totally different perspectives in these proceedings by Cannon and Hamilton respectively. The common factor across this work is the improvement in soil condition that occurs when traffic is controlled and tillage reduced.

Crop Management Innovations

Controlled traffic farming demands and fosters better field guidance systems for tractors and implements. The price of these systems -- whether GPS or Vision type – appears high at present, but we can be sure that this technology will rapidly get cheaper over the next few years. When repeatable and reliable field guidance for tractors and implements is accurate to within a few centimeters, we have an exciting new set of crop/soil management opportunities. These opportunities are particularly important when combined with the ability to access crops without damage from permanent wheeltracks during their growth and maturation.

An immediate benefit is the ability to apply rowcrop techniques to more closely spaced crops. This has already been carried out by growers who have inter-planted the summer crop between the stubble rows from the winter crop, or used small-scale surface profile changes (furrows) to concentration limited rainfall to achieve a 'planting rain' effect in the planting row only. It not difficult to envisage the use of interrow weeding equipment- mechanical or shielded spray- to deal with difficult weeds, or slow the development of resistance. Split application of fertilizer appears to have great potential for increasing crop yield in wet years, and the ability to drill it into moist soil would be a great advantage over aerial distribution, as well as cheaper. This topic is considered later in these proceedings by George and Lewis.

The level of precision will obviously determine what can or cannot be achieved within a given row spacing. There appears to be considerable potential to use systems such as twin-row planting to provide a greater margin for error – and, perhaps, a planter which delivers greater residue tolerance by using half the number of ground-tools. The ability to produce small windrows of residue, and move them precisely in relation to the planter, could also be an important part of this scenario.

It is only a small step to envisage the division of the non-trafficed, permanent beds for several seasons into zones or strips which grow only grasses, and zones which only grow broadleaves, after band-spraying soil applied herbicides. Defined band, or zone application, would certainly reduce the constraint on cropping options following the use of soil-applied herbicides.

Precision controlled traffic will be the basis for zonal management of permanent beds. Zonal management might appear far-fetched, but it will clearly become feasible within the next few years as precise guidance gets cheaper. We need to consider all the possibilities which will improve productivity and sustainability. This could usefully include systems such as relay cropping (Massaso and George, these proceedings) and intercropping (Lewis, these proceedings). Both these approaches should help to increase double-cropping opportunities, maintain residue cover, and maximize the productive use of soil moisture.

Challenges

There are, of course still many practical challenges to be overcome to ensure that the on-farm benefits of controlled traffic become readily available to larger numbers of growers, and the environmental benefits available to the community at large. Growers have already demonstrated that they can deal with the first major challenge – that of thinking differently about the way they go about their farming. It would, nevertheless be considerably easier to look at the future if some of the machinery limitations could be overcome.

The major problem is still the incompatibility of the standard tractor with the grain harvester. While there might be little structural damage when harvester wheels run on dry soil, wet harvests are not uncommon in many areas. The weight of the harvester ensures that – even with the most generous tyre equipment – it makes a nasty mess of a soft permanent bed. Its effects also go a long way down through the profile, which is a problem if there is moisture further down. It looks like we can now get rubber-track crawlers, and the rear axle of many standard FWA tractors to 3m. How long will it be before a standard, warranted front axle is available?

A further point to be addressed is the one of tyre size/pressure/trafficability of permanent wheeltracks. Those of us working in black soil know that the permanent track can usually carry heavy loads without damage, but what happens under marginal moisture conditions, and on weaker soils? What happens on black soil when we put a 15t header axle on tyres not much bigger than the 18.4 section? Its no good if the header can't operate at all when it gets of the permanent wheeltracks. Perhaps the answer is the use of a smaller diameter dual tyre outside the high-pressure narrow tyre. Perhaps the answer is rubber tracks. Perhaps the answer is to use swath or windrow systems – as suggested by Wayne Chapman (these proceedings). Alternatively, we might find that a larger header front has to be articulated on its own ground wheels anyway. With these on the permanent wheeltracks, the front axle of the header might become much lighter.

The task of the planter becomes easier in some respects in controlled traffic farming. It's easier to get seed down to moisture in softer soil. It can, however become more difficult to cut through residue with a disk. If CTF results in greater yields and more frequent cropping, we might have to look more closely at residue management, or the way we deal with the residue at planting. I still believe that depth control – for planting and/or precision tillage – is a problem which will need to be properly addressed as we separate the load-carrying and depth control functions of implement wheels. Why control position to an accuracy of about 5cm if you can't control depth?

Conclusion

Great progress has been made since the first controlled traffic conference at Yepoon in 1995. No one now regards it as a topic for purely 'academic' attention. Farmers have demonstrated it works. There are still plenty of practical problems. I have mentioned some here, but we hope that one outcome of this conference is that most such problems can be identified and addressed by those best equipped to do so.

It is also important that we continue to look ahead at some of the challenges which will emerge when we try to achieve the full potential of precision controlled traffic farming. Some of these still appear to be academic, but if progress continues at its current rate, I think I can safely predict that some of them will be urgent practical problems before the next controlled traffic conference.

The last few years have demonstrated that success has been based on good two-way communication between farmers, extension people and researchers. From my own perspective, an additional input has been the regular observation of a totally different approach to mechanised cropping in China, which provides a totally different perspective on our approach to sustainable crop production. Our major for this conference is to provide the opportunity for starting new and productive lines of communication for all contributors.

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CONTROLLED TRAFFIC FARMING - THE FUTURE

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Controlled Traffic Farming (CTF) is a very recent concept, at the 1995 Conference we only referred to Controlled Traffic. That epitomises the rapidity of change that we have established. The change from CT to CTF is only one letter but the implications are enormous. CT means a farming practice for soil compaction management in isolation of other practices, CTF means a farming system that aims to include every aspect of farming as I will attempt to describe in this paper. At the 1995 Conference I attempted much the same, but it is interesting that our definition of "farming" has broadened considerably as we all strive harder for sustainability in terms of production, profitability, resource management, environment and our social structures. And our belief that these can be and must be achieved together has been reinforced by our experiences.

WHAT IS CONTROLLED TRAFFIC FARMING?

The essential elements are permanent wheel tracks (as few as possible), runoff controlling layouts, efficient use of inputs (seed, chemicals, energy, and rainfall), and the grower's FARMING SYSTEM.

- CTF is driven by RESOURCE MANAGEMENT ("great soils" - soil compaction, infiltration/runoff, erosion, drainage, root growth, zonal management);
- CTF supports BEST AGRONOMY/CROP MANAGEMENT ("great crops" - options, minimum tillage, timeliness, effective operations, efficiencies);
- CTF protects the ENVIRONMENT (clean runoff, balanced inputs);
- CTF is PROFITABLE (reduced costs, increased income);
- and CTF builds SOCIAL SYSTEMS (viable industries, responsible custodians, community and government support).

And we need performance indicators as goals and targets. Our Central Queensland performance indicators are high cover (more than 50%), low erosion (not visible), high farm water use efficiency (annual production/annual rainfall), high returns on investment (10%), and annual holidays for growers (four weeks).

OUR KNOWLEDGE IN 1995

I will briefly review our position in 1995. In 1995 I wrote that CT provided a delivery mechanism for improved practices; that CT could develop into an integrated, functional system; and that the issues were soil compaction, low productivity, farm efficiencies and soil erosion. We had established some basic rules:

- Soil compaction is predominantly caused by wheels and growers must change to a soil management culture. CT provided the opportunity for both physical change and attitudinal change.
- Productivity is based on perceptions of what yields a region can produce - again an attitudinal constraint. Efficiency indicators, such as water use efficiency, tractor efficiency, etc. provide useful criteria for performance assessment. Higher yields, more frequent planting and more flexibility in all operations were highlighted.

- CT means permanent wheel tracks and row cropping with major increases in efficiencies within the cropping system. This introduced the concept of zonal management - wheel tracks, crop rows and inter-rows and the ability to manage each zone separately. But how to achieve erosion control?
- Water flows downhill and concentrated flows increase erosion. CT lines will direct runoff and spread it across the landscape. Our CT designs provide in-paddock control of runoff to reduce flow concentration - a first. In addition, maximising infiltration by high cover, minimising compaction and accessing cracks with CT systems will reduce runoff and sediment concentration. CT can control erosion if layouts have no reverse flows, no cross flows and drain to safe disposal points, and if zero tillage and cropping systems maximise cover.
- CT was demonstrated as feasible and practical on a range of broadacre farms.
- In conclusion, CT is better than sliced bread, it makes good sense and the only surprise was that someone didn't think of it earlier.

The conclusions from the 1995 Conference were the birth of CTF as a sustainable farming system and the confidence to "Have a Go".

OUR KNOWLEDGE IN 1998

As discussed previously, we now understand that a sustainable farming system involves at least resource management, agronomy, environment, economics and social sub-systems. This "systems thinking" and our focus on farming systems not only provided a context to incorporate improved practices, it also gave us credibility with growers because they related to the system we were working on. We all owned the same system - CTF.

The Central Queensland adoption has continued to more than double each year and virtually every grower who has tried CTF is committed to full adoption across their cropping area. This fence to fence adoption is an amazing achievement for such a complex technology. The publicity following the 1995 Conference and presentations at Field Days and Workshops across the northern grainbelt have ensured that CTF is very widely known across the farming community in Australia. At many of these presentations growers were the primary speakers and their commitment, enthusiasm and passion have been the major influence in changing other grower's attitudes and providing them with the confidence to "Have a Go".

We have welcomed many visitors to Central Queensland and they have all contributed information and ideas. Massive areas of CTF in Northern NSW and southern Queensland are now indications of our impact. More importantly this wide adoption has had a tremendous synergistic effect on development of CTF. Every paddock is an experiment and CTF growers are great observers and willing to contribute to development. A major benefit has been a close relationship with growers and consultants in northern NSW. Their agronomy has been a revelation to us and stressed that higher yields will be more important than cost reductions in the economic performance of CTF. Recent economic analyses (with economist Fred Chudleigh of Emerald) indicates possible net returns of $300 per hectare and returns on capital invested of more than 10%. A reality check with four local growers supported these conclusions as being realistic. Achievement of high returns at Dalby, Moree and Gunnedah may be due to a more reliable climate but the average conditions in Central Queensland are very similar, we just have to learn how to manage the higher variability. Not an easy task but a rewarding area for future research. The exciting response is that research results from CQ will have wide application across the northern grain belt.

Bus tours have proved to be a very successful adoption vehicle, we estimate 80% of participants have gone home and adopted our message. A captive audience for 3 or 4 days is a wonderful opportunity for discussion, clarification and reinforcement, and for planning the work program back home. We aim for many stimuli and for growers to talk to growers. I also believe a mix of enterprises is useful, particularly more intensive farms.

We now have a network across Australia, all contributing new ideas and experiences. Undoubtedly, Jamie Grant and Rob Taylor are the benchmarks for CTF and their contribution must be applauded by the industry. They challenge everything and know no barriers. Jamie's impact on our team has been pivotal as he started well before we did and is still well ahead. Jamie challenges us to look wider still and consider such diverse aspects as farm labour, legumes and floodplain management. Jamie has given us tremendous support and also introduced us to the importance of attitudinal change.

From Kingaroy, Richard Mason gave us his experience on higher slopes and red Kraznozems, and on dealing with a system and region in decline. The consultant groups of southern Queensland and northern New South Wales provided insights into crop production and efficiency, and now the Victorians and Western Australians are developing CTF for very different climates to ours. In preparing for this Conference I had several discussions with members of Southern Farming Systems in Victoria where adoption of CTF (raised beds and furrows) has increased from one ha to a few hundred hectares to 7000ha over three years. Similar to CTF in Queensland, components of their technology were tested fifteen years ago without adoption, why? Their program has many parallels to ours and the responses have almost been identical. I kept replying "we found that" and "our growers did that". This further reinforces that we are on a winner with CTF because in Victoria development is for drainage of wet soils during their wet winter.

Across the network the same principles seem to apply, the issues are similar, the solutions often similar, the technology is transferable, and the enthusiasm and optimism of the growers is just the same. The key points are systems thinking and attitudinal change. Surely this is a very powerful message - how can we harness it?

This success with adoption, with creating change, has made us analyse what we do. Why has CTF been so widely adopted, why are CTF growers so committed? We have concluded that it is the combination of a technology package with a people process. So it is a true partnership between the growers and the service providers. The strength of farming systems work is that the only place it can be done is on commercial farms, and the on-farm development program provides an effective action learning platform for all of us.

Our experience since 1995 has particularly emphasised the issue of grower attitudes. Introduction to CTF has been a great catalyst for attitudinal change - it throws away many perceptions that constrain our thinking and provides a clean slate. It is now clear that changes in grower attitudes are obvious performance indicators of our program. And those new attitudes will be the driving forces or the future.

Parallel changes in the attitudes of professional service providers are also required since we have similar entrenched beliefs that constrain both our ability to analyse problems and to find solutions. Undoubtedly the greatest challenge has been for soil conservationists who have achieved much over the last 30 or 40 years but still soil erosion is the major degradation issue across the northern grainbelt. Our approach has been to build on the sound theoretical base but to challenge the attitudes, practices and solutions that have developed. A solution developed in the 1960's demands re-examination in the massively changed farming environment of the 21st century.

Erosion is identified by growers as the main concern about our downslope layouts. However properly designed layouts on sloping lands have performed extremely well from Clermont to Gunnedah. After major storms in early 1997, we conducted aerial surveys of the erosion damage. This was a revelation to me and an experience that I would encourage everyone to share. Firstly it was very obvious that the major processes of erosion were rilling, broken contour banks, ineffective waterways and stripping of top soil in flooded areas. Due to the ease of aerial observations, these could and should be performance indicators for erosion control. To my knowledge no records of such performance have ever been taken. The damage was considerable. After some ground truthing, we estimated about 20 million tonnes of soil were moved - surely proof that new approaches to soil conservation are desperately needed The aerial inspection showed that rilling was independent of cover levels and was clearly a consequence of field operations around the contour, which concentrated runoff into rill lines. Unfortunately, rills in long term zero till paddocks were up to 0.5m deep and seriously restricted any following operations. Apparently this was due to no compacted layer in the soil profile. CTF paddocks performed extremely well. Even with low cover, erosion was small (less than 10t/ha), the contour channels were not silted and access was possible within 5 days. We concluded that downslope layouts designed to our rules would provide adequate in-paddock erosion control, and that contour banks and waterways must be better designed, constructed and maintained. Another interesting lesson has been that many growers fly over their properties and know the devastation caused by severe storms. They are extremely frustrated that all their efforts based on the best available advice have not been effective. Yet they have not demanded more research and better advice, and the service providers remain largely oblivious. Our future emphasis will be on whole farm design for runoff, erosion and traffic control.

THE FUTURE

Science

The application of a sound scientific base to develop CTF at the paddock scale is seen by many as lacking scientific rigor. Scaling-up creates challenges for science that have been highlighted by our success with adoption. Is our science ahead or behind?

On-farm research methodology: CTF can only be applied at a paddock scale using farm machinery - that clearly is the implication for any farming system research. How then can systems be compared? What is the value of replication if paddocks (plots) are hundreds of hectares in size? What measurements are useful at such scales? How can answers be achieved economically within a reasonable time frame? These questions are fundamental to farming systems research. Much current research studies cropping systems or soil management systems in isolation of the most basic component of modern agriculture - mechanisation. Our program suggests some positive directions for this scientific debate. The large scale implies considerable soil and landscape variation across sites and the multitude of inputs (weather, management) and decisions limit direct comparisons. For example, if comparing CTF and the conventional system, how are planting decisions made without bias? It is also necessary to have two sets of machinery! The most practical comparisons may be made, using appropriate indicators, between paddocks on different farms with the farmers optimising their own farming systems. But even the choice of indicators will be controversial.

And what do the growers want from science? Our experience suggests that their decisions will be based on observations of large areas, discussions with experienced and respected growers, and their own action learning. But science has a role to ensure that the science is sound and that the interpretations and extrapolations are reasonable. This implies that we have useful indicators of production, economics, resource condition and off-site impacts. Yield monitoring will provide new insights (the highest yields in paddocks suggest crop water use efficiency higher than the physiological potential); water use efficiency is a key but we need methods that relate to annual rainfall not individual crops; aerial photographs after erosive events can quantify rilling, broken contour banks and waterway effectiveness; paddock records are essential; soil health may be measured by earthworm numbers, root growth or ease of digging; and techniques to measure suspended sediments which carry most environmental pollutants off farm will provide a useful data base.

Research issues: Specific issues for science include the long term effects of permanent wheeltracks; the agronomy of uncompacted soils (what are potential yields?) - yield increases must be achieved to fully benefit from CTF adoption (do we need new varieties, practices, etc.); the opportunities from accurate zonal management (potential innovations are boundless); automated guidance is an essential requirement (cost reduction for GPS and further development of video systems); and grain drying to allow early harvesting and preparation for the next crop.

Agronomic research that specifically uses the precision made possible with CTF is just beginning. Some manipulates the soil surface by moving stubble or creating furrows, and is looking at the value of side-dressed fertiliser - how late can it be applied? When is it useful? An interesting program is looking at manipulating crop phenology to better fit our variable and unreliable rainfall patterns. Essentially, this research aims to separate crop establishment from grain production. The basic concepts are: establishment needs little soil water, established plants and root systems can produce grain much quicker after rainfall than a sown crop, and rain is about four times more efficient in-crop than for fallow storage. Similar benefits may be achieved by ratooning.

The on-farm developments will identify many research needs and opportunities. Because problems are defined within the farming system, solutions will be directly applicable to that system - assured adoption. Will our scientists be able to research these problems and provide innovative solutions? It will certainly require attitudinal change.

CTF and floodplains. An essential future role for science is to identify and answer the new questions asked when CTF is applied to larger paddocks and across different situations. A burning issue is floodplains. It is surely reasonable to question current approaches to floodplain management that have been in place for nearly 50 years and have on occasions performed poorly. Also some of the principles have not been widely adopted (a result that threatens the whole floodplain), and farm efficiencies and high cover levels are not maintained in many strip cropping layouts. Some of the theory is debatable - is it desirable to encourage runoff from one strip to wet up an adjoining strip? Our approaches in terms of questioning current practices, involving growers and achieving adoption may have application.

Farms and Farmers

Best management practices (BMP): Development of BMP or environmental management systems (EMS) with linkages to environmental monitoring seems essential. Cotton's BMP program and the links to water quality at least for northern NSW streams is a positive direction. Research is needed to study the impact of on-farm improved management such as CTF on downstream water quality. This research should be industry funded.

Change in grower's attitudes will be the catalyst for a major effort on farmer driven BMP, EMS and Quality Assurance. Is there an opportunity to develop a CTF label as an indicator of sustainable production methods? Could this be accredited internationally? There is an industry responsibility to farm efficiently and effectively with minimal environmental impact. I believe CTF is the sustainable future of broadacre cropping industries as permanent beds are for irrigated cotton, but major efforts are required to establish benchmarks and monitor performance, to increase community awareness and to gain community confidence. The cotton industry provides a template. These issues demand industry wide support. CTF growers must control their futures and provide the necessary leadership.

Whole farm layouts: CTF impacts on every activity on farm and whole farm planning is clearly needed to provide a robust, efficient and effective system. Whole farm layouts will incorporate runoff, erosion, drainage and traffic control (control the water, control the wheels). Control of run-on water and runoff disposal will be key elements. This is the next step but do we have the resources to cover the massive area of the Australian grainbelt? In many situations existing data can be used to develop layouts (as we now use contour bank layouts to design in-paddock CTF) but professional assessment will be essential as will be training of growers to assess and understand in-paddock impacts. Currently the necessary professional resources are not available and agencies have no policies to provide them. An industry priority should be to change those policies.

Machinery: The source of most of our opportunities and frustrations. But we have seen major changes with most tractor manufacturers now offering a 3m wheeltrack. If we can standardise on 3m for broadacre farming the benefits will be enormous. In fact if we don't standardise, the full potential of CTF will not be achieved. The biggest challenge could be to incorporate cotton into a 3m system. Would 3m cotton have some benefits? Growers will have to bite the bullet on sprayers. An economical, high clearance, fast tractor on 3m wheel spacings would offer more options. Surely this Conference could provide some clear directions for manufacturers.

Growers will reduce their machinery as cultivation becomes less used and lighter gear will suffice. But planting options will become even more important. Growers will have at least two planters - one for wet conditions, one for dry conditions. CTF will allow trafficability when the soil is still "too wet", and the opportunity to plant can not be lost. Are planters available to plant such soils? Soils will also be very soft and current depth control may not be successful as the raised bed farmers are finding. Can the wheel tracks provide depth control using radar systems? Stubble handling and inter-row fertilising are other essential components.

Guidance: The developments by the Mailler family are very exciting. They have developed a system for their own farm and then made it robust enough for commercial use. This pioneering development is the basis for real progress because they are testing the equipment at farm scale under field conditions - action learning. While this identifies problems it also assesses questions of quality - do we really need 2cm accuracy? Will it work over contour banks? How reliable is it?

A personal frustration of mine is that video guidance systems have not been developed for broadacre applications. I think that this technology has something to offer particularly in terms of high accuracy at a low price. If GPS can put us within 0.5m, could we then switch to video for the accurate in-field work? But there is a lot of development work needed to produce robust, reliable equipment suitable for broadacre use. As I understand, the technology is not the limitation.

National interaction: A national focal point and a national network are keys to sharing of information and rapid progress. The R,D&E program across Australia should be coordinated to reduce duplication and ensure vitality. Grower-scientist teams should be the building blocks. A communication program is essential - face to face, grower to grower works best and should be encouraged, facilitated and supported by Governments and funding bodies. Other modern communication systems must be developed in parallel. I have also identified issues where industry wide and multi-Government approaches are needed. There are obvious deficiencies in current policies and practices. A National Network for Controlled Traffic Farming could initiate these changes. Australia is alone in the World with adoption of CTF, so there must be International opportunities. A National Network could facilitate this.

CONCLUSION

CTF is a whole systems approach to improved resource management. This has been rarely attempted before. The consequences have been higher productivity, lower costs, higher efficiencies, improved soil and land resources, and reduced off-farm environmental impact. These are quantum leaps forward for sustainability that can be achieved on most grain farms today.

CTF has also achieved unprecedented rates of adoption despite its complex and controversial components. CTF is now used successfully across more and more diverse environments. Australia leads the World. But is CTF accepted as the farming system of the 21st century by all agencies and funding bodies, and supported accordingly? No, and the most sceptical seem to be those closest to the developments. Peter Cornish has highlighted the poor performance of the northern grainbelt compared to the rest of Australia and I contend that the answer is a dominant focus on resource management issues. Are the breeding and agronomy programs conducted within improved resource management systems or in bare fallow, tilled systems? There is only a small input to study weeds, diseases and pests and the whole ecology of high stubble systems. Yet, these are our future. Is research ahead or behind?

Soil erosion must be the most significant resource management issue in the northern grain belt but it is not given the same priority that salinity and acidification receive in the South and West. Is it because the obvious effects of erosion are quickly removed as farmers plant and cultivate, but salinity and acidification cannot be so easily removed? The farm condition is the prime concern of growers who all want to pass it on better than when they started, yet the scientific community has let them down. Can we now rise to the challenge? Will we be able to fly over our farming areas after a heavy storm or a flood and be satisfied that erosion is under control?

I wish to acknowledge the thousands of inputs from a large number of people that have contributed to this paper. I particularly acknowledge the Central Queensland team - Stew Cannon and Wayne Chapman, the researchers led by Bruce Radford and Ken Rohde, and the initial six cooperators who took the first step - Rod Birch, Lyall Swaffer, Ian Buss, Murray Jones, Chas McDonald and Bob Mathieson.

Finally, I wish to dedicate this paper to the memory of Bob Mathieson, an inspiration to us all, a true pioneer, a tireless innovator, and a constructive and challenging critic - we miss you Bob.

ECONOMIC ASSESSMENT AND REQUIREMENTS OF PERMANENT RAISED BEDS IN WA.

Derk Bakker, Greg Hamilton and Andrew Bathgate, Agriculture Western Australia

INTRODUCTION

Waterlogging has long been recognized as a major constraint to crop growth. Waterlogging in the South Western region of Western Australia (WA) is predominantly the result of perched water tables in duplex soils, caused by rainfall in excess to evapotranspiration limited percolation through the subsoil and lateral drainage. Surface drains have often been recommended to alleviate water logging however with little success due to poor lateral water movement. The concept of raised beds has been well established in irrigated agriculture (Tisdall and Hodgson, 1990). However, the application of raised beds to dryland agricultural area, notably waterlogged duplex soils has not been investigated. Raised beds provide short drainage pathways and reasonable hydraulic gradients. They improve lateral water movement, resulting in less water logging in the root environment, and increase in evapotranspiration and subsequent biomass accumulation.

In irrigated agriculture, raised beds are not an option but an essential feature of the irrigation layout of the farm, and exist by virtue of the necessity to introduce irrigation water along well defined pathways in conjunction with row cropping. Not so with the application of raised beds to dryland agriculture, particularly in the context of broadacre agriculture where the use of raised beds becomes an option available to farmers to deal with waterlogging. The economic impact of waterlogging is often assessed on the basis of intrafarm comparisons, between areas which are visually waterlogged and which are not. Given the fact that raised beds eliminate waterlogging (Bakker and Hamilton, 1998) an economic assessment of raised beds is required to be able to decide when raised beds are a viable and economic option to combat waterlogging. This paper describes the economic assessment of raised beds in WA based on the installation of raised beds in various locations in the SW corner of WA in two consecutive years.

ESTABLISHMENT COSTS

Surveys

The costs of establishment of raised beds is governed by the costs of the survey which, depending on the topography of the landscape, is generally done on a 50m x 50m grid basis and the contours plotted on a 20cm interval. It is not expected that for the application of raised beds in broadacre agriculture major earth moving or landlevelling will be carried out, but that the raised beds will be fitted in the landscape and that perhaps some losses will have to be accepted due to limited drainage opportunities. In some instances the topography of the landscape is such that surveys are not necessary at all.

Design

In a more complex landscape the orientation of the raised beds requires some elements of design in addition to the positioning and dimensioning of surface drains.

Soil Tests

The installation of raised beds on duplex soils has the potential to bring highly dispersible sub-soil to the surface. In that instance, soil tests should be carried out to determine the required amount of gypsum to be applied to the raised beds.

Installation costs

Catch drains and waterways are required to channel the runoff from the beds in a sustainable manner using conventional soil conservation considerations. The installation of the raised beds would, depending on the soil type, most likely require deep ripping and chissel ploughing to ensure sufficient loose top soil to form the beds and to incorporate any gypsum.

A summary of the establishment costs is presented in Table 1

Table 1. Establishment cost of raised beds.

Total costs, design, surveys and soil tests	$50	/ha
Installation		
Catch drains & waterways	$50	/ha
Raised beds	$60	/ha
Total installation costs	**$110**	**/ha**
Gypsum application @ 4t/ha	$100	/ha
Total establishment costs	**$260**	**/ha**
Total amortised establishment costs	**$20**	**/ha**

Maintenance Costs

Some degree of maintenance on a regular basis is required of the raised beds. The frequency depends on longevity of the raised beds which is related to whether the beds have been trampled on, the mobility of the gypsum and the longevity of the drains and waterways. A summary of the cost is presented in Table 2.

Table 2. Summary of the maintenance costs.

	Cost/ha	Frequency in years	Amortised Cost/ha
Gypsum application	$100	4 years	$28.86
Furrowing	$30	5 years	$7.12
Drains and waterways	$20	5 years	$4.75
Total annual maintenance cost per ha			**$40.73**

MACHINERY COSTS.

Raised beds are commonly established using customized tillage equipment. This is usually a tool bar equipped with furrowers (ripper shanks with furrower blades) and levelling blades. This equipment is readily available so straight purchasing and ownership costs can be calculated. To utilize the raised beds to their potential (i.e. zero traffic on the beds, all traffic confined to the furrows) some modifications of the seeder, spray unit and the harvester is required and some estimates of these costs are presented in Table 3. In all our costings an interest rate of 6% annually is assumed.

Table 3. Machinery and modification costs

Machinery and modifaciations	Current Value	Salvage value	Replacement Period	Amortised costs: Purchase Costs	Amortised costs: Ownership Costs
Purchase of new machinery					
Furrow bed former	$30,000	$2,500	20 years	$2,548	$1,800
Modification of existing machinery					
Seeder	$5,000	$0	15 years	$515	$300
Spray unit	$2,000	$0	10 years	$272	$120
Harvester	$10,000	$0	10 years	$1,359	$600
Total	**$47,000**			**$4,693**	**$2,820**
Total annual machinery costs					**$7,513**

CROPPING IMPLICATIONS OF RAISED BEDS

Waterlogging severely affects the yield and has implication for the choice of crops in the cropping program. The elimination of waterlogging will therefore increase the range of crops to be grown on previously waterlogged land. The crops in the our cropping program were not changed. In the cropping program we have assumed moderate increases in yield from the raised beds on all occasions, regardless whether it has been a dry or wet year (Bakker and Hamilton, 1998). A pasture phase has been included in our analyses but will not be presented here. Yields and farm-gate prices are highly variable from year to year and our figures are only indicative of what can be expected from the raised beds when an increase in yield is achieved. The expectancy of crop failure due to waterlogging before the introduction of the raised beds (i.e. 1 in 5 year heavy crop loss) can be introduced to suit ones own situation. In Table 4, the cropping program and assumed prices are presented.

Table 4. Cropping rotation, yield and prices before and after the installation of the raised beds.

Rotation before construction of raised beds							
Crops	**Yield /ha**	**Farm gate price**		**Returns /ha**	**Cropping Costs /ha**	**Net Return**	
Wheat	1.5 t	$180.0	/t	$270	$120	$150	/ha
Faba beans	0.5 t	$300.0	/t	$150	$140	$10	/ha
Wheat	0.8 t	$180.0	/t	$144	$120	$24	/ha
Canola	0.8 t	$300.0	/t	$225	$160	$65	/ha
Wheat	0.5 t	$180.0	/t	$90	$120	-$30	/ha
Average net return						**$44**	**/ha**
Rotation after construction of raised beds							
Crops	**Yield /ha**	**Farm gate price**		**Returns $/ha**	**Cropping Costs $/ha**	**Net Return**	
Wheat	2.0 t	$180.0	/t	$360	$120	$240	/ha
Faba beans	0.7 t	$300.0	/t	$210	$140	$70	/ha
Wheat	2.0 t	$180.0	/t	$360	$120	$240	/ha
Canola	1.5 t	$300.0	/t	$450	$160	$290	/ha
Wheat	3.5 t	$180.0	/t	$630	$120	$510	/ha
Average net return						**$270**	**/ha**

TOTAL BENEFITS

The total benefits of the raised beds are summarised in Table 5. The area worked after the raised beds are slightly less than before the raised beds due to the presence of drains. It is assumed that the furrows have been sown and that any yield reduction occurring in the furrows is included in the total yield of the raised beds. Increased land value and improved timeliness of operations are reflected in the increase in crop yield. Therefore, they are not to be included as separate benefits.

The value of conserved water is the cost of providing it from alternative sources.

The question of opportunistic irrigation is a difficult one and would require an investment analysis to determine the benefits of setting up the infrastructure to irrigate. However the lack of water is often not the main constraint to irrigating, it is the cost of storing and pumping water to where it is needed, and the relatively low benefits (compared to the cost).

Table 5. Benefits of the raised beds.

Area of crop before works	200	ha
Area of crop after works	195	ha
Rotation gross margin before works	$44	/ha
Rotation gross margin after works	$270	/ha
Value of conserved water	$0	
Opportunistic irrigation	$0	
Total revenue before works	$8,760	
Total revenue after works	$52,650	
Increase in revenue per ha raised beds	$257	

NET BENEFITS

The net benefits of the raised beds are summarized in Table 6. These benefits are obviously dependent on the area under raised beds. In Table 6, the area under raised beds is 195 ha compared to 200ha before raised beds (see Table 5).

Net benefits of raised beds		
Total costs and benefits		
Total amortised establishment costs	$20	/ha
Total annual maintenance cost	$41	/ha
Total annual machinery costs	$39	/ha
Total costs	**$100**	/ha
Total annual benefits	**$257**	/ha
Net benefits	**$158**	/ha

An assessment as to how costs and net benefit are related to the area under raised beds is presented in Figure 1. The base line data and assumptions used to derive that figure have been discussed in the above.

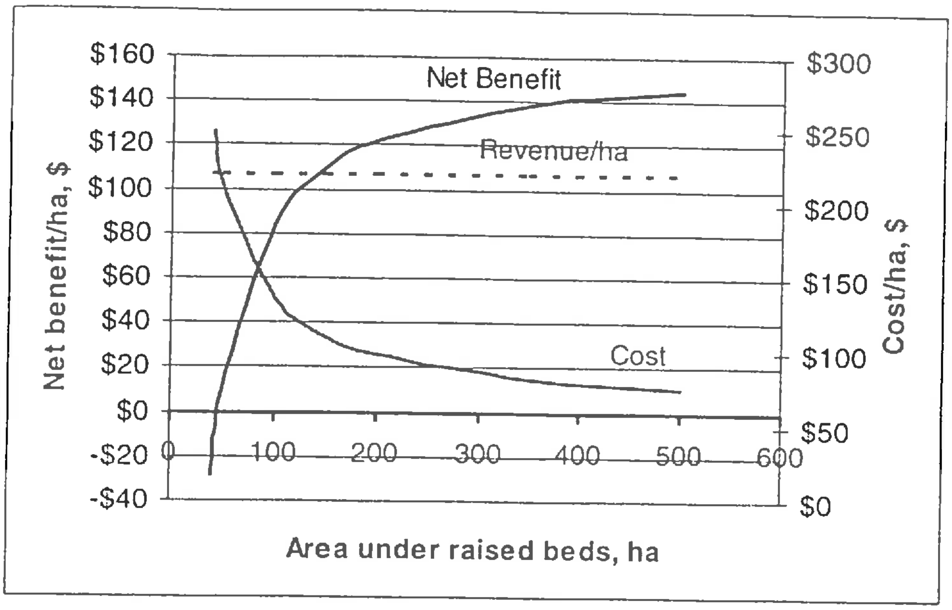

Figure 1. Net benefits and costs as a function of the area under raised beds for a full cropping program.

As one can see, the point of net return for areas under raised beds is about 50 ha. The maximum area to be worked by one implement and one machine during the window of opportunity has not been taken into account.

CONCLUSION

Based on the assumption used in our analysis it becomes quite clear that the purchase of the furrower/bedformer is by far the largest outlay associated with raised beds. However even for a relatively small area (50ha) under raised beds the investment is warranted. This area has to be enlarged when a pasture phase is introduced in the cropping program. Other factors which might influence the adoption of raised beds to alleviate waterlogging such as being locked into particular directions of cropping or problems in the pasture fase (i.e. rounding up sheep) are difficult to quantify. The extent of waterlogging is predominantly a function of rainfall and soil type and probabilities of degrees of waterlogging can therefore be predicted based on long term rainfall records. Probability simulations of waterlogging conditions, coupled to yield reductions due to waterlogging and the cost/benefit relationship can therefore become a tool to establish the economic viability of raised beds on waterlog prone land for individual farmers.

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PRODUCTION PERFORMANCE OF PERMANENT RAISED BEDS IN WIDELY DIFFERING SOIL & CLIMATIC REGIMES IN WA.

Derk Bakker and Greg Hamilton, Agriculture Western Australia

INTRODUCTION

Waterlogging has long been recognized as a major constraint to crop growth. Waterlogging in the South Western region of Western Australia (WA) is predominantly the result of perched water tables in duplex soils, caused by rainfall in excess to evapotranspiration limited percolation through the subsoil and lateral drainage. Surface drains have often been recommended to alleviate water logging however with little success due to poor lateral water movement. The concept of raised beds has been well established in irrigated agriculture (Tisdall and Hodgson, 1990). However, the application of raised beds to dryland agricultural area, notably waterlogged duplex soils has not been investigated. Raised beds provide short drainage pathways and reasonable hydraulic gradients. They improve lateral water movement, resulting in less water logging in the root environment, and increase in evapotranspiration and subsequent biomass accumulation. This paper describes the first-year crop production results of raised beds on waterlogged duplex soils in the South West of WA. The effect of raised beds on the hydrology of duplex soils has been described else where (Bakker and Hamilton, 1998).

MATERIALS AND METHODS

Four demonstration sites in Beverley (B), Woodanilling (W), MtBarker (MB) and Esperance (Esp) were installed in 1997, covering a range of soil types and climatic conditions across the South West corner of WA. The soil types at these sites are respectively, a shallow sandy clay loam over clay, a sandy loam over clay, a sand and gravel over clay and, again, a sand and gravel over clay. Two replicated treatments were installed at the sites: the conventional or district practice, being the control, and raised beds. The district practice consisted of a shallow cultivation prior to seeding while the raised bed treatment received a deep cultivation, the application of gypsum on those sites where dispersible subsoil was present (B and W) and the formation of the beds.

The raised beds were installed using a furrower/bedformer, an implement commonly used in irrigated agriculture. Curved blades mounted on ripper shanks, spaced at 1.8 m, formed furrows while horizontal blades mounted behind the shanks ensured the formation of a level bed. Three complete beds and two half beds are formed with each pass of the implement. The seeder was a conventional double disc seeder unit mounted on three-point linkage. All sites were sown to oats which has a vigorous root mass and should aid the establishment of a stable soil structure in the beds.

In addition to the demonstration sites, a research site has been established at Cranbrook where more detailed observations are carried out, such as runoff monitoring, soil moisture in the profile, degrees of waterlogging and climatic conditions. Prior to the establishment of the crop in 1998, hydraulic conductivity measurements were made on most sites using disc permeameters. In 1998 at CB the treatments, control and raised beds, were split into 'with' and 'without' stubble grazing.

On all sites crop growth and yield measurements were carried out. Growth measurements (i.e. dry matter accumulation) were obtained twice (September and October) during the season while the final yield was determined at harvest time using a plot harvester.

For the Cranbrook site only, waterlogging has been assessed manually using dip wells. The average depth to the water table has been taken from all observations.

For all the sites rainfall records during the growing season were obtained from automatic weather stations or manually recorded rainfall gauges on grower properties.

RESULTS

Dry matter content and the yield of the control and the raised beds are presented in Table 1 and Table 2, respectively.

Table 1. Dry matter content at two different times during the growing season. Standard deviation between brackets.

	Dry Matter (t/ha) Sept		Dry Matter Oct	
	Control	Raised Beds	Control	Raised Beds
Beverley	4.75 (0.25)	6.90 (1.26)b	6.17 (0.85)	8.21 (1.30)c
Woodanilling	4.30 (1.15)	5.86 (0.56)c	8.54 (0.74)	11.75 (1.08)b
Cranbrook	2.52 (0.76)	4.60 (0.77)a	6.99 (1.93)	10.54 (1.81)b
Mount Barker	4.72 (1.10)	4.55 (0.37)	7.92 (0.60)	8.29 (0.04)
Esperance	4.34 (1.01)	6.01 (0.36)	5.39 (1.91)	8.91 (0.10)

a = stat. different at P = 0.001, b = stat different at P = 0.05 and c = stat. different at P = 0.1. No letter indicates not statistically different at those levels.

Table 2. Yield. Standard deviation between brackets

	Yield (t/ha)	
	Control	Raised Beds
Beverley	1.14 (0.27)	1.44 (0.28)
Woodanilling	1.70 (0.38)	2.50 (0.20)b
Cranbrook	2.26 (0.54)	2.76 (0.42)b
Mount Barker	2.59 (0.48)	2.00 (0.40)
Esperance	1.78 (0.55)	2.58 (0.24)

a = stat. different at P = 0.001, b = stat different at P = 0.05 and c = stat. different at P = 0.1. No letter indicates not statistically different at those levels.

Good correlations were found between the average depth to the perched water table and the dry matter content (Fig. 1a) as well as the yield (Fig. 1b).

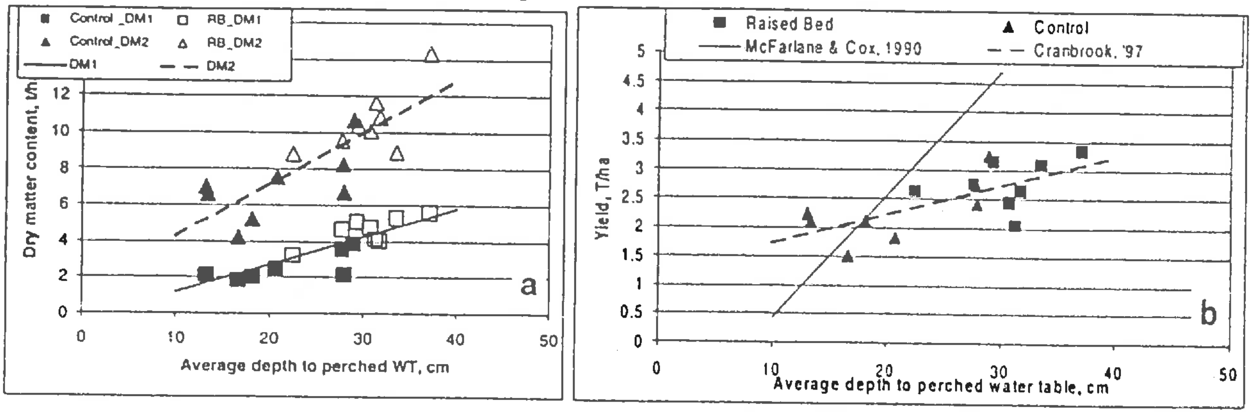

Figure 1. Relationship between average depth to perched water table and dry matter (a) and yield (b).

The rainfall summary as well as decile ranking which is the position of the monthly rainfall in a distribution of historical rainfall arranged in order of magnitude for the five sites is presented in Table 3. The decile ranking is a good indication how the actual rainfall compares to the long term average rainfall.

Table 3. Actual rainfall (mm) and decile ranking, between brackets, at the demonstration and the research sites over the growing season..

	May	June	July	August	September	October	November
Beverley	28 (2)	35 (1)	42 (2)	66 (7)	37 (5)	21 (4)	5 (3)
Woodanilling	71 (7)	76 (4)	39 (2)	65 (6)	28 (3)	14 (2)	12 (2)
Cranbrook	70 (7)	57 (4)	75 (6)	74 (7)	51 (5)	15 (1)	16 (4)
Mount Barker	40 (3)	59 (2)	71 (3)	76 (4)	76 (4)	23 (2)	20 (2)
Esperance	96 (7)	54 (3)	51 (2)	118 (8)	66 (6)	4 (1)	30 (4)

DISCUSSION AND CONCLUSION

The effect of waterlogging on crop dry matter production and yield is well documented following laboratory studies (see Barrett-Lennard, (1986) for references, or lysimeters studies (Cannell et al. 1980) but is not easily established on a field scale without going to the extent of creating artificially ponded areas as done by Barrett-Lennard et al.(1985) or selecting small quadrats (McFarlane and Cox, 1990). There is a good correlation between the average depth to the perched water table and the dry matter and the yield. The relationship derived by McFarlane and Cox (1990) using quadrats, has a much larger slope and provides an overestimation of the effect of waterlogging. The use of raised beds effectively eliminates waterlogging (Bakker and Hamilton, 1998), therefore the development of the waterlogging-dry matter/yield correlations using raised beds is a powerful tool to establish the cost of waterlogging to the industry in conjunction with waterlogging simulations.

From Table 3 it can be seen that all sites experienced less than average rainfall (Decile <5) at the time of bed mounding and seeding which was the middle of June, 1997. Cranbrook experienced average conditions in July while the other sites received less than average rainfall. Esperances received much more than average rainfall in August with the remainder of the sites apart from Mount Barker receiving more than average rainfall. All sites, except Woodanilling, received average rainfall in September and all sites experienced a drier than average drying-off season. Despite the sometimes dry conditions and therefore the lack of waterlogged conditions at the beginning of the growing season (documented for Cranbrook but not in the other sites), the raised beds produced more dry matter and yielded higher, except in Mount Barker. The formation of the raised beds is accompanied with a lot of soil disturbance, the formation of macro porosity, and the addition of soil ameliorants (i.e. gypsum). In that respect the hydrological advantance of the raised beds in alleviating waterlogged conditions is also associated with a tillage effect which explains the treatment differences even under drier conditions such as in Beverley and Woodanilling. Eventhough for the Cranbrook site, the similarities between slopes of response of the control and the raised beds to waterlogging, suggest that for the Cranbrook soil waterlogging is the main contributing factor to the variation in dry matter or yield.

There is anecdotal evidence that substantial soil disturbance associated with a dry finish to the season results in a reduction in yield. This might have to be considered in the assessment of the benefits of raised beds in soil moisture limiting conditions. The progression in treatment differences during the growing season in relation to rainfall (i.e. decile ranking) is presented in Table 4

Table 4. Changes in treatment differences, defined as: ((RB-Control)/RB*100%) for the five sites on three different occasions. The third decile ranking applies to November while most crops were harvested in December.

Location	Period	% difference	Decile ranking
Beverley	Sept	45.3	5
	Oct	33.1	4
	Yield	26.3	3(N)
Woodanilling	Sept	36.3	3
	Oct	37.6	2
	Yield	47.1	2(N)
Cranbrook	Sept	82.5	5
	Oct	50.8	1
	Yield	22.1	4(N)
Mount Barker	Sept	-3.6	4
	Oct	4.7	2
	Yield	-22.8	2(N)
Esperance	Sept	38.5	6
	Oct	65.3	1
	Yield	44.9	4(N)

In Beverley there seem to be a correlation between the constantly drier season and reduced differences, but this was not repeated in Woodanilling. The differences in Cranbrook were dramatically reduced following an average September and a very dry October, whereas the dry matter production in Esperance was boosted following the wetter than average September but the very dry October. The yield figures at Mount Barker did not follow the trend seen anywhere else. Even though the season in MountBarker has been drier than average, the dry finish seem to have had a larger effect on the raised beds than on the control.

From the changes in dry matter and yield differences between the control and the raised beds across all five sites there is no consistent pattern that suggest that raised beds are more affected by limited soil moisture availability later in the season than the control. However continuing research efforts and mor detailed observations will address this aspect of the raised beds in the 1998 growing season.

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CTF WORKSHOP Queensland 1998

Customised Controlled Traffic Farming systems, instead of standard recommendations. Or "TRAMLINES AIN'T TRAMLINES"

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Some suggestions for Controlled Traffic farming equipment have promoted a standard, modular wheel spacing for all situations. Such 'standard recipes' may be suitable for some farming systems, eg based on raised beds, but can be most inappropriate for other systems, eg broadacre agriculture on compactable sands in WA. This paper tries to encourage customisation of Controlled Traffic Farming systems, based on the physical or operational problem controlled traffic is primarily trying to reduce in a specific farming system and location. Customisation essentially applies principles, not standard formulae, and combines design features generated from the main factors which CTF is trying to control or influence.

If any technical innovation is to prove useful and succeed it must be adaptable to a range of agricultural situations. Crop varieties are bred to match variation in climate, soil and market needs, so too controlled traffic technology should be altered to match similar variation of needs. The arguments presented in this paper are only a 'first approximation' and a basis for discussion.

Design Factors in Controlled Traffic Farming

It is important to focus on the design factors being used in CTF to reduce the specific problems for each farming situation. A design factor is the expression of a solution to a problem the farming system is trying to minimise, or the means of allowing new technology to be employed in the system. Some of the design factors of a Controlled Traffic Farming System, and associated problems are listed below:-

1. Controlling overland flow to minimise water erosion and poor water entry.
2. Improving topsoil drainage to minimise surface waterlogging.
3. Improving furrow irrigation to maximise irrigation efficiency.
4. Improving traction and flotation to minimise excess fuel use.
5. Confining compaction to minimise recompaction and improve soil macrostructure.
6. Keeping all in-crop wheelings on bare tramlines to minimise crop damage.
7. Reducing overlap and misses to minimise cost of seed, fertiliser and pesticides..
8. Improving crop uniformity and quality by minimising variability of growth and yield.
9. Improving timeliness of operations to minimise sub-optimal agronomy.
10. Increasing opportunities for inter-row operations by improving access to the crop.

These design factors will have more importance in some farming systems and locations than others. Thus the customisation of the CTF system should be strongly influenced by the more important, major, design factors. At one extreme there are systems of irrigated vegetable crops in ridges or beds which demand all wheels in the furrow, to maintain furrows and maximise irrigation efficiency as well as quality in the uniformity of the product; encouraging major design factors 3 and 8, above. At the opposite extreme there are alley farming systems which only require traffic 'control' in the more precise layout of the seeding runs and the reduction of overlap to compensate for the loss of cropped area where the trees are planted; encouraging major design factor 7, above. In these situations wheel location is less important and the guidance methods of CTF are more useful. Table 1 attempts to relate the design factors mentioned above to specific examples of farming systems and identify which are the major design factors for each system. A broad observation from Table 1 is the greater number of design factors easily associated with irrigated summer crops and vegetable farming systems. Thus, it may not be suprising that the longest period of development of controlled traffic systems in Australia has been in irrigated cotton production and irrigated vegetable production; greater needs induced earlier innovation. Controlled traffic has also been most readily associated with irrigated summer crops and vegetable farming systems, even sometimes giving the impression that controlled traffic is confined to such designs. Alley farming is associated with few design factors and has not often been referred to as controlled traffic farming. However, once considered in an analysis of 'customised design' it easily classifies as controlled traffic, because it share the design factor 'overlap' with other CTF systems.

Table 1.
Design Factors (✓) and major Design Factors (✓✓) influencing the choice of controlled traffic for some farming systems.

Design Factor > Farming System	overland flow 1	topsoil drainage 2	irrigation efficiency 3	traction & flotation 4	compaction 5	crop damage 6	overlap 7	quality 8	timing 9	inter-row operations 10
Irrigated summer crops & vegetables	✓	✓	✓✓	✓	✓✓	✓✓	✓	✓ ✓	✓✓	✓
Rainfed crops in high rainfall intensity climates	✓✓	✓✓		✓✓	✓		✓		✓✓	✓
Bed farming in waterlogging soils	✓✓	✓✓		✓✓	✓		✓		✓✓	
Broadacre rotations with broadleaf crops				✓✓	✓	✓✓	✓	✓	✓	
Broadacre rainfed farming on compactable sands.				✓	✓✓	✓	✓			
Alley farming							✓✓			

We can then consider, from Table 1, a wide range of farming systems where CTF is appropriate, based mainly on the identification of design factors which can minimise primary or secondary problems for current farming methods. The farming systems most likely to benefit from CTF seem to be :-

1. Irrigated summer row crops and vegetables, on ridges or beds.
2. Rainfed row crops in high rainfall intensity climates.
3. Bed farming for reduced waterlogging.
4. Broadacre rainfed rotations, especially including broadleaf crops.
5. Broadacre rainfed farming on compactable sands, especially zero-till.
6. Alley farming.
7. Organic farming using inter-row cultivation or flame weeding for weed control.

Some farming situations or systems where CTF seems less appropriate are:-

1. Small irregular shaped paddocks, with many tree and rock islands. Because the shapes are too difficult to accommodate in a CTF layout.
2. Extensive opportunity cropping in low rainfall areas. Because speed of sowing is more important than other physical factors when suitable rains do occur.
3. Low ground pressure farming systems. Because compaction and crop damage have already been minimized by other vehicle modifications.

Design Features derived from Design factors

When we consider this wide range of farming systems more or less appropriate for controlled traffic farming, there are some common design features which can be related to the design factors in Table 1. For example, the use of bare, unsown tramlines. This may be an essential design feature to enable design factors such as irrigation efficiency and uniformity of vegetable products in irrigated agriculture. Sown tramlines are also a useful design feature in a drainage system of bed farming to slow the rate of flow down the furrows and reduce erosion risk. In broadacre cropping, to reduce compaction and improve access into the crop for spraying and spreading, some tramlines can be left unsown and some sown; depending on the relative widths of equipment and spraying strategy. The location of equipment and vehicle wheels, the use of marker arms and guidance systems and the use of single or dual tyres or tracks, are other design features associated with certain design factors which should influence a customised controlled traffic farming system. Some of these design features are related to various design factors in Table 2.

Table 2. Design features related to design factors for controlled traffic farming systems (✓).

Design Factor > Design Feature V	over-land flow	topsoil drainage	irrigation efficiency	traction & floatation	comp-action	crop damage	over-lap	quality	timing
all bare tramlines	✓		✓					✓	
all sown tramlines		✓							
some bare tramlines						✓			✓
all wheels in tracks	✓	✓	✓	✓				✓	✓
heavy vehicle wheels in tracks					✓				
sprayer and spreader wheels 'n tracks						✓			✓
guidance system for each pass of seeder							✓		
possible use of duals at seeding				✓	✓				
seeding up and down slope	✓	✓	✓		✓				
seeding across slope	✓				✓				
seeding around paddock					✓				

Thus, if compaction and overland flow, as well as crop quality need to be controlled, then beds or furrows up and down or across slope are appropriate with all wheels in furrows. However, if compaction and overlap need to be controlled, then only heavy wheels need to be on tramlines and a guidance system, such as marker arms, is needed. Clearly, there are many possible combinations of design features of controlled traffic systems and some current grain cropping systems are hybrids of random traffic, low pressure traffic and controlled traffic tramlines. E.g. seeding with large 4WD tractors using .riple tyres and spraying on tramlines for with tractors using single tyres or tracks.

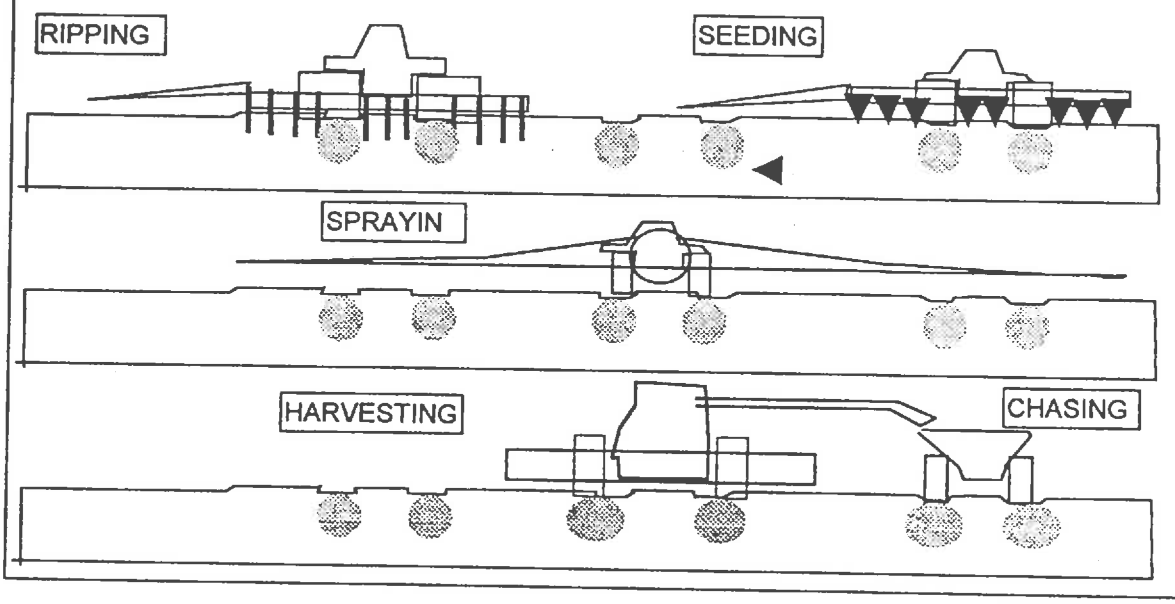
Some features and factors which are identified as more important to a customised system can be prioritised in the development of a controlled traffic farming system using this analysis. An example would be deciding to base the tramline spacing around the wheeltrack of the header, because it is the least able to be modified and creates the most compaction in wet harvests. Then matching the widths of tractors and self propelled sprayers and seeders to the width of the header wheel track and swath in later financial investments.

Example of a Customised Design

This is being used in a GRDC funded project to demonstrate and evaluate controlled traffic for broadacre grain production in WA. It is in a 170 ha paddock at Wyalong farm near Mullewa.
The customisation of this prototype Controlled Traffic Farming System (illustrated in Figure 1.) has a major design factor of confining compaction. Compaction of these sands can restrict cereal yields by 20-40%, depending on the compactability of the sand, nature of the compaction and the type of growing season. This system tries to confine the heaviest wheelings, from the seeding tractor, sprayer, spreader, header and chaser bin to permanent tramlines.

Figure 1. An illustration of a prototye customised controlled traffic farming system for compactable sands

Tramlines are prepared by leaving out ripping tines behind tractor wheels. The ripper matches the seeder width (9m). A marker arm is used on the ripper and marks out tree alleys on 144m spacing. The sprayer is 27m wide and the header 9m wide. The same tractor pulls the seeder, sprayer and chaser bin (150-180HP Fastrac). Seeding is round and round, ripping is not done every season, but usually on a 2-4 year cycle in a wheat/lupin rotation.



Therefore major design features are all heavy wheels in permanent tramlines, seeding around the paddock (because there is no need to control overland flow or drainage), possible use of duals at seeding (because there is little risk of knocking down raised beds or ridges) and only the tramlines for the spray traffic are unsown (to minimise yield loss from unsown rows). The tramlines are established at ripping by removing each tine behind the inner tyre of the 450HP 4WD tractor used for ripping. The ripper uses a marker arm to increase the accuracy of layout in the paddock and matches the airseeder width and the sprayer is three times the airseeder width. Thus the tramlines can easily be used by the seeder and the 2nd, 5th etc tramlines are unsown and used by the sprayer. At harvest the header front wheels are about 300mm wider than the tramlines. The chaser bin is pulled by the same tractor used for seeding and spraying and can sit on the adjacent tramline for unloading the header on the move. The unsown tramlines are also visible after harvest for spraying summer weeds. The next stage is to have a spreader bar to top-dress fertiliser from the tramlines on a 27m width.

Conclusions

1. The need for cusomised designs and lateral thinking.

- A customised design based on an analysis of design factors and features can be a flexible approach to tailor a CTF system to the needs of a specific enterprise. An analysis such as that presented here will even showing the steps which could be used to prioritise such a development.
- There are opportunities for lateral thoughts and 'original' ideas when fitting the system together. For example the balance between urgency to harvest a barley crop, at risk of staining in anticipated wet weather, and the later opportunity to 'renovate' harvest compaction by selective deep tillage.
- Adaptation of CTF systems is also important to accommodate complementary innovations, such as inter-row weed control, inter-row fertiliser placement, relay planting between rows of existing crop.
- Some WA farmers are even trying 'one wheel tramlines' i.e. one wheel track is left unsown, not for trick driving on two wheels, but to provide some easy guidance in the absence of automated tramline controllers for airseeders.

2. The need for automatic tramline controllers for airseeders

- Much more versatility of CTF design for airseeders could be achieved if there were commercial products which automatically shut off or opened seeding rows on airseeders which go round and round the paddock.

Using minimum tillage and controlled traffic to reduce the risk of cropping in the Burnett.

Richard Mason, Jim Page and Martin Cloete (DPI, Kingaroy and Nambour).

Introduction

The purpose of this paper is to estimate the value of applying minimum tillage and controlled traffic technology in a peanut/maize rotation in the South Burnett. These changes are evaluated over a five-year period. The addition of a wheat crop between the peanut and maize crops combined with a reduction in tillage over the whole property improves the probability of a higher equity at the end of five years. The curr`ent peanut - maize rotation where all weed control and seedbed preparation is by tillage produces a fifty percent chance that the owner will be worse off in five years time than he is now.

A small number of peanut growers have trialed and are adopting the technology described here. Their experiences over the last five years combined with the development and research work currently in progress form the basis in the assumptions of this paper.

The benefits of minimum tillage and controlled traffic.

Water is the most limiting resource in the rain grown environment of the Burnett. The aim of minimum or zero tillage and controlled traffic is to improve the efficiency of the resources that are most limiting-rainfall and sunshine (Yule, 1995). Reducing the tillage operations to a single planting operation minimises the amount of rainfall that is required to prepare a seedbed. Maximising stubble cover by reducing tillage and including a winter crop in the rotation minimises runoff in high intensity rain to the extent that it only occurs when there is a full profile of moisture.

Controlled traffic involves containing all tractor and harvesting wheels to permanent laneways. This reduces the energy requirements of most operations, and reduces soil compaction in the cropped area thereby aiding root development and water transport through the subsoil (Tullberg, 1995).

Replacing mechanical weed control with herbicides improves the timeliness of operations and allows the maize and wheat crops to be planted on time without the loss of moisture. Spraying rather than cultivating weeds reduces labour input. Over the five years of this analysis the total labour input decreased despite the increase in total crop area. The real cost of commonly used herbicides has reduced over the last ten years but the cost of tractors and tillage equipment has risen. In time, some of the tillage equipment and one tractor could be sold from this property as the benefits of reduced tillage and controlled traffic are achieved.

In a reduced tillage system peanuts and maize continue to be grown in 90cm rows and wheat in 30cm rows. Peanuts have been successfully grown under zero tillage but there is some risk of high harvest losses if the soil is dry when the peanuts are pulled. Growing peanuts in raised beds with controlled traffic where there is a permanent wheel track every 1.8m has minimised many of the problems associated with harvesting zero tillage peanuts. A possible method for growing peanuts in a controlled traffic system was described in the last peanut conference proceedings (Mason and Tullberg, 1994).

Assumptions and Analysis

Many evaluations of minimum tillage and controlled traffic have tended to focus on the short-term benefits. This evaluation recognises the long term nature of this technology and looks at the changes over a five year period. The risks inherent in farming and technical change are accounted for by using a risk analysis technique based on @RISK software. This software calculates the probability of the full range of financial outcomes associated with uncertain and unpredictable technical outcomes, climatic and market conditions.

The current and proposed farm systems are shown in table 1. Year 1 (the current system) is based on an actual property in the Burnett and assumptions have been made as the system changes over the five years. This information is used to generate enterprise contribution (the contribution of an enterprise to the un-allocated fixed costs of a farm) margins for each year.

Two scenarios are considered:

1. current (continuation of situation outlined for year 1 in the first column) and
2. implementation of minimum till and controlled traffic technology over a three year period, the inclusion of a winter cereal crop in the peanut/ maize rotation with the changes measured for a 5 year period (columns 1 - 5).

The red soils of the Burnett store very little water over a fallow (Bell 1997). It is this characteristic that allows a winter crop to be grown in most years without jeopardising a following maize crop. It is assumed that the "worst" and the "best" peanut yields will not change over the five years but the most likely will improve from 1.3t/ha to 1.5t/ha as the soil and water use efficiency improves. The worst maize yield will decrease over the five years from 1.8t/ha to 1.5t/ha because of the proceeding wheat crop but this is offset by an increase in the most likely yield from 3 to 3.5t/ha. Prices received for the crops have not been altered between the systems.

Variable costs have remained relatively constant for both systems. Savings in fuel, oil, repairs and maintenance on machinery have reduced in minimum tillage system but this is replaced by herbicide costs and higher fertiliser requirements.

Table 1: The cropping systems both current and proposed

			Year 1 (current)	Year 2	Year 3	Year 4	Year 5
Area farmed (ha)			350	350	350	350	350
Area of crop (ha)	Peanuts		154	196	154	196	154
	Maize		196	196	196	196	196
	Wheat			100	150	154	196
Labour (hr/ha)	Peanuts		4.6	4.0	4.0	3.5	3.5
	Maize		2.56	1.9	1.5	1.3	1.3
	Wheat			0.88	0.88	0.88	0.88
Total (hours)			1210	1165	1042	1022	966
Yields (t/ha)	**Peanuts**	Worst	0	0	0	0	0
		Most -Likely	1.3	1.3	1.3	1.5	1.5
		Best	4.4	4.4	4.4	4.4	4.4
	Maize	Worst	1.8	1..5	1..5	1..5	1.5
		Most -Likely	3	3.3	3.4	3.5	3.5
		Best	4.2	4.2	4.2	4.2	4.2
	Wheat	Worst		0.2	0.5	0.5	0.5
		Most -Likely		1.2	1.8	1.8	1.8
		Best		3.2	3.2	3.2	3.2
Price ($/ha)	**Peanuts**	Worst	300	300	300	300	300
		Most -Likely	650	650	650	650	650
		Best	850	850	850	850	850
	Maize	Worst	120	120	120	120	120
		Most -Likely	140	140	140	140	140
		Best	240	240	240	240	240
	Wheat	Worst		90	90	90	90
		Most -Likely		130	130	130	130
		Best		200	200	200	200
Variable Costs ($/ha)	**Peanuts**		425	425	425	405	405
	Maize		206	206	206	200	200
	Wheat			97	97	97	97
Fixed Cash Costs ($/yr)		**(000's)**	30.5	30.5	30.5	30.5	30.5
Fixed Machinery Cost ($/ha) (not included above)	Peanuts		242	242	229	219	214
	Maize		90	72	56	35	35
	Wheat			24	24	24	24

The enterprise contributions and an overhead cost budget (common to both scenarios) were linked to an accounting model of profit and loss and balance sheet. The financial model was used to calculate change in equity at the end of five years for the two systems described. The opening balance sheet position included an asset and debt structure typically associated with a peanut farm cultivating the areas denoted above.

When a risk analysis is conducted ranges of possible yield, price and cost outcomes are specified. The probability of achieving various increases in equity (equity in year five from the balance sheet) for the full range of possible yield, price and cost combinations over the five year period is then calculated by the risk analysis software. In this instance, a modified triangular distribution was used to specify expected yield and prices. A modified triangular distribution is defined by estimates of the best, most likely and worst expected outcomes with a further specification of the likelihood of the best and worst outcomes.

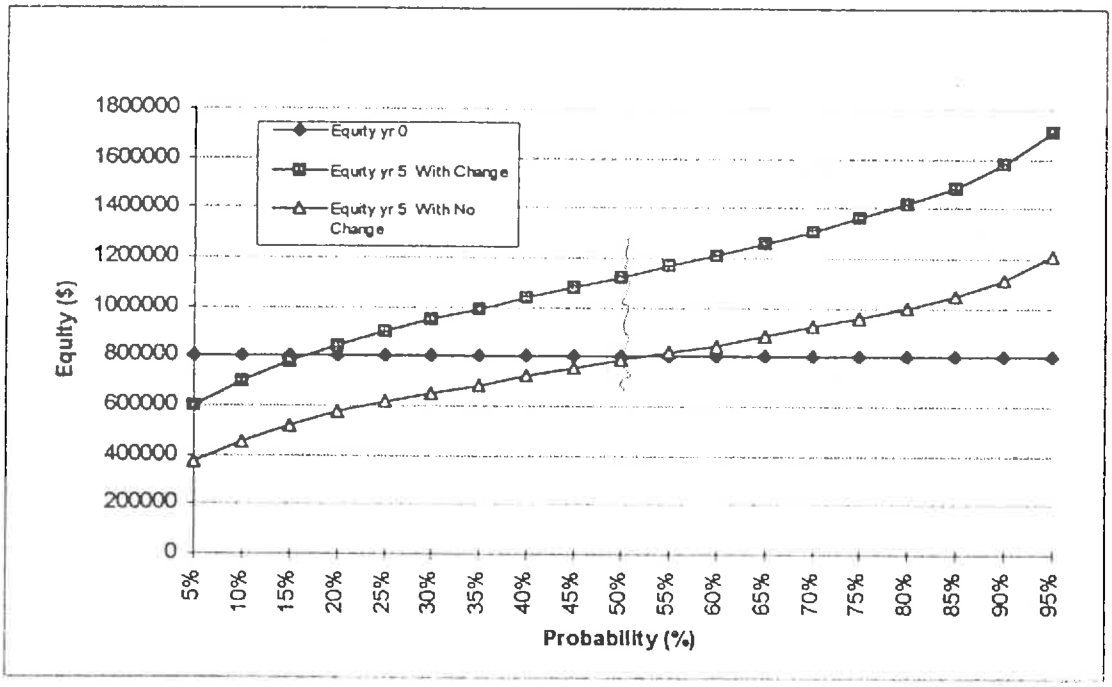
Does it pay to change?

The comparison of the current and the "new" with minimum-till and controlled traffic is shown in Graph 1. In this graph the vertical axis shows the level of equity in the business at the end of the five year period and the horizontal axis shows the probability of the different levels of equity that may eventuate depending on seasonal and market conditions and agronomic outcomes.

The change in equity due to the technology is given by the difference between the with and without lines on the graph. At each probability level a higher level of wealth ($200-250 000) is generated over the five year period compared to the current system.

This graph suggests that a peanut farmer who continues with the current method of growing peanuts has a 50% probability of negative business growth over a five year period and that he could halve his equity from around $800 000 to $400 000.

If the producer adopts a minimum till and controlled traffic the result is shown to have a high probability of increasing wealth with only a 15% chance of wealth reduction and possibility that owners equity could be doubled in five years.



Graph 1: Change in equity at end of year 5.

The assumptions this is based on are conservative. There is still the capacity for some tillage prior to the peanut crop and most of the machinery remains on the property. It was assumed that yields remained constant in the current system. Experience and research has shown that this is unlikely and yields will probably fall in the long term in the conventional system (Bridge and Bell, 1994).

Future analysis of minimum tillage and controlled traffic will be enhanced by accessing the yield probabilities generated over 85 years of rainfall data by the APSIN models for wheat, maize and peanuts. More reliable frequency distributions rather than estimates of the worst, most likely, and best yields for each of these crops will improve the accuracy of this evaluation.

Conclusion

This analysis shows the high value and low risk of including a winter cereal in a peanut - maize rotation based on minimum till and controlled traffic. The technology has a high potential pay-off with a significant reduction in the possibility that the farm will loose money as a result of the change.

This analysis goes some way to explaining why some producers in the Burnett have struggled and sold up over the last ten years and why even more will struggle in the future. If at the end of five years there is only a fifty percent chance of having a higher equity than at the start, a run of dry years will almost guarantee a lower equity. If the property has low equity to start with there is a short time frame between being viable and non-viable.

Herbicides replace mechanical weed control when appropriate and a minimal amount of capital is locked up in machinery and tractors. They use contractors and form syndicates formed to reduce the cost of machinery sitting in sheds and to achieve economies of scale. They obtain advice from a specialist that helps them with their marketing and production decisions. They see changes to the way crops are grown and sold as a challenge rather than a threat.

The system of growing peanuts using minimum tillage and controlled traffic involves change, but it can be profitable. This technology is not without its problems but the combination of innovation, development and time will overcome what today seems to be impossible. What is needed now is wide scale adoption of this technology to develop it and secure the future of the cropping industry in the Burnett.

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Challenges to Developing High Rainfall Cropping Systems

1. The Potential

The "cool climate high rainfall" zone of Southern Victoria has an extremely large potential for sustainable and profitable crop production. In most areas this potential is far from being realised. It is estimated there is conservatively 500,000 hectares of traditional grazing land that could convert to cropping or a mixed farming operation in southern Victoria alone. That is, if we can do something about our major limiting factor, namely winter waterlogging. If this change in land use was to take place, the production of high yielding crops could mean an addition of 400 to 600 million dollars to the economy on an annual basis.

2. Background

Historically, the area has relied heavily upon wool production as its major source of primary production income. It can also be argued that wool production has served the area well with very good returns being possible prior to the dramatic downturn in prices in the last decade. Despite the current low price for wool, most farmers still have wool production as their major enterprise.

There has been a significant amount of work undertaken in recent years to benchmark the performance of industries in the South-West Region of Victoria. Possibly the most important work has been undertaken by the Department of Natural Resources and Environment with the South West Monitor Farm Project. This project clearly demonstrates the high reliance on wool production in the area. According to the1998 study, the typical farm in for 1996/97 was 898 hectares in size, ran 5,596 sheep and 262 beef cattle and cropped 49 hectares. This represented an average enterprise mix consisting of 62 % wool sheep, 15 % prime lambs, 19 % beef cattle and 3 % cropping.

Why is it then that crop production has been a very low priority for most farmers? Quite simply, it has been due to the very poor returns from cropping in most years. It has been proven time and time again, that cropping for many farmers in the high rainfall cool climate zone of South-West Victoria has resulted in either failed crops or extremely poor yields. The poor performance has been due to a combination of factors including waterlogged soils, too many weeds, inadequate nutrition and poor management. In many cases, crops have been grown to supplement the livestock enterprises and have been used as a means to "clean up a paddock" to prepare for the sowing of a new pasture. Crops have often been viewed as an opportunity enterprise when conditions were seemingly right. When crops failed because of climatic conditions beyond the control of the grower, such as too much winter rainfall, then this has generally been accepted as something that could not be avoided. Farmers in the main have become locked into the cropping paradigm.

3. The Challenge

Southern Farming Systems began in 1995 to objectively look at the cropping and livestock enterprises in the high rainfall zone and realised that there needed to be a change made to the traditional farming system, to enable farmers to capture the opportunities that the area presented. One of the major driving forces was that of profitability, as it was identified that unless something was done to dramatically change the economic situation of farmers in the region, that many of them could not survive the projected long term wool downturn. The farming community was also very aware that any new system needed to be sustainable in terms of responsible land use.

A detailed analysis and consultation process undertaken to identify the strengths, weaknesses, opportunities and threats for the region. It was identified quite early in the investigation, that one of the region's strengths was the excellent rainfall, which in most years was well distributed and quite reliable for winter cropping. In fact, the growing conditions for crops were recognised as being superior to those experienced in the Mallee and in many areas of the Wimmera. It was also recognised that whilst the rainfall was a significant strength to the region, it also presented significant weaknesses with regard to winter waterlogging of the region's predominantly heavy basalt soils. This was mainly a result of the significant water-holding capacity of the soils and the low ambient temperatures resulting in low crop evapo-transpiration.

One of the real strengths of the "high rainfall cool climate" zone of Southern Victoria is its potential for crop production, particularly that of oilseeds. The long and cool growing season means that Canola is particularly well suited, with oil quantity and quality generally being very high because of the extended cool finish to the season. Linseed and Linola are also well adapted to the region and offer greater rotation flexibility. The opportunity exists to establish South West Victoria as the premier oilseed producing region of the State.

The area is also very well suited to the production of high quality malting Barley. The cool finish and extended growing season is conducive to large grain size and good malting characteristics. A large plant situated in Geelong has the capacity to service significant tonnages out of the region.

Another clearly identified strength, is the ability to grow the new winter, feed wheat varieties becoming available. The long growing season suits the genotypes well and perhaps gives the opportunity to undertake a grazing if sown early enough. The vernalisation requirement of these cultivars would also mean that the risk of frost damage at flowering, one of the real weaknesses, could be significantly reduced. The opportunity is there to significantly increase the feed grain production out of South West Victoria to service the needs of the expanding feed grain dependent intensive livestock market. Recent studies have shown that the demand for feed grain is approximately 1.1 million tonnes annually. This equates to approximately 275,000 hectares of feed grain production annually, assuming a yield of 4 Tonnes per hectare.

Another major strength for the area is the ability to grow a range of plant species and the opportunities to establish flexible rotation systems. There is the ability to grow crops and pastures for nearly 12 months of the year in many areas. This significantly reduces the likely threats associated with market collapse of individual enterprises.

The major weakness or limiting factor identified is winter waterlogging of the region's soils. The ceiling for plant yield is continually being set at a low level because of the significant waterlogging of the soils over winter. The ability of plants to extract nutrients is reduced because of this waterlogging. The weed problem, particularly that of toad rush, could also be attributed largely to the wet soil problem over winter. This weed problem is also made worse because of the need to cultivate these waterlogged soils to get them into a decent tilth prior to sowing.

Another significant problem identified is the declining soil structure in cropped soils and the ability to only grow profitable crops after a prolonged pasture phase in the dispersive heavier soil types. This declining soil structure is amplifying the negative affects of winter waterlogging and makes cropping extremely difficult. It is also significantly restricting the paddock options available to growers.

As a result of the analysis the major opportunity to come to light was to change the way that we managed our soils so that we could capitalize on the climatic strengths that the region possessed. If we could reduce our winter waterlogging problem, then significant gains could be made in plant yields. Given the opportunities emerging in the oilseed and feed grain areas, attention was turned to trying to significantly increase crop yields.

4. The Vision

Southern Farming Systems has set the target for wheat yields to increase from 2.1 Tonnes per hectare to 5.5 Tonnes per hectare as a regional average by the year 2005. It is also envisaged that 7.5 Tonnes per hectare for wheat should be a reasonable target yield for the top 10% of growers.

To achieve this significant lift in productivity may seem beyond the realms of possibility, particularly given the current very low average yield of approximately 2.1 Tonnes per hectare for wheat. The reason for thinking it is possible, is in the exceedingly dry 1997, when for the most part waterlogging was not an issue, winter wheat was yielding in excess of 7 Tonnes/Ha. Perhaps 1997 sets the base for what is possible, with yields expected to improve on this.

5. The System

Southern Farming Systems is embarking on a new system of growing crops, on raised beds using controlled traffic technology. Actually the system has been around for years, particularly in the irrigation areas in NSW and QLD and also in the vegetable growing industry. What we are really doing is applying irrigation technology in reverse. Instead of using raised beds to apply water down the furrows, we are using them to manage the excess water during the winter. The adoption of controlled traffic technology, a major feature of raised bed farming, is an integral system component in order to improve soil structure in the long term.

Why has it taken so long to wake up to trying this new approach? Well once again we have been blinded to this opportunity for many years, because we have grown to accept that our crops get water-logged over winter and that there is nothing we can do about it. We have had to unlock our minds to the new opportunity. We have in fact, had to look at converting a weakness into a real opportunity.

The system of raised bed farming simply means that furrows are formed approximately 2 metres apart and crops are grown between the furrows or on the "beds". The beds are raised approximately 20 centimetres to get the crop out of the waterlogged soil. All traffic such as planting and spraying is confined to the furrows to avoid compaction. Harvesting is the only operation to take place on the beds, although over time this too will change.

Excess water over the winter and spring months is stored on farm to be possibly re-used on high return crops over the summer.

6. The Results

The results so far have been very encouraging with significant increases in crop yield, across a range of soil types and crop types. These results have been achieved largely in broadacre farmer demonstrations and not in replicated trials. Detailed trial work using fully replicated trials will begin this year.

A detailed demonstration study into different drainage techniques has been conducted at Gnarwarre over the last two years. Table 1 gives the results from the 1996/97 season where Canola was grown on different drainage treatments

Table 1

	20 metre wide raised beds	**Underground Drainage**	**Control – spoon drained**	**1.5 metre narrow raised beds**
Yield T/Ha	3.30	3.33	2.20	3.55
Oil content	42.4%	44.3%	N/A	41.7%
Gross Margin	**$1,068**	**$1,118**	**$580**	**$1,156**

Variable Costs of $300/Ha and grain price of $400 per tonne

It is important to highlight that if spoon drainage was not used in the control area, then no crop could have been grown due to flooding of the site.

The above demonstration area was then sown to Franklin Barley in 1997. Table 2 gives the results of the 1997/98 demonstration trial.

Table 2

	20 metre wide raised beds	Underground drainage	Control – spoon drained	1.5 metre narrow raised beds
Yield (T/Ha)	6.55	6.90	5.70	6.30
Protein	11.4%	10.7%	10.8%	11.3%
Screenings	30.5%	17.2%	16.3%	12.9%
Moisture	12.7%	13.0%	12.8%	12.7%
Skinning	8%	18%	8%	14%
Classification	Feed	Feed	Malt 5	Malt 2
Gross Margin	**$703**	**$755**	**$661**	**$917**

Variable costs of $280/Ha. Feed Price $150/tonne, Malt 5 price $165/tonne and Malt 2 price $190/tonne

When we combine the gross margins over the two years, then we have the following situation as outlined in Table 3

Table 3

	20 metre wide raised beds	Underground drainage	Control – spoon drained	1.5 metre narrow raised beds
Canola Gross Margin 96/97	$1,068	$1,118	$580	$1,156
Barley Gross Margin 97/98	$703	$755	$661	$917
Total	**$1,771**	**$1,873**	**$1,241**	**$2,073**
Difference to Control	**$530**	**$632**	**$0**	**$832**

Another finding is that there also appears to be a significant improvement in soil structure in a very short period of time. Recent tests indicate that in just two years, soil structure in the raised bed treatment compared to the control at the Gnarwarre site has improved dramatically. Table 4 clearly shows this.

Table 4

Test	20 metre wide raised beds	Underground drainage	Control – spoon drained	1.5 metre narrow raised beds
PH (Water)	5.7	5.7	5.8	5.4
Aluminium	10	11	<10	<10
Electrical Conductivity (Water)	0.18	0.16	0.17	0.34
Total Soluble Salts	.06	.05	.05	.10
Olsen Phosphorus	10	11	11	12
Potassium	260	290	310	220
Sulphur	40	29	51	160
Dry aggregate slaking	Partial	Partial	Partial	Water Stable
Dry aggregate dispersion (2 hrs)	Nil	Nil	Slight	Nil
Dry aggregate dispersion (20 hrs)	Nil	Nil	Moderate	Nil
Remoulded aggregate (2 hrs)	Strong	Strong	Strong	Nil
Remoulded aggregate (20 hrs)	Strong	Strong	Complete	Nil
Oxidisable Organic Carbon	1.6	1.9	2.1	1.9
Organic matter	3.1	3.6	4.0	3.6

6.1 Discussion

In terms of dispersion and slaking, the narrow raised beds have been given a completely clear bill of health. The soil is in excellent physical condition, whereas the other treatments show some signs of slaking and dispersion. This corresponds very well with the "eyeball analysis and feel tests" conducted. Right throughout the summer period, the narrow raised beds have maintained excellent structure whereas the other treatments have set quite hard.

Further studies by Ballarat University, has indicated significantly greater porosity in the raised bed treatment compared to the control. This greater porosity is due to an increased depth of aggregates, from the self-mulching of the surface soil along with the absence of traffic.

The force required to push a probe into the raised bed soil was considerably lower than the control, with easy penetration down to 45 cm in the raised bed treatment compared to only 6 cm in the control. Given the better soil structure in the raised bed treatment, there was significantly more summer rainfall stored in the soil by comparison to the flat land control. In the latter case, the summer rainfall is thought to have disappeared down the severely cracked soil, or lost through surface run-off. There was virtually no cracking in the raised bed treatment.

These results are extremely encouraging and we are seeing changes in soil structure much faster than we had originally anticipated.

It appears that waterlogging may have a greater damaging effect on soil structure than cultivation. This however requires further analysis over time. The controlled traffic aspect also should be contributing to this improvement in soil structure.

If we can improve the soil "health", then we are well underway to developing a much more sustainable farming system.

7. Economics of the System

It is extremely difficult to accurately determine what the returns and costs are likely to be, because no two farming systems are the same, however Table 5 presents an approximate analysis. The analysis includes the cost of establishment for the system, which is amortised over 3 years.

Table 5 – Gross Margin / ha for Canola

	Contract	Own Equipment*
Returns		
2.5 Tonnes/Ha @ $350 / Tonne	**$875**	**$875**
Costs		
Surveying	$15	$15
Cultivation – 3 passes	$150	$75
Grader work	$15	$15
Bed forming	$50	$20
Total Set Up Cost	**$230**	**$125**
Amortised Cost over 3 years	$77	**$42**
Crop Variable Costs	**$350**	**$300**
Gross Margin	**$448**	**$533**

* Contract windrowing and harvesting is carried out. The yields given are regarded as being conservative.

When comparing between contract versus owning your own equipment, it is essential that the machinery overhead costs are taken into account. Obviously the overhead costs are going to be substantially higher in the situation where your own plant is used.

Table 6 shows a similar analysis this time for wheat.

Table 6 – Gross Margin / ha for Wheat

	Contract	Own Equipment*
Returns		
4.0 Tonnes/Ha @ $150 / Tonne	**$600**	**$600**
Costs		
Surveying	$15	$15
Cultivation – 3 passes	$150	$75
Grader work	$15	$15
Bed forming	$50	$20
Total Set Up Cost	$230	**$125**
Amortised Costs over 3 years	$77	**$42**
Crop Variable Costs	**$300**	**$250**
Gross Margin	**$223**	**$308**

* Contract windrowing and harvesting is carried out. The yields given are regarded as being very conservative.

7.1 Discussion

The results clearly indicate that Canola is the higher returning crop, and in most situations will be the best crop to start the rotation cycle with. The crop should give you the returns to help finance the establishment of the system.

The yields given in the analyses are reasonably conservative, however it is better to adopt this approach rather than giving expected top yields.

The high establishment costs of the system assume that significant cultivation needs to be undertaken to establish a soil condition required for the successful establishment of the beds.

The bed establishment costs has been averaged over 3 years. It is anticipated that the beds should last 3 – 5 years before total re-establishment is required. A small amount of bed maintenance work may be needed at the end of each year to reshape the beds.

The system relies on keeping grazing animals off the area in order to minimise damage to the beds and to keep compaction to a minimum.

7.2 Comparison to the Grazing System

Table 7 gives the average and top 10% of farmer results for the beef, wool sheep and prime lamb enterprises in the South West Monitor Farm Project for 1996 – 97.

Table 7

	Average	Top 10%
Beef Gross Margin per hectare	$41	$113
Prime Lamb Gross Margin per hectare	$282	$421
Wool Sheep Gross Margin per hectare	$142	$240

8. Adoption of the new System

The adoption of this raised bed technology should proceed with caution. There are many factors to consider and we would really like to see the system tested over at least 2 more wet years. The results are however at this stage extremely encouraging.

There are several system parameters that need to be carefully considered, namely

1. Movement of water off the paddock. Care must be taken that water coming off the paddock does not contain pesticides or nutrients. It is envisaged that given soil structure is improving along with significantly greater plant growth, "drainage water" may in fact decrease over time compared to a traditional flat land system. This has in fact been shown to be the case in Western Australia.

2. The timing and rates of nutrient application need to be re-assessed, given that we are looking at a totally new system. Since we are able to traffic the country at any time over winter, then I believe that we can be far more strategic in our timing of nutrient application. We will possibly see more frequent applications of low rates of fertiliser, in order to increase plant uptake of nutrients and to reduce the leaching losses.

3. The water that is coming off the raised bed country should be contained on the farm to be re-used on possibly high return summer crops. Downstream effects of water flow needs to be reduced to a minimum or in fact eliminated. Farmers should be encouraged to collect all their run-off water. In no circumstances is water to be allowed to flow onto road ways or directly into water-ways.

4. A filter trap should be installed before collecting water in dams. This could consist of at least a 50 metre wide pasture buffer across the direction of water flow. This is aimed to trap any soil particles, which may contain pesticide residue and other contaminates.

5. The slope of the country is critical to the success of the system. Any more than 2.5% - 3% slope could cause significant erosion problems in some soil types. Any less than 1% slope may not drain the water effectively.

The water flow and water quality parameters are being assessed at our research site at Gnarwarre with a system of weirs installed in a large scale drainage and farming system trial.

9. Further Potential

The system certainly does uncover the possibility of more crops and pasture species being adapted to the high rainfall cool climate zone. If we can overcome waterlogging, crops such as lupins and other pulse crops along with lucerne may be a possibility on our heavier basalt soils.

There is the possibility that the system may have some application in saline country. Given that we can keep the plants out of the salty water in the beds, then we should be able to establish the seedlings in a relatively salt free environment. By the time the plant roots reach the soil containing higher salt loads, plant tolerance will have increased.

The investigation so far certainly indicates that cropping may be a far more viable option for farmers in the high rainfall cool climate zone of South West Victoria than it has been in the past. It certainly is not suggested that cropping should replace the grazing enterprises, however if carried out in such a way as to reduce the possible risks, then it should offer greater flexibility to the producer in the region.

The new system I believe should provide the producer an ability to be more flexible in the choice of enterprises for the farm and with this, hopefully result in a much more sustainable and profitable farming system for the future.

Machinery Needs for Controlled Traffic Farming on Dryland Grain farms.

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The ongoing resource based benefits of Controlled Traffic Farming (CTF) are well documented in these proceedings, therefore this paper will only provide a summary. They are:-

- decreased soil erosion
- decreased soil compaction
- increased water infiltration
- increased root growth
- increased water stored
- increased surface cover
- improved soil physical fertility

Likewise, the innovations and opportunities for management allowed by CTF are:-

- planting
    - directed planting
    - furrow planting
    - relay planting
    - improved timeliness
- spraying
    - trafficability
    - timeliness
    - night operations
    - directed spraying
- operational efficiencies
    - no overlap
    - no misses
    - no double spraying
    - no double planting
    - low draft
    - high tractive efficiency
- agronomic manipulation
    - side dressed fertiliser - summer and winter crops
    - increase population beside wheeltracks
    - variable row spacing - for wheeltrack identification-summer/winter
    - directed tillage -inter-row or under-row cultivation
      - weed control
      - promote secondary root development in corn and sorghum

There are opportunities, yet to be tested in the field, to manipulate stubble and plant phenology to achieve more reliable crops and planting opportunities. Certainly, there are many possibilities afforded by this system to be explored and refined.

GLOSSARY

Operational width	- the width of a harvester platform, spray boom or planter.
Wheel Centres	- the distance, left to right, from the centre of one tyre or track to the centre of the other tyre or track.
Wheeltrack width	- the width left unplanted for a tyre or track to run on.
Controlled Traffic Farming	- a crop production system where the paddock is divided into crop zones and wheel zones on a permanent basis with zones orientated to provide drainage of surface water to a safe disposal point.
Guess Row	- the row created between subsequent passes of an implement, should equal row spacing.

CURRENT SYSTEMS

Grouping systems by wheel centres results in three basic scenarios.

60"(1.52m)	- 4WD ute used for spraying, often in conjunction with 15"(381mm) row spacing. Harvest equipment not included in system, although operational widths may be the same.
~80" (2.03m)	- Truck, tractor or 4WD ute used for spraying. Harvest equipment not included in system, although operational widths may be the same.
120"(3.048m)	- Tractor or specialist high clearance sprayer used for spraying. Harvester in system up to operational widths of 30 ft (9.144m).

Major areas of concern in these systems are:-

1. Incompatible wheel centres between spray rig, tractor and harvester.
2. Incompatible operating width between harvester and planter.
3. Implement depth wheels not standardised.
4. Many of the benefits depend on accuracy of operations.

Which of these basic systems best suit CTF?

By definition, no wheels should run on the crop zones. It is also expedient to minimise the total number of wheel zones in a paddock. This implies major modifications would be needed to the harvester and ancillary equipment, chaser bins etc., before they could be used in a either a 60" (1.52m) or 80" (2.03m) system. Similarly, truck and 4WD spray systems are unsuitable in a 120" (3.048m) system, however alternatives do exist. The 120" (3.048m) system with variable operating widths, appears to offer the only practical solution at this stage. Modules of 160" (4.064m) have been promoted in the past, but require modification to both tractor and harvester as well as limiting road transport options.

The future of CTF depends on overcoming the lack of standardisation of wheel centres, increasing the operating width of the harvester and the development of an efficient and effective guidance system. The incorporation of crops, such as dryland cotton, which require specialist harvest equipment, pose an additional challenge.

How then, can we make a good system better?

The Way Forward

1. Wheel Centres

Tractors

Tractor manufacturers have been quick to respond to incompatibilities between tractors and harvesters, with almost all offering tractors on 120" (3.048m) centres, albeit with some provisos. Commercial systems are now available allowing farmers to match harvester, tractor, air seeder cart and spray rig on 120" (3.048m) centres provided they:- use either a high clearance, self propelled sprayer or a tractor mounted or drawn trailing unit and do not exceed 30 ft (9.144m) operational width for the harvester.

While platforms are available to 42 ft (12.8m), they are offset to the right, making them unsuitable for CTF. In expansive broadacre areas, operational widths of 30 ft (9.144m) or less has limited appeal. What opportunities exist to overcome these difficulties?

One solution uses 60 ft (18.28m) or 90 ft (27.432m) as an operational width for spraying and planting and a 30 ft (9.144m) harvester running on it's own permanent wheeltracks. However, this results in ~18% of the paddock under wheeltracks, compared to ~9% if we increase the harvest operating width to match the planter.

Spray Technology
Truck and 4WD based spray systems will not suit a 120" (3.048m) system. It may be possible to extend the axles on a truck to cater for the wider centres. A company in Sydney does axle modifications for oil and gas exploration vehicles, however it may be difficult to register as a road going vehicle.
Spraying choice within a 120" (3.048m) system is therefore limited to either high clearance machines or tractor based units. High clearance spray rigs have the disadvantage of high capital cost per unit, although this is offset by higher work rates, better operator environment and the ability to apply pre-harvest sprays. The use of tractors offers some extra utilisation of capital, although this is negated if a second tractor was needed to cover the area. Castor (1998) recommends one tractor and 80 ft (24.384m) boom spray to 4000 acs (1618ha) of cultivation. However, there are many growers farming areas greater than this with only one tractor. Without suspension, tractor spray speeds are limited to about 10 mph. (16kph) and in Queensland at least, the opportunities to extend the operational width past 80 ft (24.384m) are limited. Given the importance of timeliness to spray efficacy, additional capacity, in the form of a contractor or alternative sprayers appears necessary.

The challenge, indeed the opportunity, is before the Australian manufacturing industry to develop a low cost, high clearance spraying system for 120" (3.048m) CTF system.

2. Operating Width
Grain platforms could be made wider, especially the draper types. The use of multiple ~ 20 ft (6.096m) sections would substantially improve ground following ability and reduce harvest losses in undulating terrain. This may allow operating widths up to 60 ft. (18.288m) Grain could be moved from the harvester to transport by unloading to either the front or rear of the harvester. The benefits from increasing the operating width of the harvester are:-

1. The harvester can operate at design capacity in light crops without excessive speed.
2. The number of wheeltracks in a paddock is reduced.
3. Timeliness of harvest is improved through improved trafficability. (One grower was able to harvest on the wheeltracks two weeks earlier than the rest of the paddock.)

Swathing or windrowing prior to harvest is a technique being evaluated for CTF. Early investigations of swathing in QLD yielded mixed results and were limited by the short duration of the study. (Tullberg & Rogers, 1982) Later reports indicate the technique is widely used in southern and western regions, particularly for canola. (Greenslade, 1993)
The attractions of such a system involves faster dry down, less lodging, decrease in losses due to wind, rain, hail & insects. It promotes even ripening and allows earlier starts and later finishes to the harvesting day. (Greenslade, 1993)
With these benefits, how can we make it work under our conditions?
The main difficulty reported by Tullberg & Rogers was the inability of the stubble of light crops to support the windrow. However, target plant populations for cereals have increased significantly since 1980 - 81, as has row spacing. What is the effect of this interaction in a CTF system?
CTF is based on zonal management, it is therefore possible, to create a zone of narrow rows specifically to support a windrow, between the wheel tracks. This is necessary because:-

1. Row spacing up to 18" (45.7cm) are common in CTF systems. This has been influenced by:-
   a) the high capital cost of zero till planting equipment (>$1,000 / row.) and
   b) stubble handling capacity.
2. Windrows need <10" (250mm) row spacing for support.(T. Greenslade, pers. comm.)

The benefits of swathing to CTF are:-

- only the narrow rows need specialist trash equipment therefore lower capital cost.
- allows harvester to match the operating width
- facilitates use of PTO harvesters with pick up (less capital investment)
- allows better utilisation of horsepower and capital (main tractor used for swathing and harvest)

Winter cereals and all legumes appear to suit the system. Summer crops grown in the region, corn, sorghum and sunflowers present more difficulty. There are anecdotal reports of sorghum being swathed in the Orion district (CQ) in 1995 to prevent losses due to lodging. If sorghum could be swathed successfully, it would provide significant management options with regard to pre-harvest spraying and lodging avoidance.
With corn, cotton and sunflowers requiring some form of specialised harvesting, there appears little option at this stage, other than continued direct harvesting with the harvester not necessarily following CTF wheel tracks.
Swathers are available up to 60 ft (18.28m) and one company is assessing a 72 ft. (21.9m) model, allowing the harvester to have an operational width compatible with most CTF systems. The expectation is that modern harvesters have sufficient capacity to cope with the increased crop flow, given throughput is usually limited by forward speed, rather than processing capacity.

3. Implement wheels
Implement wheel spacing does need to be standardised across the industry. Implement wheels can fit between rows without modification to plant spacing, whereas this is not possible with tractor and harvester tyres or tracks. Ideally, gauge wheels should run on their own permanent wheeltracks with scrapers or spray nozzles for weed control. As a compromise, vertically adjustable tynes behind wheels could be used or placed in front of the tyre(s). This enables the majority of tillage to be carried out at optimum depth and avoids the draft penalty associated with setting the whole machine to dig weeds from its own wheel tracks. All equipment, whether trailed or mounted, should run the outside wheel in the guess row.
The placement of wheels across an implement could vary with the operating width. Large trailing machines may need wing modules widths of either 120"(3.048m), 160"(4.064m) or 200"(5.08m) to achieve stability and various transport needs.

4. Accuracy of Operations
Many of the innovations and opportunities occur because CTF is a system allowing operations to be carried out in close proximity to plants or in relationship to previous or future operations. In practical terms, this implies a high degree of skill on the part of the operator to carry out such operations repeatedly and accurately for the duration of his or her shift. Current systems are predominantly based on the use of marker arms for initial marking and following the wheeltracks for subsequent operations. Depending on the operator, accuracy's in the order of ±10" (250mm) are possible. Various organisations and individuals have funded the development of guidance systems in an attempt to provide a higher degree of accuracy to every operation, regardless of the skill level of the operator. The advent of dGPS and automatic tractor steering systems, in conjunction with existing technology, are signs of light at the end of the tunnel. However, much remains to be done before the humble marker arm is consigned the way of the foam marker, to the dump!

Conclusion
CTF is a farming system which delivers enormous benefits in terms of resource sustainability, improved agronomy and efficient use of labour and capital. The continued development of machinery systems to adequately service those opportunities is the challenge before us today.

References
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DESIGNING FOR IMPROVED PERFORMANCE FROM A FURROWER-BED-FORMER

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Introduction

Various forms of furrower-bed-formers are used across Australia in both irrigation and dryland farming conditions. In Western Australia the soil and climatic conditions impose somewhat unique demands on this type of machine. Our soils have shallow structureless topsoils which are underlain by dense clayey subsoils at varying depths. These subsoils are also poorly structured and are commonly sodic. The climate is distinctly Mediterranean, with cool and wet winters, sparingly moist but short autumns and springs and almost completely dry summers.

To create permanent raised beds in this environment requires that:

i) the initial ripping (to 20cm depth) and cultivation is done when the soil is at a moisture content close to its Plastic Limit, to maximise the formation of clods and aggregates and minimise soil pulverisation;
ii) the excavation of soil from the furrows/drains/traffic lines and the spreading of the spoil onto the surface of the intervening beds be done in the most gentle way possible, to avoid unnecessary compaction and/or pulverisation.
iii) the formation of the furrows and beds be accomplished with one pass of the machine, consistent with the need to reduce operational time and costs when farming large areas.

Mark I Version

Gessner Industries Inc. Qld., a manufacturer of a large variety of row-cropping equipment, was prepared to assist with the design and supply of a furrower-bed-former for WA conditions. The machine design that evolved from discussions with this company comprised their standard heavy duty (180 mm square section) 3-point linkage toolbar with adjustable furrowers and spoil spreading grader blades. The furrowers consist of four maxitil ripper shanks with furrower (hiller) attachments. These are mounted on the front bar at multiples of tractor wheel-track widths. The small grader blades are mounted on adjustable shanks on the rear bar.

The four pairs of these grader blades are raked backward from the centre of each furrow and they extend laterally to the middle of the beds. The initial rake angle on the grader blades was 56°.

Trailing/gauge wheels are mounted on the rear of the tool bar to provide greater depth control and stability during the bed forming operations. The height/depth of these is adjusted with a ratchet extension arm.

A view of the Mark I version operating in 1997 is shown in Figure1.

1997 Performance

The performance of the Mk I version of the WA furrower-bed-former was satisfactory. With inexpert operators the beds formed with two passes of the machine were quite acceptable (Figure 2).

1998 Performance

This year, with one season's experience, our appraisal of the machine's performance was more critical. We were seeking to achieve good bed formation with a single pass of the machine in soil which had been previously ripped and chisel-ploughed to a depth of 20 cm.

On close inspection over a number of sites in which the soil varied from a gravelly-sand to a sandy loam with some clayey subsoil included, the grader blades were bulldozing too much soil. In consequence, a considerable proportion of the spoil from the furrows was being pushed back into the furrow or compacted beneath the blade, and a fairly large amount of spoil was carried in front of the blade. A relatively small portion of soil actually flowed off the trailing end of the blades. Two passes of the machine were again required to adequately shape and clear the furrows of spoil, and an unacceptable amount of compaction occurred on the tops of the beds.

Design analysis for improving the performance

To have the spoil from the furrowers flow along the grader blades clearly required them to be raked backwards at a steeper angle to the direction of travel.

From the Mohr-Coulomb analysis of soil stresses at failure (i.e. when soil slides across itself) we can calculate the angle of the failure plain of soil (θ_f) for given angles of internal soil friction (ϕ), where

$$\theta_f = 45° + \phi / 2$$

For the sands and sandy loam soils we deal with, ϕ ranges from 20° to 30°, suggesting that a rake angle of around 30° to 35° would be the minimum required for soil to 'fail' and flow easily. That is, the soil would fail at an angle equal or close to that of the blade, with the consequence being that it would roll along the blade surface, assuming the angle of friction between the blade and soil produced a soil-blade failure angle of similar magnitude. Common values of the angle of friction between soil and steel are around 20°, confirming that such a requirement would be achievable. (Both angles of friction vary with soil moisture according to the relative magnitude of cohesive and adhesive forces within and between them.)

To test this semi-quantitative analysis the horizontal draft force required to move a blade and soil was calculated using the method in McKyes (1989, pp. 193-194), where:

$$P = \{ \gamma.h^2.K_p + c.h.K_c + ca.h.K_{ca} \}.w$$

$$H = P.\sin(\alpha + \delta) + ca.h.w.\cot\alpha$$

and	P	=	blade force on the soil	(kN)
	γ	=	bulk density of soil	(kN/m^3)
	h	=	height of blade	(m)
	c	=	cohesion pressure	(kPa)
	ca	=	adhesion pressure	(kPa)

q	=	bearing pressure	(kPa)
K_p	=	passive pressure coefficient	
K_c	=	cohesion coefficient	
K_{ca}	=	adhesion coefficient	
w	=	width of blade	(m)
H	=	horizontal draft force	(kN)
α	=	blade rake angle	(degrees)
δ	=	angle of surface friction	(degrees)

Results of analysis

Two hypothetical soils with appropriate soil mechanical properties were used for the analysis. These had angles of internal friction covering the range likely to be found in WA's coarse textured surface soils, a bulk density typical of freshly cultivated soil and cohesion and adhesion pressures typical of a range of moisture contents likely to exist when the soil would be worked, i.e. dry and moist. These were: $\phi = 20°$ and $30°$; $c = 5$ kPa and 20 kPa; $ca = 0$ and 5 kPa; $\delta = 20°$; and $\gamma = 10$ kN/m^3.

Table 1. *Horizontal draft forces (kN) for grader blades at two rake angles*

Rake angle	Internal friction angle of 20°		Internal friction angle of 30°	
	Dry soil c = 5; ca = 0	**Moist soil** c = 20; ca = 5	**Dry soil** c = 5; ca = 0	**Moist soil** c = 20; ca = 5
Existing rake angle of 56°	1.36	6.24	2.05	10.14
Proposed rake angle of 35°	0.80	3.97	0.87	4.37
% reduction in draft forces	41%	36%	58%	57%

These calculations confirm the conclusion of the semi-quantitative analysis on soil failure angle relative to internal friction angle. That is, the rake angle has a greater effect in reducing the horizontal draft force on the grader blades when the soil has a larger internal friction angle.

They also illustrate that the cohesion and adhesion forces in soils, which change substantially with soil moisture content, exert a greater influence on horizontal draft force than the internal friction angles of soils, which do not change as much - a conclusion which was not apparent from the earlier analysis.

Field testing

New mounting brackets were constructed which allowed the leading end of the grader blades to be moved outwards and forwards relative to the vertical shank bolted onto the toolbar frame (Figure 3.). New rear mount brackets were also made for the trailing end of the blade, to accommodate the sharper rake angle.

The field performance of the blades raked at 35° has been subject to a field test in a gravelly sandy loam soil at Mt. Barker. At the time the soil was moist to wet.

The performance of the Furrower-Bed-Former was markedly improved. Furrow shape was much more clearly parabolic and deeper, and the flow of spoil along the grader blades was smooth and easy despite its wetness. Beds were well-formed with a single pass of the machine (Figure 4.).

Further improvements

The furrowing tools could be modified to provide a smooth but steeper rake along their surface whilst maintaining the same cross-section. This would improve the throw of spoil from the base and walls of the furrow, reduce side wall compaction and further facilitate the spreading of spoil by the grader blades. Such improvement is subject to on-going negotiations with the Gessner Industries company.

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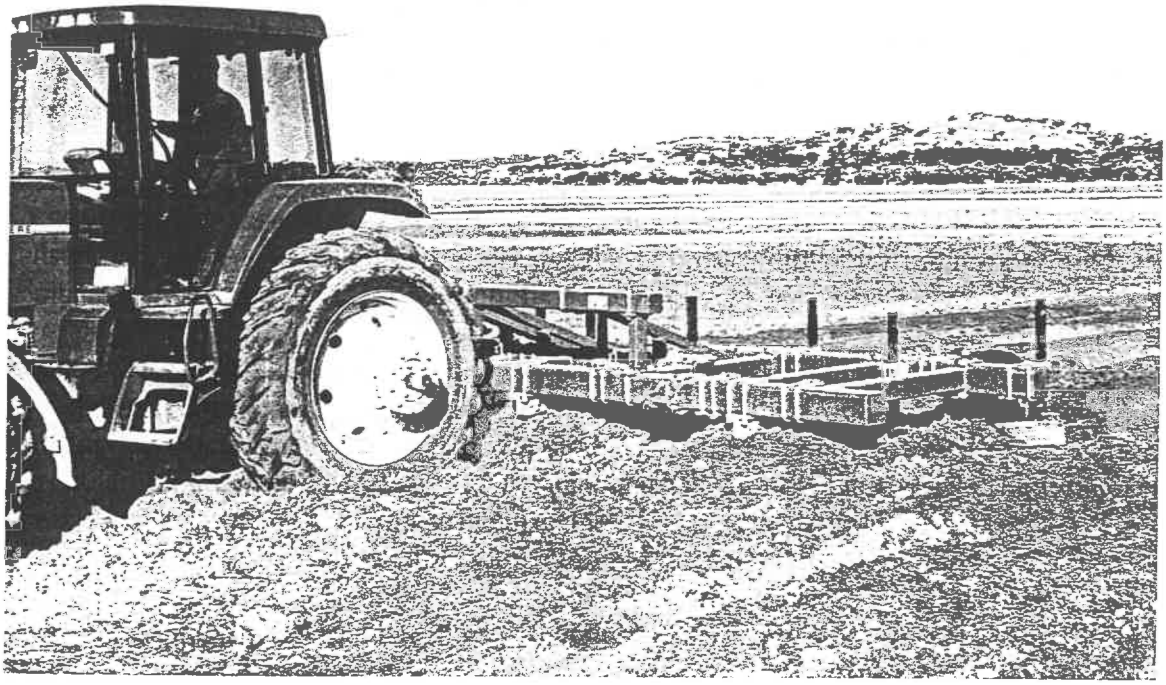

Figure 1. View of the furrower-bed-former in operation in 1997 in a sandy loam soil at Woodanilling, WA. Note the mound of soil being pushed along in front of the furrowers and the grader blades.

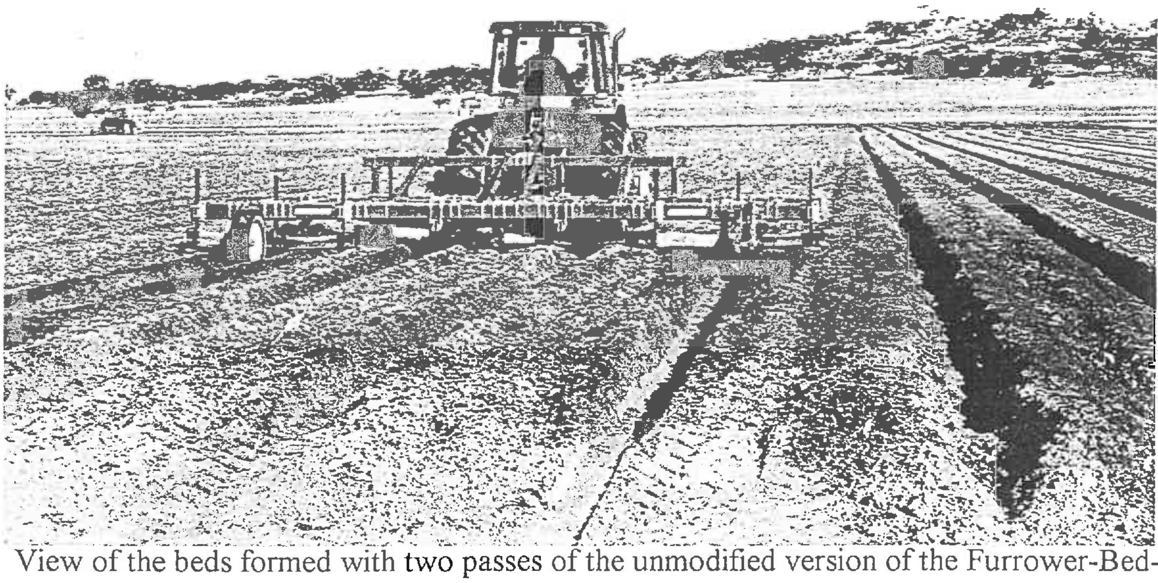

Figure 2. View of the beds formed with two passes of the unmodified version of the Furrower-Bed-Former.

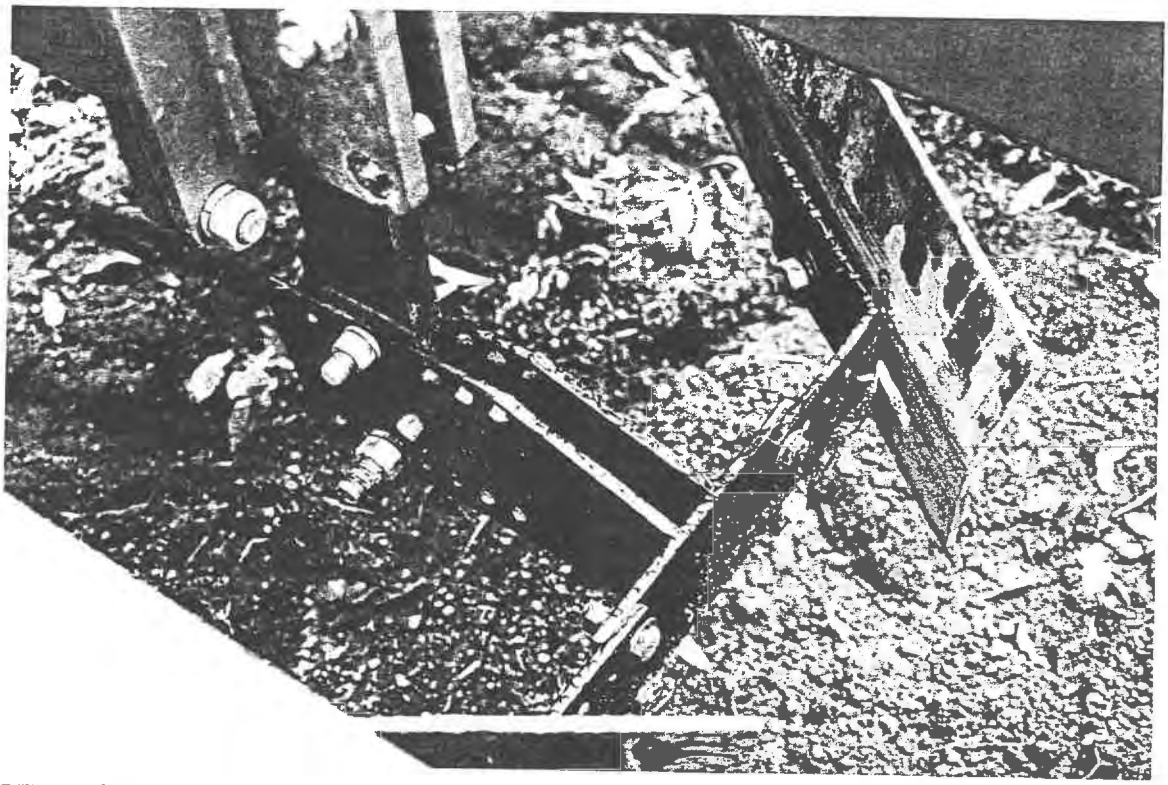

Figure 3. View of the brackets modified to mount grader blades at a rake angle ≤ 35°.

Figure 4. View of the furrows and beds formed by the Furrower-Bed-Former after its grader blades were mounted at a rake angle ~ 35°.

DESIGNING A SEEDER FOR NO - TILLAGE STUBBLE RETENTION CROPPING ON PERMANENT RAISED BEDS

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Introduction

Most of Western Australia's agricultural topsoils are shallow and dense. For permanent raised beds to work effectively and prevent waterlogging on soils that are essentially structureless, macroporosity has to be created and maintained. This will only occur through the combined effects of prolific numbers of undisturbed roots, active soil biota, gypsum if the soil is sodic and cropping practices which do not cultivate or compact the soil.

To facilitate the rapid development of the required macroporosity, our raised beds are formed by ripping and chisel-ploughing to 20 cm depth, incorporating gypsum in the process, if necessary, and then forming the beds and furrows with a furrower-bed-former. The furrows become the traffic lanes and no farm traffic ever traverses the beds. The beds and furrows form a complete controlled traffic regime. After formation, no-tillage crop establishment practices are imposed and there is no grazing. Total stubble retention is also imposed.

The soil in the beds presents special challenges for the design of a no-tillage seeder with an assured stubble handling capacity. The floor of the furrows is between 25 to 35 cm below the surface of the beds , and the furrows are spaced 1.8 m apart. The soil has a low density and very low load bearing capacity, particularly when moist or wet, placing it at the opposite end of the scale to "normal" no-till seedbeds. "Normal" seedbeds commonly have compact surfaces, and the seeders designed to handle these conditions have high break-out-pressure tines and large disc pressures to allow them to "penetrate" the soil and cut the stubble.

Just to be compatible with the raised beds seeders must:

a) be mounted on a bar with gauge wheels compatible with furrows spaced at 1.8 m centres;
b) be capable of being raised above the beds and still have its openers operate satisfactorily over a 35 cm height range, from furrow floors, up bed shoulders and across bed tops;
c) have openers which can accurately control the depth of seed and fertiliser placement without causing unacceptable compaction of the soft soil in the beds.

In addition, seeders for raised beds must exhibit high performance characteristics of the attributes required of normal seeders, i.e.:

- stubble cutting and/or clearance;
- separation of fertiliser from the seed, either to the side and/or beneath seed;
- mixing some fertiliser with the seed;
- accurate seeding rate settings and even distribution of widely varying seed sizes;
- accurate seed placement in terms of depth and spread within a row;
- good soil coverage and contact without compaction;
- furrow shaping; and
- easily varied opener position to adjust the width of row spacing.

Review of seeder performance in 1997 & 1998

The machine used to seed our raised beds in 1997 and 1998 was a Great Plains 3-point linkage 20 feet double disc seeder (provided by Perkins Machinery, Narrogin). Of the machines available in 1997 this was the only one known to the senior author with compatability attributes a) and b), listed above.

Seeding in 1997 was done in drier than optimum moisture conditions and the crop sown was oats. Establishment was good to excellent at all sites. With the advantage of hindsight, the crop was insensitive to sowing depth and the dry soil provided adequate load bearing capabilities.

Seeding in 1998 involved Canola (as the 2nd crop on most sites), barley, oats and wheat, the last three on new (Quairading, and Toolibin) or renovated (Mt. Barker) sites. Seeding conditions at all sites was done in optimal to wet moisture conditions, and the soil in all the beds, new, renovated and 2nd year was soft and had very little load bearing capacity. In consequence, seeding depth at all sites could not be adequately controlled by press wheels and the seed was sown too deep. Despite the too-deep seeding, the cereal crops in the beds established satisfactorily, but the Canola crops on all the beds and some of the control areas had to be re-sown at three sites (Beverley, Woodanilling and Cranbrook). The Esperance site was sown last, in drier condit and with wiser operators. Seeding of the second sowing sites and the Esperance site was accomplished by carrying the seeder totally on the 3-point linkage hydraulics with the double disc openers held just above the soil. The Canola seed was thus dropped on to the surface and lightly pressed by the largely suspended press wheels.

Lessons learned

a) Depth of seeding

The Great Plains seeder, which to the best of our knowledge was the only compatible machine available has been shown to be lacking in depth control capabilities on raised beds. Conventional press wheel mechanisms alone cannot be relied on with soil as soft as it is in raise beds. The stop-gap method used in 1998 to control seeding depth, by way of the tractor driver suspending seeder on the 3-point linkage, places too great a demand on the driver and will not be a viable proposition over large cropping areas.

A easily adjusted mechanism which provides a far greater range of pressures (particularly towards zero pressure) needs to be developed so that seeding depth and the compaction of soil above the seed can be accurately and reliably controlled.

b) Distribution of seed

The distribution of seed across all the openers was effectively uniform with cereals, but not with the small seeds of Canola. There was wide variation in the performance of the seed dispensing mechanisms, with the result that some rows had very little Canola seed dispensed.

A mechanism which reliably delivers a wide range of seed sizes to all openers on a seeder is required.

c) Stubble clearance

Harvesting raised beds requires the harvester to have a very effective straw chopper/spreader. Without a spreader, straw trails tend to fall on to one or two beds, making sowing of the next crop very difficult. Stubble was burned at all but one of the 1997 sites because of this problem. Significantly, the site where it was retained and sown through was the site with the lowest yield of oats in 1997.

Notwithstanding this, the ungrazed, standing stubble at this site presented no problems for the double disc openers on the Great Plains seeder. This was largely due to the standing stubble and the row cropping consequence of bed farming. The double discs parted the stubble easily as they passed down precisely the same row as existed in the previous crop.

Perhaps the stubble cutting capabilities required of seeders used in raised beds will not be stringent because stubble will be standing and openers will pass precisely along previous rows, splitting or pushing the crown and stalks of last year's crop to one side.

Choice of a replacement seeder

The stark realisation that seedbed conditions in raised beds are grossly different from normal soil conditions led us to assemble the following criteria for selection of a replacement seeder:

i) *A disc machine is needed* (rather than a tine machine) because only minimal disturbance is desired in order to leave the maximum possible number of undisturbed roots (to facilitate macropore development and organic matter build-up) and achieve good control of seed placement, particularly for small seeded crops, something which is not possible with the shattering and spraying of soil that occurs with a tine machine.

ii) *A machine that cuts stubble and places fertiliser away from the seed is needed.* Preferably one which also provides the options of either mixing the fertiliser with the soil or placing it as a concentrated band at variable depths relative to seeding depth.

iii) *A machine is needed with an easily adjustable press wheel/seed covering device which is capable of adjusting wheel pressures to close to zero and so controls the depth and compaction of soil above the seed.*

The capabilities and reliability of the triple disc units of Walker's, Merredin came to our notice. These openers satisfy 5 of the 8 performance characteristics required of normal seeder (listed above, Figure 1.). Furthermore, these openers offered the prospect of simple adaptation to satisfy a 6th (easy adjustment of row spacing) and possibly a 7th (good soil coverage and contact without compaction).

In addition, the Walker openers are compatible with mounting on a bar with gauge wheels and brackets that ensure compatibility requirements a) and b) are met (listed above).

Adaptations undertaken

a) Press wheel pressure adjustment

The effects on crop emergence, growth and yield of high soil bulk density and soil strength are well-established (Barley & Greacen, 1967; Collis-George & Williams, 1968; Mc Kyes, 1989; Taylor, 1971). Although the optimum values of bulk density or strength vary with soil type and season, the shape of the relationship shows reductions either side of an optimum density/strength, which itself is not widely varying. In terms of bulk density, the optimum over a wide range of soils, climatic conditions and crops lies within the range of 1.0 to 1.4 t/m^3. In Australian soils densities approaching 1.0 t/m^3 are found only in freshly cultivated soils, and values of settled topsoil are commonly > 1.5 t/m^3. Our challenge is to keep the bulk density of soil ≤ 1.4 t/m^3.

In order to identify what press wheel pressures are required of any adaptation to their adjustment mechanism, the method and standard soil parameter values presented in McKyes (1989; pp224 - 225) were used. This involves the equation:

$$\rho_{dry} = \rho_o + A.\log [N.p (1 + S) / p_o] + B.\log \theta_g$$

where				
	ρ_{dry}	=	compacted bulk density	(t/m^3)
	ρ_o	=	initial bulk density	(t/m^3)
	A,B	=	soil constants	
	N	=	number of passes/repeated applications of pressure	
	p	=	applied compaction pressure	(kPa)
	p_o	=	precompaction soil pressure	(kPa)
	S	=	wheelslip (fractional speed)	
	θ_g	=	% gravimetric moisture content	(g/100g)

Note: The constant B is the coefficient of a soil's sensitivity to compaction (or its load bearing capacity). It increases to a maximum at the "optimum" compaction moisture content after which it becomes negative.

The analysis used a range of press wheel weights from 1 to 40 kg. (The existing mechanism on the Walker triple disc seeders recorded a weight of 34 kg when the spring producing a downward pressure, to achieve penetration, was taken off.) These weights were then converted to pressures by considering a range of press wheel contact areas (contact angles ranged from 30° to 60°). The pressures generated by this analysis ranged from 0.07 kPa to 5.76 kPa. Two initial bulk density conditions were used, 0.8 t/m^3 and 1.1 t/m^3, which are typical of freshly cultivated soil.

This analysis showed:

- The moisture content at which compaction will be maximised for a given pressure is ~ 15% by weight
- In order to maintain a bulk density ≤ 1.4 t/m^3 in soil above the seeds a pressure of ≤3 kPa is required.
- Only in soils with $\rho_o > 1.1$ t/m^3 which are also wetter than 15% by weight will this maximum need to be reduced.

Hence, an adaptation to the Walker triple disc arm which allows the press wheel pressure to be reduced to < 3kPa ought to provide the flotation necessary for good seeding depth control and seed coverage without deleterious compaction above the seed.

The bracket and spring attachment shown in Figure 2. is capable of producing pressures form zero kPa at the lower limit of the seeder arm's 150 mm of vertical travel to 3.2 kPa at the upper limit, assuming the press wheel has a 30° contact angle.

b) Low rolling resistance of discs

One of the consequences of having soft soil in the beds is that pressure cannot be put on the leading coulter or double discs to ensure they turn. Hence, as a means of reducing the rolling resistance the seals in the disc hubs were reduced from two to one.

c) Creation of loose soil and enhanced stubble cutting

There is a need in a complete no-till regime to create some loose soil. This is needed to

- mix and so dilute fertiliser with the soil
- mix soil with herbicides, such as Treflan™ to ensure their efficacy
- disrupt the hyphae of some pathogens, e.g. rhizoctonia, and so assist with its control
- provide some loose soil for covering the seed.

Hence, rippled discs were mounted for the double disc openers and a wavy disc for the leading coulter. The self-sharpening attribute of a wavy or rippled coulter will facilitate stubble cutting and clearance(Figure 3.).

The use of these types of disc also assists in reducing rolling resistance, because of the extra friction caused by the waves and ripples. This extra turning efficiency means their angular velocity will exceed the seeder velocity, further enhancing soil loosening.

Field testing

The specially designed and adapted triple disc openers are to be field tested in the Spring of 1998. The openers are to have the seed and fertiliser delivered to them by way of a Simplicity airseeder.

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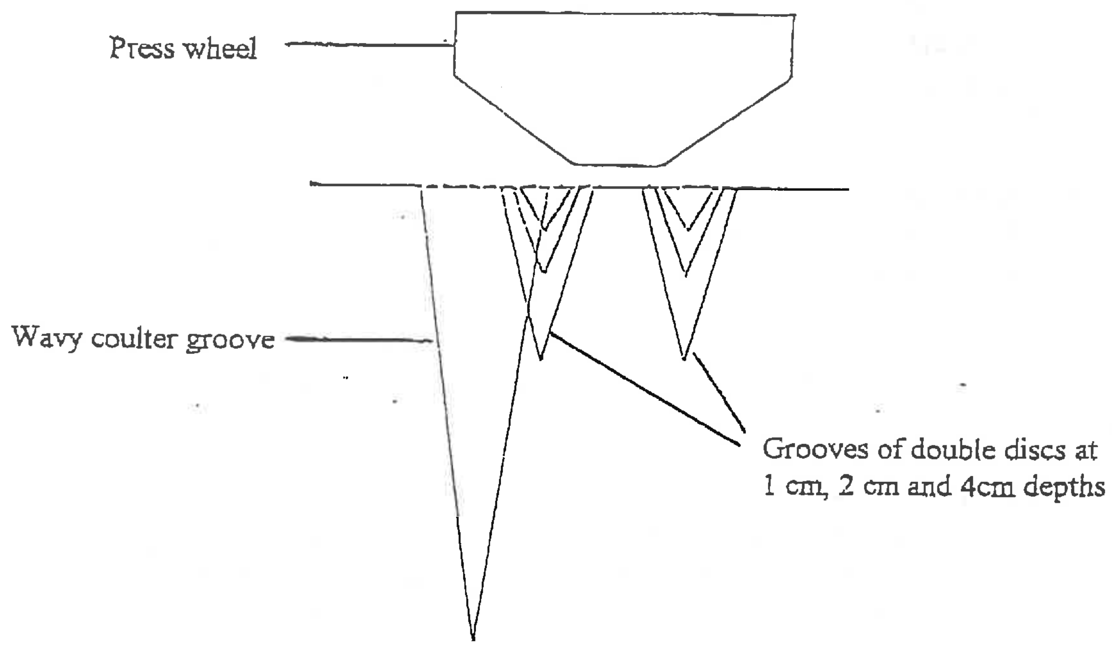

Figure 1. Scale diagram of relative dimensions and juxtaposition of grooves cut by the Walker triple disc seeder when the leading coulter penetrates (a) 10.5 cm & (b) 5.5cm, and the double discs penetrate (c) 3.0 cm & 0.8 cm. Note spoil from the leading coulter passes either side of the double discs and the soft rubber press wheel presses on the shoulders of the double disc cut.

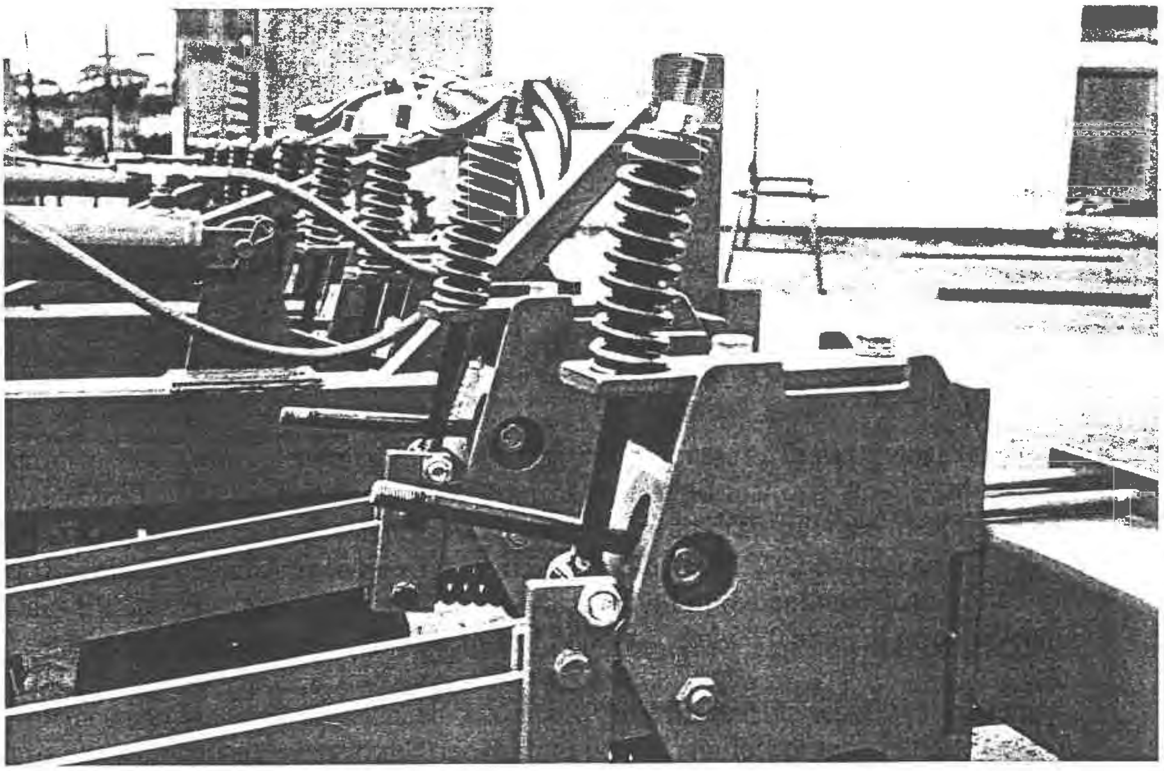

Figure 2. View of the extra bracket and spring added to the opener to adjust the pressure exerted by the press wheel to between 3 kPa and zero kPa. The adjustment is accomplished by tightening the nut above the spring.

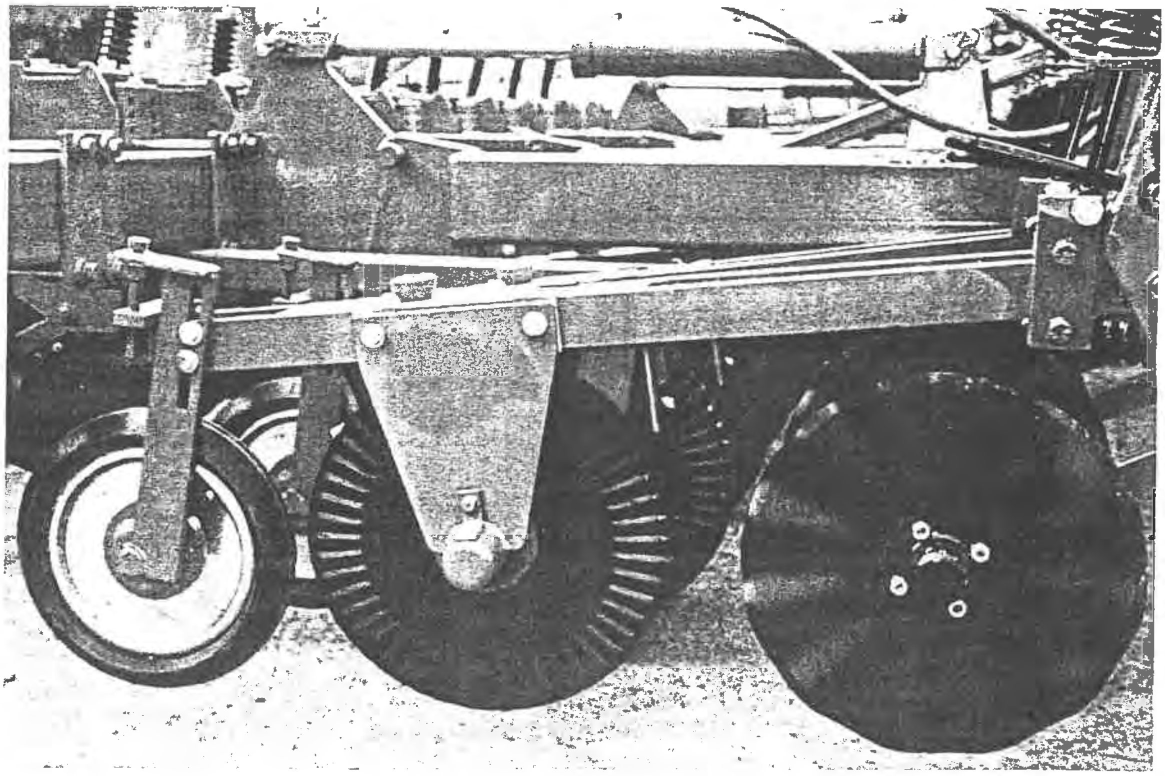

Figure 3. Side view of the triple disc openers mounted on the frame designed for use on the raised beds. Note the wavy leading coulter and the rippled double discs. The bar will be mounted on the 3-point linkage of a tractor and the gauge wheels on the rear of the bar will track in the furrows between the beds.

WHEEL EFFECTS ON TILLAGE ENERGY

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1. INTRODUCTION

Tractor and/or implement wheels precede tines, and compact the soil immediately before it is loosened in most tillage and planting operations. Soil compaction effects generally ameliorate with time, so the most severe wheeling should be observed in the performance of tillage tools following immediately behind wheels. This aspect of tractor/implement system efficiency appears to have received little attention in the literature, which is surprising when wheels usually cover 15% --30 % of implement width. Tractor drive wheels are likely to be most important in this respect, although the implement wheels providing depth control and frame support will have some effect.

In controlled traffic farming this effect is avoided as all field traffic is confined to permanent laneways, and all crops grown in permanent unwheeled beds. This should have a direct effect on the energy requirement of tillage because unwheeled soil requires less tillage energy than wheeled soil. Traction should also be more efficient when tyres are working on compacted permanent tracks.

The severity of compaction has been found to be dependent on wheel load (Ronai *et al.*, 1993) and tyre pressure (Raper *et al.*, 1993). This has lead to the widespread adoption of dual and triple tyres by producers in an attempt to reduce compaction. Although dual and triple tyres reduce the severity of compaction, the increased wheel width causes an increase in the area of soil compacted. It is debatable whether or not these measures actually reduce the overall effect of compaction on factors such as tillage energy.

Trials have been undertaken to assess the effect of tractor and implement wheels on the draft of the tillage tools following immediately behind them, and to determine the effect of tyre pressure and wheel load. The results will be used to quantify the impact of field traffic, and its control, on tillage energy requirements.

2. MATERIALS AND METHODS

2.1 Instrumented Plough

Draft-sensing tines were designed using 450 mm chisel plough shanks attached to parallel link assemblies. Rearward movement of the tines was restricted by shear beam force transducers connected to a data logger which scanned transducer outputs at 0.1s intervals, and recorded the mean draft force measurement for all tines at 10 s intervals. The draft-sensing tines could be fitted with 50mm chisels, normally used for primary tillage, or 450mm sweeps, normally used for weedkill and seedbed preparation.

The draft sensing tines were mounted on a 4 m wide three-point linkage toolbar fitted with adjustable depth control wheels at its extremities.

2.2 Overall Wheeling Effect

The initial series of tests were carried out in order to determine the overall effect of tractor and implement wheels on tillage energy. The toolbar was attached to a tractor modified for work in permanent wide beds, with front and rear wheel track centres set to 3 m, and stabilizers to prevent lateral movement of the toolbar relative to the tractor. Four draft-sensing tines were fitted to the toolbar at 1 m centres so the two outer 'wheeltrack' tines operated directly behind the tractor wheel centrelines, and tilled soil immediately after wheeling by the tractor. The two inner 'control' tines worked in soil not previously wheeled by the tractor.

An implement wheel was mounted on a frame on the front of the tractor to simulate the action of a trailed implement depth control/frame support wheel. This was fitted with a 10x16 implement tyre and carried a load of 9.0 kN. The tractor was a 2WD John Deere 4040, total weight 65 kN. The rear axle was fitted with two 16.9x38 R1 tread bias ply tyres, operated at a pressure of 120 kPa.

Chisel points were used in test A, where a relatively loose and dry surface soil mulch overlay a moist, compact layer. The implement wheel was not available during this test, representing primary tillage effects to a depth of 220 mm. Subsequent tests with sweeps in secondary tillage and planting conditions rarely exceeded 125 mm depth. Tests B and C were carried out under conventional secondary tillage and planting conditions respectively. Test D was carried out in sorghum stubble with some weed growth, to represent reduced tillage planting or weed control, and test E, with dry surface soil, represented a secondary tillage operation delayed until soil moisture was sub-optimal.

2.3 Wheel Load and Tyre Pressure Effects

A further three tests were undertaken to determine the effects of wheel load and tyre pressure on tillage energy, using same instrumented plough with different tractors.

Both pressure and load effects were investigated in trial F and H. Differences in wheel load were obtained by fitting a dual wheel to one side of a tractor in trial F and extending the rear axle on one side in trial H. Trial G was limited to pressure treatments as the dual wheel was not available. Tractor and treatment details are shown in Fig. 1.

Trial	Tractor	Weight	Tyre Pressures	Depths
F	2WD Ford 6640	40.7 kN	55, 83, 110 kPa	5, 10, 15(cp) cm
G	2WD Ford 5640	46.7 kN	83, 93, 124 kPa	10, 15, 20(cp) cm
H	2WD J.Deere 3120	40.2 kN	69, 138 kPa	10(sw), 20(sw) cm

Figure 1. Experimental Details of Trial F-H. (cp = Chisel Points, sw = Sweeps).

2.4 Sites and Layout

All tests except trial F were carried out at the University of Queensland Gatton College farm, on self-mulching alluvial black earth of the Lawes or Blenhiem profile classes (ug

5.15, clay~55 %, silt~25 %, sand~25 %). Trial F was conducted on a non-cracking Ferisol in Crawford. Soil conditions approximating those of Australian dryland grain production were obtained by selecting plot areas from fields at the appropriate stage of land preparation. No special preparation was involved other than the choice of areas which appeared to be uniform. Before each set of tests, core samples were taken for gravimetric moisture determination.

Mean tine draft for each treatment was measured while traversing two plots orientated at approximately 30° to the longer dimension of field. The purpose of this angle was to minimize the possibility of systematic error due to tines following pre-existing wheel tracks. The toolbar depth wheels were set using a 2m straight edge laid across undisturbed soil surface. The actual depth of wheeltrack tines was always smaller due to the wheel rut.

3. RESULTS

3.1 Overall Wheeling Effect

Relatively smooth draft:depth characteristics were obtained for wheeltrack and control tines in all cases except test C, where some inconsistency occurred at 75 mm depth. In all cases the draft of tractor and implement wheeltrack tines was less than that of control tines at depths <50 mm. This effect occurred because wheeltrack tines did not engage the soil until tillage depth exceeded wheeltrack depression (ie rut depth). When wheeltrack tines did engage the soil, tractor and implement wheeltrack tine draft always increased more rapidly with depth than control tine draft.

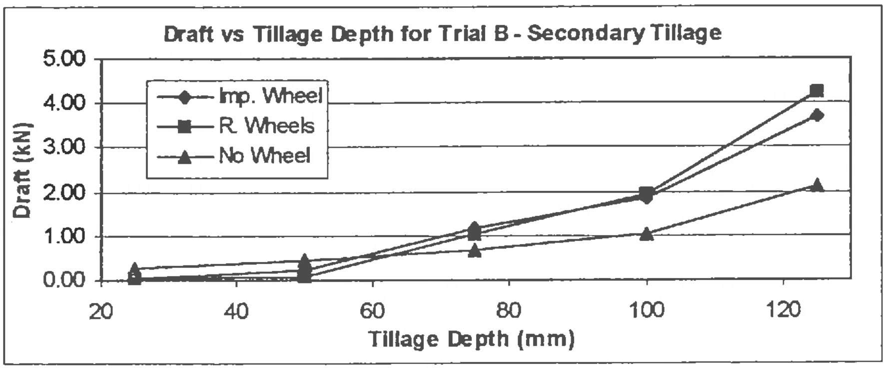

Figure 2.

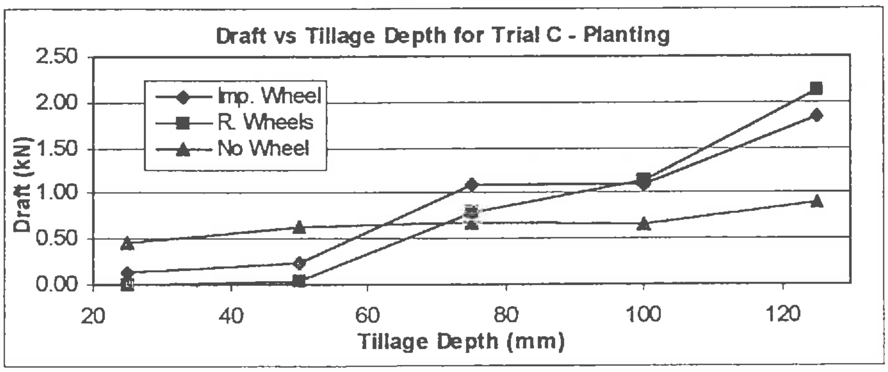

Figure 3.

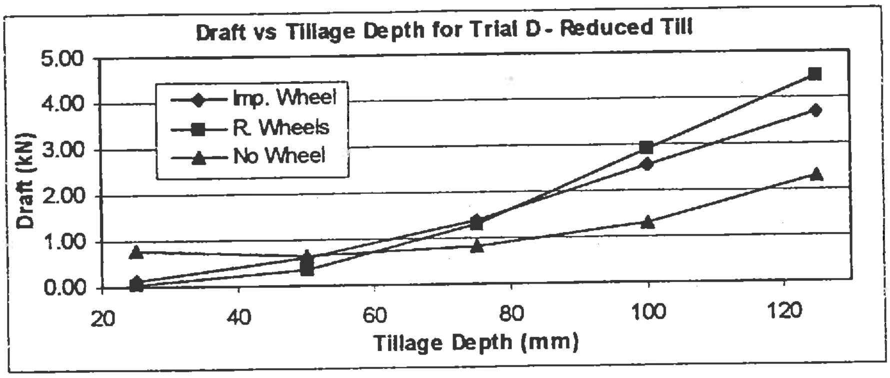

Figure 4.

In all cases except test E (secondary tillage in dry conditions) the draft of wheeltrack tines was significantly greater than that of control tines at normal operating depths. For chisel tines in primary tillage at depths >150 mm, the mean draft of wheeltrack tines was greater than that of control tines by a factor of approximately 2.2. For sweeps in secondary tillage (Fig. 2) at depths >75 mm, tractor and implement wheeltrack tine draft was greater than control tine draft by factors of approximately 2.0 and 1.8 respectively.

When surface soil was drier, the wheeltrack effect was different. In test E with sweeps, and in test A with chisels, wheeltrack tine draft appeared similar, or less than the control tine draft at depths <100 mm. Tillage of dry surface soil in these conditions appeared to simply rearrange the existing aggregates, while producing little effect on aggregate size distribution. There is rarely any useful purpose for tillage in these conditions. In both cases, however, at depths >100 mm, wheeltrack tine draft appeared to increase relative to control tine draft when the tine started to work in more moist soil.

At normal soil moisture content and operating depth (100 mm) for secondary tillage with sweeps, these results indicate an overall mean control tine draft of 1.07 kN (Fig. 2). If these tines were at their normal spacing of 305 mm this is equivalent to a unit draft of approximately 3.5 kN/m implement width (ignoring any between-tine interaction effects). In a typical extensive tillage situation, tractor and implement wheeltracks might represent 20 % and 15 % of implement width. If tine draft in these wheeltracks increased by factors of 2.0 and 1.8 respectively, the overall unit draft would be 4.6 kN/m, or > 30% greater than control tine draft.

3.2 Wheel Load and Tyre Pressure Effects

Although increased wheel load was found to significantly increase tillage energy at all tested depths, it can be seen in that higher wheel loads (single) had a greater effect at depth than lower wheel loads (duals) (Fig. 5). This effect was also found in trial H and is consistent with previous research which has found wheel load to be the major determinant of compaction depth (Adawi and Reeder, 1996).

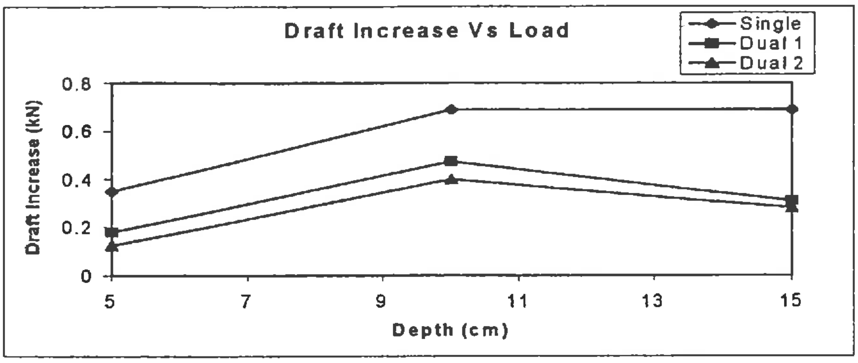

Figure 5. Draft Increase With Depth and Load – Trial F.

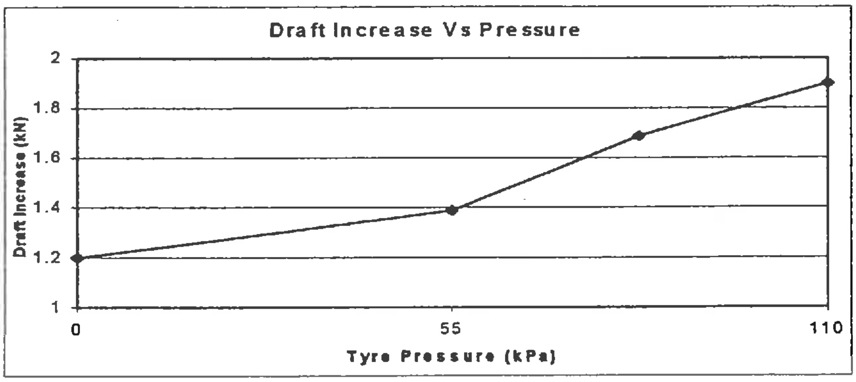

Figure 6. Draft Increase With Tyre Pressure – Trial F.

It was difficult to demonstrate a significant difference between different tyre pressures at the same depths but when all depths were considered, tillage energy was found to increase significantly with increasing tyre pressure (Trials F and H - Fig. 6). The results from trial G were erratic due to variation in soil moisture. No consistent relationship was found between tyre pressure and depth of compaction.

The comparison between dual and single wheels in trial F revealed that duals have little or no advantage over singles in terms of tillage energy. Even when the dual wheels were inflated to half the pressure of the single (55kPa vs 110kPa) there was no significant difference in draft. The draft of tines immediately behind the dual wheels was considerably lower than that of the single wheel, but the increased area of compaction caused by the duals meant that the overall draft increase was approximately the same.

4. DISCUSSION

The simple analysis presented here demonstrates that >30 % of implement input energy was used to undo wheeltrack effects. When tractive efficiency is ~ 80 %, however, at least 25 % of implement input energy (= 20% of tractor axle output energy) has already been dissipated by the tractor in the soil/tyre interaction. Total energy input to the creation and removal of wheeltracks is thus >55 % of implement input energy under very good tractive conditions. A mean tractive efficiency level of 75% was found in a survey of 4WD tractors on Queensland grain farms. At this tractive efficiency approximately 65 % of implement input energy, or almost half the tractor's output energy will be dissipated in the creation and removal of wheeltracks. In a controlled traffic situation where tractor and implement wheels would be repositioned to the permanent laneways and the wheeltrack tines removed, drawbar pull would be >65 % of an equivalent conventional system.

Increasing wheel load and tyre pressure were both found to have a positive correlation with tillage energy. However, attempting to overcome compaction by lowering tyre pressure and spreading axle load over dual wheels would appear to be ineffective if tillage energy can be taken as an indication of compaction. The measurements taken did not consider the compaction caused below the tillage depth and as wheel load has be correlated with compaction depth, it is likely that the single wheel caused greater compaction below the tillage layer.

5. CONCLUSIONS

Investigation of the impact of tractor and implement wheels on the performance of tined tillage equipment operating at normal soil moisture and depth in a clay soil has demonstrated that:

- The draft of sweep and chisel tines operating in the wheeltracks left by a 2WD tractor of approximately 6t was increased by more than 100% compared to tines in non-wheeled soil.
- The draft of sweep tines following an implement tyre carrying approximately 0.9t was increased by approximately 80% compared to tines in non-wheeled soil.
- Under these conditions, almost 50% of the power output of the tractor can be absorbed in the creation and partial removal of wheel tracks.
- The use of dual wheels causes little or no reduction in tillage energy.
- Controlled traffic operations can reduce tillage energy requirements by > 50%, although the change in tillage objectives might be equally significant in terms of reduced energy requirement.

These phenomena did not occur during tillage of dry soil, and different effects might occur with varying soil type, implement type tyre type and pressure.

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TOWARDS A STANDARD FOR CONTROLLED TRAFFIC MACHINERY

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Introduction

There currently exists a unique opportunity to provide a major benefit to Australian farmers and our agricultural machinery industry. Farmers are rapidly adopting controlled traffic farming now. To do this they must modify existing equipment or specify custom built equipment. Australian manufacturers have limited research and development budgets. They are currently reluctant to invest in CTF machinery because the size of the market is unknown and customer requirements appear to vary widely. The international manufacturers have sufficient R&D budgets but Australia represents a small component of their market with little immediate influence on decisions.

The expertise exists in Australia to quickly develop uniquely Australian machinery for CTF and the potential exists to export it. The major constraint to this exercise is the lack of any standard for CTF machinery. Because of the lack of a standard, manufacturers are not confident to produce products for the market and farmers are unable to purchase items from different manufacturers with confidence. The alternative is to leave the development of CTF machinery to slowly evolve. This approach will greatly delay the adoption of CTF and require that Australian farmers continue to improvise until an international manufacturer eventually picks up the technology and exports it back to us.

The development of a standard for CTF machinery will improve the profitability and sustainability of broadscale farms nationally by ensuring the efficient supply of appropriate machinery for CTF. It will facilitate the ongoing success and continued expansion of Controlled Traffic Farming (CTF). It will necessarily involve farmers, researchers and the machinery industry. It will add value to current initiatives by GRDC and other agencies toward developing CTF nationally

This paper proposes a framework for the development of a standard for CTF machinery and explores the various approaches to standardisation, as well as listing a number of systems that are currently in use that may form the basis for the standard.

Standards

Why Standardize

The American Society of Agricultural Engineers (1983) explains that " *standards are normally generated for one of the following reasons:*

1.1 To provide interchangeability between similarly functional products manufactured by two or more organisations, thus improving mechanical compatibility, safety and performance for users.
1.2 To reduce the variety of components required to serve an industry, thus improving availability and economy for manufacturer and user.
1.3 To improve the degree of personal safety during operation and application of products and materials.
1.4 To establish performance criteria for products, materials, or systems.
1.5 To provide a common basis for testing, describing, or informing regarding the performance and characteristics of products, methods, materials or systems.
1.6 To provide design data in readily available form.

1.7 To develop a sound basis for codes, education and legislation related to the agricultural industry; and promote uniformity of practice among states.
1.8 To provide a voice in international standardisation.
1.9 To increase efficiency of engineering effort."

And additionally:
"2. *Standards are developed and adopted because of a need for action on a common problem. Their effectiveness is dependant on voluntary compliance with the standards adopted. It is, therefore, essential that affected groups be invited to participate in the development of and conformance with such standards."*

Sections 1.1 and 1.2 summarize the major benefit that adherence to a standard would provide for CTF machinery in Australia. That is the ability of manufacturers to confidently produce products for the market and the ability of farmers to purchase items from different manufacturers with confidence.

Similarly Section 2. summarizes the opportunity that currently exists within Australia, as well as emphasising that participation in the process of developing and implementing the standard should include all affected groups.

Informal or formal Standard?

Part of the process of developing a standard for controlled traffic machinery will be the necessity to decide whether the standard should be informal or formal. An informal standard is simply an agreement in principal to work toward some agreed principles. Alternatively it may be beneficial to involve a relevant organisation such as Standards Australia in the development and implementation of a formal standard. This would add cost and complexity to the process, but would greatly enhance Australia's ability to lead machinery developments for CTF.

Standards Agencies and Relevant Standards

The Standards Association of Australia, The American Society of Agricultural Engineers, The Society of Automotive Engineers, The Tyre and Rim Association of Australia and The International Standards Organisation are agencies that produce standards with relevance to Australian Agriculture. Although not immediately apparent to the end user, standards from one or more of the above organisations impact on n of the machinery currently in use on farm. For example, the ASAE standard ASAE S217.10 "Three-Point Free-Link Attachment for Hitching Implements to Agricultural Wheel Tractors" ensures that implement linkage masts are designed within tolerances that will allow ready attachment to all tractors comforming to the relevant linkage category.

Although there are some existing formal standards with relevance to CTF, there are currently no standards that relate directly to CTF. For example the ASAE (1983) Standard S343.1 "Terminology for combines and grain harvesting" indicates how to measure the discharge height of the unloader (auger) as well as the reach of the unloader.It does not specify standard dimensions for these despite the value that such standarisation would provide for designers of CTF systems. Similarly the Tyre and Rim Association of Australia (1993) produces standards to ensure that implement tyres are matched to appropriate rim sizes, but no standards currently exist to propose appropriate placement of implement tyres within the implement for CTF.

The Need for A Standard

Australia leads the world in the on-farm adoption of CTF. Hence we are in a unique position to set standards for CTF. If we do not take the opportunity to do this at this time, we risk similar problems to those that have occurred with imported machinery in the past. Imported machinery conforms to standards and voluntary codes in its country of origin, but in many cases these are incompatible. An example is break-away couplings for remote hydraulics. Due to differing standards across and even within manufacturing countries, farmers often must have multiple sets of couplings to allow an implement to be used on different tractors.

If standards for CTF are developed in other countries, such as the USA, it is highly likely that resulting machinery will be at best a compromise for Australian conditions and at worst, no better than the existing situation where tractor track width is invariably incompatible with the grain harvester.

There has been some research done to estimate the potential benefit of moving to CTF. The estimates range from an increase of $140 /ha. in whole farm net margin (Mason et al,1995) to a reduction of $19/ha for machinery costs alone (Robotham and Walsh, 1995). Such economic benefits, and the availability of "off the shelf" standardised machinery for CTF could readily increase the adoption of CTF by 1% above the current adoption rate. The benefits of this increased adoption would be applicable to our cereal production area of around 20M Ha. Hence the value of adopting such a standard could range from around $19M per year to $140M per year, Australia wide.

Developing a Standard

Some of the methodology that would be required to develop a standard for CTF is listed hereafter. A more detailed plan should be developed as part of the process.

Development of a standard will only succeed if farmers are convinced of the benefits, and are involved in the process. To assist the process, organisations such as The Kondinin Group, with it's farmer surveying expertise and the Tractor and Machinery Association's (TMA) with it's data on available machinery combinations should be involved. Hence it would be possible to quantify existing on-farm configurations and compatible machinery currently available. A publication and database could be produced and distributed.

Using this information as background, a national working group to consist of farmers and representatives from TMA, Kondinin Group, the NCEA and government agencies should be convened. Financial assistance from GRDC and other Research and Development organisations should be sought.

The working group should consider the best options for the rapid production of machinery for CTF. These might include:

- "best bet" wheel track configurations for the various farming systems;
- possible standardisation including a voluntary Australian Standard for wheel configurations and tracking ability;
- mechanisms to influence International manufacturers (eg harvesters);
- mechanisms to facilitate local innovation and machinery production (eg innovative companies such as A.E. Bishop, wide harvester fronts);
- regional issues and GRDC and other funder involvement.

- production of a national controlled traffic machinery information package explaining the proposed standard
- production of regional and farming systems additions to the package,
- Coordination with other initiatives on CTF.

Likelihood of Success of this standard

Is it still possible for Australia to set the direction for world machinery development, as we have done in the past? There are a number of indicators that the answer to this question should be a qualified yes:

1. The major overseas tractor manufacturers, at the request of Australian farmers and dealers, have taken major steps to ensure that tractors are available with factory warranty for use on 3m track width.
2. The major overseas tractor and machinery manufacturers are acutely aware of the Australian lead in CTF and are actively and overtly monitoring developments in Australia.
3. Australian manufacturers such as Janke Brothers and Australian Farm Machinery have manufactured prototype and "made to order" CTF machines. Other manufacturers are developing equipment, or have expressed interest in developing equipment.
4. Because a ready market exists and is expanding within Australia, our manufacturers have an opportunity to have developed and tested technology well in advance of overseas equipment manufacturers.
5. If such an installed base of equipment is in operation in Australia, and it has been shown to be successful under an Australian developed Standard, there will be pressure on international manufacturers to adopt, or at least conform to, the standard

Existing Systems as possible component of the Standard

One feature of CTF that has the most need for standardisation is the wheel track width of tractors, harvesters implements. A number of farming systems with differing approaches to matching wheel-track widths have emerged. The more prominent are summarised below

System 1

Location	Queensland, NSW, WA
Features	Forget the grain harvester
Tractor	Large 4WD usually on Singles or rubber track, track width varies
Implements	Remove tines behind Tractor tyres. 8-21m width.
Boomspray	Linkage or SP to match tractor tracks, width 1, 2 or 3 times implement width
Harvester	Random traffic, harvest is conventional

System 2

Location	Queensland, NSW
Features	Match the Grain harvester, 3m track-width
Tractor	Large FWA, 3m track width on singles.
Implements	Remove tines behind Tractor tyres 10-12m width.
Boomspray	Linkage or SP to match tractor tracks, width 1,2 or 3 times implement width
Harvester	Harvester front to match implement width

System 3

Location	Queensland

Features	Landcruiser or trailer based spraying
Tractor	Large FWA, 1.5m track width on singles.
Implements	Zero till. Lift assist wheels on parallelogram seeder. Width 10m
Boomspray	Landcruiser or trailer based spraying, width 2 times implement width
Harvester	Harvester front to match implement width. Harvester straddling tractor tracks.
Haul out:	Haul out bin running on adjacent harvester tracks.

System 4

Location	Queensland
Features	Smaller farms, eg Kingaroy area
Tractor	Small FWA or 2WD, 2m track width on singles.
Implements	Zero till. Lift assist wheels on seeder. Plant over contour banks. Width 5-8m
Boomspray	Linkage, width 2 or 3 times implement width
Harvester	Harvester front to match implement width. Harvester running on adjacent tractor tracks. For example, one farmer has a 5 m planter and 5 m harvester front, so his tractor is on a 2m wheel-track with the tracks 3m apart. The harvester on 3m wheel-track fits perfectly.

Other systems to consider are permanent bed systems, mostly in use in irrigation or poorly draining soils. These include 2m permanent bed systems with the harvester track width increased to 4m, and 3m bed systems to match the grain harvester.

As well as standardisation of wheel track widths, there are other components of CTF systems that will benefit from efforts toward standardisation. The most important of these is tractor steering control systems. Standardisation in this area is important t
readily added to different tractor steering systems. Similarly, tracking systems to ensure that trailed implements accurately follow the tractor are under development and efforts in standarisation of the control interfaces will greatly assist matching of tractors to implements.

Conclusion

This paper has put forward a proposal for development of a standard for CTF machinery. The arguments supporting some standardisation are compelling. The success of standardisation will depend on the committed involvement of farmers and the machinery industry, as well as research and information organisations such as the Kondinin Group.

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EXPERIMENTAL PERFORMANCE OF RAISED BEDS IN PREVENTING WATERLOGGING AND DRAINING EXCESS SURFACE WATER

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INTRODUCTION

Waterlogging has long been recognized as a major constraint to crop growth. Waterlogging in the South Western region of Western Australia (WA) is predominantly the result of perched water tables in duplex soils, caused by rainfall in excess to evapotranspiration limited percolation through the subsoil and lateral drainage. Surface drains have often been recommended to alleviate waterlogging however with little success due to poor lateral water movement. The concept of raised beds has been well established in irrigated agriculture (Tisdall and Hodgson, 1990). However, the application of raised beds to dryland agricultural area, notably waterlogged duplex soils has not been investigated. Raised beds provide short drainage pathways and reasonable hydraulic gradients. They improve lateral water movement, resulting in less water logging in the root environment, and increase in evapotranspiration and subsequent biomass accumulation. This paper describes the first-year results of research into raised beds on waterlogged duplex soils in the South West of WA.

METHODS

Four raised bed demonstration sites and one research site (Cranbrook) were established at different locations across the South West . Two treatments, raised beds and control, were imposed on all sites. The raised beds were installed with a bed former after a deep cultivation of the soil as opposed to the control, which only received a shallow cultivation without changing the relief of the soil surface. The Cranbrook site is instrumented to establish the dynamics of soil-water, which provides information on the various components of the water balance.

The monitoring regime in Cranbrook is described as follows. The soil moisture changes were obtained with a TDR (Time Domain Reflectometry) instrument. The instrument relates the propagation and dissipation of electromagnetic pulses along a cable and steel pins (probes) to the soil moisture content. The system is fully automated and collects soil moisture information every 15 minutes. To establish the shape and the depth to the perched water table from the soil surface, an array of observation wells is installed perpendicular to the interceptor drains. Five wells are installed in every block and readings are taken manually at regular time intervals. Interceptor drains intercept the overlandflow as well as the interflow from the blocks. The flow in the drains is measured with 'V' notch weirs, located at the block boundaries and the water height across the weirs is measured using automated water level recorders. Space limitations in the field enforced the layout of the drain in such way that the flow from the blocks cumulate in the direction of the flow. The flow from the individual blocks is therefore obtained by subtracting the inflow of the drain-section draining a particular block from the outflow of that section.

SOIL MOISTURE DYNAMICS

The soil moisture changes are obtained in various positions and depths of the raised beds and the control. The following diagram (Fig. 1) illustrates the position of the respective probes. Due to the dramatic changes in soil bulk density on the duplex soil, soil moisture changes in the treatments have been converted to degrees of saturation. These have been depicted in Figure 2a and 2b.

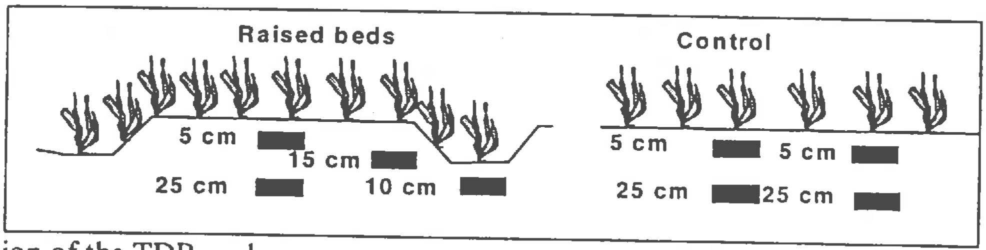

Figure 1. Position of the TDR probes

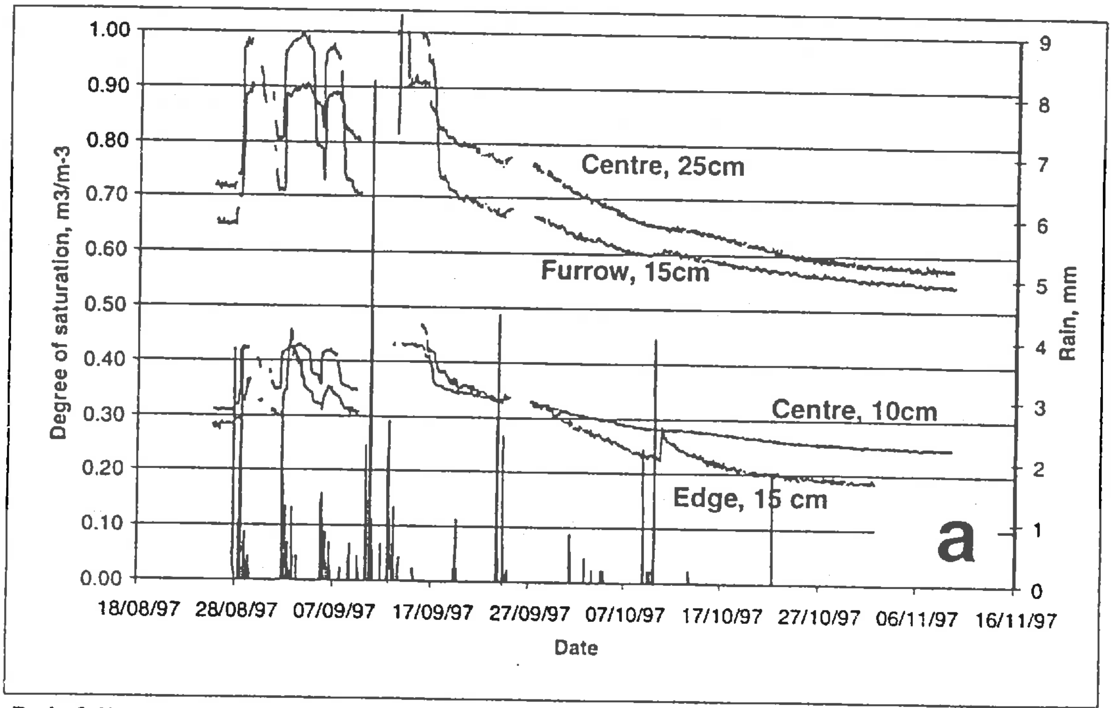

Figure 2a. Rainfall and changes in degree of saturation at different depths and positions of a raised bed.

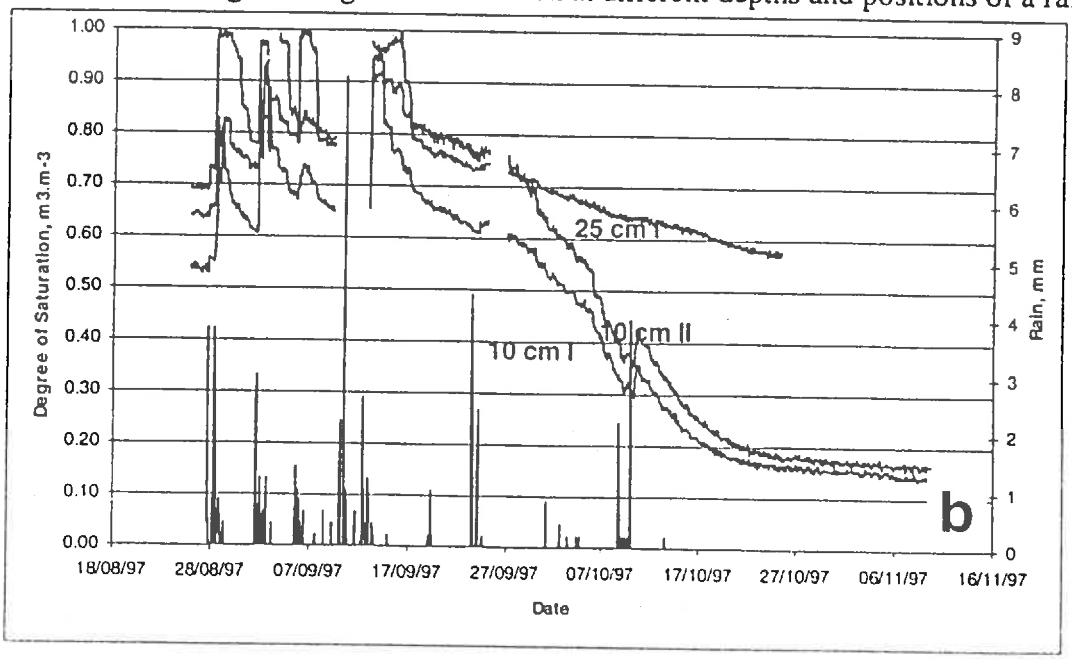

Figure 2b. Rainfall and changes in degree of saturation at different depths and positions of the control.

The centre of the raised bed (Fig. 2a) did not reach saturation at any time during the period of observations whilst during the same period the top 10 cm of the control remained saturated or close to it.

Of interest is the rapid decrease and the low soil moisture content in the edge of the bed. The soil at that depth has a maximum water holding capacity of 0.26 m^3/m^3, 56% gravel and a low clay content and close to the edge, and is therefore able to store only very little water between field capacity and wilting point. It should also be noticed that a rapid decrease in the moisture content occurs at a depth of 25 cm in the raised bed as well as in the control, several days after the rainfall ceased. This decrease (5 mm/day) occurs too fast to be caused by moisture extraction by the roots and should be contributed to internal drainage, resulting in deep percolation or interflow (seepage).

The total soil moisture extraction in the raised beds in the top 30 cm between 17/09 and 27/10 equated to 37 mm and 33 mm in the control. If the total rainfall (11 mm) over that period is included a total of 48 and 44 mm has been evapotranspirated through the crop and the soil which is not unreasonable for a post-flowering period. During that period the raised beds increased 5.94 t/ha in biomass while the control increased only 4.47 t/ha, resulting in the raised beds using the soil moisture more efficiently, 123 kg/mm and 104 kg/mm for the raised beds and the control, respectively. It should be realised that the observation depths have been limited to the top 30 cm due to limited number of probes. To establish the water extraction patterns as well as the total soil moisture extracted by the crop, the observation period has to be extended to cover the entire growing period and the number of observation depths increased.

CONDITION OF WATER LOGGING

The degree of waterlogging has also been established using the manually monitored dipwells. From the observations, the shape of the perched water table has been established. This was clearly affected by the presence of the interceptor drain. Figure 3, illustrates this point through the presentation of the mean depth to the perched water table of 8 plots on three different days.

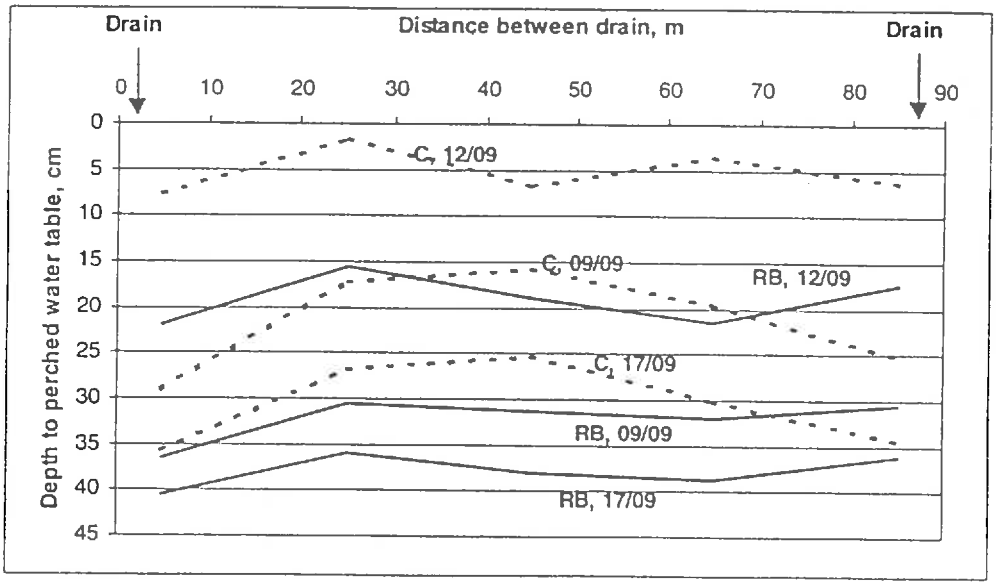

Figure 3. Shape of the perched water table at different days. Before (09/09), during (12/09) and after a rainfall event (17/09).

Before the rainfall event during which 15 mm fell, 09/09, during the event (12/09) and 7 days after the event (17/09). In the control, the water table was close to the soil surface during the event, while in the raised beds the water table remained parallel to the soil surface with some evidence of the effect of the drain on the shape of the water table. The average depth of the water table in the raised beds is 20 cm while the depth of the furrow in the raised beds is 20 – 25 cm. It can therefore be expected that the centre of the beds experience a water table which was temporarely above the level of the furrows, which is explained using conventional drainage theory. Even though the effect of drain on the perched water table is clearly illustrated, the extent of waterlogging was such, even the vicinity of the drain, that the crop was severely affected.

The frequency distribution of the number of observations for a given depth (Fig. 4) indicates that the number of observations at which the depth to the water table was between 0 – 10 cm in the control exceeded the number of observations in the raised beds. While a water table between 11 – 20 cm occurred more frequently in the raised beds than in the control.

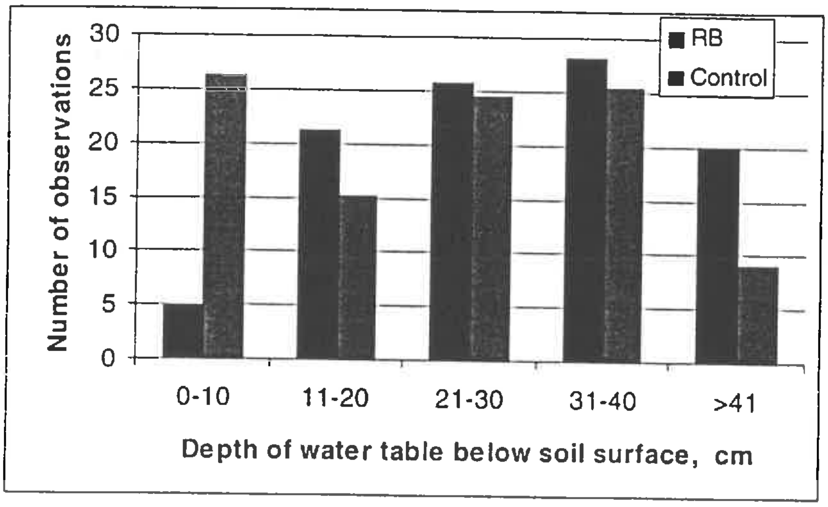

Figure 4 Frequency distribution of the number of observation for a given depth to the perched water table.

RUNOFF DYNAMICS

The runoff from the plots has been measured during the latter part of the winter period. The runoff from the raised beds was usually larger than from the control. This is depicted in Fig. 5.

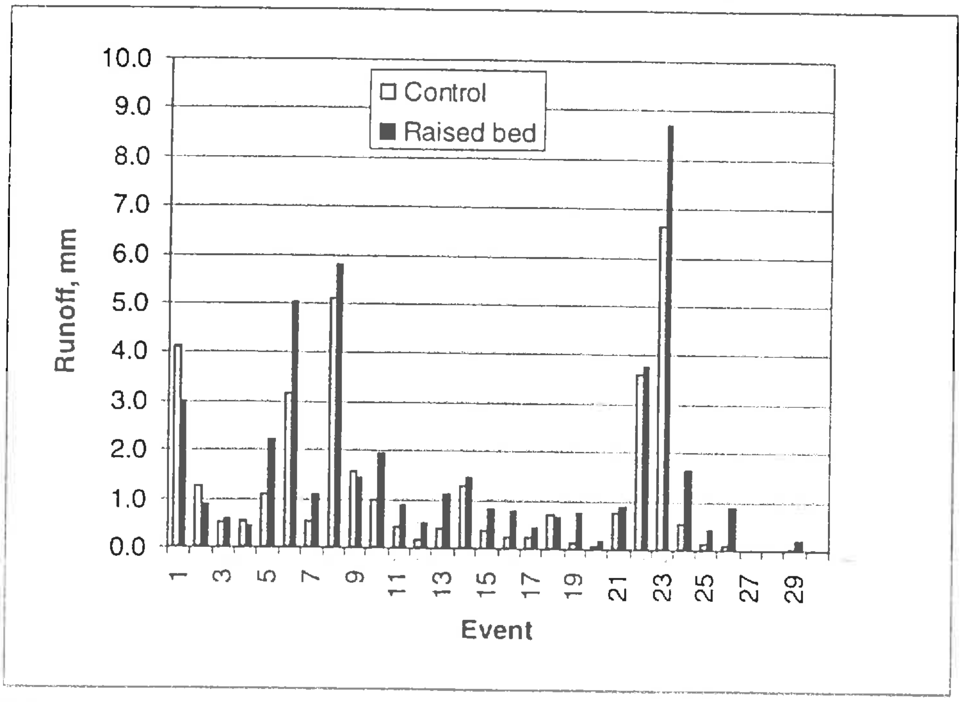

Figure 5. Runoff from the control and the raised bed following various rainfall events.

It was found that on average 25% of the rain disappeared from the control plots and 33% from the raised beds in the form of run off and seepage. These figures from the control correspond with data presented by Cox (1988) for interceptor drains in Mount Barker on a similar soil type.

The differences in runoff behaviour (i.e. time of concentration) has to be distilled from the runoff hydrographs from the individual plots. The incremental method of measuring the runoff increases the complexity of the data analysis. A typical pattern of the runoff is presented in Figure 6.

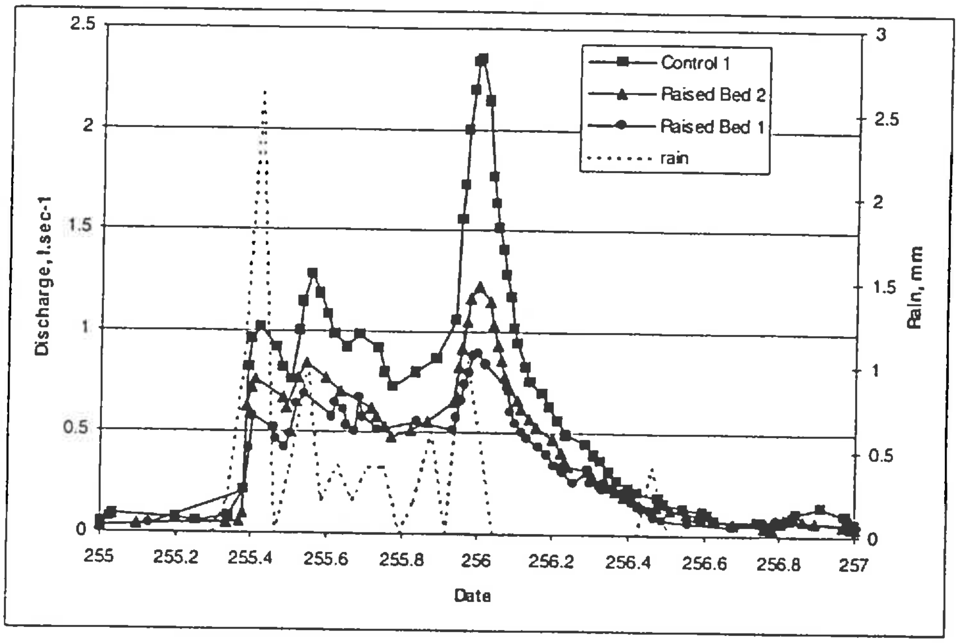

Figure 6. Rainfall and runoff behaviour (discharge over the weir, l/sec) of raised beds and control plots.

There is a delay between the peaks measured from RB1, RB2 and Control1, which is due to the distance between observation points of RB1, RB2 and Control1 (the flow is in the direction: RB>RB2>C1). All three plots show a very rapid rise following rainfall. From the initial data analysis it does not appear that the raised beds behave differently from the control apart from the magnitude of the runoff, but we are still in the process of a more thorough analysis of the data using HYDSYS, a hydrological data analysis package.

CONCLUSION

From the TDR observations it is concluded that the raised beds remain unsaturated in the top 10 cm of the centre of the beds while the control experienced extended periods of water logging during the same period. Equal amounts of soil moisture were depleted between 17/09 and 27/10 but the dry matter increase from the raised beds was substantially higher over that period, indicating that the crop in the raised beds was able to utilize soil moisture more efficiently.

Observations of the perched water table indicated the lower water table in raised beds, during August and September. Given the positive correlation between yield and average depth to the water table (Bakker and Hamilton, 1998), it can be concluded that raised beds can play a major role in the South West of WA in achieving maximum yields on waterlog-prone land.

From the observations of the weirs, it was found that the raised beds had a higher percentage rainfall runoff (33%) than the control (25%). The yield in the raised beds was substantially higher (2.76T/ha) than the control (2.26 T/ha) (Bakker and Hamilton, 1998), it can therefore be concluded that the raised beds made more efficient use of the soil moisture than the control. Provided the evapotranspiration term has been similar for both treatments, it can be concluded from the above that the closing term in the water balance, the deep drainage, has been higher in the control. Apart from an increase in yield, the use of raised beds will have therefore also a beneficial impact on the reduction of the recharge of the ground water system.

ACKNOWLEDGEMENT

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Erosion control in southern Queensland - experiences and the future developments.

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Introduction

Conservation tillage systems have provided an effective set of practices to greatly reduce soil erosion. These systems have generally been applied within soil conservation earthworks such as contour banks and waterways in upland situations or as part of a strip cropping layout in flood plains. Improvements in fallow water storage also provide improved yields and with declining costs of key herbicides, the relative cost of mechanical cultivation have risen compared to chemical weed control. In general, conservation cropping systems make better use of rainfall and maintain soil in place and in better condition. The main questions we have relating to controlled traffic are; what are the extra benefits to a) machinery efficiency and b) soil management and yield and c) soil erosion control.

Broad acre developments in control traffic have been initiated in central Queensland (the traffic triplets -Yule, Chapman and Cannon), with the longer term research based mainly at Gatton campus (Tullberg et al). Controlled traffic promises to improve farm machinery efficiency, efficacy of herbicides, and through zonal tillage, improved soil conditions. Fine tuning of farming systems involving confining machinery to specific tracks offers improved efficiency in operations, reduced soil compaction and better root growth. Potential savings in energy use appear large, and farmers are adopting elements of this technology rapidly. Experimental results are highly variable both in magnitude and direction of responses to tillage treatments. This variation is probably due to different seasonal conditions, operators, crop and soil type. Early results show that yields may be improved, although the weight of evidence is not yet strong. It appears to us that controlled traffic has sufficient benefits to be justified without a yield bonus.

The concept of up and down cultivation has raised some questions about the relative erosion control benefits compared to "contour' based conservation tillage systems. It appears to us that we often compare the worst system with the very best, thus not attributing incremental benefits where they belong. It is proposed to trail alternative tillage systems at the farm scale with farmers and agencies being co-researchers. In the end, hard evidence will be needed to justify any sustained revolution in agricultural practice.

The contour bank story

Adoption of contour or graded banks as a means to reduce slope length and control runoff water has been well accepted by farmers for more than 60 years. These hydraulic structures have been constructed at considerable expense by farmers even though their presence often entails reduced cultivation efficiency with cultivation time increases due to smaller blocks and extra overlap in corners and cut outs.

What happens when the big storms occur?

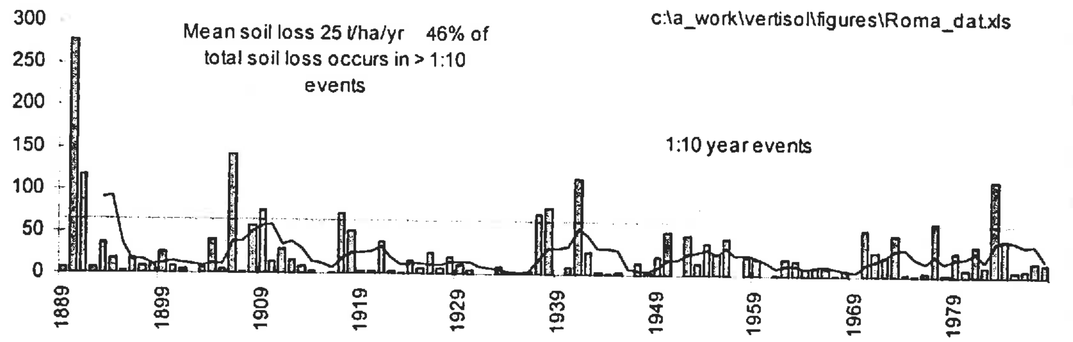
Like all hydraulic structures, contour banks are designed to contain the flow resulting from a specified design storm or runoff event. The normal design criteria for contour banks is that they be able to contain the 1:10 year event (the storm which has a 10% chance of being exceeded in any one year) (Figure 1).

By definition, these structures will fail on average once every 10 years, and in the case of contour banks, when failure of one bank occurs, a cascade of failures further down slope will also occur. Such a failure will result in much of the soil conserving effectiveness of the banks being lost, with concentrated flow often causing severe damage in the form of wide rills and gully initiation. Such failures invariably need ameliorative action soon after the event to avoid further concentrated flow.

Structures are generally constructed to 'over design' standards, but through the life of a structure ie between 'top ups', specifications may be below design standard. The most common reasons for structure failure are; an over design storm occurs, loss of capacity due to cultivation or previous erosion deposition, or self destruction during 'the big storm' due to deposition from a rill, or overtopping of a structure above such as a diversion bank or dam failure.

We would expect that the frequency of over topping would decrease in a controlled traffic system due to a) better stubble cover associated with reduced tillage (not exclusively a CT advantage) and b) better distributed overland flow with less occurrence of self destructive silt fans blocking channel flow.

Figure 1. Time series of estimated annual soil loss in southern Queensland, showing 5 year running mean. Events greater than 1:10 year return period are above the horizontal line. For events larger than 1:10, contour banks are designed to fail.



The stubble story

Retention of crop residues and reduced or no till systems have been adopted to varying degrees across the northern cereal belt. The main drive for this change has been the realisation that better water conservation in fallows can be achieved, and this improvement in water supply for crops results in improved yields, especially in drier growing seasons (Marley and Littler, 1989, 1990; Thomas et al., 1990; Radford et al., 1995, Freebairn et al., 1991). Also, with a decline in the relative cost of glyphosate, a major herbicide for fallow weed control, the economy of chemical weed control has become more favourable. Use of chemicals for weed control still has several challenges - cost, effectiveness of weed control and efficiency of application.

Figure 2 and 3 show the impact of stubble retention on runoff, runoff rates, erosion and sediment load in runoff water. It is clear that stubble has a large effect on the hydrology and sediment movement from agricultural systems. Stubble reduces soil losses by an order of magnitude, and can reduce peak runoff rates by 50%. At this stage it is unclear what down hill cultivation will do to peak flow rates and channel flows.

Figure 2 Influence of soil surface conditions on hydrology and soil erosion from a 6% slope Vertisol on the eastern Darling Downs, Queensland. Tillage treatments referred to are Bare - stubble removed at harvest by burning, Incorporated - stubble partly buried by disc tillage, Mulch - stubble retained on the surface using 1 m sweeps, and Zero till - weed control by chemicals, no tillage. Average soil cover is shown in brackets.

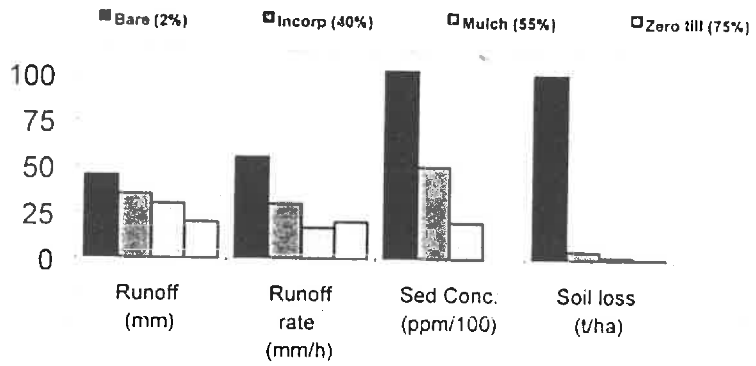
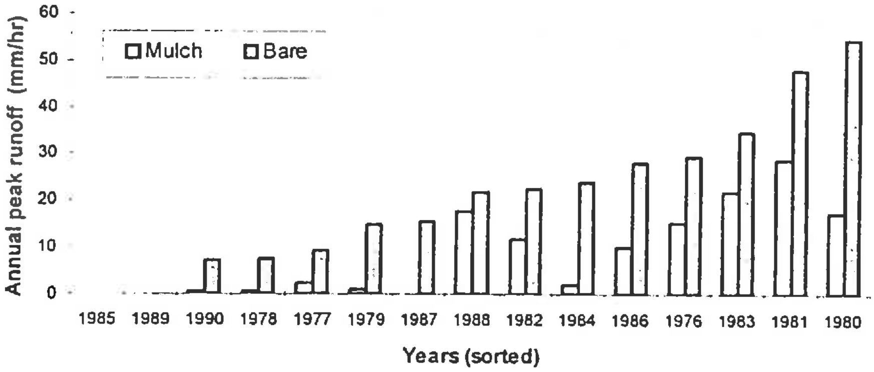


Figure 3 Series of annual peak runoff values from 1.2 ha catchments with two tillage treatment; winter wheat and stubble burnt after harvest in November - *bare fallow*; and winter wheat with stubble retained on the surface with sweep tillage - *stubble mulch*, for the period 1976 - 1990. The maximum peak runoff from the conservation tillage catchment is 50% of that from the bare fallow - when combined with a 10 fold reduction in soil movement, enables soil conservation structures to withstand greater than 1:10 year deign storms.



Modifying slope and slope length

Slope can be managed in some cropping systems where there is control of the direction of runoff. Row crops are one such case where each row carries all the water from its own 'catchment'. Within the limits of practicality, slope can be modified by a scheme similar to that shown in Figure 4. By running furrows oblique to the slope, slope is reduced while slope length may be increased. The main consideration is that each furrow is capable of carrying its own water without overtopping, hence the two systems will perform in a similar manner. One advantage of the oblique furrows is that when erosion does occur, sediment is deposited evenly along the interception channel (contour bank) thus reducing the chance of self-destructing silt fans which reduce channel capacity and cause the structure to fail. A simple empirical model such as the Universal Soil Loss Equation (USLE) can be used to determine whether the risks of erosion are reduced sufficiently to justify the change in tillage layout.

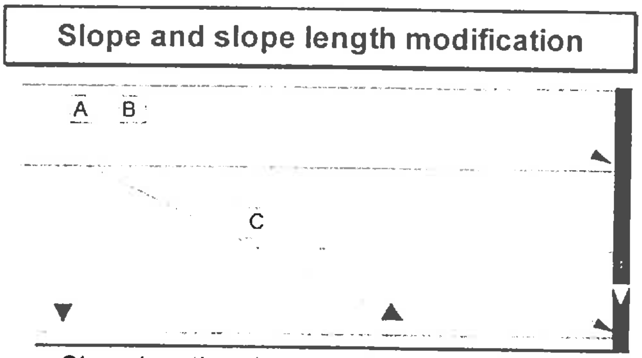
It remains to be determined whether cultivation down slope in a stubble system results in acceptable soil losses in all environments.

Controlled traffic so far?

Tullberg (1995) started exploring the possibilities of energy and time improvements associated with confining wheel traffic to alleys in the early 1980's. His team also are investigating whether there are improvements in soil conditions as a result of removal of tractor wheel loads and compaction. Yule (1995) and Chapman et al., (1995) began developing with farmers, practical approaches to implementing controlled traffic on broad acre farms in central Queensland. His team put forward the proposition that tillage could be oriented with the slope as long as the field was managed with maximum crop or crop residue cover. This approach has the following attributes; by confining runoff flow to single cultivation furrows, catchment size between contour banks rarely exceeds the slope length by one row width (100 m^2). This is considerably smaller than 'rill" catchments which may collect 30-50 m width of water with a slope length of 100-150 m at 1-2% slope (3000 -7500 m^2), sufficient to generate enough erosive power to cut significant rills (> 20 cm depth) regardless of surface cover (Yule, Cannon and Chapman, personal communication). The spreading of water prevents rilling and associated sediment deposits from creating "failure" points in graded or contour channels. Visual evidence after large storm events (> 1 in 10 year return period) suggest that this system is much more resilient than the traditional "contour" cultivation, although anecdotal evidence in southern Queensland suggests that rilling may be exacerbated by down hill cultivation. Ziebath and Tullberg (1995) showed that a trafficked micro catchment yielded considerably more runoff (30-60 mm) than an un-trafficked area over a one month period of above average rainfall.

Additional benefits of controlled traffic can be more efficient tillage and spray operations (10-20% saving in overlap), ability to apply chemicals sooner after rain and at night (lower temperatures → lower chemical rates and more efficacious), lower tractor draft requirement (Tullberg, 1995),

Figure 4. Slope and slope length can be modified by soil conservation structures and tillage/planting direction in a row crop situation. Case A is before any water control structures have been constructed, Case B is when the paddock is divided into three units by banks, and Case C is where slope has been reduced by oblique cultivation furrows. Note that slope length increased in C, but slope was reduced, reducing the erosivity of the layout, according to the USLE LS relationships (Wischmeier and Smith, 1978).



Slope length configuration	*Length (m)*	*Slope (%)*	*Slope length factor*
A	150	5	1.19
B	50	5	0.69
C	150	2	0.33

compaction confined to wheel tracts where it is needed, and eliminated or reduced from where crops are grown, and more timely operations (spraying, planting) because of a firmer traffic zone. Benefits above are not always expressed in yield improvements (Yule and Tullberg, 1995), although Ziebath and Tullberg (1995) have found consistent yield advantages on a clay loam near Gatton.

Regardless of the scientific details, farmers in some areas are adopting controlled traffic as a means of applying no till principles in a practical and efficient system of farming. While there are some issues as to the generality of applying down slope cultivation, it is fair to say that scientific and farmer interest is high in this relatively new development.

Erosion and controlled traffic -how we are going about filling the knowledge gaps

Focus groups with farmers on the central Downs (Meandarra, Condamine) (Peterson and Neale) found that farmers were interested in the concepts of controlled traffic, but were wary of some perceived evangelical messages. A common statement made was " we want well researched facts to base changes in practices upon". While the concepts of controlled traffic were accepted by some, even the keenest farmers indicated that they would not cultivate down the slope wherever they had contour banks. This suggests that they would only try controlled traffic layouts on their low slope areas. These farmers had observed rills cutting back from the steep cut slope immediately above the contour channel.

To address some of the areas where we appear to have differing opinions, we are setting up simple experiments on a number of farms. The aim is to compare at least two contrasting practices and observe relative soil losses, machinery efficiency and any other issues that may evolve. An ideal setup is to have contour bay catchments either side of a waterway, where one side is cultivated as normal, and the other cultivated/planted down the slope. The level of instrumentation will be determined by what farmers and scientists want to get out of the exercise. It is our belief that by testing the issues on farm, at real farm scale with farmers applying the treatments, that we can learn most effectively. We are confident that the basis of science - objective observation, will provide useful insights. We do not expect to be able to detect yield difference in such large area comparisons.

To accompany this broad scale research, a number of scenarios can be examined by simulating runoff conditions using rainfall simulators and water flow, run on experiments. Computer models can also be used to explore the hydraulic consequences of changing flow regimes. We currently have the ability to simulate changes in soil structure (compaction, soil surface sealing) on water balance and grain production (Connolly, 1998). By employing these tools and experiments, our confidence in and knowledge of the implications of controlled traffic will grow. While this may seem a cautious appoach to those who are already adopting controlled traffic, it must be remembered that not all approaches work everywhere. It is the responsibility of science to provide support for improved practice, and hopefully with this better understanding, we can implement improvements more effectively.

How much soil is lost from a paddock when erosion occurs ?

The following section is included to provide some perspective on the relative impacts of different erosion control measured. Long term records of hydrology and erosion are difficult to find -at best we can muster up to 14 years of detailed erosion data at one site but most sites have less than 10 years; insufficient is we are considering design criteria in 10 to 50 year recurrence interval range. To examine how much soil erosion might occur during the so called over design events (>1:10) we used the PERFECT cropping system model to stretch our data base from a relatively short experimental period of 10^{+} years to 100 years (the period of available climate record). (Figure 1). Nearly half the soil loss occurs in the 'big' events where banks are likely to fail, especially if sediment loads are high.

Table 1 shows estimates of relative erosion for a range of configurations. Some of these numbers are estimates based on USLE relationships, model analysis and measured soil loss. Catchment studies have shown that the amount of soil lost from a paddock via contour banks and a grassed waterway can range from 10% to 50% of soil movement to the contour channel, depending on soil type and the relative slope between land slope and channel slope. The question mark for controlled traffic reflects our lack of experience

Table 1. Estimated relative soil movement from a range of conditions, based on measured soil loss from the eastern Darling Downs and predictions using a cropping system model. (+ indicates that the estimate is conservative and may be larger).

	Loss from a cultivated plane with no contour banks	Loss from a paddock with contour banks
No contour banks, no stubble	100+	
Contour banks alone, no stubble		55+
Stubble alone, no contour banks	10+	2+
Contour banks and stubble		2
Contour banks, stubble, controlled traffic down slope		?

Assumption 10 - 50 % of eroded soil is lost from paddock, with contour banks - 20%

Assets and liabilities statement

As a summary of the key features of conservation tillage and controlled traffic systems, Table 2. compares a number of attributes of two contrasting systems. While figures used as semi-quantitative, they are presented to give an idea of key elements of these scenarios. Magnitude of values need to be customised for each location, soil type and cropping system.

Successful farming is about getting all the important elements together in a system. Since there is often considerable interaction between factors in a natural system, it is generally very challenging to sort out exactly what element is producing what improvement. Traditional scientific methos tries to isolate each factor, but this approach risks missing out on the synergies between factors. The challenge is for us to exploit those factors that give us the greatest return.

Table 2. Assets and liabilities for two contrasting tillage systems

	Frequent tillage	*Reduce/no tillage/controlled traffic*
Runoff	10% rainfall	
Fallow water storage	20% fallow rain	25% fallow rain (extra 25-50 mm)
Erosion (eg 60m slope at 6%slope)	40 t/ha.yr poor management	< 5 t/ha/yr
Contour bank failure	1 in 10 years	less than 1 in 30-50 years
Soil nitrate at planting		10-20 kg/ha less NO_3-N
Yield - water supply	higher in wet years due to better N supply	100-400 kg/ha extra in dry year
- water use efficiency		10% extra yield potential in controlled traffic -less compaction
Protein		lower protein in high yield season
Fuel	67 L distillate/ha (conventional tillage)	46 L distillate/ha (minimum till) 20-40% fuel saving with controlled traffic
Fertiliser	long term- crop export replacement	an extra 10-20 kg/ha N
Herbicide input	in crop only	incrop + 2- 5 x 1L/ha glyphosate + other
Area cultivated	overlap high (10-20%)	Controlled traffic 10-20% less area
Timeliness	wait for soil to dry after rain longer	timely spraying and planting
Machinery	no machinery changes	modifications may be needed
Earthworks -construction of broad based contour banks	required if not existing, but at lower cost	*broad based* banks essential if not existing
Repair of contour banks	at least every 5 years on average	much less frequently, possible once every 10-20 years
Diseases -soil and foliar	least	more likely

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LESSONS LEARNED IN THE ART OF LAYING OUT PERMANENT RAISED BEDS

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Introduction

The adoption of raised bed systems in dryland agricultural areas is in its infancy in Western Australia. In 1997, the first demonstration trials of any size were installed, following a successful trial in 1996 of a 2ha area. The five sites installed in 1997 range in size from 2ha to 16ha. Each is situated on a section of landscape that is effectively planar. None of the difficulties of laying out a system of permanent raised beds on slopes which vary in three dimensions was encountered.

Whilst the avoidance of such complexities was deliberate in our first year, we were aware that such challenges had to be confronted and, if possible, solved in advance through the formulation of strategies to overcome them. The experience of Victorian and Queensland dryland farmers has helped in both regards.

We had hoped to enlarge our program in 1998 to include realistically large areas (>50ha) in three contrasting landscape-soil type-rainfall regimes. These were to be at Toolibin east of Narrogin, on a flat (<1% slope), waterlog-prone ancient floodplain, at Coyrecup east of Katanning, on a convex hilltop with varying slope (1-3%), and at South Stirlings, north east of Albany on a subtlely convoluted but flat landscape(<1% - 2%). Clearing roots and stumps from the first and waterlogging at the last of these sites allowed only the Toolibin site to be installed in 1998. This paper records the lessons learned from our experience at Toolibin.

Principles

Whilst effectively embarking on a process of learning-by-doing, we identified a number of principles to guide what was to be done and how it would be done. These are:

1. The layout of beds and associated drains, waterways and dams must allow farming operations to be done with ease, and the maximum possible proportion of croppable land should be retained.

2. Furrows between beds should always drain: They should not pond water.

3. Wherever possible, cross-drains installed to remove water from localised hollows should be contained within the area of raised beds by emptying them into other furrows lower in the catchment. The furrows between raised beds should be used as a network of safe disposal channels.

4. Any drains built to conduct runoff and drainage should be of sufficient capacity to drain the water they catch at a velocity equal to or greater than the that of inflow from furrows and drains leading into them.

5. Drainage water should, wherever possible, be stored for re-use on the land/property from which it came.

6. Any drainage water leaving the area/property should remain in the catchment from which it originates.

7. Ideally, the number of beds constructed should be equal a number of complete passes of seeding, spraying and harvesting equipment.

Lessons learned

Surveying

Beds and drains need to be laid out on the existing land surface

Given the reality in WA that topsoils are shallow and the subsoils are dense, impermeable and dispersible, landplaining would expose too large an area of this infertile soil. It would be too costly and counter-productive. The best strategy is therefore to rip to a common depth (20 cm) and mix the topsoil with any subsoil brought up in this operation. This is more likely to enhance the properties of the mixed layer over those of the separate layers.

Furrows need to drain completely

As the intent of permanent raised beds is to prevent waterlogging, it is necessary to ensure the furrows drain completely. Ponding in the furrows will create or illustrate the presence of a perched water table at the same height within the beds. When soil saturates it has no strength. It collapses under its own weight. The consequence of ponding in furrows will thus be slumped beds which have none of the macroporosity required for them to drain and aerate. Slumped beds will therefore be ineffective in preventing waterlogging.

Surveying needs to be intensive and accurate

Surveying needs to be undertaken at an intensity which ensures any minor changes in slope direction are detected (i.e. elevation changes of ≤ 10 cm). A contour map generated with this amount of detail will identify the need and best location for cross-drains.

Intensive and accurate surveys should be sufficient to plot at least 10 cm contours. Our experience at Toolibin required the intensity of a 50m x 20m grid. We used a differential Global Positioning System (GPS) and a laser level. This equipment is probably the least sophisticated technology capable of undertaking the task at a reasonable cost. More sophisticated survey equipment, such as a GPS-Glonass surveying system can be bought for around $ 70,000 or hired for a fee of $ 500/day, and this includes software to print detailed contour maps. Our survey data were put into a mapping program which produced a map with 5cm contours (Figure 1.).

Orientation of Raised Beds

Landscape slope direction Vs that which is operationally efficient

Because the landscape slope at Toolibin runs East to West and the paddock has a large open drain on the southern and western boundaries (Figure 1.), the obvious choice for the direction of the beds was E-W. This would ensure the machinery passes were long and the amount of turning was minimal.

However, with a slope of 0.14% the greater concern was the removal of water. The low slope dictated that the raised beds be orientated in the direction of the landscape slope, which ,fortuitously, was also E-W. This orientation also ensured the beds and furrows required only a small amount of cross drainage.

Had the considerations of operational efficiency and drainage direction been in conflict, consultation with the farmer would probably have resulted in a decision in favour of operational efficiency. Operationally inefficient layouts of raised beds will raise input costs every time a paddock is cropped, whereas any extra drainage costs incurred to maximise operational efficiency will be incurred only once.

Drain installation

Drains need to be installed first

In the Western Australian conditions of shallow topsoils and clayey and infertile subsoils, the installation of drains before any preparatory work is done for raised beds provides the opportunity for spoil from drain excavation to be spread and cultivated into the ripped and cultivated soil that will form the raised beds. Such homogenisation diminishes the risk of particularly unproductive areas of subsoil spoil causing poor plant growth which would make beds less effective than they would otherwise be.

Drains need to be in a form compatible with machinery and erosion control

a) Cross drains within raised bed runs

Good drain design and construction dictates the *batters of drains have slopes of ≤ 1:6.* This ensures that machinery can drive through them easily and they can grow crop or pasture without an excessive risk of erosion. Our experience is that a batter grade should not exceed this slope. With a drain depth of 40 cm, a need for which can easily arise, the slope length of a 1:6 batter is 2.43m, which is less than the length of a tractor let alone one with a toolbar on its 3-point linkage.

Good drain design and construction also dictate the channel floor be wide in order to provide a large flow capacity at non-erosive velocities. In addition, ease, and thus quality, of machinery operation dictates the *channel width should be about the length of a tractor wheel base, i.e. 3m.*

Drains at angles other than 90° to the direction of the beds cause pitch and roll of machinery, particularly 3-point linkage equipment.. This phenomenon is further exacerbated if the drains have a triangular cross-section (i.e. a narrow channel floor). In our case, the weight and width the furrower-bed-former and seeder bars, both of which are carried on 3-point linkage, means the elimination of pitch and roll as machinery enters drains is essential to minimise machinery maintenance and maintain good operational standards. *Drains should be oriented at or close to an angle of 90° to the direction of beds.*

b) Drains at the end of raised beds

The same lessons apply at the ends of raised beds as for drains within beds. However, other considerations come into play here. The end of beds become headlands on which all farm traffic must turn or operate. These headlands need to be wide enough for machinery used for bed construction, seeding, spraying and harvesting to easily turn and operate. At the upslope end of the beds there may not be a drain, in which case only turning space considerations are relevant. At the downslope end drains need to have at least the minimum requirements mentioned above, with some enlargement in flow capacity to carry the accumulated outflow of furrows and/or feeder drains. *The width of the channel floor and batters of end-drains should be compatible with the width of seeder, boom sprays and harvesters*, so crops can be easily grown on them.

Conclusions

- Accurate contour maps, with contours at 5cm or 10cm vertical intervals, are a prerequisite for achieving operational efficiency and effective layouts of raised beds to drain waterlog-prone land.
- Operationally efficient areas of raised beds require: smart drain location; hydraulic design of drains which accounts for machinery dimensions; orientation of drains at angles close to 90°to the direction of beds; and good earthwork construction standards.

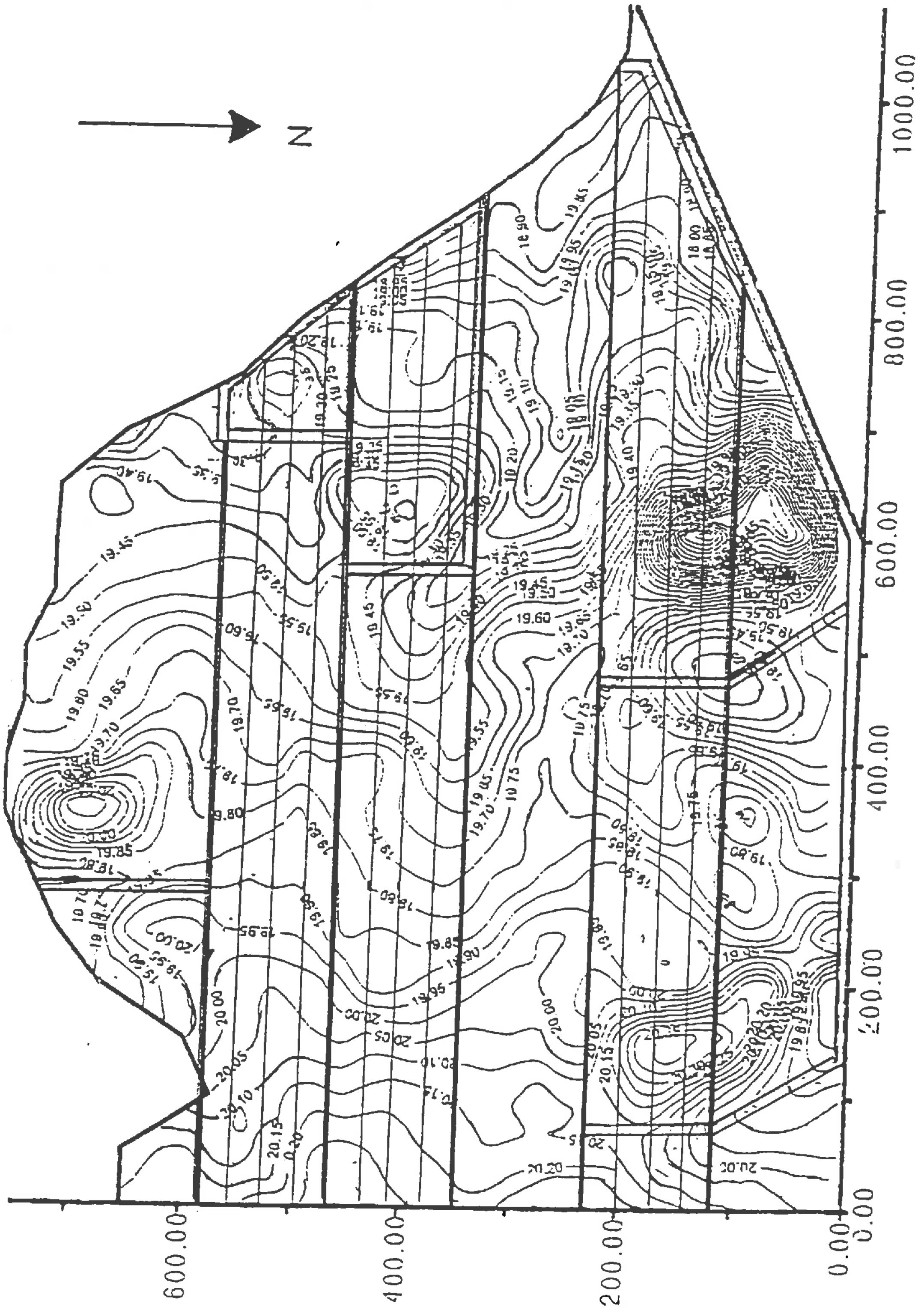

Figure 1. Contour map of the Raised Bed demonstration at Toolibin. Note the low slope and the cross-drains at angles approaching 90° to the direction of the beds. Major collection drains run along the northern and southern edges and join to leave the paddock in the north west corner.

SPECIFICATIONS FOR ENGINEERING A DRAINED AND AERATED ROOT ZONE TO PREVENT WATERLOGGING

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Introduction

Broad scale studies (Anon. 1989 & McFarlane et al., 1992) indicate that seasonal waterlogging is an extensive and costly problem in the western and southern sections of the WA agricultural area. These studies have estimated that 1 million hectares are affected in a 'wet' year, with an attendant loss of income worth $ 156 million.

Simulation modelling is perhaps the best way to improve our understanding of complex systems where the consequences are either unforeseen or poorly understood. Such modelling, however, can only provide new perspectives on a problem, it cannot solve the problem. Experience has shown that, when models are based on fundamental mechanisms, the perspectives produced often identify very good directions for research and thus hasten the development of improved soil and water management practices (Hillel, 1977).

Our objectives in undertaking this modelling exercise were to:-

a) study the waterlogging process to:
   - gain a better appreciation of the extent of agricultural land and the prone to waterlogging;
   - obtain the basis for an improved costing of production lost from waterlogging;
   - generate a capacity to predict the occurrence of waterlogging for given soils and locations; and
   - identify the better treatments to control waterlogging:

b) study the drainage process to:
   - understand what soil conditions and drain spacings would be required to prevent waterlogging;
   - assess whether the requisite conditions were practically achievable.

In addition, the literature on soil management was reviewed to identify those practices capable of creating and maintaining the soil conditions required for drainage and the prevention of waterlogging

This paper outlines the analyses undertaken and the root zone specifications needed for waterlogging to be prevented on texture contrast soils in Western Australia.

Methods

a) Waterlogging modelling

A one-dimensional daily water balance model was constructed in which the key assumptions are:

- Waterlogging occurs at air-filled pore space < 8% (Wesseling, p. 18 *In* van Schilfgaarde 1974).]
- Drainage to the groundwater system is effectively zero.
- When the A-horizon reaches a moisture content of 0.20 mm^3/mm^3, water drains into the B-horizon at 1 mm/day until a recharge of 20 mm is reached.
- Infiltrating rainfall redistributes in a 24 hr period
- All rain infiltrates up to the total absorption capacity of the soil profile.
- Maximum water absorption capacity of the A-horizon is its total porosity minus 0.03 mm^3/mm^3 entrapped air, plus 5 mm surface detention. A-horizon bulk density is 1.5 g/cm^3.

- All rain in excess of this storage capacity is assumed to runoff.
- Potential evaporation from a wet soil is $0.8E_{pan}$.
- Bare soil evaporation applies until August 31. Thereafter transpiration rates are adjusted relative to soil moisture content and E_{pan}, according to the Denmead & Shaw relationship (1962).

Bare soil evaporation was calculated by the equation of Gardner and Hillel (1972) using a diffusivity function derived from Hillel (1977, pp. 81, 83 & 84). This equation is

$$E_{soil} = \frac{D(\theta) . \theta_{zw} . \pi^2}{4 Z_w}$$

where: E_{soil} is bare soil evaporation *(mm/day)*; $D(\theta)$ is soil-water diffusivity relationship *(mm²/day)*; θ_{zw} is the average soil-water content of the A-horizon *(mm³/mm³)* and Z_w is A-horizon depth *(mm)*.

Historical rainfall and pan evaporation data have been used, from 1907 to 1996. The model was run for:

(a) *sand over clay soils* with 100 mm, 200 mm and 300 mm depths of A-horizon; and
(b) *loam over clay soils* with 100 mm, 200 mm and 300 mm depths of A-horizon, for
(c) 33 locations in the southern and western agricultural area of WA.

The frequency of waterlogging on a given day of the year for particular soil types and locations is derived from this analysis. The model also predicts daily changes in soil-water content.

b) Drainage modelling

The Glover equation (van Schilfgaarde, 1974) was used to predict the time taken for a water table (WT) to fall a given distance for the range of soil conditions and drain spacings presented in Table 1, where:

$$t = \frac{L^2 . f_d . \ln [4m_o/\pi . m]}{\pi^2 . K . D}$$

and: t = time (h); L = distance between drains (m); f_d = fractional drainable porosity; m_o = mid-point of initial water table height (cm); m = final midpoint height of water table (cm); K = saturated hydraulic conductivity (cm/h); D = average initial depth of water table to be drained (cm).

Table 1. Soil properties and drain spacings/bed widths used in drainage calculations

Soil property/drain dimensions	Unimproved soil	Improved soil
Bulk density	1,500 kg/m³	1,400 kg/m³
Drainable porosity at - 10 cm suction	0.01	0.05
- 20 cm suction	0.01	0.05
Saturated hydraulic conductivity	20 mm/h	50 mm/h
Bed heights	12 cm	13 cm
	24 cm	26 cm
Drain spacing/Bed widths	1.5 m	1.5 m
	2.0 m	2.0 m
	3.0 m	3.0 m
	10.0 m	10 .0 m

Results

The waterlogging model illustrates the dramatic effect of individual rainfall events on soil moisture content, particularly when evaporation is low. When evaporation is between 1mm & 2mm/day, waterlogging is determined by the amount of rainfall and the number of wet days per month, which average 15 days or more in June, July and August. Waterlogging frequency does not decline until September-October when evaporation increases and rainfall decreases (Figure 1.).

The historical frequencies of daily waterlogging on varied soil types (Figures 2) illustrate that (i) shallow A-horizon soils are highly prone to waterlogging in the WA winter; (ii) soils with deeper A-horizons are *marginally* less prone to waterlogging; (iii) the frequency and duration of waterlogging is less in drier sections of the agricultural area; (iv) there is little difference in waterlogging frequency between sand and loam topsoils.

Maps of isolines of daily frequency of waterlogging for the south west section of the agricultural area illustrate (Figure 3.) that June, July and August are the most prone to waterlogging, with July having the highest frequency. These modelling results, when overlain by soil maps of shallow texture contrast soils clearly illustrate that very large sections of the agriculture area are regularly affected by waterlogging.

The results of the drainage analyses (Figure 4.) show that when a 2 day drainage time is used as the minimum time to lower a water table, soil in poor condition requires drains spaced at ~ 1.5 m apart: for soil in good condition, drains may be spaced at ~ 4 m.

Of greater importance, however, is the fact that although the water table may have fallen the required distance, the small drainable porosity does not provide enough air space for plants to avoid suffer the physiological stresses of waterlogging - the soil remains saturated by capillary forces.

A review of published R&D work on the soil physical benefits of no-tillage practices (Table 2.) indicates that the hydraulic conductivity and aeration properties required for water tables to drain rapidly and aerate the soil can be achieved.

Table 2. Changes in soil properties with no-tillage practices

Location, soil physical properties	Source (ref.)	Duration (years)	Tillage practice: District practice	Tillage practice: No-tillage
Ginninderra, ACT	6.	8		
• Hydraulic conductivity (mm/h)			16	54
• Total Porosity (%)			47	54
Tatura, VIC	1.	6		
• Macropores (%)			3	15
Cowra, NSW	9.	6		
• Hydraulic conductivity (mm/h)			14	65
• Total porosity			37	43
Grafton, NSW	5.	14		
• Hydraulic conductivity (mm/h)			28	187
• Total porosity (%)			47	54
• Macroporosity (%)			12	15

Conclusions

- Deepening the topsoil by whatever method may diminish waterlogging in the short term, but without drainage to maintain unsaturated conditions, loosened soil will quickly subside and approach the original, dense waterlog-prone condition.
- Without tillage and traffic, no-tillage crop establishment can create and maintain good soil physical conditions.
- Soil in good condition can have drains spaced as wide as 4 m apart and still avoid waterlogging. In these circumstances machinery track widths can be the determinant of drain spacing.
- Tractors, being the major implement with the narrowest track width mostly determine drain spacing. Commonly this is 1.8 m or 2.0 m.
- Assuming crop rotations allow sustainable and good weed and disease control, it is possible to engineer root zones that will prevent waterlogging.

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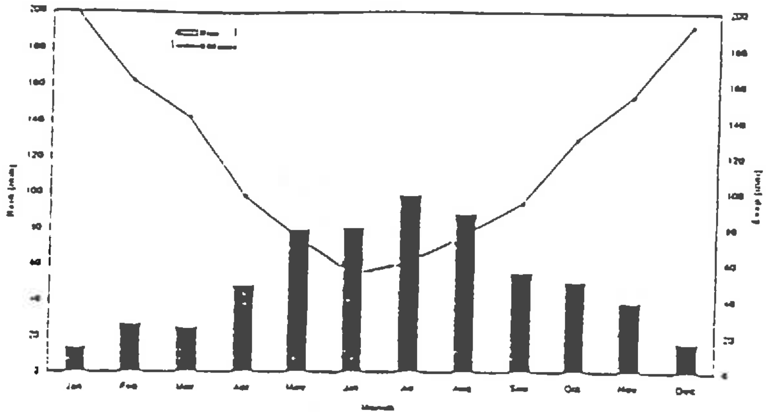
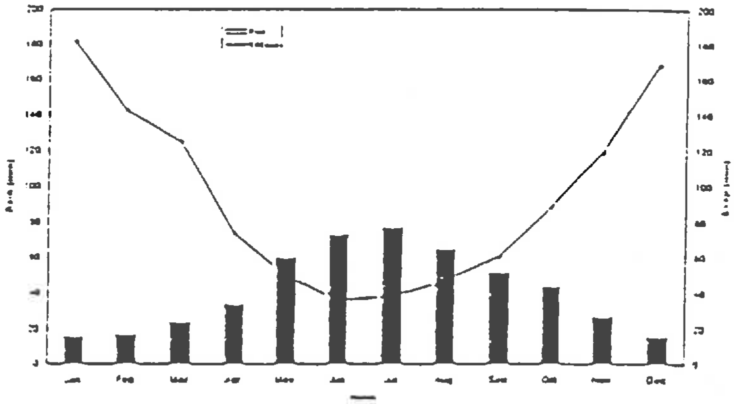
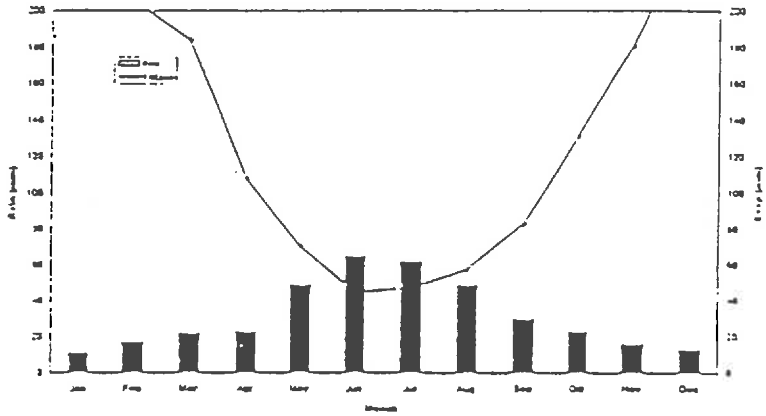
a) Esperance



b) Cranbrook



c) Corrigin



d) Wagin

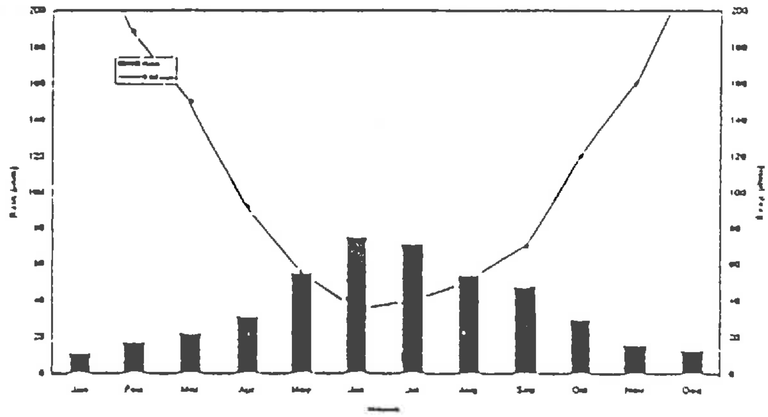


Figure 1. *Long term average rainfall and (0.8) pan evaporation data illustrating the coincidence of winter dominant rainfall with the winter trough of evaporation. The locations shown and the amount of excess rain over evaporation at each site are: (a) Esperance - 80 mm; (b) Cranbrook - 103mm; (c) Corrigin - 35mm; (d) Wagin - 80mm.*

a) Esperance

b) Cranbrook

c) Corrigin

d) Wagin

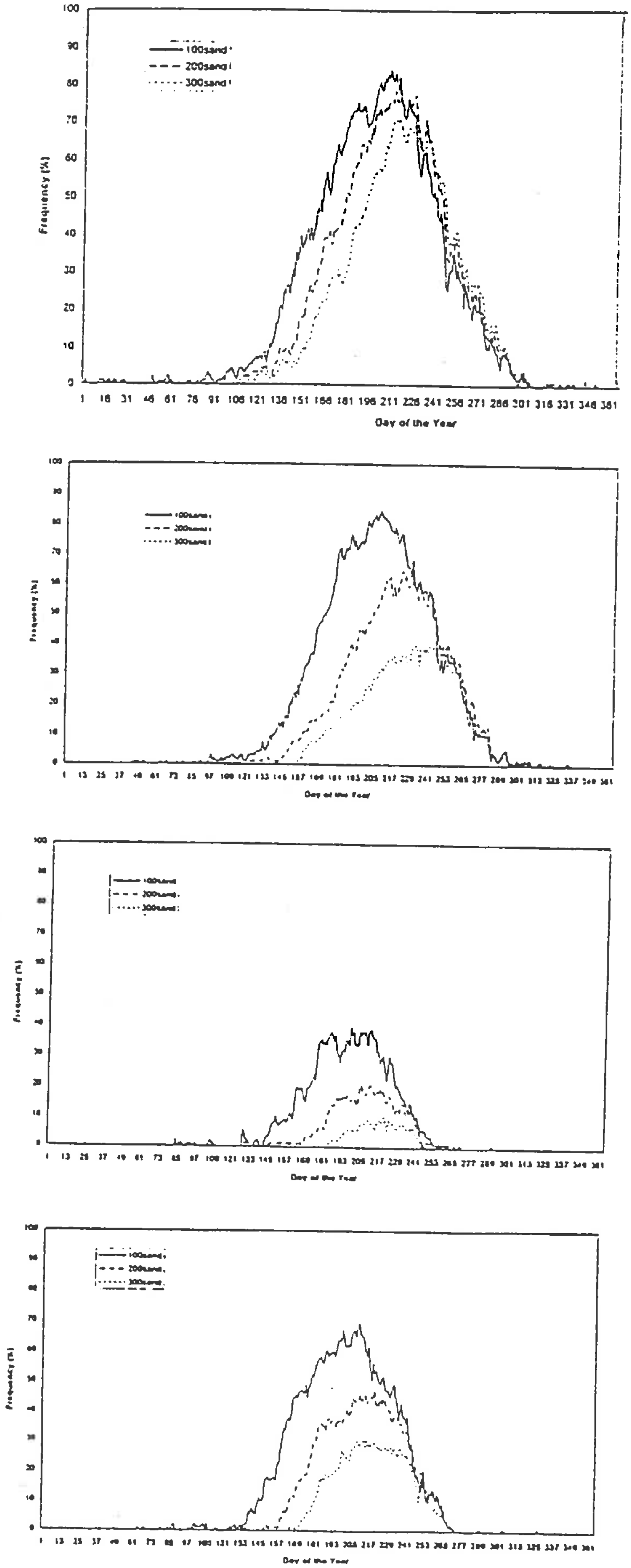


Figure 2. *Predicted daily frequency of waterlogging for sand-over-clay soils with 100mm, 200mm and 300mm depths of sand, for (a) Esperance; (b) Cranbrook; (c) Corrigin; (d) Wagin.*

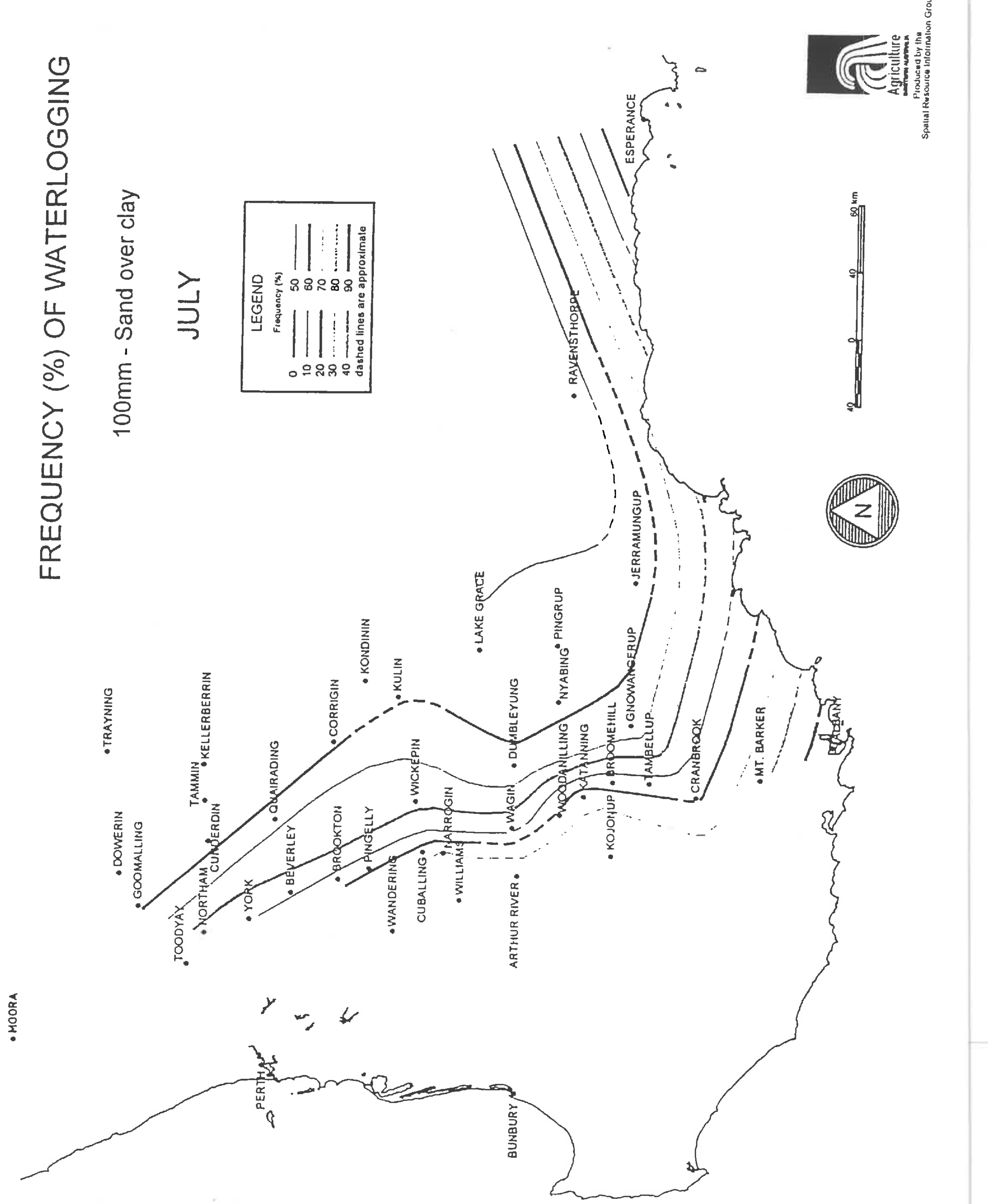


Figure 3. One of a series of maps showing lines of the same frequency of daily waterlogging over much of the WA agricultural area. The data shown are the waterlogging frequency for July 31, for a shallow (100mm) depth of sand-over-clay soil.

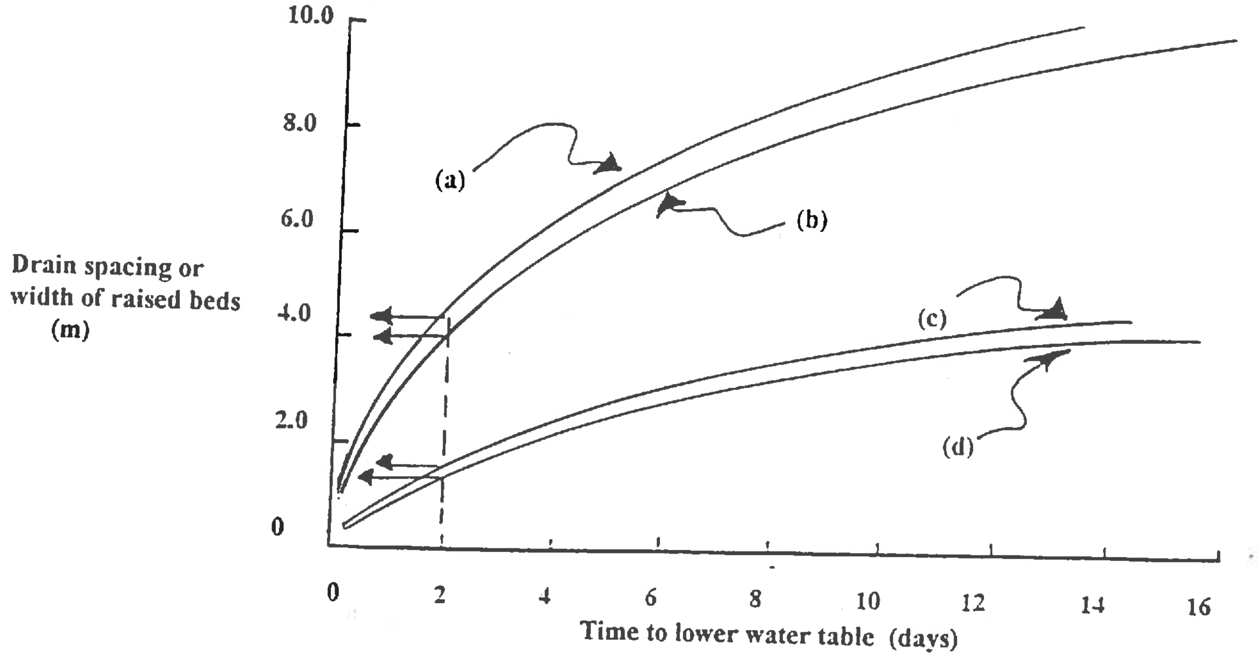


Figure 4. *Relationship between time to lower the water table from the surface of saturated soil and the spacing of drains (or width of raised beds) for: (i) a soil in an improved condition with two bed heights, 13 cm and 26 cm - curves (a) and (b); and (ii) a soil in an unimproved condition with two bed heights, 12 cm and 24 cm - curves (c) and (d).*

WESTERN AUSTRALIAN APPROACH TO THE DEVELOPMENT AND ADOPTION OF PERMANENT RAISED BED FARMING

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Introduction

"Tell me and I'll forget
Show me and I may remember
Involve me and I'll understand"
(Unknown author)

This quotation, the origin of which is unknown, is the maxim by which the raised bed work in Western Australia is being undertaken. It really relates to ownership and the synergy that results when people with a shared vision and complementary expertise work together.

It has and is being applied to all aspects of the work. Beneath it there has been a structured approach which takes account of the stages that both work and individuals must pass through in order to progress:

- awareness
- knowledge of the problem/opportunity
- analysis of the available information
- formulation and testing of potential solutions
- trial and refinement of solutions
- demonstration and reward of success
- encouragement and support - (the provision of expert advice and assistance)

Technology development

Development of the technology to overcome winter waterlogging has gone through the following stages:

- Climatic analysis of rainfall and evaporation patterns for the agricultural area
- Water balance analysis of the soil-climate interaction and an analysis of the frequency and duration of waterlogging throughout the agricultural area
- Drainage analysis of the soil properties and drain spacing needed to drain excess water from soil quickly enough to prevent plants from suffering waterlogging stress
- Review of the soil management R&D literature to establish the feasibility of creating and maintaining the soil properties required to ensure drains work
- Review of eastern states farmer and machinery experience, to establish the practicality of applying the technology to broad area dryland farming
- R&D to test the system of raised beds and soil management practices to create and maintain the required soil properties

- R&D to assess the runoff and groundwater implications of the systems application on a broad scale
- R&D with machinery companies to develop and test machinery suited to the atypically good soil conditions in raised beds at a farm scale and to ensure equipment known to operate successfully on a system of raised beds is available

Adoption

Throughout the work from the beginning of R&D to test the ability of raised beds to prevent waterlogging, farmers have been involved in genuine partnership arrangements in which they literally own the results - the crop yield - since they carry the input costs. Beyond this, they have all been selected for their interest and cooperative nature. This work has involved:

- Paddock scale trials on farmers' properties to demonstrate and involve farmers and their peers in the assessment of the system's success
- Large scale demonstrations on farmers' properties to gain experience with the design and layout of raised beds on a broad scale
- Involvement of farmers and technical staff with the large scale demonstrations, to train infrastructure support services for the initial adopters
- Media releases and field days featuring co-operating farmers
- Display of machinery adaptations at major farm machinery field days
- Encouragement and assistance for farmers prepared to implement a raised bed farming system on their properties
- Investment analysis of the costs and benefits of implementing a raised bed farming system, including cashflow projections over the first 5 - 10 years
- A newsletter informing farmers, machinery dealers and professionals of developments and farmer experience with the system
- Intra and inter-state bus tours of interested and involved farmers

Progress

1996 First successful trial of raised beds. Five year R&D project approved

1997 Four demonstration trials and one research site established. Several farmers expressed intentions to purchase a bed forming machine. Lots of publicity and casual interest. One farmer committed to purchase and adoption

1998 One farmer purchased bed former and achieved good results. Other farmers interested. One more farmer has ordered bed former. Three other farmers committed to large scale demonstrations. One of these is installed. The other two to be installed for the 1999 crop season

Plans

- Tours with interested farmers from other states and within WA
- Talks to farmers initiated by machinery dealers
- Installation of two more large scale demonstrations, and no more beyond this.
- Demonstrate machinery adaptations of bed-former, seeder and harvester
- Set up a newsletter to committed/interested farmers and commercial companies
- Publish investment allowance and encourage farmers to talk to farmers and purchase their own machines

Conclusions

Many farmers have passed the sceptical/disbelieving stage where they sat back and watched the results.

Signs are emerging that quite a number will purchase bed formers and proceed on their own initiative. Efforts will be made to encourage these farmers and assist them to develop their own networks. In addition, training on the layout and design requirements will be undertaken within AgWA to ensure local expertise is available for farmers.

Next year, 1999, ought to see a small number of practising farmers. No doubt these will stimulate further adoption which will increase exponentially.

CHANGE IN SOIL STRUCTURAL FORM ASSOCIATED WITH CONTROLLED TRAFFIC ON A CRACKING CLAY.

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Introduction

Sustainable land use practices must, over the long term, maintain soil structure which is optimum for a range of processes related to crop production and environmental quality. Soil structure is a major influence on the ability of the soil to receive, store and transmit water, to cycle carbon and nutrients, to support and enhance root development, to resist erosion and the dispersal of agricultural chemicals (Kay *et. al.*, 1994). A number of authors have described optimal soil growing conditions for plant growth and linked the various aspects of soil structure to the processes influencing plant growth (Russell, 1977; Russell, 1973). Yet, there are very few mechanised cultural practices that actually optimise soil conditions for long term sustainability and food production. Better than average climactic conditions and or expensive soil amendments have often masked the short comings of a poorly structured soil (Amir, 1994; Gibbs and Reid, 1988). Controlled traffic farming systems (CTFS) appear likely to optimise soil structural characteristics by enhancing form, stability, resilience and by decreasing vulnerability to stress.

Definitions:

- Structural form: The arrangement of solid and void space. Characterised by total porosity, pore size distribution and pore continuity, which determine the availability of water and oxygen and resistance of soil to root penetration.
- Structural Stability: The ability of the soil to retain its arrangement of solid and void space, when exposed to stresses.
- Structural resilience: The ability of the soil to recover its structural form through natural processes when the applied stresses are removed or reduced.
- Structural vulnerability: The inability of the soil to cope with stress.

Structural stability and resilience relate to the dynamic nature of structural form. A structural form that changes in response to stress and natural processes implies a concept of temporal dependence. A cracking clay therefore, given time, may improve its structural form under optimal conditions and seasonal crop growth (Probert *et. al.* 1987; Kay *et. al.* 1994; Pillai-McGarry, U. and McGarry, D., 1996.).

Objective

The objective of this study is to quantify the changes of structural form of a cracking clay after the implementation of a CTFS in a dryland area, previously cropped conventionally for 50 years.

Methodology

The main objective will be achieved by studying;

- The zonal influence and persistence of single and multiple wheeled permanent tracks.
- The change in soil structural form after each planting within each treatment.
- Contrasts between soil structure at implementation of CTFS, at subsequent plantings and in a long term non-trafficked area.

The study is being conducted on two 80m by 12 m blocks. Each block is divided into four beds by permanent tracks at 3m centres. The measurements are taken on the inner two beds while the outer beds act as guards. The soil is a black cracking clay, classified as a vertisol, which is typical of this area and the Darling Downs.

The soils structural form is assessed by; hydraulic conductivity, pore size distribution, bulk density, porosity and soil moisture retention characteristics. Soil data was collected at tl implementation of CTFS and after each subsequent planting of a continuous cereal/legume rotation. Measurements are also being collected from a small fenced area of the same soil type, which has not been trafficked since 1979.

The measurements are taken at depths of 100, 200 and 300 mm, in 3 locations, in track, beside the track and in the centre of the bed. The different treatments are simply the number of wheelings in the tracks. That is, 1 wheeling is applied during both harvesting and planting and subsequent wheelings, 2 and 3, are applied to simulate other operations during the growing season.

Results

The results to date are encouraging, in the sense that the soil structure appeared to be uniformly poor at the outset of this study in terms of visual evidence, and it has visibly improved in this qualitative sense. In terms of quantifiable differences however, the results are less encouraging.

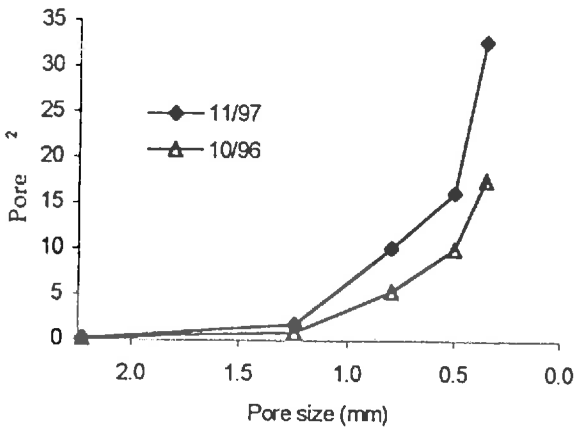

Figure 1. The change in average pore size class distribution to 300mm depth from October 1996 to November 1997

Figure one indicates a slight trend towar' structural regeneration but the results to date are not conclusive. The data in Figure 1 is averaged over the profile depth, however the change in pores/m^2 at 300 mm is more significant when individual depths are compared over time. The trends are similar at all depths and positions, yet there is no discernible difference between treatments. Although the current available data does not provide conclusive results, the effect can be clearly seen. The first two excavations of the Summer of 96 and the Winter of 97, revealed a soil which was virtually structureless and easily smeared. The Summer of 97 pits were a complete contrast, the soil was not as susceptible to smearing and digging was much easier. Roots had penetrated to 300–400 mm, where they had created failure zones, causing the once massive soil to form angular clods. The clods broke away from the pit floor with ease. This makes a most refreshing change to the preparation time of the measuring surfaces of the pit floor. A task, that in the beginning, was measured in days now only takes few hours. The tracks however have remained massive and hard, which is easily discerned in the excavated profile. As expected, large singular, longitudinal cracks form in the tracks, in marked contrast to the fine multiple cracks in the beds. The zonal influence of the track is readily observed in the pit wall, expanding laterally in a bulge under the beds.

Discussion

It is visually apparent that the soil profile is demonstrating its resilience and regaining some structural form. The process, as reported by previous workers, is long term and dependant on a large number of variables such as; climate, biological drilling and shrink swell cycles. (Bridge, *et al.* 1983; Cotching, 1995) It is hoped that this last data set to be taken in September and October 1998 will clearly and quantitatively confirm the direction and extent of the soil regeneration processes over the last 3 years.

In the first two years of the study there were few wetting and drying cycles at depth, much of the self mulching activity was restricted to the surface. This was attributed to unseasonal rain maintaining a full profile and poor soil drainage. Also the roots of the Barley, Wheat and Lab Lab apparently failed to access the moisture in the profile. Since last Summer the rain has been more seasonal, forcing the Lab Lab to forage further. The roots have extended to a depth of 400 mm, leading the way for the soil to recover its structural form.

Conclusion

Given the right climactic conditions a CTFS will allow a cracking clay soil to regain some structural form in a relative short time. Complete regeneration to an optimum state, so that soil processes function efficiently, will take many years, depending on the start point, the amendments used at implementation of CTFS, crop type, soil type and climactic conditions. The act of allowing the soil, plants and animals to live undisturbed, without seasonal destruction of the soil habitat, can save farmers substantially in time and money. The short term gains of reduced inputs are a rewarding step on the way to the long term gain of sustainability.

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COMPACTION EFFECTS ON CROP GROWTH, RUNOFF AND SOIL LOSS

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Abstract

Applied compaction, at varying frequencies and weight, was used to determine the effects on establishment, growth and yield of sorghum, and on runoff and soil loss. This compaction reduced establishment where no rainfall fell immediately after planting, reduced early growth, and significantly reduced grain yield in one of three seasons. Compaction on 15/12/96 doubled runoff and soil loss on 3/1/96. These effects are much more severe than any cropping effects measured. Applied compaction decreased ground cover by more than 50%, with cultivation decreasing it by a further 58%. Farming systems which minimise compaction and maintain high cover levels provide a sustainable future for the dryland grain industry by improving the on-farm and off-farm natural resources while maximising potential grain production.

Introduction

Soil compaction has been estimated to reduce Australia's annual productivity from field crops by $300-850 million (So, 1990), and has been recognised as the most costly form of land degradation in Australia (McGarry, 1993).

Between 1982 and 1986, the area of grain production on the Central Highlands of central Queensland expanded from 250 000 to 512 000 ha, with the area of crop grown since 1986 varying from 222 000 to 518 000 ha, depending on seasonal rainfall (Carroll *et al.*, 1997). McGarry (1990) found compaction in various forms and extents across all soils and cropping systems in this region, with the principle causes being load bearing wheels, tillage tools and animal hooves.

Under conventional farming techniques, field traffic is uncontrolled and often carried out when the soil moisture content is optimum for soil compaction. During one cropping cycle, it has been estimated that over 30% of the field area is trafficked in a zero tillage system, over 60% in a minimum tillage system, and over 100% using conventional tillage practices (Soane *et al.*, 1982; Tullberg, 1990).

Compaction problems and the possible reduction in crop growth and yield are caused by soil water status, intensity and timing of machinery operations, and size and weight of the machinery used. Chamen *et al.*, 1992 and Rusanov, 1991 reported yield responses are variable, and both positive and negative. The interacting effects of climatic conditions (mainly in crop rainfall) and pre-planting wheel traffic on crop yield are discussed by Hakansson *et al.* (1988). Increased yields were obtained in dry conditions, and depressed yields when rainfall was high, on a clay loam soil in Minnesota.

Poor seed germination is often attributed to poor seed-soil contact. This contact may vary with soil water availability and soil hydraulic conductivity (Brown *et al.*, 1996). Tillage operations undertaken to increase the degree of contact may have other adverse effects - aggregate size reduction may increase the vulnerability to soil erosion, while compaction can cause impedance of seedling roots and shoots.

The high variability of rainfall in central Queensland produces insufficient rainfall to plant a crop, or times of very high rainfall causing severe soil erosion (5% of rainfall >100 mm/day) (Carroll *et al.*, 1997). A major concern is that many management practices have an adverse effect on the infiltration of rainfall, and subsequent runoff and soil erosion. For example, significant reductions in macropore volume and continuity can affect soil aeration, infiltration, drainage, water holding capacity, mechanical impedance etc., all of which are known to reduce crop growth (Murray, 1994).

Parker *et al.* (1995) showed that the velocity of runoff water near the soil bed and erosion rates increased as bulk density increased. Soil compaction can decrease or increase erosion by water (Voorhees, 1977), and can produce erosion control benefits and hazards (Voorhees *et al.*, 1979).

In 1994, a study commenced to study the effect of soil compaction on crop growth and yield, and the rate of repair of soil structural degradation using various management options. This paper presents results from the study in terms of the effect of compaction on crop growth, yield, runoff and soil loss.

Materials and Methods

Location and Climate

The experimental site was located on the Queensland Department of Primary Industries Emerald Research Station (latitude 23°29' S., longitude 148°09' E., 190 m a.s.l.), central Queensland. The average ground surface slope was 1.0%. Long term mean annual rainfall is 639 mm with 75% falling in the summer months, and mean annual pan evaporation is 2265 mm.

The soil type was a black cracking clay (Vertosol). The Australian soil classification (Northcote, 1977) is Ug5.12. Particle size distribution in the 0-10 cm depth was 28% sand, 10% silt, and 61% clay.

Treatments and Design

Treatments were first imposed during September, 1994, with the initial compaction treatment applied. Treatment application is described in Rohde and Yule (1995).
T_1: *Control* - nil compaction, chemical weed control
T_2: *Extreme compaction* - heavy compaction each year when wet, mechanical and chemical weed control
T_3: *Current best advice* - initial compaction, chemical weed control
T_4: *Zero tillage* - initial compaction, chemical weed control, double cropped
T_5: *Traditional practice* - light compaction each year when wet, mechanical and chemical weed control.
Soil management practices and planting dates for each sorghum crop are shown in Table 1. Main compaction treatments were 120 x 5.4 m.

Measurements

Crop Establishment - determined in each crop as a percentage of seed sown, by calibrating the planter for seed output and counting the established seedlings. Counts were taken 15-25 days after sowing from a total row length of 6.0 m in every main treatment.
Above ground drymatter production - plant tops at anthesis and harvest were cut at ground level from an area of 1.0 x 1.8 m in each fertiliser sub-plot and dried to constant weight at 80°C in a fan-forced dehydrator. All above ground drymatter is expressed on an oven dry basis.
Grain yield - grain was thrashed from drymatter samples taken at harvest and dried at 80°C to constant weight. Grain yields were standardised to 12% moisture content.
Runoff and Soil Loss - automated measuring instrumentation was located at the bottom end of each main compaction treatment. Runoff was collected from one permanent bed and wheel track (contributing area 237.6 m^2), and measured by a tipping bucket, with the data recorded at one minute intervals by a data logger. Each bucket was calibrated. Soil loss was measured in two components: the finer suspended material was sampled using a splitter sampler, and the coarser bedload material was collected in a trough. Rainfall intensity was measured by a pluviometer, and rainfall volume by a raingauge. Soil surface cover was measured after each runoff event in two locations per treatment.

Table 1 Soil management activities undertaken in the five treatments

Activity	Date	Treatment				
		Control	Extreme compaction	Current best advice	Zero tillage	Traditional practice
Compacted	12/9/94		■	■	■	■
Cultivated	23/9/94		■			■
Planted crop 1	3/10/94	■	■	■	■	■
Cultivated	20/4/95		■			■
Planted wheat					■	
Compacted	15/12/95		■			■
Planted crop 2	17/1/96	■	■	■	■	■
Planted wheat	21/5/96				■	
Cultivated	27/6/96		■			■
Compacted	16/10/96		■			■
Planted crop 3	13/12/96	■	■	■	■	■

Results and Discussion

Crop growth

Table 2 summarises the effect of each compaction treatment on the dryland growth and yield of three sorghum crops.

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

	Crop 1				Crop 2			
Treatment	Establish. (%)	DM at anthesis (kg/ha)	DM at harvest (kg/ha)	Grain Yield (kg/ha)	Establish. (%)	DM at anthesis (kg/ha)	DM at harvest (kg/ha)	Grain Yield (kg/ha)
T_1	81	5754	7220	1879	83	4597	6200	2861
T_2	58	3515	4728	997	50	1823	2107	806
T_3	70	4612	6523	1913	72	4394	4967	2095
T_4	64	4760	6238	1702	67	4241	4956	1905
T_5	77	4616	6427	2020	56	2946	3731	1583
	n.s.	*	n.s.	n.s.	P=0.064	*	**	***

	Crop 3			
Treatment	Establish. (%)	DM at anthesis (kg/ha)	DM at harvest (kg/ha)	Grain Yield (kg/ha)
T_1	83	4429	5625	1968
T_2	63	1423	3183	1251
T_3	76	4457	5244	1936
T_4	80	5426	5823	2055
T_5	68	2354	4532	1932
	n.s.	***	**	n.s.

DM - drymatter; n.s. - P>0.10; * - P<0.05; ** - P<0.01; *** - P<0.001

Sorghum establishment was only significantly reduced by compaction (T_2 and T_5, 50 and 56%, respectively) compared to the control (T_1 83%) in crop 2. After planting crop 1, the trial area was spray irrigated. No rain fell immediately after planting crop 2, but 27 mm of rain fell within three days of planting crop 3. We conclude that rainfall or irrigation soon after planting can overcome the establishment reduction caused by compaction. The relatively good establishment in the compacted treatments may be due to the zero tillage planter used. We expect traditional planting equipment to result in greater reductions in establishment.

Compaction significantly reduced drymatter at anthesis and the effects of annual compaction were cumulative. The initial compaction of T_3 and T_4 prior to crop 1 showed no effects by crop 2.

In crop 1, there was no difference between treatments in drymatter production at harvest (6227 kg/ha). Crop 2 showed reductions in T_2 (2107 kg/ha) and T_5 (3731 kg/ha), compared to T_1 (6200 kg/ha). T_4 (5823 kg/ha) produced higher drymatter at harvest of crop 3 than T_2 and T_5 (3183 and 4532 kg/ha, respectively).

Sorghum was generally able to compensate for lower establishment on reduced early growth to produce similar grain yields except for crop 2. Slower root development in the compacted treatments (calculated from weekly neutron moisture meter measurements) delayed peak water use, allowing for more stored soil water at the critical time of grain filling.

Runoff and soil loss

Nine runoff events were measured between December 1995 and May 1998. Six of these events are summarised in Table 3.

Table 3 Treatment effects on ground cover, runoff and soil loss

	11/12/95 (Rain=10mm) (I_{15}=66mm/hr) (pre-comp.)	3/1/96 (Rain=59mm) (I_{15}=43mm/hr) (post-comp.)	1/5/96 (Rain=110mm) (I_{15}=30mm/hr) (harvest)	9/10/96 (Rain=69mm) (I_{15}=30mm/hr) (pre-comp.)	21/11/96 (Rain=26mm) (I_{15}=50mm/hr) (post-comp.)	5/5/98 (Rain=43mm) (I_{15}=24mm/hr) (fallow)
Ground cover (%)						
T_1	44.8	42.3	52.3	52.1	25.2	37.1
T_2	33.9	14.2	34.0	13.9	6.4	16.2
T_3	39.1	44.7	52.0	48.9	29.6	35.9
T_4	34.5	35.9	48.4	58.5	29.9	37.2
T_5	31.2	17.1	41.9	18.3	7.9	21.2
	**	***	**	***	***	***
Runoff (mm)						
T_1	8.3	21.9	3.1	62.0	3.0	2.9
T_2	11.5	44.7	12.0	52.0	4.7	8.7
T_3	13.1	24.7	1.9	51.7	1.3	3.3
T_4	1.8	21.2	3.3	49.7	3.4	3.4
T_5	12.9	40.1	12.0	65.0	5.5	10.0
	P=0.094	***	*	n.s.	**	***
Total soil loss (t/ha)						
T_1	1.07	2.28	0.04	0.81	0.31	0.18
T_2	1.63	4.73	0.21	2.12	0.63	0.80
T_3	1.57	2.44	0.00	0.63	0.12	0.20
T_4	0.24	1.43	0.01	0.64	0.33	0.20
T_5	1.56	5.28	0.14	1.97	0.45	0.72
	*	***	***	***	*	***

n.s. - $P>0.10$; * - $P<0.05$; ** - $P<0.01$; *** - $P<0.001$

On 11/12/95, T_4 produced least runoff and soil loss. This was due to a drier profile from double cropping. Treatments T_2 and T_5, compacted on 15/12/95, produced double the runoff and soil loss on 3/1/96. Compaction reduced ground cover in these treatments by 45-58%. Even though runoff from T_4 was similar to T_1 and T_3, soil loss was significantly reduced, presumably due to the double cropped wheat.

Runoff and soil loss at harvest of crop 2 (1/5/96) was significantly higher in T_2 and T_5 than all other treatments. This may be attributed to the lower ground cover levels in these treatments.

On 9/10/96, runoff was similar across all treatments, but soil loss in T_2 and T_5 was more than double that of other treatments. T_2 and T_5 had been cultivated during the fallow, repairing any compaction that may have been present at the previous event. This cultivation removed any treatment effect on runoff, but soil loss increased dramatically associated with 56-59% reduction in ground cover (Table 3).

Following a twelve month fallow after crop 3 when all treatments had been zero tilled, runoff and soil loss on 5/5/98 were significantly greater in T_2 and T_5. Even though there was no difference in grain yield in crop 3 (Table 2), lower ground cover levels were measured in these two treatments.

Conclusions

These results show that applied compaction reduces establishment when dry periods are experienced after planting (crop 2). Early crop growth was reduced, but the crop was generally able to compensate and produce similar grain yields. The performance of T_4 (zero tilled following initial compaction) shows that natural amelioration due to cracking and self-mulching properties of this soil are an important phenomenon in the compaction/repair process.

Compaction dramatically increased both runoff and soil loss. The cumulative total runoff and soil loss for T_5 was 175 mm and 12.12 t/ha, respectively, where T_4 produced 89 mm runoff and only 3.54 t/ha soil loss. Cultivation is known to quickly repair compaction, but the resulting decrease in ground cover increases soil loss dramatically.

A combination of reduced compaction (controlled traffic) and maintaining high ground cover (growing good crops and zero tillage) will minimise runoff and soil loss. These farming systems provide a sustainable future for the dryland grain industry by improving the on-farm and off-farm natural resources while maximising grain production.

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CONTROLLING RUNOFF, SOIL LOSS AND SOIL DEGRADATION WITH CONTROLLED TRAFFIC AND CROP ROTATIONS

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Abstract

A research project in central Queensland commenced in 1993 to assess the effects of downslope Controlled Traffic Farming and crop rotations on runoff, soil loss and soil structure. It aims to develop sustainable land management systems that will reduce runoff and soil loss, and optimise soil structure. Runoff is confined within a down slope bed and furrow controlled traffic system. This eliminates cross flows, and runoff is distributed across the plots and not concentrated. Mean annual runoff and soil loss have been 12-48 mm and 1.35-5.30 t/ha, respectively. These losses have been minimised by Controlled Traffic Farming (optimising soil structure), crop rotations (maintaining a high soil water deficit and producing high ground cover) and minimum tillage (maintaining high ground cover). Soil compaction is confined to an area directly below the permanent wheel track (penetration resistance 2.0-2.5 MPa at 5-10 cm depth). The crop bed has low penetration resistance (0.5-1.0 MPa at 5-10 cm depth), suitable for crop growth. These farming systems provide a sustainable future for the dryland cropping industry by improving the on-farm and off-farm natural resources while optimising crop production.

Introduction

Soil conditions optimal for traffic during field operations (firm and compacted) are in conflict to those desired for plant growth and crop production (loose and friable). There is therefore a conflict between the requirements for traffic and crop growth. A management system which overcomes these conflicts is Controlled Traffic Farming (Yule, 1995).

Controlled Traffic Farming is a system in which the crop zone and traffic zone are permanently and distinctly separated. Combined with zero tillage and crop rotations, this system has the potential to optimise soil structure, reduce runoff and soil erosion, and increase water availability.

The farm efficiencies and soil compaction control benefits of Controlled Traffic Farming were accepted by farmers, but the major constraint to adoption was the implications of down slope layouts on soil erosion. Controlled traffic layouts will strongly influence water flow when runoff occurs. Runoff water will flow along wheel tracks, crop rows, tillage furrows, etc. Yule (1995) developed two rules to control soil erosion in controlled traffic layouts:

1. The controlled traffic lines must drain to a safe disposal point - no reverse flows, no low spots. When runoff occurs, the goal is safe disposal - into a contour bank or waterway.
2. All the runoff generated within a controlled traffic line must be retained in it - no cross flows.

A study commenced in 1993 to assess the effects of down slope Controlled Traffic Farming and crop rotations on runoff, soil loss and soil compaction control. Runoff is confined within permanent bed and furrow units. This prevents cross flows, and runoff is distributed across the plot and not concentrated.

Materials and Methods

The study is being undertaken near Emerald (148° 10'E, 23° 32'S), central Queensland. The region has a semi-arid sub-tropical environment, with summer dominant rainfall. Long term mean annual rainfall and evaporation are 639 mm and 2265 mm, respectively. The soil is a shallow black cracking clay (Vertosol), with a particle size distribution in the 0-10 cm depth of 20% sand, 18% silt, and 62% clay.

Nine plots, 550 m long and 8 m wide are oriented down a 1.0% slope. Each plot consists of permanent one or 2 m wide beds. Traffic is restricted to the furrows between these beds. Dryland cotton, wheat and sorghum are grown as rotation crops to produce a range of antecedent water contents and ground cover levels at all times.

Since late 1994, runoff and soil loss have been measured from bed and furrow units of each plot (Figure 1). Runoff is measured through flumes, with the water height recorded on a data logger at one minute intervals. A discharge rating curve is used to calculate discharge rate and runoff. Soil loss is measured in two components: the coarse bedload material is collected in a trough, and the finer suspended material is collected by a flow based integrated sample. Rainfall volume is measured on a daily basis at two locations within the study area. Rainfall intensity is recorded by a pluviometer. Ground cover levels in each plot are assessed at two locations following runoff.

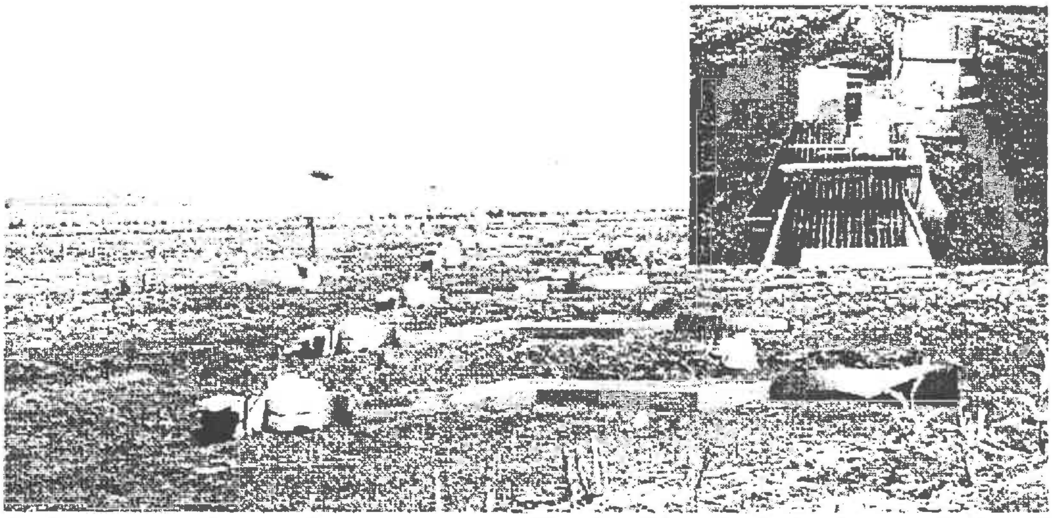

Figure 1 - Instrumentation used to measure runoff and soil loss in dryland controlled traffic layouts

Soil compaction control was assessed in a 2 m transect across a permanent wheel track ("WT") and root bed ("bed") using a recording cone penetrometer. Increments of 1.5 cm to 45 cm depth, and 10 cm intervals across the transect were used. Changes in water content at 20 cm intervals across the transect were measured over a five week period using 5 cm diameter cores, with increments of 10 cm to 100 cm depth.

Results and Discussion

Runoff and Soil Loss

Nine rainfall events since 1994, ranging in amount and intensity, have produced runoff. At the time of runoff, the plots provided a range of ground cover levels and soil water contents. Figure 2 shows the effects of available soil water on runoff, soil loss and suspended sediment concentration on 9/10/96 using data from four cropping histories. The rotation crops had produced plots of various fallow lengths and water contents. The shortest fallow (ex. wheat, 70 mm available soil water) had the driest profile. No runoff or soil loss occurred from this plot. Plots which were ex. cotton had been fallowed longer, and were subsequently wetter (100-130 mm soil water). Runoff was low (1-3 mm), and soil loss was low (0.02-0.03 t/ha). The plot with the longest fallow period after harvest (ex. sorghum, 150 mm soil water) was the wettest, and produced the most runoff and soil loss - 25 mm runoff and 0.10 t/ha soil loss. Suspended sediment concentration reduced when the soil profile was dry (less than 100 mm available soil water). Wetter soils result from long fallows, and produce the highest runoff and soil loss.

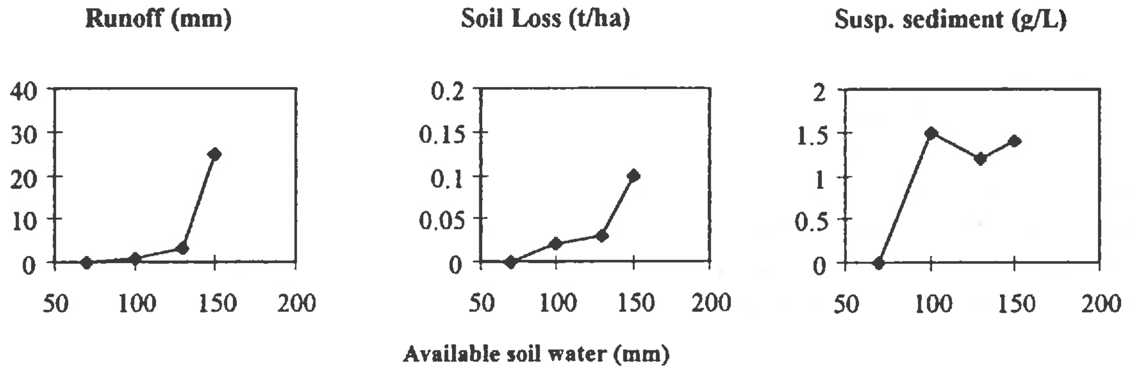

Figure 2 - Effect of available soil water on runoff, soil loss and suspended sediment concentration (9/10/96, rain = 62 mm, I_{30} = 29 mm/hr)

On 15/12/96 (Figure 3), the effects of ground cover levels on runoff, soil loss and suspended sediment concentration are shown. All plots had similar soil water contents due to previous rainfall. Increasing ground cover levels decreased runoff and soil loss. The lowest cover (9%) was produced from plots of 1995/6 cotton. 47% cover was provided by a wheat plot, and 52% by a growing cotton crop. The highest ground cover level (68%) was provided by a growing sorghum crop. No runoff or soil loss occurred from this plot. Carroll *et al.* (1997) found that 30% ground cover was required to control erosion, but these results suggest that 50% cover is needed. Suspended sediment concentration decreased with increasing ground cover. Concentrations were decreased from 12.0 g/L with 9% cover to 8.3 g/L with 52% cover. Suspended sediment concentrations in this event are much higher than the event presented in Figure 2. This is due to the higher maximum rainfall intensity (55 mm/hr compared to 29 mm/hr) and subsequent increase in runoff rates (0-14 mm/hr compared to 9-52 mm/hr).

Suspended sediment concentration is more sensitive to soil water deficit and ground cover than runoff or soil loss. Less than a half full profile and more than 50% cover are required to reduce suspended sediment. The implications are very significant, as suspended sediment moves long distances in rivers and carries enhanced levels of nutrients and pesticides, and generally has high off-farm environmental impacts.

Other runoff events were described by Rohde and Yule (1995) and Yule and Rohde (1996). Stubble from dryland cotton crops generally produced less than 10% ground cover by the end of the fallow. Wheat and sorghum stubble, and growing crops produced greater than 40% ground cover. These results show that rotation crops and minimum tillage practices, which produce and maintain high cover levels and soil water deficits, are essential in minimising runoff and soil loss.

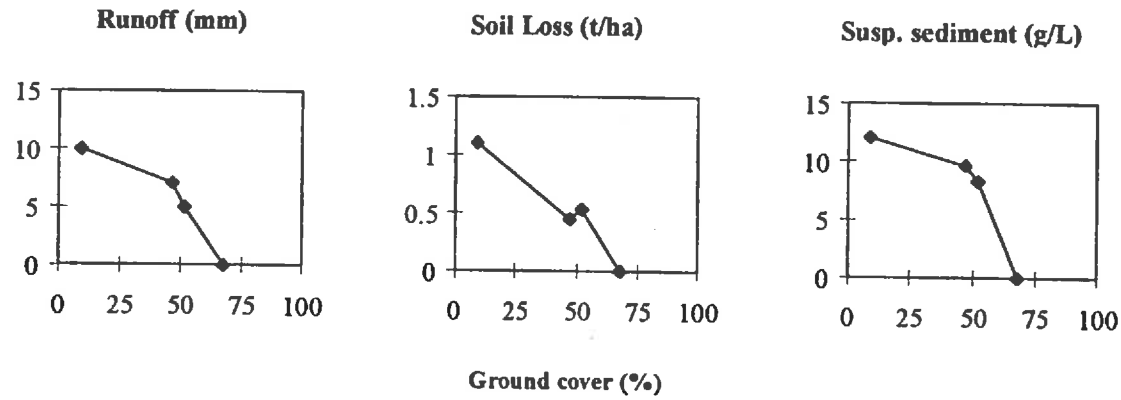

Figure 3 - Effect of ground cover on runoff, soil loss and suspended sediment concentration (15/12/96, rain = 31 mm, I_{30} = 55 mm/hr)

Table 1 shows the annual rainfall and range of runoff and soil loss produced by the plots. Mean annual runoff was 12-48 mm depending on plot history (ground cover, soil water deficit, etc.), and soil loss was 1.35-5.30 t/ha. Work by Carroll *et al.* (1997) showed that annual mean runoff and soil loss was 19-33 mm and 1.42-4.01 t/ha, respectively, depending on tillage history. The median cover level for this study (16%) was lower than the study undertaken by Carroll *et al.* (1997). Results of Freebairn and Wockner (1982) showed that annual soil loss was in the order of 50 t/ha. Results from this study highlight the benefits of down slope controlled traffic layouts in controlling soil erosion.

Table 1 - Annual rainfall, runoff and soil loss for the study area

	Rainfall (mm)	Runoff (mm)	Total soil loss (t/ha)
1995	408	10-59	0.78-7.59
1996	620	25-84	3.26-8.31
1997	374	0	0
Average	467	12-48	1.35-5.30

Compaction

The WT was trafficked three months prior to the soil structure sampling. The bed had not been trafficked since 1993. Penetration resistance below the WT was higher than the bed (Figure 4). Values over 2 MPa occurred within 5-10 cm of the soil surface directly below the WT, and again at 20-40 cm below the soil surface. This narrow band of high resistance is only 20 cm wide. Penetration resistance over 2 MPa is considered to restrict the taproot penetration of cotton (Taylor and Gardner, 1963). Values over 3 MPa have stopped the development of cotton roots (McGarry, 1994). Penetration resistance was lower in the bed. At 10-20 cm below the soil surface, the average penetration resistance was 1.69 MPa below the WT, and 1.48 MPa in the bed.

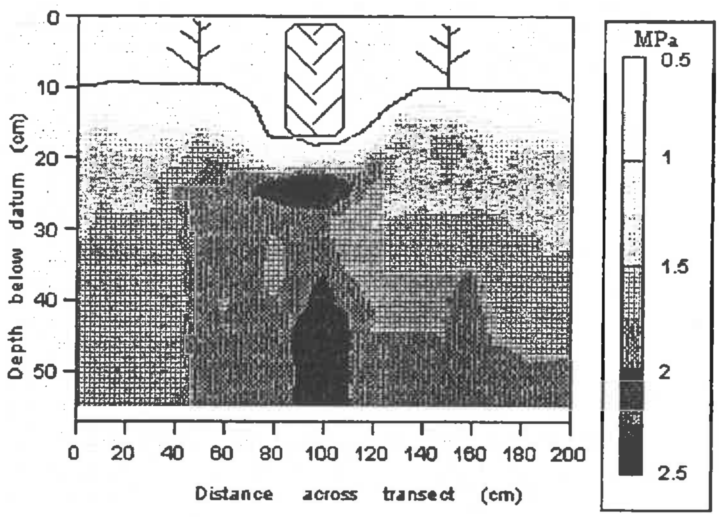

Figure 4 - Penetration resistance (MPa) across a 2 m transect of a permanent wheel track and bed. The soil surface profile, wheel track and plant rows are also shown.

These results show no evidence of soil compaction in the bed, or lateral spread from the WT. Any soil structural damage is restricted to a zone 40-60 cm wide directly below the WT. Soil structural damage in the WT did not affect the change in soil water content measured over a five week period. The change in water content in the WT is similar to that in the bed (0.045 Mg Mg^{-1}).

Conclusions

High soil water deficits and high ground cover levels have reduced soil loss by minimising runoff. Ground cover levels greater than 50% dramatically decreased suspended sediment concentration, further reducing the rate of soil loss. Suspended sediment moves long distances in rivers and carries enhanced levels of nutrients and pesticides, and generally has high off-farm environmental impacts. The average annual soil loss of 1.35-5.30 t/ha is less than that measured at other sites. These data show the benefits of down slope controlled traffic layouts in controlling soil erosion. Dryland crops which do not provide high ground cover levels (e.g. cotton) can not be grown sustainably, as runoff and soil losses are high. Rotation crops, such as wheat and sorghum, will reduce these losses.

Penetration resistance is greater in the wheel track than the root bed. Restricting all traffic to permanent wheel tracks has maintained the bed in an uncompacted condition so that plant root development and crop production are optimised.

These dryland farming systems provide a sustainable future for the dryland cropping industry by improving the on-farm and off-farm natural resources.

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Controlled Traffic and Split Fertilizer Application in Dryland Farming

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Background

Controlled traffic is a system where machinery movement is restricted to a set of wheeltracks on which all machinery runs. It has been shown that unwheeled soil produces higher yielding crops while permanent wheeltracks facilitate more timely machinery operations and reduced fuel costs (Tullberg 1995). Controlled traffic is one aspect of conservation farming.

Controlled traffic facilitates split application of fertilizer in a crop in that fertiliser can be applied later in crop growth, rather than all at or before planting, with minimal damage to the crop. Strong (1981) found that for irrigated wheat on the Darling Downs less than half of the N available at planting was converted into grain and concluded that this low (and variable) assimilation rate made fertilizer applications at planting an unattractive strategy for ensuring high protein wheat.

Subsequent research by Strong (1986) found that the same amount of N applied before planting or as equal amounts at planting and tillering (or at planting, tillering and boot stages) produced similar grain yields. Thus N could be profitably applied up to the boot stage. Split applications of fertilizer at tillering and boot stages increase grain protein only marginally usually by less than 1% but later applications (flowering onwards) can cause large increases which may give an economic return (Strong and French 1998). Strong (1986) suggests that N application after sowing could be a useful option for both dryland and irrigated crops because it allows additional N to be applied when crop needs are more easily assessed and when its utilization by the crop is more assured.

The split application rate will be highly dependent upon such factors as moisture levels in the soil profile, SOI levels and expected rainfall probabilities and thus the yield and/or protein improvement expected relative to the cost of applied fertilizer. Strong and French (1998) recommend that the crop's yield potential and anticipated nitrogen supply from the soil be determined and any other factors such as waterlogging, disease, weeds or other nutrient deficiencies be taken into account in determining the fertilizer rate and timing of application.

Split application of fertilizer in a controlled traffic system has several advantages for crop management especially for dryland farming. Growers may delay their decisions on fertilizer rates by applying a low rate of fertilizer at or before planting and then deciding on the final rate to be applied later in crop growth taking into account the seasonal conditions. In a poor season, no further fertilizer may be applied with a subsequent saving in cost. In contrast, in a good season, there may be considerable yield and/or protein benefit from a split application. Hence split fertilizer application offers growers more flexibility in crop management.

The decision support package, WHEATMAN, provides information on the performance of the cultivar, Hartog, sown on June 1 with 150 mm of available water for a 'good season' and 80, 130 and 180 kg/ha of available N at planting (Table 1).

Table 1. WHEATMAN output (after Strong and French 1998)

	No N top-dressing		Top-dressed 50 kg/ha N		Increase due to top-dressing	
Available N kg/ha sowing	Grain yield (t/ha)	Grain protein (%)	Grain yield (t/ha)	Grain protein (%)	Grain yield (t/ha)	Grain protein (%)
80	3.0	9.7	3.3	12.3	0.3	2.6
130	3.7	11.4	4.3	12.5	0.6	1.1
180	3.9	12.4	4.7	12.7	0.8	0.3

These results suggest that the yield improvement is relatively higher if there was 130 kg/ha or more of N available at planting but the improvement in grain protein was relatively small (grain protein increase inversely related to yield increase). The crop needs to be growing well without any check to its growth for significant yield improvement to occur from split application. These figures suggest that top-dressing this cultivar with 50 kg/ha of N would not produce the prime hard grade protein content of 13%.

Assuming urea costs $406.70/t, the cost of 50 kg/ha N as urea would be $44.21. If application costs $6/ha and AH quality wheat receives $138/t, then for 80, 130 and 180 kg/ha N available at sowing and top-dressing with 50 kg/ha N, the expected increase in returns from top-dressing with 50 kg/ha N would be -$8.81, +$32.59 and +$60.19 respectively. If growers can produce prime hard quality, then a premium of $22/t would be available; this may be sufficient incentive for a late application (flowering) of fertilizer.

Using controlled traffic, a ground rig should be able to traverse a crop with minimal damage provided there is a guidance system to keep the tractor on the wheeltracks and there is sufficient clearance. Because it is possible to get on the ground earlier with a controlled traffic system than for a conventional system, fertilizer can be applied to moist soil. This has several advantages over aerial application:

- some fertilizer will be immediately available as it will dissolve quickly; thus the need for subsequent rain increase fertilizer availability is reduced. This should result in an assured response in the crop.

- fertilizer is less likely to be lost through volatilisation or by leaching, thus reducing the rate which needs to be applied

- no leaf burn because fertilizer does not come in contact with the foliage

- lower costs due to lower application costs and reduced fertilizer rates

Drilling of fertilizer into dry soil may be necessary in some seasons but is heavily reliant on subsequent rain to make it available. All but the first advantage listed above would still be gained. Of course, it would be possible to broadcast fertilizer using a controlled traffic system. However, several of the advantages listed above would be lost.

Trial Methodology

A wheat trial was planted on 3 m beds on June 11 at Gatton College with the following aims:

- to compare drilling fertilizer with broadcast application to determine whether drilling adversely affects the crop at late tillering and flowering; possible adverse effects include loss of plants, pruning of the root system and damage to stems and ears

- to compare fertilizer applications at sowing with split applications at late tillering and flowering on dry matter accumulation, grain yield and protein

Prior to seeding a basal dressing of 30 kg N/ha was drilled in all plots with an additional 70 kg N/ha being applied to four plots. The nitrogen was applied as ammonium sulphate (Granam) as the site was shown to be deficient in sulphur as well as nitrogen (the preceding crop was grain sorghum).

Eight weeks after planting, a further 70 kg/ha of N was drilled or broadcast on the plots. Drilling appeared to have minimal effect on the crop. A light irrigation was applied after the fertilization. A further 30 kg N/ha will be applied at flowering (both drilled and broadcast) to study the effect on yield and yield components as well as damage to the crop.

Conclusions

There are good theoretical reasons to suggest that applying nitrogen fertilizer as a split application will increase yield, protein and fertilizer use efficiency.

The current trial will supply further information on these aspects. This trial has demonstrated that it is possible, using controlled traffic technology, to drill fertilizer between rows 25 cm apart eight weeks after planting without any apparent adverse effect on the crop.

This system offers exciting possibilities for wheat, barley, sorghum, millet and other crops which are capable of being traversed by a modified fertilizer applicator late in crop growth. For some crops, the system may not be feasible late in crop growth because of physical limitations of height and canopy spread. Row spacing in winter cereal crops may be increased to allow more rapid drilling of fertilizer in a split application; however, a guidance system may overcome this limitation. More research is also needed to investigate the effects of timing of split applications on dryland crops.

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Effect of Wheeltracks on Yield in Controlled Traffic

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Introduction

Controlled traffic is a crop production system in which the crop and traffic areas are permanently and distinctly separated. In Australia, this system has been shown, in general, to increase yield by 15.9% on non-wheeled cultivation (Tullberg 1997). The increased yield results from less compaction which allows greater water infiltration (80% for controlled traffic plots vs 76% for wheeled plots) for storage and crop availability (Tullberg 1997) and probably from greater porosity which facilitates more gaseous exchange of oxygen and carbon dioxide between the soil environment and the atmosphere (Eriksson *et al.* 1974). The effect of increased porosity on yield is more difficult to quantify.

If the main effect on yield is derived from increased stored water, then there is likely to be less response to controlled traffic in a season with favourable moisture than in a dry season. This may account for some of the variability in yield response to controlled traffic: 22.8%, 5.0%, 14.9% and 21.0% for wheat, sorghum, maize and wheat over a three year period (Tullberg 1997).

Comparison of yield on controlled traffic plots with non-wheeled plots needs to take account of the loss in crop production from wheeltracks. Obviously, this loss will be minimised for widely spaced, narrow wheeltracks. In conventional cultivation, the whole area is planted including the wheeltracks made by the planting rig.

Several other aspects of the effect of wheeltracks on yield need to be considered. Crop rows adjacent to wheeltracks may be subjected to at least two opposing factors. For a winter cereal crop planted at a conventional row spacing of 20 cm or less, these rows will receive more light especially during later growth stages when the canopy cover is complete. Thus it is common for plants in such rows to be shorter (due to less elongation) and to grow larger. The plants in these rows are potentially able to exploit a greater soil volume, and therefore water and nutrients, because of the reduced competition from the wider rows.

However, the opposing factor of soil compaction would be expected to reduce root growth and exploitation of the soil for water and nutrients. The extent of this reduction is largely unknown but So (1990) has suggested a productivity loss of 5 - 10% in field crops. The balancing forces of compaction and its effect on root growth, and reduced competition for light for top growth have not been determined.

For row crops planted at wider spacing (70 cm or greater), the situation is different in several aspects. There may be no loss of production area due to wheeltracks if these fit in the inter-row spaces. Theoretically, then, controlled traffic should produce higher yields in row crops than a closely planted crop because there is no area lost to production. This will, in turn, remove the competition effects from 'unguarded' rows. However, compaction will still occur in rows adjacent to the wheeltracks and these would be expected to be lower yielding.

In this paper, I will discuss the effect of row spacing on yield in wheat and relate this to the loss of production due to wheeltracks. I will then compare this loss with the gain expected from controlled traffic to arrive at an overall yield estimate.

Row Spacing

Doyle (1980) found that in trials conducted over 5 years at Narrabri in northern New South Wales that increasing the row spacing from 18 to 36 cm reduced yield in 3 of the years and was not significant for the other years (Table 1). Only in 1975 was yield reduced in the 27 cm spacing. There was no interaction of row spacing with plant population.

Table 1. Influence of row spacing on grain yield in kg/ha (after Doyle 1980)

Row Spacing (cm)	1974	1975	1976	1977	1978	Mean
	Grain Yield (kg/ha)					
18	3440	3230	3680	1600	3060	3002
27	3650	2980	3810	1560	3040	3008
36	3620	2940	3340	1440	2730	2814
lsd	ns	200	280	ns	190	

Thus averaging across years the maximum grain yield loss which can be expected for 36 cm rows would be 6%. Note that while 36 cm rows occupy only half the area that 18 cm rows occupy, the yield reduction was only 6%, indicating considerable yield compensation at the wider row spacing.

In extensive trials conducted in Western Australia, Burch (1986) found a similar reduction of about 6% grain yield reduction when row spacing was increased from the standard 18 cm rows to 27 cm or 36 cm rows (Table 2). Wider rows had a greater effect on yield.

In a sense, the wider row spacing of rows adjacent to the wheeltrack simulates the situation referred to above. However, there is likely to be additional yield reduction due to compaction from the wheeling though this only occurs on one side of the row. Thus the values for yield reduction from wider rows in the research by Doyle (1980) and Burch (1986) would be under-estimated for wide rows adjacent to wheeltracks.

Other researchers (Lamers *et al.* 1986 and Tullberg and Lahey 1990) showed that the yield of wheat from rows immediately adjacent to the wheeltracks was 150% higher than for inner rows.

Overall, research indicates that wider rows due to wheeltracks will yield higher than narrower rows and hence will compensate to some degree for the loss in area of production from wheeltracks.

Table 2. Wheat yields at different row spacing expressed as a percent of 18 cm yields; averaged over seeding rates and within years (after Burch 1986)

Row spacing						
Year	**9 cm**	**18 cm**	**27 cm**	**36 cm**	**45 cm**	**54 cm**
1982 (4 trials)	-	100.0	98.9	96.9	-	-
1983 (5 trials)	101.0	100.0	90.8	89.0	71.6	72.2
1984 (5 trials)	125.2	100.0	100.0	92.5	82.8	78.1
1985 (3 trials)	133.0	100.0	82.6	99.5	86.3	-
Mean 1982-1985 (17 trials)	-	100.0	94.0	93.7	-	-

Row Spacing and Controlled Traffic

If we consider a bed with six rows at 20 cm spacing and 50 cm wheeltrack on either side, we effectively have four rows at 20 cm spacing and the two outside rows at 35 cm spacing (mean of 20 and 50 cm).

We can then consider the yield reduction due to the two wider rows:

From Doyle's work we conclude the maximum yield reduction would be approximately 6% for these rows.
If we consider the yield reduction for the whole plot, we have a 6% yield reduction in both of the outside rows and no reduction for the four centre rows.
Thus over the whole plot the yield reduction is (6x2)/6 = 2.0%

A 15.9% yield increase has been shown for controlled traffic plots compared with wheeled plots (Tullberg 1997). Because both treatment plots were bounded by wheeltracks, edge effects were common and hence treatments were strictly comparable.

Thus if we compare a controlled traffic plot (with bed arrangement described above) with a wheeled plot with a constant row spacing of 20 cm, a minimum net yield improvement of 15.9% - 2.0% or 13.9% can be calculated. This is the estimated gain from controlled traffic less the reduction due to the two wider rows.

For wider beds, the proportional loss from the two outside rows will be even lower. For example, a three metre bed will have 12 rows of 20 cm resulting in a yield reduction of (6x2)/12 = 1% and a net yield improvement of 14.9%.

The unplanted wheeltrack area is not wasted in that the rows adjacent to them can utilise, at least to some degree, the moisture and nutrients from this soil space. However, nutrient levels for this area will be lower because normally the wheeltrack area would not be fertilized.

More research is needed to separate the yield reduction due to compaction from that due to wider rows. It would also be interesting to separate the yield reduction from compaction due to reduced moisture availability and that due to lower porosity. Further research is needed to investigate the long term effects of compaction on yield. Is yield reduced by continued compaction season after season, or does the reduction stabilise after several crops?

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Intercropping Summer Crops Into Winter Oilseeds and Legumes: Possibilities and Challenges.

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Introduction.

Intercropping is a form of agriculture which is widely practiced in the developing world. It involves growing a mixture of crops together in the same field. The combined yield of mixtures of two crops is frequently higher than either of the crops grown as sole crops (Natarajan and Willey, 1980a; Nadar, 1983b). If the intercropping takes the form of establishing a second crop into an existing crop stand it is known as relay cropping. Relay cropping is a specialised form of intercropping where a second crop is sown into an established crop stand (Nadar, 1983a). Unlike ordinary intercropping the field only supports two crops for the period of time between planting of the second crop and harvesting of the first crop.

Many areas practising relay cropping have similar climate and soils to those of eastern Australia so this approach has the potential to increase both the efficiency of resource use and the profitability of mechanised cropping enterprises in this area (Natarajan and Willey, 1980b). However, in order to realise this potential the agronomic and engineering technology associated with this system must be adapted to mechanised agricultural systems. Controlled traffic will be an important part of this technological package because it is necessary to have precise placement of the seed of the second crop between rows of the first crop in order to avoid crop damage. This paper will discuss the reasons why a farmer may choose to adopt relay cropping and the problems which may arise with reference to establishing summer crops (sorghum and sunflower) into two winter broadleaf crops (faba bean and mustard).

Reasons for Adopting Relay Cropping.

There are a number of reasons why a producer may choose to use relay cropping to grow a winter and a summer crops rather than double cropping. These revolve around the availability of resources (water, light and nutrients) and the length of the growing season. These reasons include:

1) the duration of the summer growing season may be insufficient for summer crops such as sunflower and sorghum to complete their life cycle unless the crop can be established before the winter crop is harvested.

2) planting the summer crop (sunflower and sorghum) into the standing broadleaf crops enables them to be established as close as possible to their optimal time of sowing (Nadar, 1983a).

3) a grower, who has already established a crop of faba bean or mustard, may wish to take advantage of favourable spring conditions to establish the sorghum or sorghum on an opportunistic basis. This flexibility would be particularly advantageous if the winter faba bean or mustard are relatively low yielding (but still too profitable to plough them in) yet the spring rains have refilled the soil water profile.

4) the grower may wish to take advantage of the rotational benefits associated with nitrogen fixation by faba beans and bio-fumigation by mustard. Protein content of wheat grown as an intercrop with beans has been shown to be higher than when grown as a sole crop (Bulson et al., 1997). It is possible that nitrogen fixation by the faba beans will increase the proten content of the sorghum.

5) maintaining ground cover to control erosion (Nadar, 1983a)

Risks

The underlying assumption on which relay cropping is based is that there are resources available to the initial crop (faba beans or mustard) which are not being fully utilised (Snaydon and Satorre, 1989) and are therefore available to the developing sorghum or sunflower seedling. Once established subsequent rainfall must be sufficient for the sorghum or sunflower to produce commercially acceptable yields. Therefore, the first risk associated with a relay cropping strategy is that there are insufficient resources available to establish the second crop. In dry years the winter broad leaf crops will have exhausted the water supply in the surface layers of the soil, prohibiting seed germination and seedling establishment. Conversely, in wet years vegetative growth of the winter crop may be such that insufficient light is reaching the soil surface for growth of the spring crop. If relay cropping is to be practiced as a regular part of the cropping system it may be necessary to reduce plant population to ensure sufficient resources are available for establishment of the second crop. In Mediterranean environments leaf area of mustard is drastically reduced by the coincidence of water stress in spring and flowering (Lewis and Thurling, 1994). If this pattern is repeated in sub-tropical and uniform temperate climates this may provide a window of opportunity for planting the spring crop

Nutrients will not be as limiting as light or water because the seedling nutrient requirements are relatively small and fertiliser can be applied to the sorghum or sunflower either at planting or once the faba bean or mustard has been harvested.

Soil temperature beneath the canopy of winter crop may also inhibit establishment of the spring crop. Massaso (1997, unpublished) found that sorghum planted into a wheat crop at Gatton in mid-September failed to emerge, although there was good emergence in the absence of the crop, because temperature of the soil beneath the canopy was several degrees cooler than exposed soil. If planting is to take place in early spring then japanese millet or sunflower should be grown because they will germinate at lower soil temperatures.

Planting Difficulties.

The canopy of the winter crops is a substantial impediment to passage of the tines and undercarriage of the planting implement through the crop. This is easily overcome in cereals by increasing the row spacing and increasing the clearance of the tractor and planter. The branching habit of faba bean and mustard will impede the planter substantially more than the culms of a cereal. It may be possible to reduce this restriction by planting the crop at high density within the rows in order to restrict branching. The resulting increase in crop height will be a disadvantage during the planting of the summer crop, but will provide a wider window of opportunity for harvesting the winter crop.

Increasing the row spacing may have the unintended consequence of reducing the yield of the winter crop. Experiments with wheat show that widening row spacing from 18 cm to 27 cm decreased yield by 6.1 % while increasing row spacing to 36 cm reduced yield by 7.3% (Doyle,1988)

Sowing winter crops into summer crops, particularly if the summer crop is a species such as mungbean which is relatively short, provides fewer technical difficulties because of the wider row spacings commonly employed. However, the depletion of the soil water by the summer crop makes it unlikely that the winter crop will be profitable. In those areas of south-eastern Australia which have a winter rainfall pattern and produce irrigated summer crops this may be feasible.

Passage of the planter through the faba bean or mustard stand may cause substantial damage to the winter crop because of removal of plants by the tines as it attempts to place seeds of the sunflower or sorghum between the rows of winter crop. The number of plants removed will be reduced if row spacing is increased and precision of tine placement is increased. This impact can be reduced by planting the spring crop while the faba bean and mustard are relatively short, have immature flowers and pods and still retain flexibility within their stems. My current research will involve measurement of crop damage caused by the planting implement.

Weed Control

Weed biomass was reduced by intercropping of beans and wheat, due to the increased level of competition between the crops and the weeds (Bulson *et al.*, 1997). Likewise, presence of a well established, actively growing winter crop together with the seedlings of the summer crop should reduce the biomass of spring weeds in the current experiment. These weeds have the potential to greatly reduce the yield of the sunflower and sorghum. Mustard will be much more effective in suppressing the growth of weeds within the crop, because it has a higher plant population than faba beans.

On the other hand relay cropping greatly complicates selection of herbicides, because any herbicide residues applied to the winter crop must have broken down sufficiently by spring that they do not interfere with establishment of the summer crop. The presence of sorghum (a cereal) within the stand of faba beans and mustard will greatly restrict the use of selective herbicides.

Harvesting the Winter Crop.

When a summer crop is planted into a winter crop , the winter crop will mature much earlier than the spring/ summer crop and will therefore need to be harvested earlier. This raises two issues a) ability to harvest the winter crop.and damage to the summer crop.

In a cereal, such as wheat, the grain is borne on the top of the plant, so a conventional harvester will be able to remove the grain from the crop with little impact on the developing seedlings, provided the seedling of the summer crop is beneath the level of the heads. Both faba beans and mustard bear pods on a number of levels within the canopy, in the case of faba beans pods may be set to the base of the plant whereas the podding zone of mustard may begin 50 to 90 cm above the ground depending on the variety. In the current experiment the faba bean is 20 cm shorter than the mustard in early August (flowering of the mustard). Given this it is likely that a greater proportion of the mustard will be able to be harvested than the faba beans. The exact proportion will depend on the height of the summer crop when the winter crop is ready for harvest.

The final consideration is the impact on seed yield of the sorghum or sunflower on harvesting the winter crop. In third world countries such as Kenya, where harvesting is done with hand tools, harvesting a bean crop from a tall crop such as maize does not pose any difficulties (Nadar, 1983a). However, when the crop is to be mechanically harvested their is a risk that the process of harvesting the winter crop will severely damage the summer crop. In this respect sorghum may be a better choice as the summer tag crop than sunflower because it grows more slowly, has a shorter mature height and responds to removal of the main stem by tillering. Sunflower on the other hand as a rapidly growing, tall crop will restrict the window for harvesting the winter crop and will be severely affected by removal of the growing point, because the grain is borne on a single large capitulum.

Taking into account these harvesting considerations it is likely that the mustard/ sorghum system will be more successful than the faba bean/ sunflower or faba bean/ sunflower systems.

Conclusions

Relay cropping has the scope to increase the productivity of cropping enterprises in eastern Australia by enabling them to use resources more efficiently and to increase their cropping frequency. However, there are a number of significant obstacles to widespread adoption of this system relating to both the agronomic and machinery aspects. Research is underway to identify the impact of the possible constraints discussed in this article and to develop strategies to overcome them. Controlled traffic will play an important role in this system because of the necessity for precise placement of seed of the summer crop between the rows of the winter crop.

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Controlled Traffic and Surface Runoff Experiments At Gatton College, South-East Queensland

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Introduction

Interested in conservation tillage has been widespread in Australia, where large areas of land are susceptible to soil erosion. Despite a general understanding that zero tillage should be the optimal systems in terms of soil and water conservation, however, few farmers have been able to avoid all tillage. This suggests that surface and subsurface soil compaction is often a major practical problem of zero tillage. Controlled traffic is expected to control soil compaction, increase infiltration of rainfall and reduce surface runoff. Runoff is the driving force of water erosion, so the extent and magnitude of the controlled traffic effect on runoff or rainfall infiltration capacity on black cracking clay soil is of considerable importance. A research program to establish these effects started in 1994 at the University of Queensland, Gatton College with an initial focus on the assessment of tillage and traffic management options in terms of runoff, and crop yield (Tullberg *et al.*, 1996). This paper reports the effects of field traffic - its control - on runoff, infiltration capacity and crop yield within the first phase of project between 1995 and 1997.

Methods

The experimental site is located in the crop research unit at Gatton College, South-East Queensland (27 °30'S., 152° 27'E.). Soil type at the site is a self-mulching black earth (Ug5.15) (Northcote, 1979) of Lawes series with a mean slope of 5% (table 1). Average annual rainfall is 785 mm with 70 % expected between October and March; pan evaporation is about 2000 mm.

Table 1. Characteristics of Lawes black earth at Gatton

Depth (cm)	pH	Cation exchange capacity (m.e./100g)	Particle size distribution (% of total) Coarse sand	Fine sand	Silt	Clay	Moisture holding capacity (%) 1/3 bar	15 bars
0-10	8.3	47	3	19	23	59	44	26
20-30	8.2	49	3	15	20	63	54	30
50-60	8.4	46	2	14	18	66	56	34
80-90	8.7	51	13	18	16	57	46	27
110-120	8.8	53	2	47	16	34		
140-150	8.7	46	3	36	29	36	43	23

Adopted from Powell, Agricultural Chemistry Branch, QDPI

Controlled traffic trials were set up in the early 1994 after the site was deep ripped to 60 cm. Four replicates (blocks) of three tillage/residue treatments (zero till, minimum till and conventional practice) were established, each plot was split into wheeled (conventional traffic) and non-wheeled (controlled traffic) with subplot dimension of 3m × 30 m. Runoff from each sub-plot was channeled through a tipping bucket unit. Tillage treatments were normally completed with a scarifier or spring tine cultivator with 3 passes and 1 pass for conventional practice and minimum till respectively. Wheeling was applied using a

9t tractor with 6t draw bar pull on the bare soil. The sequence of soil compaction, tillage treatment, crop and fallow management is given in figure 1. Residue levels were those resulting from the cropping practice appropriate to that treatment, unless otherwise noted.

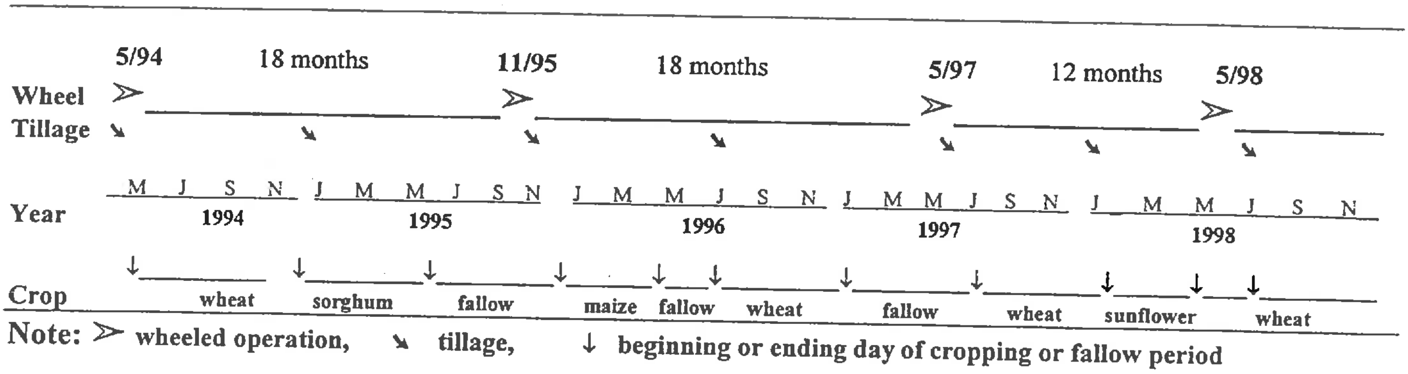

Figure 1. Tillage, traffic and cropping management at experimental site, Gatton

There are 6 treatments :
Controlled Traffic/Zero tillage (CTZ)----No wheeling on the seedbed, no tillage;
Controlled Traffic/Minimum Tillage (CTM)----No wheeling on seedbed, 1 pass of spring tine or scarifier;
Controlled Traffic/Conventional practice (CTC)----No wheeling on the seedbed, 3 passes of spring tine or scarifier;
Wheeled/Zero tillage (WZ)----Wheeled on the seedbed, no tillage;
Wheeled/Minimum Tillage (WM)----Wheeled on seedbed, 1 pass of spring tine or scarifier;
Wheeled/Conventional practice (WC)----Wheeled on the seedbed, 3 passes of spring tine or scarifier;

Rainfall and runoff has been recorded since Jan.1995 using 2 pluviometers for rainfall, 24 tipping bucket units for runoff, monitored at one minute interval by data loggers. Tip rates were converted into data such as total amount of rainfall and runoff daily-based and/or event-based (Ciesiolka *et al.*, 1995) and crop yields measured.

Results and Discussion

Runoff in 3 years
On average, controlled traffic produced 33% less total runoff than conventional traffic treatments during 1995, 1996 and 1997 (figure 2). About 16% and 24% of total rainfall ran off from controlled traffic and wheeled plots respectively, although there was great variable from storm to storm. In the largest runoff event on 5 May 1996, for example, 78% of rainfall ran off from both wheeled conventional practice and wheeled minimum tillage, while 47% ran off from controlled traffic/zero tillage. Over 90 % of total runoff occurred in 1995, and 1996. It was very dry in 1997 with total annual rainfall of 628mm and runoff less than 20mm.

A total of 64 runoff events occurred during experimental period. Runoff varied greatly among treatments in every event, but there was an excellent correlation between wheeled and non-wheeled treatments in terms of total runoff (figure 3).

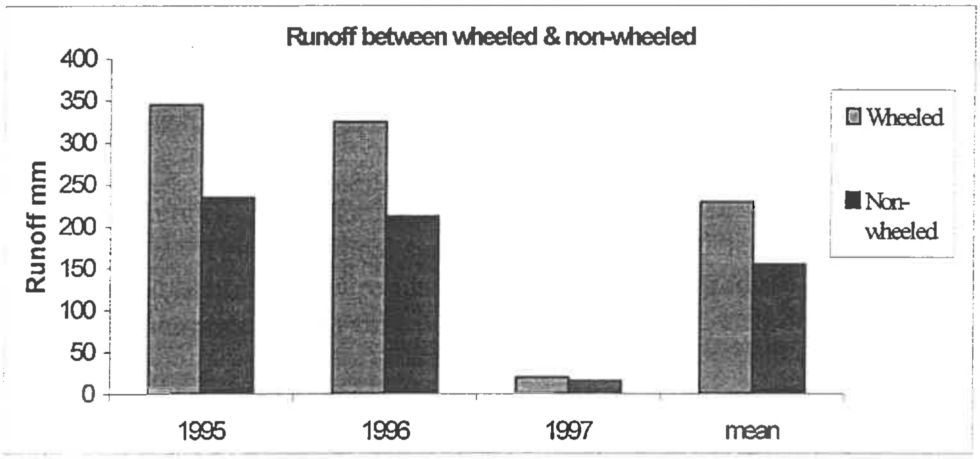

Figure 2 total runoff for wheeled and non-wheeled in 3 years

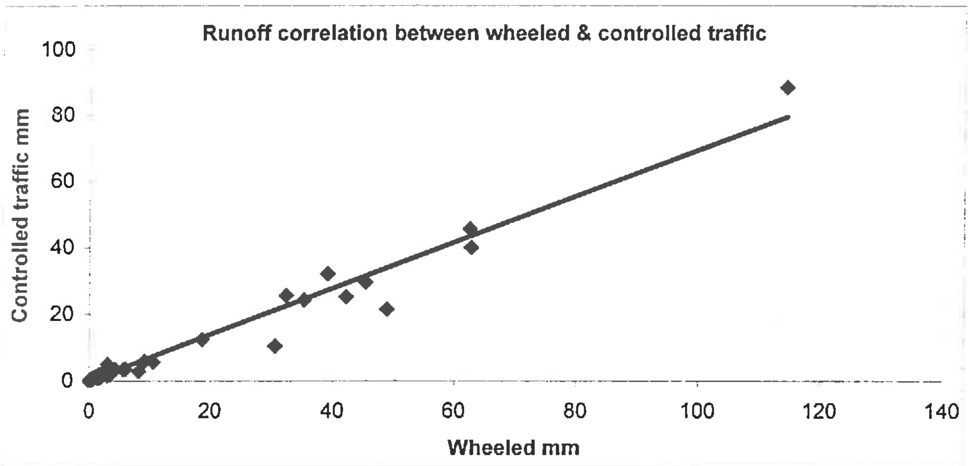

Figure 3 Correlation between wheeled and non-wheeled treatments

The correlation between controlled traffic and wheeled is:

$$Y = 0.696 X - 0.0443 \qquad R^2 = 0.97$$

Where Y ---- runoff for controlled traffic in mm

X ---- runoff for wheeled practice in mm

The relation line also demonstrates that about 30 % less total runoff occurred from controlled traffic treatments in each runoff event compared with conventional traffic practices.

Infiltration capacity in fallow periods

In general, controlled traffic reduced runoff and increased infiltration capacity during two periods of fallow. 12% more rainfall infiltrated into controlled traffic/zero tillage plot compared with wheeled/conventional practice plot in the fallow from June to November 1995, when the soil surface was bare for all the treatments after sorghum stubble was removed in August. 27% more rainfall entered the controlled traffic/zero tillage plot in the short fallow between April and June 1996, when all the plots were covered by maize stubble.

Table 2. Infiltration capacity during fallow periods for 6 treatments

	Water supply			Treatments					
	Rain	Irrigation	Total	WC	WM	WZ	CTC	CTM	CTZ
Jun. - Nov.1995	344	171	515	147	147	140	121	114	90
RIR				71%	71%	73%	77%	78%	83%
Apr.-Jun. 96	561		561	300	300	246	216	207	151
RIR				46%	47%	56%	61%	63%	73%

Note: RIR means Ratio of Infiltration to Rainfall, RIR = (rainfall + irrigation - runoff) / (rainfall + irrigation).

Study of single event

Runoff analysis has been carried out for each treatment and runoff event, using the curve number method of the Soil Conservation Service, US Department of Agriculture (USDA-SCS method). The curve number method is based on the following equation, which represents a nonlinear relationship between rainfall and runoff (Littleboy *et al.*, 1989).

$$Q = \frac{(P-0.2S)^2}{(P+0.8S)} \qquad P \leq 0.2S$$

$$Q = 0 \qquad P > 0.2S$$

Where Q----runoff volume (mm)

P----rainfall (mm)

S----retention parameter

The major input parameter into the USDA curve number method is the runoff curve number (CN). The value of CN is related to S, which reflects the capacity of surface storage.

$$S = 25.4\left(1000/_{CN} - 10\right)$$

In USDA-SCS procedure, curve number was selected based on wet, average or dry antecedent conditions, which depend on total rainfall in the previous 5 days or 10 days preceding the runoff event (Freebairn and Boughton, 1981).

The individual curve numbers for wet soil moisture conditions (5 days rainfall from 37.5 to 255m preceding the runoff event) are shown in table 3, grouped according to surface cover.

Table 3. UDSA-SCS curve numbers for single runoff event under wet moisture conditions and residue management

Treatment	Wet soil moisture condition			
	With residue cover	mean	without cover	mean
WC	70, 84, 89, 90, 92	85	88, 89, 93,	90
WM	73, 85, 88, 90, 92	86	89, 90, 93,	91
WZ	60, 78, 84, 87, 89	80	89, 90, 93	91
CTC	57, 73, 77, 78, 84	74	86, 86, 91	88
CTM	55, 72, 73, 75, 85	72	85, 86, 86	86
CTZ	56, 62, 72, 75, 78	69	82, 81, 90	84

Generally speaking, controlled traffic/zero tillage gave the smallest in curve number, whereas wheeled/conventional practice gave the greatest curve number under wet soil moisture conditions. The curve number for controlled traffic/zero tillage with residue cover in average was about 16 units less than for wheeled/conventional practice. Controlled traffic without residue cover did not give very much reduction in curve number because surface sealing restricted infiltration on bare soil and overrode the improved subsoil infiltration of controlled traffic with zero tillage. Similar results were found by Silburn *et al.*, (1995). Compacted treatments had little benefits from stubble mulching because subsoil structure had been destroyed by wheel traffic.

Crop yield

In general, winter crop increased crop yield by 23%, 21% and 27%, in controlled traffic plots compared with wheeled plots in 1994, 1996 and 1997 respectively, while 5% and 15% for summer sorghum and summer maize in 1995 and 1996 respectively (figure 4). Zero tillage increased crop yield by 5.5 % on average compared with conventional practice except for the first (1994) winter wheat crop (8% reduction).

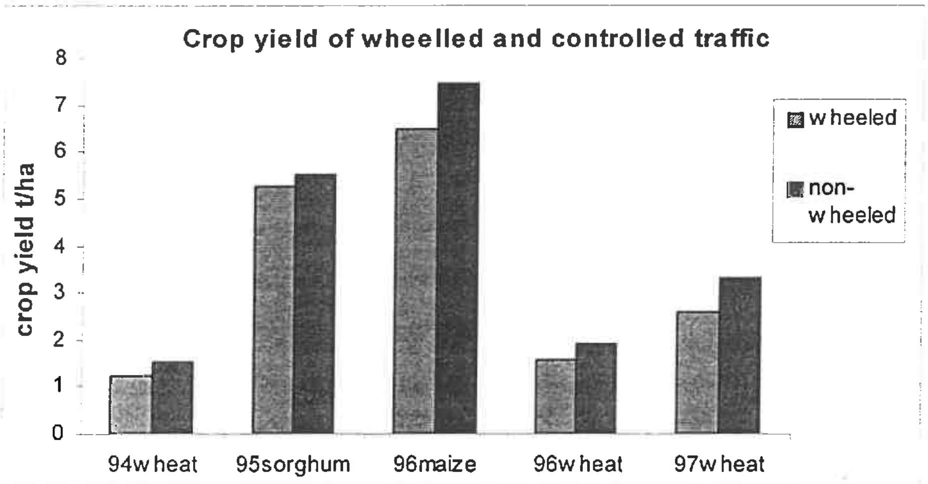

Figure 4 . Crop yield of winter and summer crop during experimental period

Conclusion

In summary, controlled traffic farming reduced runoff, improved infiltration capacity, and increased crop yield compared with random traffic farming. The optimum practice was controlled traffic with zero tillage.

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Relay Cropping and Controlled Traffic: Preliminary Results

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Introduction

Relay cropping as practiced in developing countries involves the planting of a second crop before harvest of the first crop occurs. This traditional system of farming is efficient in the utilisation of resources such as water, nutrients and light and may result in greater output of produce per hectare per year. In addition, crop cover is maintained for a longer time period thus minimising evaporation, runoff and soil erosion.

In developing countries, manual labour is most commonly been used to produce crops under relay cropping systems. This is not an option in developed countries due to high labour costs. A mechanised system using controlled traffic can facilitate relay cropping in several ways:

- passage of planting and harvesting machinery through a standing crop with no or minimal damage to it
- a guidance system that keeps machinery on the same wheeltracks thus limiting wheel track effects to non crop zones

For this system to be successful, all machinery needs to have the same width wheeltrack, preferably as wide as possible to minimise land area lost from production. The issue of matching harvester wheeltracks to that of the planting equipment needs to be addressed. Planting equipment may need to have higher clearance than conventional planters to avoid damage to developing grain heads especially late in development when stems are less flexible. Other crop injury could arise from root damage to the first crop when planting the relay crop.

For dryland farming in northern Australia, this strategy would be highly dependent on stored moisture sufficient to produce an economic yield, timely planting rains, pest and disease pressure and crop options. However, even under drought condition, Durrand (1995) found that in some cases intercrops outperformed sole crops.

Relay cropping may not be possible every year but could be undertaken when the opportunity arises. It does allow growers to sow earlier than if they waited until the first crop was harvested, or even to sow at all, if no subsequent planting rains are received. Earlier planting reduces potential moisture loss to weeds and evaporation. If earlier planting results in earlier maturity, then it may be possible to plant a second crop in the same season. In addition, relay cropping may enable sowing to occur closer to the planting time which optimises yield for that crop.

Relay cropping of winter crop into a summer crop is not likely to be as viable as relay cropping of summer crop into a winter crop due to:

- the need for stored moisture from the predominant summer rains; this stored moisture will be depleted by the summer crop
- most summer crops are harvested earlier than the optimum planting time for many winter crops

Some crop options may not be available due to the physical nature of the first crop. For example, it would be difficult to plant into a chickpea or faba bean crop due to the spread of the canopy. Harvesting of these crops without damage to the relay crop would be also difficult due to pod development throughout the crop. It would be difficult to plant into a tall crop such as maize due to height limitations of the planting machinery. Other issues that need to be addressed include row spacing, fertilisation and weed control.

Wider rows may be needed to facilitate planting of the second crop. Slightly wider rows should not reduce yield significantly. Guidance systems which allow planting machinery to stay on track will be essential for precise placement of rows between those of the first crop and may reduce the need to increase row spacing greatly in the first crop.

Fertiliser may be needed for many of the second crops and can be applied before and/or at planting. Fertiliser will need to placed such that seed germination is not affected. Ideally, fertilisation and seeding could be done simultaneously. Split application of fertiliser may be applied after harvest of the first crop.

Weed control could prove to be one of the most challenging issues for relay cropping systems. It is likel that as the first crop reaches physiological maturity and starts leaf senescence, then more light will penetrate to the soil surface where it will stimulate germination of weed seeds. Selective herbicides will be needed to control these weeds to enable establishment and growth of the second crop. Lack of selective herbicides may result in relay cropping being practiced on relatively weed-free country. For herbicides applied prior to physiological maturity of the first crop, these will need to be safe for that crop. Residual activity of herbicides applied to earlier planted crops will be an important consideration in the choice of second crop.

Methodology

Wheat (cv. Hartog) was planted with a JD 4040 (3 m wheeltracks) and John Shearer planter at the University of Queensland, Gatton College on June 3 1997 in a controlled traffic system. A row spacing of 35 cm which is wider than for a normal crop was used to facilitate intercropping.

Sorghum was planted at a row spacing of 35cm at two dates during the development of the wheat crop. These were:

- one week prior to physiological maturity (2/9/97)
- two weeks after physiological maturity (28/9/97)

A third planting date, four weeks post harvest (1/12/97) was used for sorghum and sunflower. This was done to (1) allow comparsion of the two crops under a stubble canopy, and (2) assess the gains associated with an intercropped versus double cropped strategy.

Sorghum was planted using a hand planter due to difficulties in developing a specially modified tractor and planter in time.

For the sole sorghum treatment, wheat was cut and left on the plots; sorghum was planted into these plots. Thus these plots had the same history as the intercropped plots prior to sowing. This treatment was required so that sorghum planted alone could be compared with intercropped sorghum.

Data was collected on moisture usage, light interception, weed density and yield of first and second crops.

Results

Sorghum seed failed to germinate in the first sowing and germination was poor for the second sowing date for the intercropped treatments, even though germination and establishment were successful in the sole sorghum plots . This was most likely due to low soil temperatures under the wheat canopy (Figure 1). Minimum temperatures experienced by the intercrop were consistently lower by 1 – 2 degrees C than that of the sole crop. Temperatures frequently fell below 15 C, the minimum temperature required for sorghum germination.

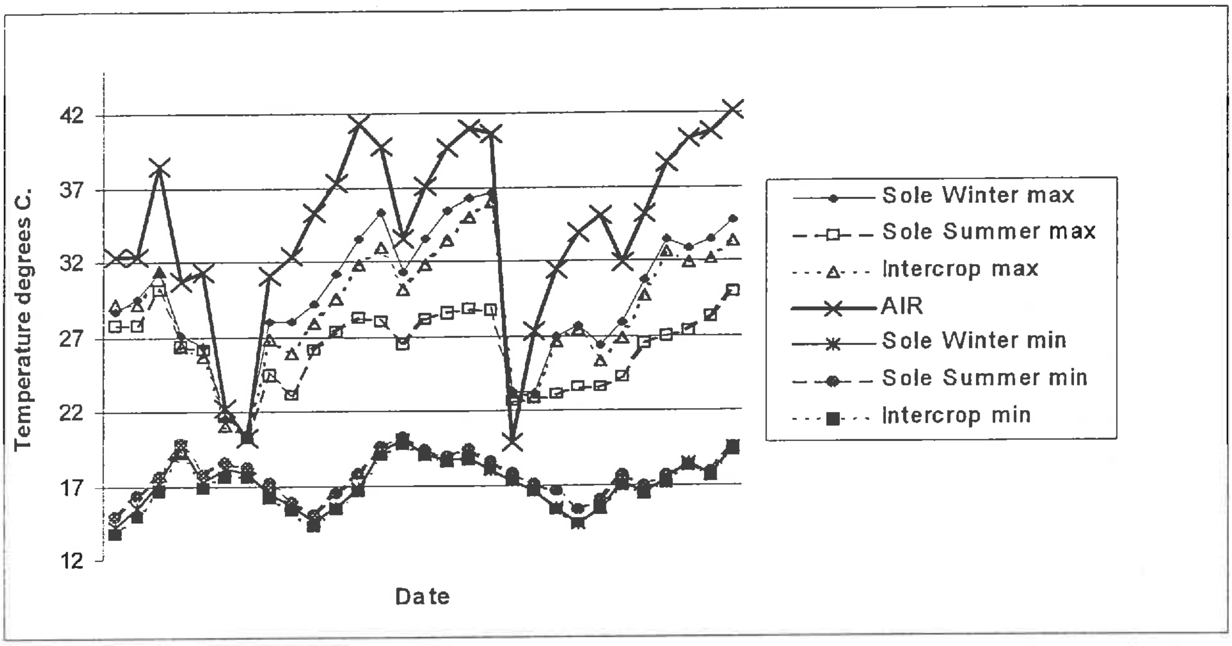

Figure 1. Daily maximum and minimum soil temperatures

Further investigation into the effect of rainfall and overcast conditions on the soil temperature beneath the canopy will be undertaken in this seasons trial.

Monetary Returns

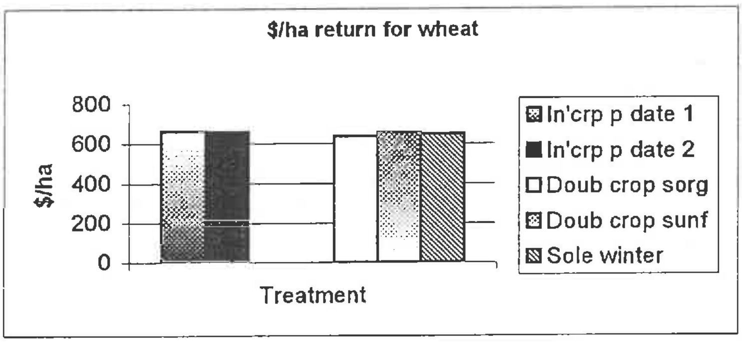

Figure 2 Yield of Wheat only

The crop yield was expressed in terms of dollars per hectare with Figure 2 showing that planting the sorghum into the wheat crop had no negative effect on the wheat yield.

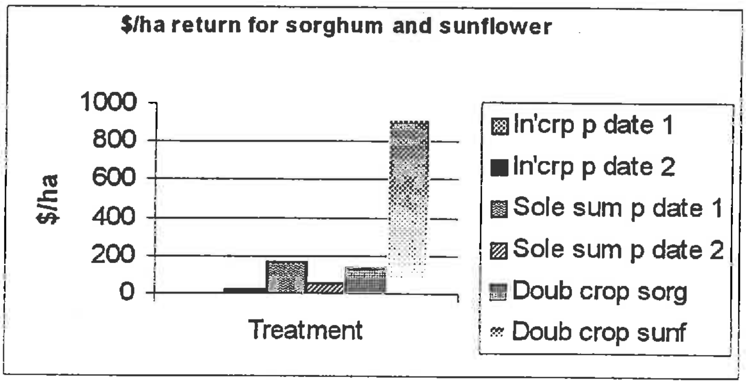

Figure 3. Yield of summer options only

Sunflowers yielded more in the double crop system. In this season's trial, it will be used as the preferred summer option because of its lower temperature requirement for germination (8 – 10 degrees C).

Yield data showed no adverse effects on wheat yield due to the intercropped sorghum from the second sorghum planting onwards (the first planting failed to establish). The wheat was harvested with a tractor mounted stripper harvester with some adverse effect on the young sorghum plants of the second sowing date. This was due to the similarity in height of wheat heads and sorghum leaves.

Weeds became an increasing problem as the wheat crop matured, particularly in the final planting date due to the four week period between harvest and sowing. Unfortunately the method used to score weed pressure was not accurate enough to relate crop yield to weed pressure. This has been altered to improve the measuring precision. It was found that plant height did relate to weed pressure with higher plants having a lower weed burden. Measurement of plant height has also been reviewed and both weed pressure and crop height will be monitored for this seasons crop.

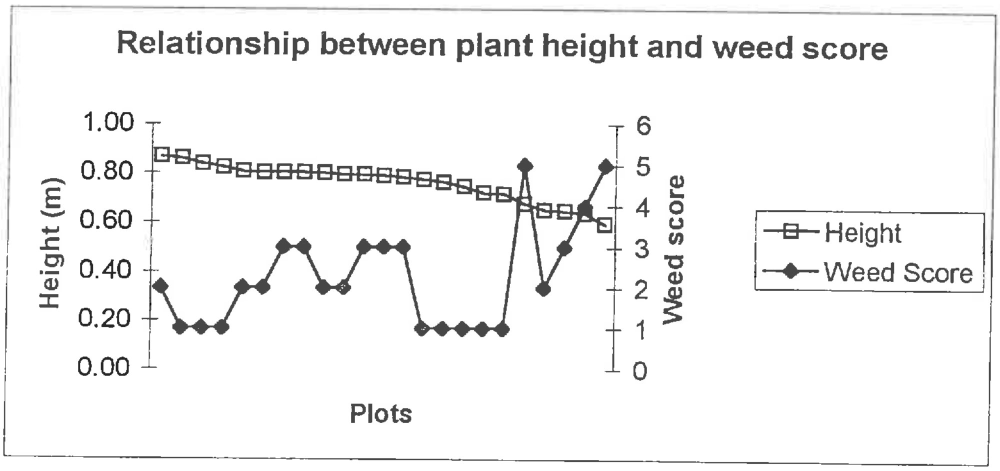

Figure 4. Weed score information

Conclusions

Preliminary results indicate that relay cropping of a summer crop into a winter cereal crop is possible and may be a useful strategy in the northern grain belt. There is a high probability of spring rains in October - November when the wheat crop is physiologically mature but awaiting drydown to moisture content safe for storage. Given sufficient moisture stored in the soil profile and a planting rain, it is feasible to plant sunflower, millet, sorghum or a legume crop as a relay crop. Thus these crops may be planted up to five to six weeks earlier than would be the case without relay cropping.

Lower soil temperatures due to canopy cover of the first crop may pose a limitation to some crops such as sorghum which requires a minimum temperature of between 15 and 18 degrees for germination. In this trial the planting date (2 weeks after physiological maturity) used for sorghum was too early as plants reached a similar height to wheat. This meant sorghum was damaged when the wheat was harvested. Sorghum grown under the wheat canopy, compared to bare plantings, seemed to be more erect as a result of light competition with the wheat. Later planting dates will be trialed in this season and sunflowers, with their planophile leaves, should cope better in the shaded environment.

To overcome soil temperature limitations sorghum may be relayed into an early maturing crop of mung bean or millet in a late summer planting. Before this is attempted,the risk of midge infestation should be assessed.

Weeds were a major consideration in the late sorghum plantings and have highlighted shortcomings of the method in the pilot trial. These have been altered and further research will occur.

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EFFECTS OF COMPACTION ON CROP PERFORMANCE

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Abstract

An alluvial soil at Biloela (24° 22'S, 150° 31'E) was compacted in various ways to determine the effects on soil water storage, crop establishment, growth, yield and water use efficiency. Annual compaction with header tyres on wet soil reduced grain yield by reducing soil water storage at sowing. When compaction had no effect on soil water storage, it did not reduce wheat or sorghum yields, provided satisfactory crop establishment was obtained. Biological repair of compacted soil by crop or pasture roots is recommended in preference to deep ripping. This requires suitable machinery for sowing into compacted soil.

Introduction

Wheel traffic in fields has been recognised as a major source of forces causing undesired soil compaction (Schafer et al., 1992). The first pass of a wheel causes most of the total soil compaction (Burger et al., 1983). Wheel damage increases on wet soil, which has reduced strength (Kirby and Kirchoff, 1990). A large proportion of the area of a field is covered by wheel tracks during a cropping cycle. The ground area trafficked by heavy tyres is estimated at 30% under zero tillage, 60% under minimum tillage and 100% under conventional tillage (Tullberg, 1990; Soane et al., 1982; Erbach, 1986).

The aim of this work was to measure the effect of applied soil compaction on crop performance and to determine ways to repair compaction damage. Such data show the value of controlled traffic systems, which avoid the problem of soil compaction.

Materials and Methods

Site

The site is located on the Queensland Dept of Primary Industries Research Station, Biloela, Queensland, Australia (latitude 24° 22'S, longitude 150° 31'E, altitude 173 m). It was cleared in the 1930s. The ground surface is relatively level (slope = 0.2%).

The soil is a black cracking clay developed on an alluvium, locally termed Tognolini series (Shields, 1989) or Vertisol (Soil Survey Staff, 1975). The soil had minimal, visible structure degradation before the experiment (P.G. Muller pers. comm.). However, a former owner reported a history of subsoil "hardpan" formation and deep ripped in 1977 to a depth of 0.45 m. The clay content in the 0-0.1m layer is 47%.

The long-term mean annual rainfall is 685 mm with 73% failing in the summer months (October-March). The long-term mean annual evaporation is 1868 mm.

Treatments

The experiment commenced in April 1993 when all but a control treatment were initially compacted with the lugged rubber tyres of a commercial header on wet soil. This is a short-term economic necessity when grain is ready for harvest and summer storms threaten heavy yield losses. The entire area of each compacted plot received a single pass of a front header wheel. This experimental treatment is not unrealistic because random wheel traffic during a fallow typically covers most of the ground area. Average mass on each front wheel of the header was 5 t. Inflation pressures were deliberately kept high to maximise compaction: 235 kPa (front) and 205 kPa (rear).

Subsequently there were 6 compaction repair treatments and the uncompacted control:

C_0: Control - nil compaction, reduced (dry) tillage (only on soil drier than the plastic limit);

C_1: Extreme compaction - annual compaction with a header on wet soil, minimal tillage;

C_2: Traditional practice - annual compaction with a tractor on wet soil, frequent tillage;

C_3: Reduced tillage - annual compaction with a tractor on dry soil, reduced (dry) tillage;

C_4: Zero tillage - initial compaction with a header on wet soil, no tillage;

C_5: Current best advice - initial compaction with a header on wet soil, deep ripping (dry) after first crop, no tillage thereafter; and

C_6: Pasture - initial compaction with a header on wet soil, pasture ley (lucerne + Gatton panic) for 3 years, reduced (dry) tillage thereafter.

When tillage was avoided, weeds were controlled with herbicides.

Design

The experimental design was a randomised block of 2 main treatments (raingrown, supplementary irrigation) and 2 replications. The main plots were split into 14 subplots: the 7 compaction/repair treatments x 2 fertiliser treatments (control, fertilised with N and Zn). Each plot measured 30 x 9 m (3 passes of a tractor with wheels spaced 3 m apart).

Crop sequence

Crops grown were wheat (Hartog) in 1993, wheat (Hartog) in 1994, sorghum (MR31) in 1995 (double crop), wheat (Hartog) in 1996, wheat (Sunstate) in 1997 and maize (DK689) in 1998 (double crop).

Measurements

The following measurements were taken:
Soil water storage: 0-1.5 m in 0.1 m increments, by neutron moisture meter;
Crop establishment: percentage of seeds sown (from 5-15 m of row for wheat and 50 m for sorghum and maize);
Aboveground dry matter at anthesis: from 1 m^2 quadrats in each plot;
Grain yield at 12% moisture content: by small plot header and grain moisture meter;

Water use efficiency: grain yield/(soil water use + incrop rainfall).

Results

Soil water storage

In all years, particularly 1993, some rainfall was already stored in the soil prior to the application of the annual compaction treatments. Nevertheless annual compaction with the header significantly reduced total soil water at sowing in all years except 1993 and 1995. Mean soil water content was reduced from 543 (control) to 489 mm (Table 1). Annual compaction with tractor tyres on wet soil significantly reduced soil water content at sowing from 1995 to 1998. Reduced tillage, zero tillage, current best advice and the pasture treatment attained the level of soil water at sowing in the control in all years.

Table 1. Effect of compaction/repair treatments on total stored soil water (0-1.5 m) at sowing (mm)

Treatment	Wheat 1993	Wheat 1994	Sorghum 1995	Wheat 1996	Wheat 1997	Maize 1998
C_0	556	561	472	549	571	547
C_1	537	528	448	474	501	448
C_2	-	546	416	484	536	499
C_3	-	567	472	551	556	526
C_4	-	583	542	559	571	554
C_5	-	538	470	536	540	533
C_6	-	-	-	-	562	559
lsd, P=0.05	ns	27	37	58	32	46

Crop establishment

Compaction with the header significantly reduced crop establishment in 1993, 1994 and 1995 (in comparison with the uncompacted control treatment) (Table 2). In 1996, however, the rate of seed metering was found to have varied during planting, and in 1997 seed was sown at a shallow depth and the soil was wet up with spray irrigation. Reductions in establishment occurred only in the extreme compaction treatment, and even these reductions were only small. This result is attributed to the use of "state of the art" zero tillage planting machinery (smooth coulters, spearpoint soil openers, rigid tines and press wheels).

The small reductions in establishment percentage (and hence plant populations) are unlikely to have caused significant variation in crop dry matter production or grain yield.

Table 2. Effect of compaction/repair treatments on crop establishment (% of seed sown)

Treatment	Wheat	Wheat	Sorghum	Wheat	Wheat	Maize

	1993	1994	1995	1996	1997	1998
C_0	93	76	35	55	53	87
C_1	71	59	22	56	56	79
C_2	-	73	39	51	55	85
C_3	-	82	39	53	60	78
C_4	-	67	41	38	56	80
C_5	-	76	46	50	65	86
C_6	-	-	-	-	57	84
lsd, P=0.05	8	15	11	ns	ns	9

Aboveground dry matter at anthesis

Compaction with the header did not reduce anthesis dry matter for wheat in any year (compared with control) but reduced it for sorghum (1995) and maize (1998) (Table 3). Zero tillage and current best advice significantly exceeded control in 1995.

Table 3. Effect of compaction/repair treatments on weight of aboveground plant dry matter at anthesis (t/ha)

Treatment	Wheat 1993	Wheat 1994	Sorghum 1995	Wheat 1996	Wheat 1997	Maize 1998
C_0	5.77	5.21	3.54	5.71	4.35	7.00
C_1	5.49	4.67	2.49	5.12	3.64	4.01
C_2	-	4.77	2.88	6.09	4.00	5.22
C_3	-	5.48	4.10	6.45	4.52	6.27
C_4	-	4.60	4.33	5.76	4.15	6.58
C_5	-	5.49	4.52	5.30	4.47	6.78
C_6	-	-	-	-	4.59	7.76
lsd, P=0.05	ns	0.66	0.65	0.77	ns	1.38

Grain yield

Compaction with the header significantly reduced the grain yield of wheat in 1996 and 1997, and of maize in 1998 (by 2.43 t/ha or 43%) (Table 4). In 1997 and 1998 the former pasture treatment outyielded all other treatments.

Table 4. Effect of compaction/repair treatments on grain yield at 12% moisture content (t/ha)

Treatment	Wheat 1993	Wheat 1994	Sorghum 1995		Wheat 1996	Wheat 1997	Maize 1998
			Dryland	Irrigated			
C_0	5.32	2.55	1.61	3.52	3.51	3.25	5.63

C_1	5.18	2.40	2.36	2.70	3.04	2.33	3.20
C_2	-	2.41	2.08	1.90	3.32	3.10	4.45
C_3	-	2.61	1.92	4.02	3.45	3.31	5.02
C_4	-	2.35	3.17	3.68	3.30	3.01	5.92
C_5	-	2.52	2.77	3.40	3.25	3.21	5.96
C_6	-	-	-	-	-	3.58	6.54
lsd, P=0.05	ns	ns	0.95	0.95	0.26	0.12	0.58

Water use efficiency

Compaction with the header significantly reduced water use efficiency in 1996 and 1998 (compared with control) (Table 5). In 1998, the former pasture treatment had significantly higher water use efficiency than control, current best advice and the three annually compacted treatments.

Table 5. Effect of compaction/repair treatments on water use efficiency (kg/ha/mm)

Treatment	Wheat 1993	Wheat 1994	Sorghum 1995		Wheat 1996	Wheat 1997	Maize 1998
			Dryland	Irrigated			
C_0	10.2	6.6	5.4	9.6	10.5	9.9	13.2
C_1	10.2	7.0	9.0	9.2	8.5	9.6	9.2
C_2	-	7.7	9.9	6.3	9.8	10.0	11.3
C_3	-	7.7	6.7	11.7	10.9	10.8	12.8
C_4	-	6.9	9.7	9.4	9.8	9.8	14.0
C_5	-	7.0	9.2	9.8	10.3	9.6	13.1
C_6	-	-	-	-	-	10.1	14.9
lsd, P=0.05	ns	ns	3.8	3.8	0.9	0.8	1.7

Discussion

Annual compaction with header tyres on wet soil generally reduced the amount of water stored in the soil at sowing compared with control (Table 1), which resulted in reduced grain yields (Table 4). When compaction with the header was not associated with reduced soil water content at sowing (in 1993 and 1995), compaction did not reduce yield. This result is attributed to repair of the compaction damage by the fibrous root systems of the crop species tested (wheat in 1993 and sorghum in 1995). Any effects on crop establishment were small and unlikely to affect yield (Table 2). Compaction by the header reduced water use efficiency in 1996 (wheat) and 1998 (maize) (Table 5).

Annual compaction with tractor tyres on wet soil generally reduced soil water content at sowing and grain yield, despite subsequent tillage operations to repair the compaction damage (Tables 1 and 2). Annual compaction with tractor tyres on dry soil combined with subsequent tillage of dry soil (reduced tillage) generally did not reduce soil water at sowing or yield.

The pasture treatment not only repaired the compacted soil but resulted in a better soil condition for grain yield than the control in both 1997 and 1998 (Table 4).

Compaction repair by crop or pasture roots can only be effected with suitable planting machinery to establish plants in the compacted soil. Although costly, this option is recommended in preference to deep ripping, which is costly and delays cropping.

Acknowledgements

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Beware - Agency Staff Bearing Gifts : Our Action Learning Adventure

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Farming has long been a challenging business. Historically government agencies have provided support for our farming communities to help meet these challenges. Traditionally these services were delivered on an individual basis by extension staff. Researchers were 'institutionally' separated from extension services and indeed from the farming practitioners. AS we have entered the later phase of this century the situation has been changing. Rural communities have been inundated by advice from all fields. Action learning has reached the 'conservative' realms of agricultural extension and posed yet another challenge for our farming practitioners.

Traditional extension practices have focused on the linear research extension implementation model. This model did serve a vital role. However, in the current climate of rapid change and limited resource staff, it is not an easy model to sustain. For development and implementation of Controlled Traffic Farming (CTF) a new medium had to be found. Enter the action learning model. This mode of delivery has been able to better integrate research, development and extension. However this mode of extension has brought its own challenges.

Attempting to change from the linear research extension adoption model to the circular action research model is not simple. The traditional linear model tends to deal with single practices eg contour banks/stubble cover and has not subjected extension staff significantly to developing the scientific/technical base. Indeed an advantage of the linear model is that there is a substantial research base to start with.

When reviewing the development of CTF the difficulties associated with the lack of science appears. It is a real challenge to involve producers and extension staff very early in the research and development timeline when there is a lack of factual research data. However, with the linear model the research staff had little or no direct contact with the 'real world' or a systems approach which farmers deal with on a day to day basis (farmers being the target audience of the research). Researchers could not be positive that their efforts were addressing the needs of those directly involved in the field.

With all the acknowledged problems of the process, imagine the challenge faced by Central Queensland (CQ) farmers in the mid 90's when confronted by three speakers - a research officer, an extension officer and a development officer - all offering advice:

- 50% reduction in fuel bills by removing compaction!
- Gantry farming and worse!
- Working up and down the slopes as opposed to contour cultivation to increase efficiency and reduce erosion!

Where did it all begin?

Controlled Traffic is not a new concept as a dryland or irrigated agricultural practice. Much research, development and on-farm work has occurred over at least the last 20 years. USA and Great Britain have looked at the practice mainly for rotational cropping, herbicide and insecticide spraying and vegetable growing. In Australia, South Australia has looked at 'Gantry' farming and researchers such as Dr. Jeff Tullberg at the University of Queensland (Gatton), have had positive results from Controlled Traffic including reduced energy requirements, reduced fuel use and improved trafficability (Cannon et al. 1997).

It could be argued that the use of roadbeds for dryland cultivation probably started with traction engines - it was certainly tried in the 1940's. Combine this with the positive results from Tullberg's work and the question arises - why did producers not take up the practice? It had been proved that large savings in energy requirements could be made. It is not simple to arrive at an answer to the question but 'let's have a go'.

What happened in C.Q.?

'Can we get six growers to give a best bet system a go?' That was the question posed by Yule and Cannon in 1991. From that beginning, Controlled Traffic farming on over 200,000 hectares has been the result. A result which is about the triumph of attitude change over traditional paradigms. Why did large-scale broad acre dryland growers in Central Queensland 'Have a go?' Action learning underpinned the process.

As noted above, traditionally extension was based on a linear adoption model - basically a positivistic approach. As Carr & Kemmis (1986 pg.186) highlight:

> *Positivistic research relies on prediction based on laws established in past situations expressed as controlled intervention as its basis for informing future action. Interpretative research relies on a notion of practical judgement based on the understandings of the practitioner derived from the observation of previous situations. Action research involves both controlled intervention and practical judgement...conducted by individuals and groups committed to not only understanding the world but to changing it*

The moments of action research (Fig. 1 - Carr & Kemmis 1986 Pg.186) were integral to the process.

Fig. 1 The Moments of Action Research

4) Reflect →	1) Plan ↓
5) Observe ↑	← 2) Act

Action is essentially risky, but is retrospectively guided by past reflection on which basis the plan is made and prospectively guided towards observation and the future reflection which will evaluate the problems and effects of the action. (Carr & Kemmis 1986 Pg.186). Despite the complexity that CTF is dealing with it is possible to define the stages of the action learning process. For farmers in CQ the planning stages commenced with a number of workshops run from Biloela in the Callide Valley to Clermont on the Central Highlands.

The 'action' moment of the cycle is often likened to a 'probe into the future'. At least one Co-operator in each district was prepared to try the practice of controlled traffic on sloping dryland areas. Reflection based on previous 'compaction' workshops and practical judgements encouraged these growers to 'have a go'. Action generally entails a risk that judgements might not turn out the way expected.

Perceived difficulties were machinery adaptation, ability to drive straight and potential increase in erosion, weds in the wheeltracks and effects of driving into the sun. With planning, action, observation and reflection, many of these problems have been largely overcome or moved on. And so the cycle continues.

The original six growers in CQ have now multiplied significantly. The outcomes have demonstrated the power of the process. Once the basic concepts were in producers hands, the innovations flowed and the perceived problems faded to the background.

Practitioners as Researchers

It has been said that action research can bridge the gap between research and practice. That certainly has been the case in Central Queensland.

The selling points of CTF were mainly the cost savings - from $10 to $30/ha. As growers have 'cycled' forward, this point has been largely surpassed by the potential and demonstrated potential of major bottom line cash flows from opportunity cropping and significant increases in yields. Another one of our support factors for involving farmers in the research and development process, was their deep concern for their land. Farmers have been observing the massive problem of soil erosion and the threat it is posing to the long term sustainability of their businesses, especially for future generations of their families.

When CTF began in CQ one of the difficulties was that we did not have all the answers - much of the research was still continuing on compaction in CQ or on erosion processes for downhill layouts.

What we learned though, was that if you have a best bet systems approach - **put it in the hands of the producers**. As Dr Don Yule always says 'Each paddock becomes an experiment. Each producer an advocate for positive results.'

Are there any negative aspects?

It would seem that all CTF practitioners - producers, development officers, extension officers, research officers - have some constraints to overcome in the search for both a viable and sustainable agricultural future. Action learning strategies have allowed our learning community to overcome many constraints. Indeed, 'action research is a deliberate process for emancipating practitioners from the often unseen constraints of assumptions, habit, precedent, coercion and ideology. Of course any particular project only achieves these results in a partial way; to imagine that it could be otherwise is to seek a scientific vantage point beyond the reach of history and human interests'. (Carr & Kemmis 1986 Pg.192)

Many were wary of the proposed 'CTF Gifts'. Although we acknowledge that CTF is not a panacea for all the problems and plight of agriculture, there now exists well trialed and well accepted benefits of the system.

Leadership, Vision, Inspiration, Purpose, Direction & Resolve

Thanks to the early adopters who ventured into uncharted areas and into the action learning cycle. Also thanks to those that were out in front of Don, Wayne and Stew - who made their properties available for the benefit of other producers and our industry.

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ACHIEVING CHANGE
"It's the Package which counts"

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Introduction

At the1995 Conference we reported that Controlled Traffic Farming (CTF) was established on four farms and covered an area of 2500 ha. Three years later, it is closer to forty farms and 35,000 ha with another sixty farms expected to adopt in eighteen months raising our total above 80,000 ha. In addition, there is approximately 250,000 ha of Controlled Traffic in Southern Queensland and Northern New South Wales that has been influenced by our Central Queensland experience

What factors have contributed to this "dryland revolution"? What conditions predisposed Central Queensland growers to consider CTF? What has allowed a small team of people to have such a significant impact, when other projects have resulted in little change to grower's attitudes and practices.

The First Step

This paper attempts to layout the processes and content behind the success of CTF.
CTF was developed by Dr Don Yule and Stewart Cannon as a "best bet" package solution to erosion and compaction. The combination of permanent wheeltracks for compaction control and downslope orientation of crop and wheel zones for erosion control, although based on sound scientific theory, had never been tested before. What were the impacts on-farm, was it possible at a farm scale? To assess the system, a number of growers were approached and asked to trial the package.

The co-operators "had a go", usually on one paddock of their farm. CTF delivered on resource management issues, facilitated the adoption of zero-till and dramatically improved the efficiency and effectiveness of operations. It seemed there were many benefits, no weaknesses and only some doubts. The work with co-operators' showed CTF delivered more than first thought, further enhancing the attractiveness of the system.

Table 1

1. Immediate and significant input cost savings[1]
2. Little machinery modification needed as significant benefits from partial CTF, change was low cost[2]
3. Our co-operators moved from experimentation to enthusiastic advocacy, as a result of their experience which gave the promotion more credibility.[3]
4. They became committed to fence to fence adoption, itself a powerful message to their peers.
5. The package enabled them to innovate.
6. There was an attitude change, particularly to resource management.[4]
7. The close working relationship between the CTF team and co-operators established trust and credibility, this gave the team community credibility and recognition.[5]

Much credit for the success of CTF must go to these early pioneers later, advocates of CTF.

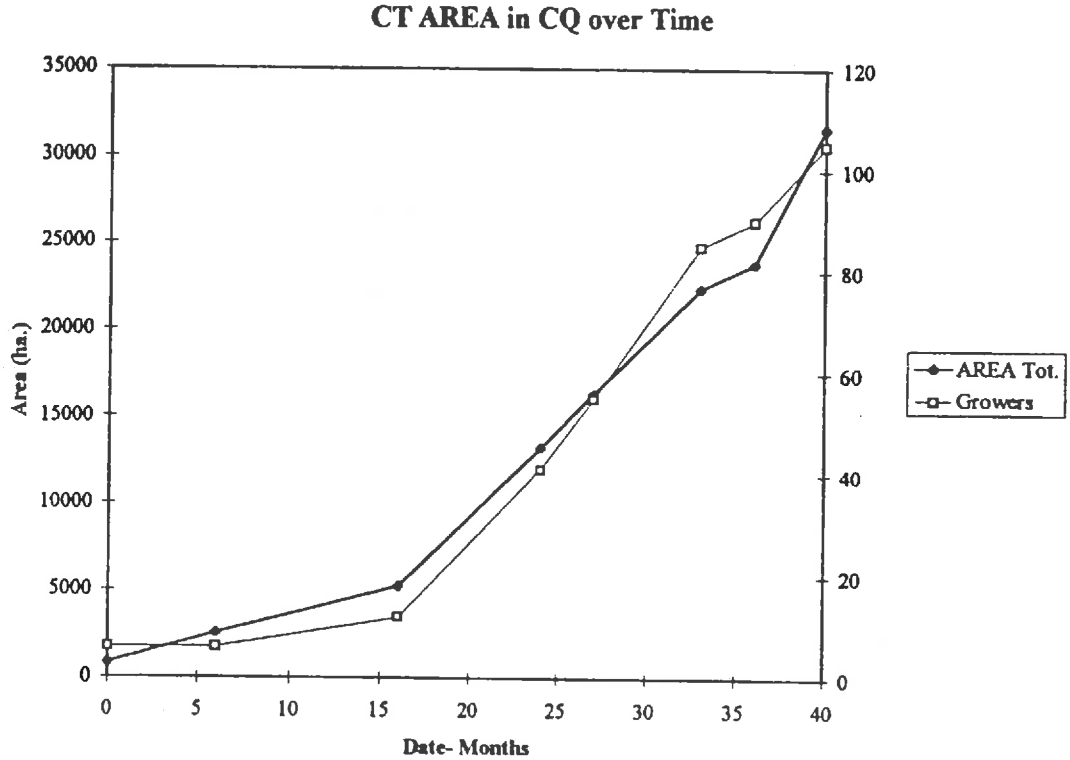
The trial of CTF on-farm, each paddock an experiment, in six different locations, led to rapid development. Indications were that the package was robust enough to take to the wider community. The package or content certainly worked, but how best to achieve adoption, what process would work? Were they aware of the problems, did they care? History shows much extension but little change.

Certainly they were aware of the problem of erosion. Major efforts had been made to control runoff, with the installation of contour banks and the adoption of stubble retention but there were still many difficulties. Zero-till had been tried by many but practised by few.

Compaction, on the other hand, was less widely recognised. Fortunately, it was easily exposed in the field and a few digs with a shovel soon challenged people to think about what was happening beneath the soil surface.

Could the adoption approach follow the same pathway as the work with the co-operators? Because CTF was a farming system, specific to each paddock, it had to be developed on-farm. Just as the co-operators were involved in co-learning and action research, so too would each new adopter.
This has defined our first step, which bought content and process together. We use this to give others the confidence to take their first step and lead to the catchcry, "Have a go, try a paddock."
That this strategy has worked beyond expectation is testified to by the exponential growth curve below.

Figure 1. Adoption areas and farms since March 1995.



The Second Step.
Professionals are currently fulfilling two roles. The first to provide necessary ongoing support for basic implementation of CTF, as the first step process repeats. Implementation on farm focuses on solutions - erosion, compaction, layout planning, machinery adaptations. In the development phase for each property this means one on one interactions between researchers, extension staff and farmers. This action learning builds relationships, credibility, acceptance and facilitates information interchange.

Secondly, to keep in front of the pack and challenge the future. As the saying goes, "You don't know what you don't know." There are a number of "glass ceilings" which need testing. Growers are never allowed to think they have "arrived". CTF as a system is evolving - as professionals our job is to push the system. We suggest outcomes which are impossible without CTF or something which is, as yet untried or just starting in CTF. " What are you going to go home and do differently." "If you have been doing something the same way for a number of years, look at it, is it the best way?"
This action learning environment has delivered innovations such as:-

Furrow planting
Directed Tillage
Side dressing fertiliser in wheat
Directed spraying

Relay planting

Conclusion

The "dryland revolution" is a result of :-

A sound package developed from a systems approach to a systems problem. Much previous work had focused on components within the farming system and each solution led to new problems somewhere else in the system.

CTF having enormous benefits for farmers and no negatives.

The previous system being so bad.

On-farm action research coupled with action learning.

A committed, motivated, multi-disciplinary team which continually challenged, motivated and encouraged farmers to do something differently

The combination of science and on-farm action research has developed a package which marries relevant, sustainable and robust content with a process which has delivered the goods.

Notes from Table 1.

1. Because CTF is an accurate guidance system there were immediate benefits. The reduction in area and hence inputs as a result of this accuracy reduced the cost of establishing a crop by around $30/ha.
2. It was demonstrated there were substantial benefits to be had from partial adoption and highlighted the gross inefficiencies associated with farming between contour banks. This meant that producers could move towards CTF by adapting existing equipment, thereby reducing the need for capital expenditure. It didn't matter if the harvester wasn't on the same wheel spacing or operating width as the remaining equipment. The inclusion of an on-farm development person within the team facilitated the sharing of information amongst growers as well as provide suggestions and ideas for machinery modification.
3. Thanks to our co-operators, visiting farmers could see paddock scale working examples of CTF and talk through problems, perceived or otherwise with "practising" growers.
4. Adopting growers were changing their attitude to a number of issues very rapidly. One grower, two hours into laying out his first paddock said, "Why weren't we doing this twenty years ago, it makes everything so easy." Attitude to erosion changed from it being considered a normal part of farming to "We will change the layout, tolerate shorter runs, hence field inefficiencies, in order to minimise the erosion potential." Compaction suddenly became an issue, growers who had previously grazed cattle on crop residues, sold some of their herd, others locked then off the cultivation. Random traffic across cultivation became a thing of the past, machinery was modified, sometimes extensively to ensure minimum wheeling across a paddock.
5. For success the growers needed to have confidence in the technology and in the advocates of such technology. Through our involvement with the co-operators we developed a co-learning environment, involving farmers in action learning. We did not claim to have all the answers, we were interested to learn from their experiences. Through this we demonstrated we were prepared for a long term supporting role. Farmers could enter the system confident of continued support from the project. Farming is a multi-disciplinary amalgam of systems therefore a multi-disciplinary team was assembled to deliver CTF. It included soil scientists, hydrologists, machinery specialists, agronomists plus weed scientists, economists, specialists in crop nutrition, group facilitators and top interstate farmers.

"Where is Controlled Traffic Farming in Southern Queensland Going?"

T. Neale[1], G. Powell[1], (Team Members N. Booth[2], P Harris[2], D Freebairn[2], J Voller[2], T Peterson[2])

1 - Queensland Department of Primary Industries, 2 - Queensland Department of Natural Resources

Introduction:

After its inception in many areas of Australia in the late 80's and early 90's, Controlled Traffic Farming practices have witnessed exponential growth and development, especially in Queensland. In Southern Queensland we have seen the use of varied levels of niche practices in crops ranging from irrigated and rainfed cotton, pulses, summer and winter cereals and vegetables.

As opposed to the Central Queensland story, much of the CTF development in Southern Queensland has occurred without the immediate involvement of Government Agencies. In the south we have however, held 15 farmer discussion meetings, a departmental DPI / DNR workshop, trips to Central Queensland and Northern New South Wales and numerous field day activities in the past 2 years to provide awareness of Controlled Traffic principles. Additional on-farm discussion and development is being supported by local extension and development staff enhancing the adoption of Controlled Traffic Farming practices throughout the region.

To continue the positive development we have seen here in the past few years, a team of extension people has been formed to tackle "where CTF is going in southern Queensland", where some major land type differences on the floodplains of the Darling Downs and the broardscale sloping areas of the Western Downs, Maranoa and Balonne, are requiring different management practices.

This paper describes briefly what activities have been conducted so far, and where CTF delivery and development is heading.

Activities so far:

CTF Info Days - Providing general information on the broad range of subjects under the CTF banner. These were presented as an opportunity to help farmers understand the philosophy behind controlled traffic practice.

CTF Issue Days - Providing a forum for interested farmers to indicate areas of concern regarding CTF. These may include erosion, chemical application or machinery matching issues.

CTF Focus Groups - This involved coordinating farmer groups to examine certain aspects of CTF. A typical activity was organised trips to view successful CTF farms.

Publicity - Numerous articles have been produced and distributed through the rural press as well as the Kondinin Groups 'Farming Ahead' and the DPI's CropLink information service.

Common Interest Groups - Members of the DPI and DNR involved with CTF have participated as guest speakers at a number of meetings. Through this, the group has a strong association with farmer organisations like 'Conservation Farmers Inc.', not only locally but into northern NSW.

DPI & DNR Staff Day - Controlled traffic Farming requires a multi-discipline effort, thus requiring support from specialists in different areas. This is seen as an ideal vehicle to bring departmental staff together. A workshop was run to identify the best way to work towards a common goal without duplication of activities.

One on One Activities - Farmers wanting specific answers, have contacted the departments directly. Some of these approaches have been initiated through extension activities and the farmers involvement in other departmental initiatives such as PMP and Landcare. Personal assistance has been given in areas covering farm layout and contour banks as well as machinery modification and agronomy.

The next 2 to 3 years:

CTF can't promise to be the solution to every farmers' problems. We believe that CTF should b promoted as a solution to farmers' concerns regarding costs of production, soil degradation anu sustainability. To achieve this, a workgroup has been formed to illustrate how CTF can be used as an "Option for Improving Farm Efficiency", initally planned for the Dalby/Chinchilla areas. This exercise has been planned to cover the following areas:

1. Resources:	Soil, water, farm layout, and vegetation
2. Agronomy:	Nutrtion, disease and spray efficacy
3. Machinery:	Planting, spray equipment, and harvesting
4. Costs:	Economic evaluation and management issues

These workshops will be presented using adult and action learning principles to ensur that the topics are delivered in the most appropriate manner. It is envisaged that these workshops will be facilitated by a "local bloke". This person will have had direct contact with a number of local farmers through previously established groups such as "Landcare", and be able to identify the target audience and their level of understanding of CTF. With this input, the structure and content of individual workshops will be tailored to producer's needs. Conducting a workshop where the content is particularly relevant tc the audience's interest, will ensure positive delivery and the best potential for adoption of the principles.

In conjunction with the extension component of CTF in South Queensland, some team members are participating in the Eastern Farming System project, which will help provide some answers to commonly asked questions such as "Is there more erosion using CTF?", "How is my machinery going to fit?" The EFS sites, whilst still being developed, will look at a range of facets of on-farm layout, efficiencies and soil loss in CTF systems. These sites will also link into the GRDC funded project "Speeding the adoption of CTF through on-farm research and development", in which a Development Extension Officer has been appointed.

The Purpose Story [1] Controlled Traffic Farming & Futureprofit - Towards an interactive and integrative model for agency initiatives

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One of the few predictable features of the 1990's and the approaching twenty-first century is that these times have been and will continue to be marked by significant change. Change involves people. Change also, inevitably involves conflict. However, wisely managed conflict can have positive outcomes. An initiative such as Controlled Traffic Farming (CTF) has facilitated major changes within farming practices that conflict with traditional ideas and concepts. In dealing with these changes producers, research and development officers, extension officers, consultants, manufacturers and business groups have been employing one of the most powerful tools available - stepping outside of existing paradigms. This paper will examine how producers and agency staff have been facilitating change in Central Queensland (CQ) enterprises. Within the context of this study an aspect of the future direction of the CTF initiative in CQ will be explored - this aspect focuses on linkages with other major agency and rural projects such as Futureprofit and is in response to a perceived problem. Before highlighting these linkages though, it is useful to examine the nature of change and how it has progressed in CQ.

The Nature of Change

Change is a complex process underpinned by a range of models, concepts and ideologies. By definition change is a generic term, which subsumes a whole family of concepts such as 'innovation', 'development', and 'adoption', It can be either planned or unplanned. As Pascale (1997: Pg 39) notes:

> *Change happens - to paraphrase a bumper sticker!.....The only question is, will you effect change or will change affect you ? ...One way of thinking about change is to imagine that you are standing in the surf on a beach. As the waves roll back you feel the water attempt to pull you out.... If you go with the pull, more than likely you will glide over the crest of the next wave.*

Adopting change often requires a person to move outside of his/her established ways of operation. Barker (1990) refers to these people as the 'Paradigm Pioneers'. In the area of cropping the CTF 'revolution' and its inherent changes, is gaining momentum across Australia. Many people have decided to effect change.

In CQ 'over the last five to six years CTF has been adopted partly or completely on nearly fifty cash cropping properties' (Cannon et al 1997). Change has occurred at unprecedented rates since 1991 when six producers decided to 'adopt' and trial this 'innovation' or 'development' known as CTF. As explained by Cannon (1997) at the National Landcare Conference:

> *Farmers who trialed areas rapidly moved to whole farm adoption. Why?*

[1] The Purpose Story as referred to by Senge (1992) places the projects within a context of 'where we've come from and where we're heading'. 'We' goes beyond individuals, groups or agencies. The power of the Purpose Story is that it provides a side of ideas that integrates and gives meaning to the area being examined.

- *CTF is a whole-farm, systems package*
- *CTF has scientific and financial benefits*
- *CTF involves action learning and adult education*

Certainly the increasing number of producers adopting the system change indicates that CTF is proving a safe bet. Certainly the system provides tools for change.

Tools for coping with change

Farmers carried out much of the early research which enabled Australia to develop profitable agricultural industries. The development of wheat-harvesting and cultivating machines such as the stripper harvester by Bull in 1843, the stripper harvester and winnower by McKay in 1884 and stump-jump cultivating equipment by Smith in 1876, were the result of research work carried out by farmers. During the 20th century, scientists have carried out most agricultural research. State Government departments have carried out most of the applied research and extension (Reid pp 16/17). With CTF as with several other current initiatives, there is a move to once again involve farmers directly with research efforts. This has meant a change with 'extension techniques. Various strategies or tools have been used.

Descriptors of the processes and types of strategies being employed by Department of Natural Resource CTF staff in CQ include the following:

- *Action Research*
- *Adult Learning*
- *Individual & Group Support*
- *Focus Groups*
- *Conferences*
- *Workshops - producer, agency & external perspective's*
    - *SWOT Analysis*
    - *Action Plans*
- *Networking*
- *Research & Publication*
- *Practical*
- *Results & Outcome Orientated*

If change is to be effective there must be a common understanding of the 'project' and a commitment to learn from all involved. Producers and agency staff involved with the CTF project demonstrate a commitment to team learning (Pers comm. Yule, Cannon, Chapman, Radel, Ross, Prior, Reddy, Dunn & Seng). As Senge (1992 pp234/35) states:

> *When a team becomes aligned, a commonality of direction emerges ...*
> *A synergy develops... There is commonality of purpose, a shared vision*

Within the CTF team there is evidence of dialogue and discussion[2].

[2] Dialogue comes from the Greek 'dialogos' - dia meaning through and logos meaning the word. In dialogue people are no longer primarily in opposition, nor can they be said to be interacting, rather they are participating in this pool of common meaning which is capable of constant development and change. Dialogue goes deeper than discussion. Discussion is where views are presented and defended providing a useful analysis of the whole situation (Senge 1992 pp.240/41)

Review of the SWOT Analysis from the Challenging the Future Conference[3] suggests that participants have been engaged in critical reflection and have taken time to think insightfully about and to explore complex issues.

A critical issue to emerge from the Conference was confirmation by producers that it is becoming increasingly difficult to deal with multiple government initiatives. A common understanding , shared by agency staff, is that problems emerge when multiple initiatives/projects demand implementation and evaluation. A major area of concern is that those initiating change often display a lack of understanding of the many elements of change impacting on the farming system at various levels and within various contexts.

Dealing with Difficulties: Collaborate, Co-Ordinate & Support

Dealing with this issue of how producers and agencies are coping with multiple priorities has led to closer linkages being developed between projects. For example, collaboration between CTF and Futureprofit (FP) staff has started to overcome this difficulty.

Futureprofit is part of the national property Management Planning (PMP) Campaign. Within Queensland PMP is implemented as the Farm Business Planning Program - Futureprofit. Futureprofit delivers an integrated workshop series and one off workshops that address holistic management of farming enterprises.

In Central Queensland, CTF staff regularly contribute to Futureprofit workshops, as do staff from the Sustainable Farming Systems project. A coordinated and integrated effort on the part of local staff in Central Queensland is a major strength for producers involved with the projects. Following is an example of a joint activity between project staff and producers.

A combined Controlled Traffic Farming and Futureprofit one off Workshop has been trialed in Central Queensland where a conventional farming system was compared with zero till and CTF. The focus of this Workshop was to enable participants to economically 'map' their management systems prior to and after the implementation of Controlled Traffic Farming.

Participants developed a financial model of their business without change. Changes with Controlled Traffic Farming were then identified and assessed. Whole farm profit budgets were prepared for the without and for the with change enterprises. Figures used were based on what participants expected to happen within their enterprises on average.

Calculated Business Return on Assets was quite different with the implementation of Controlled Traffic practices. The major differences were in overall farm costs - with savings on fuel, oil, repairs and maintenance / machinery replacement allowance and labour. It was felt that there was potential for long term yield increase with the greater potential for opportunity cropping. According to Chudleigh (pers comm) 'Changing from a conventional system to fully implementing the CTF option has the potential to significantly increase the financial performance of a farm business - it is estimated that there is potential to at least double the return on assets with a change from

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[3] 'Challenging the Future' was the Controlled Traffic Farming Conference held in Yeppoon, Central Queensland on February 28th and March 1st 1998.

conventional farming to implementation of the CTF option.' Farmers concurred that there are real benefits from implementation of the system.

Working with another project area enabled this group to test management changes in a different environment to a 'focused' CTF activity. Such opportunities must add rigour to the CTF research and findings.

Where to from here?

Developing meaningful linkages between project development and delivery is a key concern for agency staff and producers in CQ. There are substantial gains for all stakeholders to better co-ordinate the development, implementation and evaluation of projects. Currently high profiled projects are achieving results for producers. Developing teams across projects has the potential to improve cohesion, working relations, impact, motivation, performance and success. 'Teams have the potential to change the mathematics of work. For high performance teams the productivity math is 2+2=6' (Dewhirst pg33). The potential exists to develop truly high performance teams across agencies/project areas and producers.

Initiatives such as Controlled Traffic Farming and Futureprofit are proving to be both participatory and functional programs/practices for producers. Dialogue and discussion are supporting people with decision-making and planning. It is critical that such initiatives continue to interact and develop co-ordinated approaches to help achieve the vision of a viable and sustainable rural community in our region.

Moving beyond our 'project paradigms' towards a more interactive and integrative model for agency initiatives will challenge us all. Without doubt there may be 'conflict' but it is timely to bring together our many agency and community elements. Synergism is paramount.

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Controlled Traffic: a perspective from the sugar industry

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Introduction

The sugar industry practices a pseudo form of controlled traffic, in that all harvesting traffic occurs in approximately the same position for a crop cycle (plant crop and 4 ratoons). This process is then repeated for the next crop cycle unless a conscious decision is made to relocate the positions of the previous rows and inter-rows. Generally, this entails swapping the row and inter-row positions.

There is, however, a mismatch between the current row spacings used by the industry (1.5 – 1.65 m) and the track widths of harvesting and haulout equipment (1.83 m). This results in harvesting traffic occurring close to the row and quite often directly over the row. As a result, soil degradation occurs in the plant growth zone and the traffic zone encroaches onto the plant growth zone.

Recently there has been a gradual move towards high density planting strategies, whereby dual rows 0.5 m apart are planted on 1.8 m centres. This fits the concept of controlled traffic since the row spacing matches equipment track widths. The impetus for this is to increase productivity rather than to adopt the concept of controlled traffic per se.

This work was undertaken to determine the effect of matching crop row spacing and harvesting equipment track widths on the longevity and yield of ratoon crops planted in dual rows.

Materials and Methods

Trials details

Field trials were established at Tully and Ingham in 1993 and 1992, respectively. Single rows spaced at 1.5 m were compared with dual rows (0.3 m apart) at 1.8 m spacing. Dual rows were planted to achieve the same plant population as the single rows, since there would be fewer rows per unit area. Both treatments were fertilised at the same rate on an aerial basis.

Two varieties were trialed at each site, Q117 and Q138 at Tully and Q115 and Q124 at Ingham. The experimental layout was a randomised block design with four replicates at Tully and five replicates at Ingham. Plots consisted of four rows, with the two central rows being the datum rows. Results were analysed by ANOVA using the Statistix® statistical package.

Soil measurements

Soil bulk density (BD) and saturated hydraulic conductivity (Ks) were measured on undisturbed cores (0.075 m dia, 0.05 m high) collected before, and then after each harvest, to a depth of 0.3 m from the row and a near-row position.

Soil cone resistance was also measured before and then after each harvest to a depth of 0.6 m using a recording penetrometer (30° included cone, 12.5 mm dia. cone).

Crop measurements

Crop yields were assessed by weighing the two central rows in each plot at harvest. The plots were mechanically harvested.

Results

Data for the row position is presented, since this is where the crop grows and to determine whether traffic encroachment into the row was occurring.

Soil properties

Bulk density in the row was uniform with depth at the Tully site with no significant difference between the single and dual rows (Fig 1). There was a small increase in the immediate surface under the single rows compared with the under dual rows.

There was a significant increase in bulk density under the narrow single rows compared with the wider dual rows at Ingham (Fig 1). Density also tended to increase with depth at Ingham.

Saturated hydraulic conductivity was only significantly higher in the immediate surface under the wide dual rows compared with the narrow single rows at Tully (Fig 2). The conductivities tended to be higher under the wider dual rows than under the narrow single rows. At Ingham saturated conductivities were significantly higher under the wider dual rows than the narrow single rows at the 0.15 and 0.2 m depths only (Fig 2). There was a strong tendency for saturated conductivities to be higher at the wider row spacing compared with the narrow row spacing.

There was no significant difference between the wider and narrow rows in soil strength at Tully, except at the 0.6 m depth where the wider rows were stronger than the narrow rows (Fig 3). The single rows were significantly stronger than the wider dual rows in the 0.05 to 0.25 m depth at Ingham (Fig 3).

Crop response

Crop yield was variable between sites, with the narrow single rows yielding higher than the wider dual rows at Tully (Table 1). However, the reverse was the case at Ingham (Table 1). There were few significant differences between treatments for the yield parameters measured at both sites. The exceptions were first and second ratoon tonnes cane per hectare for Q138 and plant and second ratoon tonnes sugar per hectare for Q138 at Tully. At Ingham, the exceptions were third ratoon tonnes can per hectare and ccs for third and fourth ratoon for Q115, and third ratoon tonnes sugar per hectare for third ratoon Q124.

Discussion

There is some evidence of soil degradation in the row under narrow single rows compared with wider dual rows at one site, namely Ingham. Soil bulk density has increased, soil strength has increased and saturated hydraulic conductivity has decreased in the narrow single rows compared with the wider dual rows. However, at Tully both the narrow single rows and wider dual rows have similar soil physical properties. This suggests that traffic is encroaching the rows under both systems. It was observed that during harvesting operations, traffic did occur near and over the row in some instance in the dual row plots. This was due in part to the inexperience of operators and the fact that the elevator on the harvester was short which resulted in the haulout travelling closer to the row to fill the bin. If the sugar industry is to adapt controlled traffic, there will be a need for some equipment modification to fit the system, such as increasing the elevator length on the harvester, and the development of guidance systems to ensure accurate tracking of harvesters and haulouts to reduce the spread of traffic zones into the plant growth area.

Crop yield was variable, with narrow single rows yielding less than the wider dual rows at Tully for the plant and 1st and 2nd ratoons, however, yields for the third ratoon crop were greater for the wider dual rows than for the narrow single rows. The wider dual rows produced greater yields than the narrow single rows at Ingham, with the exception of the second ratoon crop for Q115 where the reverse occurred. There were few significant differences between yield parameters at both sites. Yield differences between the two row spacings at Tully are due to the fact that the wider dual row plots lodged early in the season resulting in yield loss. For the third ratoon crop, the dual row plots did not lodge and as a result produced slightly higher yields than the narrow single row plots. Consideration needs to be given to selecting varieties to suit soil conditions and the environment (A Hurney, personal communication 1998).

Results for Ingham suggest that there is some benefit in adopting a controlled traffic system for sugarcane. Yields although not significant, tended to be greater where traffic occurred further from the crop row. This trial was harvested by more experienced operators, so harvesting traffic was restricted to the inter-row area. Yields tended to be maintained at similar levels to the narrow single rows, but soil conditions in the wider rows were not as degraded compared with the narrow single rows.

Other workers have measured little or no improvement in crop yield due to the instigation of a system of controlled traffic (Braunack *et al* 1995; Gerik *et al* 1985). In instances where yield increases have been measured a physical impediment to plant growth was removed (Tisdall and Adem, 1988) and controlled traffic restricted the redevelopment of the problem (Taylor, 1986).

It is speculated that the benefits of controlled traffic may not occur in the short term in the sugar industry, but will occur with time. The fact that sugarcane is a long growing crop (12 – 18 mths) means that there is opportunity for the crop to grow through a compacted layer when rainfall occurs or irrigation is applied.

It is thought that controlled traffic in conjunction with minimum tillage planting strategies, where only the row is disturbed, the advantages of controlled traffic may be further realised. This will result in a system where distinct traffic and plant growth zones are developed. Compaction will be further restricted and structural degradation minimised through less soil disturbance.

There are many benefits to be gained from the adoption of controlled traffic by the sugar industry. The between row spacing of 0.3 m may not be the optimum spacing as other trials with dual rows at 0.5 m on 1.8 m centres have resulted in yield increases of up to 50% over current single row spacings. However, soil properties have not been assessed in these trials. The fact that yields have not significantly increased suggests that benefit in the short term may not be immediately evident or that a constraint has not been effectively removed. Also, the selection of variety for soil type and environment needs to be considered.

Commercial cane varieties have been selected growing in a system of single rows at a certain row spacing and this may not translate into benefits when the agronomic environment changes to dual rows at a wider row spacing.

Long term benefits, if adopted with minimum tillage planting, are perceived to be less soil degradation in the row due to restricting soil compaction to the inter-row area and wet weather access may be improved due to the maintenance of the compacted inter-row areas. This would ensure continuity of cane supply to the mills during wet weather.

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Acknowledgement

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Figure 1 Change in soil bulk density at the two row spacings

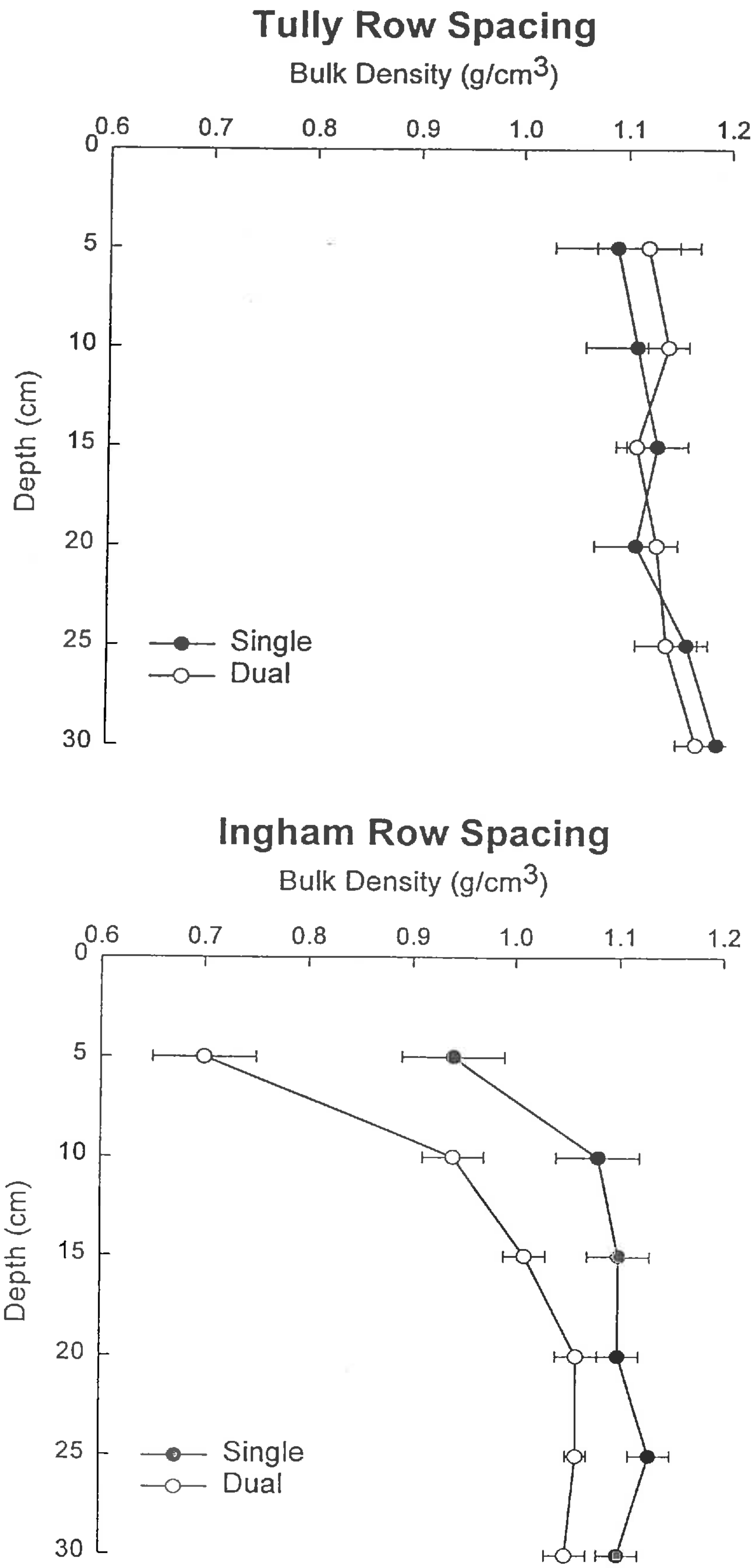


Figure 2 Saturated hydraulic conductivity under the two row spacings

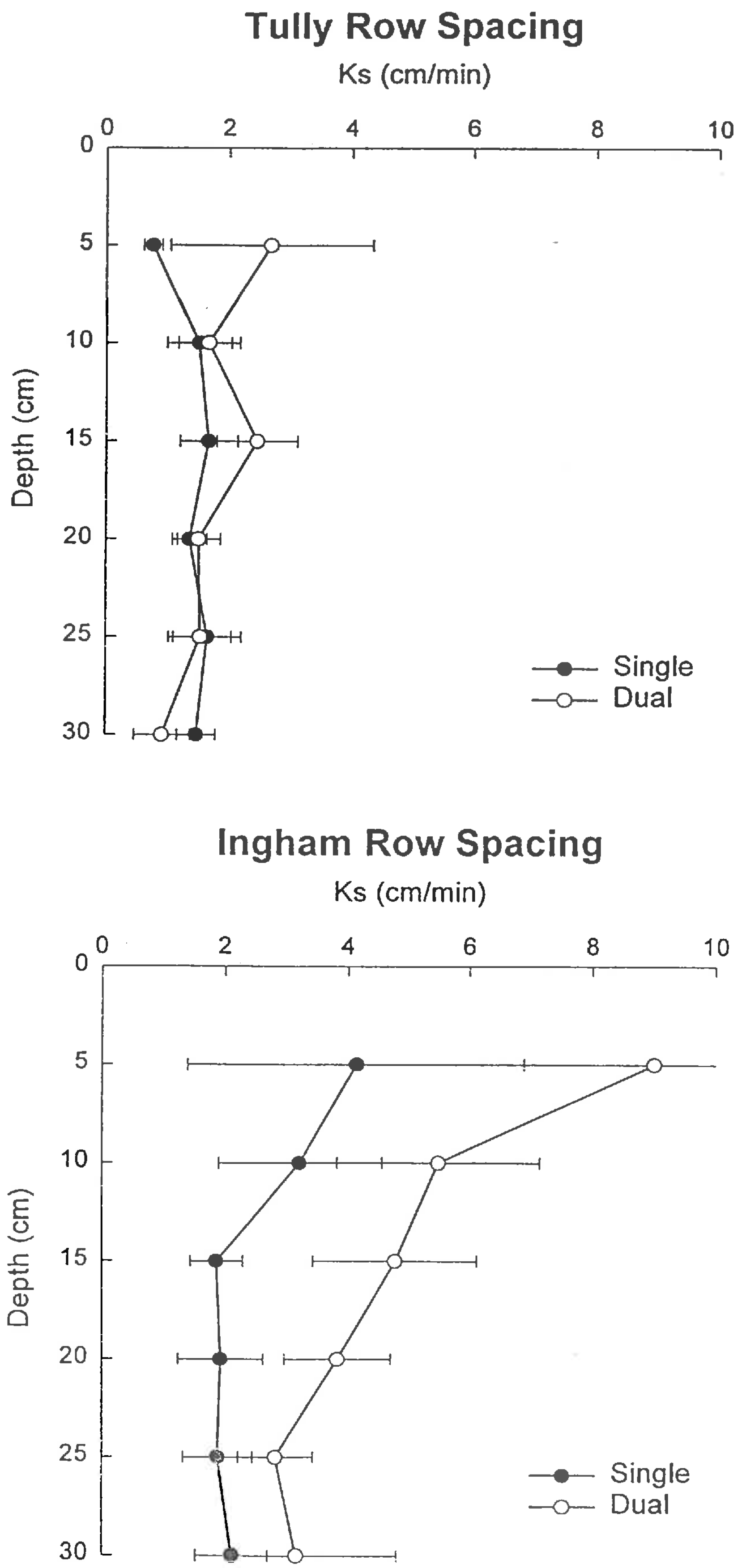
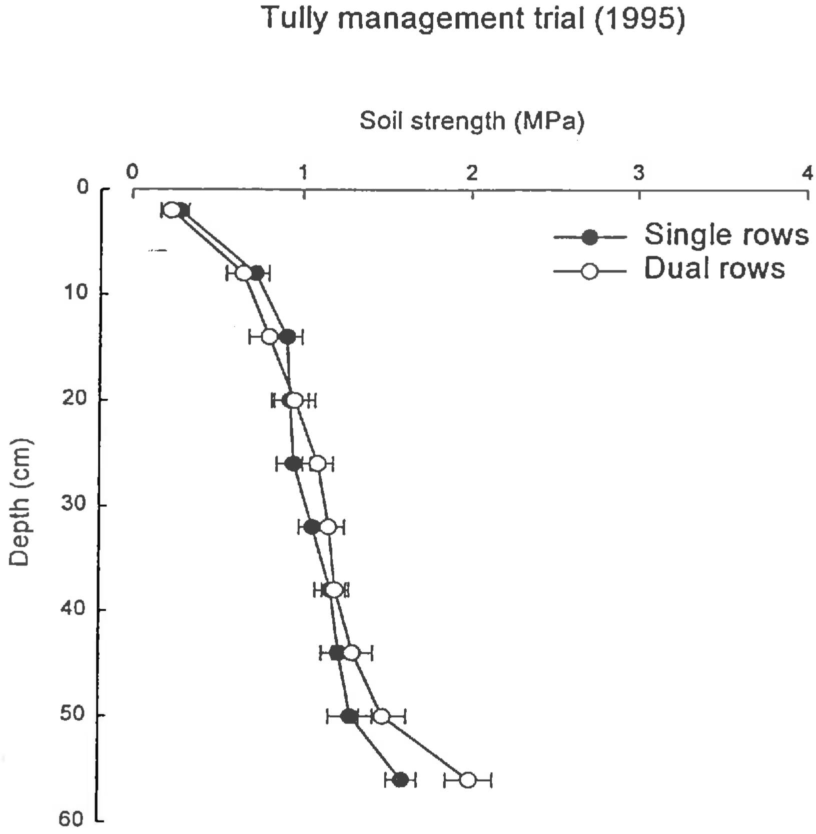


Figure 3 Soil strength under the two row spacings



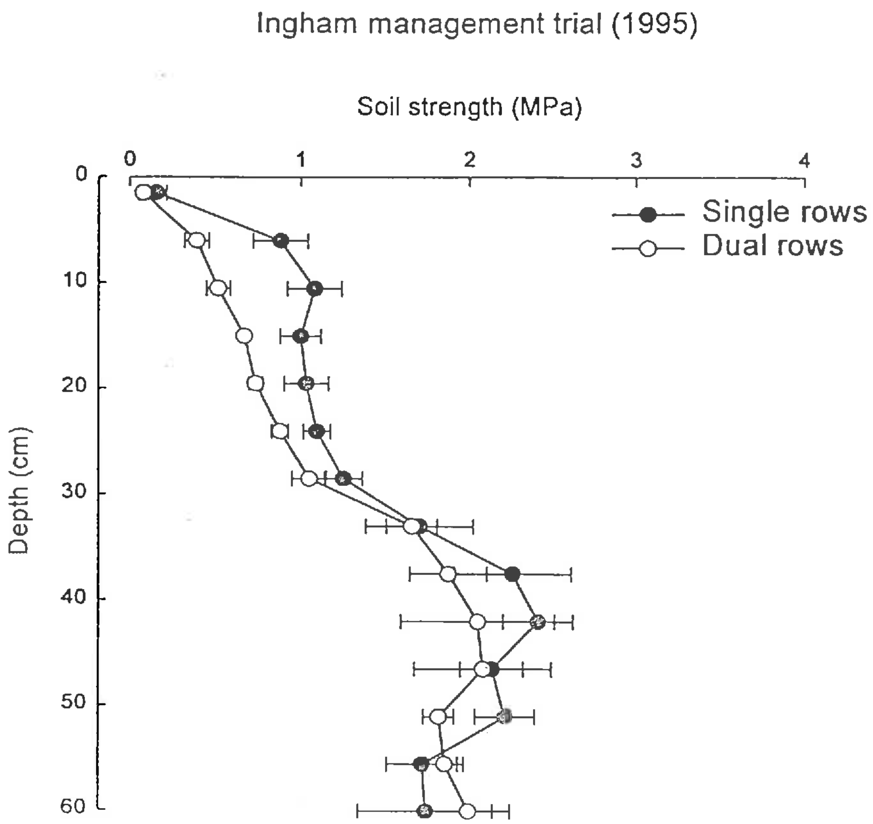


Table 1 Effect of matching crop row spacing with equipment track width on crop yield (t/ha cane, sugar and ccs)

Site	Variety	Crop class	Treatment								
			1.5m Singles			1.8m Duals			LSD (P<0.05)		
			TCPH	TSPH	ccs	TCPH	TSPH	ccs	TCPH	TSPH	ccs
Tully	Q117	P	89.7	13.1	14.6	97.7	13.9	14.2			
		1R	94.1	10.7	11.4	92.3	10.1	10.9			
		2R	127.3	15.5	12.1	106.5	13.0	12.1			
		3R	86.4	12.5	14.4	96.4	13.9	14.4			
	Q138	P	111.6	15.7	14.1	102.4	13.9	13.6	13.0	1.3	0.6
		1R	129.4	11.1	8.6	101.1	9.4	9.3	17.5	2.7	1.2
		2R	169.3	18.4	10.9	125.6	13.7	10.9	25.9	3.7	1.6
		3R	115.4	15.5	13.4	124.4	17.9	14.4	20.2	3.3	1.3
Ingham	Q115	P	87.1	13.6	15.7	91.6	14.9	16.3			
		1R	81.6	13.8	16.9	84.7	14.9	17.7			
		2R	120.3	19.0	15.8	119.9	17.3	14.4			
		3R	75.3	11.1	14.8	88.6	11.5	12.9			
		4R	85.5	13.4	15.7	86.7	12.3	14.2			
	Q124	P	109.4	18.5	16.9	113.9	18.8	16.5	13.3	2.1	0.6
		1R	97.9	16.9	17.3	101.6	17.6	17.2	6.2	1.3	0.6
		2R	119.0	16.9	14.2	124.6	18.4	14.7	9.6	3.2	1.8
		3R	85.3	11.5	13.5	94.0	12.8	13.6	8.7	1.3	1.2
		4R	104.8	16.4	15.7	111.2	17.3	15.5	11.3	1.6	0.6

LSD values refer to comparisons (between treatments and varieties) within the appropriate ratoon for the indicated yield parameter

Quantification of Wheel Traffic and its Effect in Lucerne Hay Production

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1. Introduction

Lucerne hay is a significant rural industry in Australia, producing approximately one million tonnes of hay valued at around $300 million per year (ABS, 1996). It is usually grown on irrigated land and farmers often take 6-8 cuts each year. Unlike other field crops, lucerne is not sown each year and thus there is no opportunity to loosen the soil every season or year. As a result of repeated wheel traffic cut after cut and year after year, the compaction effects accumulate on lucerne fields and result in reduction of hay yield (Douglas, 1994). Grimes et al. (1978) reported that up to 70% of crop area may be covered by wheel traffic during each lucerne harvest. The annual traffic loading on lucerne fields is likely to be many times more than that on fields where grain crops are grown. Annual traffic loading in lucerne hay production depends upon the type of haymaking machinery system. For example, unconditioned haymaking systems use lighter cutting equipment (mower) and require more trips to the field for raking operation due to prolonged drying. On the other hand, mechanically conditioned haymaking systems use heavier cutting equipment (mower-conditioner) and require fewer trips to the field for raking operation because of enhanced field drying process. The objectives of this paper are:

(i) To describe the method of quantifying wheel traffic in lucerne hay production;
(ii) To compare the wheel traffic loading for unconditioned and conditioned haymaking systems;
(iii) To compare the wheel traffic loading of lucerne hay production system with grain crop production system; and
(iv) To review the effect of wheel traffic on lucerne hay production and suggest various methods for minimising wheel traffic.

2. Analysis of Quantification of Wheel Traffic

Numerous criteria have been used to quantify wheel traffic in crop production. They range from a simple single parameter such as rut length per hectare (Frese, 1969) to a very complex mathematical model predicting crop yield loss due to wheel traffic (Arvidsson and Hakansson, 1991). Kuipers and Van de Zande (1994) have comprehensively reviewed these criteria and suggested that the Field Load Index is the most appropriate criterion for assessing the compaction risk from wheel traffic on a field scale. Thus, this criterion will be used for quantification and comparison of wheel traffic intensity under different lucerne haymaking systems.

The Field Load Index is defined as the product of load and loading time per unit area. Mathematically, it can be expressed as follows:

$$FLI = (m_t + m_i) \times T$$

where

FLI	=	Field Load Index (t h ha^{-1})
m_t	=	Mass of tractor (t)
m_i	=	Mass of implement (t)
T	=	Field time (h ha^{-1})

A typical haymaking system involves four field operations in a sequence: cutting, raking, baling and carting. Field time for these operations can be determined as follows:

Cutting/Raking

$$T = \frac{10}{width\,(m) \times Speed\,(km\ h^{-1})} \tag{2}$$

Baling/Carting

$$T = \frac{Yield\,(t\ ha^{-1})}{Capacity\,(t\ h^{-1})} \tag{3}$$

3. Comparison of Wheel Traffic for Two Haymaking Systems

To compare the wheel traffic intensity in lucerne hay production, the two most common haymaking systems were considered: (i) unconditioned haymaking system and (ii) mechanically conditioned haymaking system. Specifications of machines and implements used in each system are given in Table 1. Reasonable estimates of the mass of machines and implements, and their operating speeds were derived from TMA (1997) and Anon. (1998).

All operations other than raking are single pass operations ie. they are carried out only once in a harvest. However, number of rakings carried out in any cut could vary depending upon whether the crop is conditioned or not. As the field drying time is different for summer and winter periods (Akkharath *et al.*, 1996), the number of rakings could also vary whether the crop is cut during summer or winter periods. The number of rakings used for these situations is given in Table 1.

Estimates of Field Load Index (FLI) for different haymaking operations were carried out using Eqns (1) to (3). Table 2 presents Field Load Index for unconditioned and conditioned haymaking systems under summer and winter weather conditions. The FLI for a single cut during winter periods is approximately 18% more than that during summer periods primarily because of greater number of rakings carried out during the field drying process.
Most farmers will have eight cuts per year - usually five in summer and three in winter. Table 3 presents the annual traffic load on a typical farm using either unconditioned or conditioned haymaking system. The annual traffic load for unconditioned haymaking system is 160 t h ha^{-1} and raking contributes nearly 60% of wheel traffic. The annual traffic load for conditioned haymaking system is only 96 t h ha^{-1}, which is 40% less than that of the unconditioned haymaking system. The annual load due to raking in conditioned system is only 40% of that of unconditioned system.

Table 1: Specifications of machines and implements for unconditioned and conditioned haymaking systems.

Operation	Equipment
Unconditioned Haymaking System	
Operation	Equipment
Mowing x 1	35 kW tractor, 1.6 m disc mower
Raking x 3 (summer) Raking x 4 (winter)	35 kW tractor, 2.5 m oblique reel rake
Baling x 1	35 kW tractor, 8 t h^{-1} rectangular baler
Carting x 1	35 kW tractor, , 8 t h^{-1} pull-type bale wagon
Conditioned Haymaking System	
Operation	Equipment
Mowing x 1	35 kW tractor, 2.8 m mower-conditioner
Raking x 2 (summer) Raking x 4 (winter)	35 kW tractor, 2.5 m oblique reel rake
Baling x 1	35 kW tractor, 8 t h^{-1} rectangular baler
Carting x 1	35 kW tractor, 8 t h^{-1} pull-type bale wagon

Table 2: Field load index for a single harvest during summer and winter weather conditions.

Operation	Summer Periods				Winter Periods			
	Unconditioned System		Conditioned System		Unconditioned System		Conditioned System	
	t h ha^{-1}	%	t h ha^{-1}	%	t h ha^{-1}	%	t h ha^{-1}	%
Cutting	3.4	18.2	2.4	21.4	3.4	15.3	2.4	18.2
Raking	10.5	56.1	4.0	35.7	14.0	63.1	6.0	45.5
Baling	2.1	11.2	2.1	18.8	2.1	9.4	2.1	15.9
Carting	2.7	14.5	2.7	24.1	2.7	12.2	2.7	20.4
Total	18.7	100.0	11.2	100.0	22.2	100.0	13.2	100.0

Table 3: Annual traffic load in lucerne hay production.

Operation	Annual Traffic Load			
	Unconditioned Haymaking System		Conditioned Haymaking System	
	t h ha^{-1} $year^{-1}$	%	t h ha^{-1} $year^{-1}$	%
Cutting	27.2	17.0	19.2	20.1
Raking	94.5	59.0	38.0	39.7
Baling	16.8	10.5	16.8	17.6
Carting	21.6	13.5	21.6	22.6
Total	160.1	100.0	95.6	100.0

4. Comparison of Wheel Traffic Intensity in Lucerne Hay Production and Grain Crop Production Systems

Field load indices for various operations under wheat production system were calculated using a method similar to the one explained in Section 2. Specifications of machines and implements commonly used in wheat production are given in Table 4. The annual traffic load in wheat production is estimated to be 15.6 t h ha^{-1}, out of which approximately 65% is exerted during tillage, 19% during planting, 3% during spraying and 13% at harvest. Annual traffic load in wheat production is 6-10 times less than that of lucerne hay production.

Table 4: Specifications of machines and implements for wheat production system.

Operation	Equipment
Ploughing x 2	100 kW tractor, 5 m chisel plough
Cultivation x 1	100 kW tractor, 6 m scarifier
Planting x 1	100 kW tractor, 6 m scarifier/planter
Spraying x 1	35 kW tractor, 18 m boom sprayer
Harvesting x 1	Self propelled grain harvester with 6 m cutterbar

Table 5: Annual traffic load in wheat production system.

Operation	Annual Traffic Load	
	t h ha^{-1} $year^{-1}$	%
Ploughing	7.2	46.1
Cultivation	2.9	18.6
Planting	3.0	19.2
Spraying	0.4	2.6
Harvesting	2.1	13.5
Total	15.6	100.0

5. Effect of Wheel Traffic on Lucerne Hay Production

Studies conducted overseas (Meek *et al.*, 1988; Meek *et al.*, 1989; Rachel *et al.*, 1987; Rachel *et al.*, 1990; Rachel *et al.*, 1991; Sheesley *et al.*, 1974) and in Australia (Neale and Tullberg, 1996) have indicated a significant reduction (10-26%) in hay yields due to soil compaction. The reduction in yield is mainly attributed to:

- Increased soil strength
- Increased bulk density
- Decreased hydraulic conductivity
- Decreased root density
- Decreased water use efficiency
- Mechanical damage to regrowth

6. Methods of Minimising Wheel Traffic in Lucerne Hay Production

Eliminating the wheel traffic damage in lucerne will save $60 million per year to lucerne growers in Australia. Complete elimination of wheel traffic may be practically difficult in lucerne hay production due to various sizes of machines used. However, substantial reduction in soil compaction can be achieved by following methods.

Controlled Traffic

Sheesley (1978) in USA and Neale and Tullberg (1996) in Australia have demonstrated that by slightly modifying the existing haymaking equipment, traffic lanes can be created to reduce traffic coverage from 70% to 20% of the field area. Establishing permanent uncropped wheel tracks is unlikely to be beneficial, as 20% increase in yield will be offset by the reduction in similar yield loss due to decrease in 20% of uncropped area.

Low Ground Contact Pressure Systems

Low ground contact pressure systems are those harvesting systems in which machines and implements are fitted with larger-than-standard tyres with low inflation pressures (Douglas, 1994). These systems have the potential to reduce soil compaction by reducing tyre/soil contact pressure. Douglas *et al.* (1992) found comparable dry matter yields of grass in zero-traffic and low ground contact pressure silage harvesting systems. Compared to conventional traffic, these systems resulted in 16% increase in dry matter yields. There is a scope to use such systems in lucerne hay production but presently information is scanty and research in this area would be useful.

Superconditioning of Hay

Superconditioning (hay maceration) is a new technology which has the potential to further improve the drying rate, allow baling within one day of mowing and minimise the number of rakings. Preliminary studies conducted in the USA (Koegel *et al.*, 1988) and Canada (Savoie and Beauregard, 1991) have shown that macerated hay can be dried to a baling moisture content within 5 to 8 hours during sunny weather. Adoption of such technology by Australian farmers will not only reduce wheel traffic substantially but also result in reduction of production costs.

Use of Double Rakes

Wheel traffic can also be reduced by using double rakes which can rake two adjacent swaths together. As raking contributes more than 50% of wheel traffic, such machines should reduce the annual traffic load by 25%.

7. Conclusions

(i) Annual traffic load in mechanically conditioned haymaking system is 40% less than that of unconditioned haymaking system.

(ii) Raking induces majority of soil compaction during haymaking - 40% in conditioned haymaking system compared to 60% in unconditioned haymaking system.

(iii) Annual traffic load in lucerne hay production is 6-10 times more than that of the traffic load in wheat production system.

(iv) Significant increases in hay yields are possible by minimising soil compaction in lucerne fields. Further research in the following areas would be useful:
- Assessment of benefits of low pressure machinery systems in hay production
- Development/modifications of machinery systems for adoption of controlled traffic
- Development of methods/machines to enhance the drying rate of hay to reduce number of rakings during the field drying process.

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Controlled Traffic in Lucerne Hay Production

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1. INTRODUCTION

Separate cutting, raking and baling operation required in lucerne hay production involve 3-5 tractor based operations. In each operation heavily laden wheels cover approximately 20% of implement width, so a large proportion of crop area, (approximately 50-70%), is wheeled at each harvest, if traffic is random. Douglas, (1994), has reviewed the work of a number of authors who have demonstrated direct, (plant), and indirect, (soil), damage by wheels in lucerne production. Crop and soil damage can be reduced by controlled traffic, where all heavy wheels are restricted to laneways. This has been shown to improve lucerne hay yields, (eg. Sheesley, 1974). This paper describes a controlled traffic hay harvesting system based on conventional haymaking machinery with minor modifications, and sets out production data from the first three harvests of a lucerne crop.

2. METHODS

The experiment was set out in a 1.6ha paddock of medium self-mulching alluvial soil. Seedbed preparation started with deep tillage to 0.5m under dry conditions. The area was planted to 'Sequel' lucerne using conventional seedbed/planting equipment at right angles to the proposed controlled traffic laneways and divided longitudinally into approximately equal areas of controlled and random traffic, (or Grower simulated).

In this trial, the implement operating width was 2.5m, and the tractor/baler/bale wagon wheeltrack width was 1.9m, with one mower conditioner wheel not tracking a tractor wheel. Using an in-line baler, the only equipment modifications were drawbar off-set adjustments and a swath deflector plate for the mower-conditioner.

The controlled traffic lanes were marked out by driving the harvesting pattern in soft soil after planting and irrigation to produce clearly visible, depressed laneways. With the tractor on 0.35m, (14.9in), section tyres, these laneways occupied 28% of field area within the controlled traffic treatment area. The 'total traffic' treatment, produced by four adjacent tractor passes, was superimposed on both controlled and random traffic areas to provide four treatments.

3. RESULTS

Dry matter yield was determined using an implement-width quadrat which allowed separate assessment for different zones within the controlled traffic plots. Results for the first three harvests are illustrated in Figure 1 and 2, as the overall mean yield for each treatment, and the means of traffic lane and non-wheeled area within controlled traffic plots. There were no yield differences at the first harvest between treatments, but some had developed by the second. Yield differences between controlled traffic and all other treatments was significant, ($P<0.05$), by the third harvest. Similar significant differences were noted in plant height, and there were corresponding, but non-significant differences in crown density.

4. CONCLUSIONS

Results of this preliminary experiment confirm that controlled traffic can increase lucerne hay yields, but further work is needed to establish long-term yield effects, and investigate other important production parameters such as stand life and irrigation efficiency. Controlled traffic can be achieved using the conventional hay-making machinery available on many farms. Some inconvenience was associated with the controlled traffic operation, but initial purchase of equipment with compatible working and wheeltrack widths would minimise this problem.

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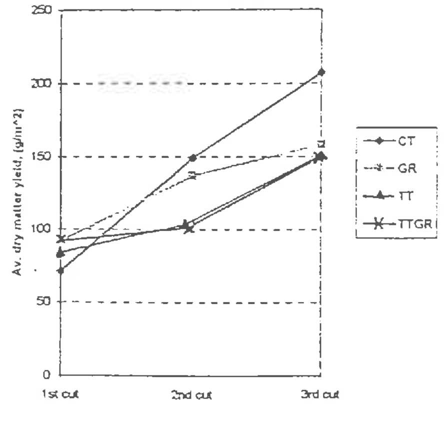
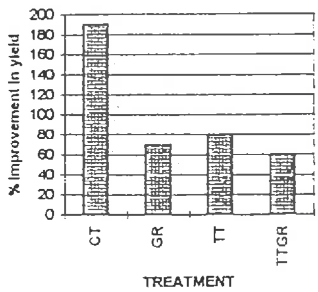
AV. DRY MATTER YIELD OVER THREE CONSEQUTIVE CUTS FOR EACH TREATMENT



TREATMENTS

CT	controlled traffic
GR	grower simulated
TT	total traffic
TTGR	total traffic/grower combination

% IMPROVEMENT IN YIELD FROM CUT 1 TO CUT 3 FOR EACH TREATMENT



A whole farming system on controlled wheel tracks.

Hugh Ball
"Gorian"
Burren Junction, NSW, 2386.

"A whole farming system" aimed at more efficient use and absorption of rainfall, hence increased planting opportunities and cropping frequency in an environmentally sustainable manner.

"Gorian"

Location: Burren Junction (North-west New South Wales)
Soil Type: Black, self-mulching
Area: 5000 ha, member of "Walgett Sustainable Agricultural Group"
Crops: Predominantly cereal with rotations of pulse and summer crops

* Module width 12 m, wheel centre 2 m.
* 1997 commenced CT removing centre tyne (guide for in-crop spraying) using marker arms during planting.
* 1997-98 summer fallow marked with Bee Line Navigation GPS system on a contract basis using auto-steer. Marked off mathematical line without compounding errors.
* Fallow sprayed with Spra-Coup and Hayes and Baguley booms on FWA 250 Hp tractors using width of 24 m.
* Well equipped water truck and batching tank.
* Planting - 12 m Janke on-track parallelogram unit on 40 cm spacing.
* Water Use Efficiency used as benchmark tool, kg/mm/ha.

Agronomy and management

Has to be sharper in relation to:
- Weed control
- Disease control
- Fertiliser application
- Crop rotations/frequency
- Sourcing of markets

Why controlled wheel beds?

Reduce paddock compaction from 80% to 12%, thus:
- increase moisture infiltration
- improve soil structure
- increase plant opportunities/crop frequency
- increase yields
- increase bottom line $$$

* Less rolling resistance, less fuel consumption, up to 50% (50-75% of tractor power utilised in creating and destroying wheel tracks)

* Less seed, fertiliser and spray overlap - ease of application, able to spray at night and reduce chemical rate = reduce chemical cost and no need for foam markers

What we don't know.

- How to adapt headers in the system
- Wheel track widths ie warranties on axle width modifications
- Method of marking country (GPS vs toolbar = $$$)
- Suitable sowing equipment (stubble clearance)
- Tracks vs rubber tyres
- Will tractors need auto steer

Controlled wheel beds deliver!

1. Soil compaction management
   - improved soil structure
2. On-time operations
   - plant to dates vs plant to seasonal influence, ie spraying, planting
3. Precision and innovations
   - management
   - machinery
   - labour ie operators vs drivers
4. Efficiency = $$$

Remember!

* Be positive - problems are created to be solved
* Challenging, precise, exciting way to crop - rewarding
* Turns what was once regarded as marginal farming country into more reliable
* Controlled traffic will increase production but one mistake can alleviate some benefits
* HAVE A GO!

MERRILONG

Gordon Brownhill
The Brownhill Family, trading as Merrilong Pastoral Company Pty Ltd

I have been asked to talk to you today on my experiences of "farming on the Liverpool plains and more particularly, the contribution control traffic and Zero Till has made to our farming operations.

The Brownhill family, which consists of my wife Anne, my brother Dai and his wife Liz, along with my parents, operates a farming enterprise of 4000 has, which is situated on the slopes of the Liverpool Plains. My parents came to Merrilong in 1959 and since then many changes have occurred.

The country in those days was mainly Plainsgrass with Lucerne being the first of the man made crops sown. That was used to fatten lambs. In the 60's wheat was the main crop, the 70's summer crops were introduced and in the late 70's stubble retention and strip cropping also came into the picture.

In my view this is when we made our biggest mistake. Because of Strip cropping which put you into stringent rotation and because of our stubble retention, we created a situation of immense stored moisture but not necessarily sowing moisture and coupled with what you could call invisible banks when rain events occurred unbelievable soil erosion were multiplied. This part of farming was also coupled with the notion of get big or get out, so we then had bigger tractors pulling bigger gear. And for what reason, to produce a seedbed and to also break down stubble so that we could get the combine that was designed for the last decade through the trash.

Agriculture in the farming sense changed the day they invented Roundup. Zero till had the trigger to start and we all learned along the way. The first crop to be Zero tilled successfully was Sorghum into wheat stubble with the combination of Roundup and atrazine. This system fell down after that though because we still farmed the country for a full 12 months back to a winter crop which was usually wheat.

Opportunity cropping was introduced, theoretically easy to say, practicality hard to manage. For example you would go to one of these talkfest's hear all these good ideas, go home, look at the array of machinery that was on offer in your back yard, you would then improvise and after leaving one of the main ingredients out or using up too much moisture you usually ended up with a stuff up.

Legumes were the main crops used to take advantage of increased moisture content. You could talk all day about Legumes but you would have to say that this crop has come a very poor 2nd to cereals in the amount of funding that has been allocated. Funding has to be stepped up in legumes so farmers can sow legumes that will be financially viable, not hit and miss like it is at the moment.

Fertiliser became an issue during this time as we had partly accomplished out goal of satisfactory crops. Our usage of nitrogen started at levels as low as 40 units and now we have come to a level of no less than 100 units with a more common rate of 120 units. Trace elements are being addressed with Zinc and Sulfur seemingly being the 2 that are being targeted.

We now have machinery to do these operations and also the mentality to sow a crop whenever we have a full profile of moisture. More work can be done in this area.

Tramlining, control traffic is now our next goal. We have set out our goal of having 40-ft tramlines i.e. 40ft planter 80ft boom spray. And a header with a 40-ft front. The last might be a little way off. I believe not. Some farmers of which there are a couple here today, have done the full thing 60ft booms 30ft planters 30ft headers and pickup bins to match.

There are massive savings in this common sense approach to zero till, and we must not discount them. For example in the spray operations on our farm to go from 60 ft to 80 ft and having an average spray of 5 weeks on any one block and with our total cropping of 3500 has. Trust my maths but on average we spray the place 10.4 times = 36400 has at 18 mtrs we do 2022kms at 24 mtrs we travel 1516 kms that is a difference of 506 kms. The big saving is in overlapping. Before tramlining let's say our overlapping was an average of 500mms. 2022 * .5 = 1011has * $15 average spray cost = $15165 that's a 60 ft boom. 80 ft boom is 758 has * 15 = $11370. In tramlining there is no overlap.

Compaction is another hidden saving that the more technical people might be able to put a cost on but in farmers terms where we see the biggest loss is the establishment of the crop we are about to grow. Most of the damage could be contributed to the previous harvest and more so if it is wet.

My brother and I have these meaningful conversations on harvesting operations in a Tråmlining situation.

Costs can be saved in all the other operations that you do which will enable you to either mechanically put the tramlines in or go to the GPS method. What should be a major factor in your decision is the speed you want to do your sowing operation. How many acs are you sowing in the one operation. How many inputs are your putting into those acs i.e. what amount of fertiliser seed trace elements etc.

I believe this machine is the most important machine you should own - no good having a big header, truck or car if you haven't sown the crop!

If you were to start from scratch then some advice from the relevant experts wouldn't go astray so you could run your tramlines "downhill" in the most efficient and common sense way. It stands to reason that if you are to run your tracks across the slope that in a major rain event the runoff culminates in the tracks and after a few more combinations of water engineering you create your own erosion.

My belief is we need a whole farming system approach that entails Zero till response cropping tramlining and downhill farming.

We must no drop the ball with 20 mins to go and press on with new technology. This I believe comes in spray technology - electronic weed activator spray units.

Go back to the spray equation 36400 ha' average spray $15. You come to a figure of $546,000. Save 50% of this and it comes to $270000. In some of the work we have done with the old technology which was developed by Warrick Felton some 10 years ago, we have had up to 70% savings in chemical. Attack the ball not the player i.e. the weeds not the paddock.

This will also enable us to use different families of chemicals to combat the resistance to some chemicals and possibly the development of more sustainable ways of fallow spraying. There has been discussion on Quality Assuring the Farms on which we produce products for the consumer. This could be the vehicle by which the farming community will incorporate the "whole package" of farming systems.

If we are to go to the consumers and educate, explain, show and work with the industry, then surely all of us starting with the worms in the ground to the food put on the plate will benefit.

At the end of all of this you have to ask yourself why has there been such a massive adoption of controlled traffic. And the answer is simple. It's common sense combined with a small outlay for a major financial gain. Ask yourself the same question on Zero till.

THE FARMING SYSTEM AT "KIELLI"

Jamie Grant,
"Kielli", Jimbour

Why Controlled Traffic?

- Started Zero-till with odd sized machinery which made planters too hard to set up.
- We had a compaction problem.
- We had inefficiencies with boomsprays with foam markers

Setting Up Controlled Traffic

Swath Width - Limitations was 30 ft header front so went to 30 ft planter and 60 ft boomspray.

Tramline Widths

Limitations were:

- Track width of Toyota L/C (spray rig)
- tractors could match Toyotas but not header
- set up on 60 inch centers
- marked out controlled traffic layout with rifle sight and markers on planter

Evolution of Controlled Traffic

- started out addressing planter tracks and spray rig tracks
- soon realised that harvest machinery also had to fit into system

Machinery Adaption

Tractors - back to single 18.4 inch tyres on 60 inch centers.

Planters - downsized to 30 ft
- tramlines not planted
- multiple headstocks to allow side shift of planter
- seed cart to 60 inch centers with side adjustable hitch

Boomsprays - nozzle arrangements for alternating tramlines
- wide tyres on 60 inch centers.

Header - changed to dual 18.4 tyres on 120 inch and 180 inch centers
- hydraulic cutters (traffic way trimmers)

Chaser Bin - 18.4 inch boggie singles (radials) on 120 inch centers.
- top mounted fill auger and sweep

Results

- Allowed us to run a successful farming system (either Zero-till or Controlled Traffic on its own has limitations for the production of crops).
- Compaction levels are decreasing and water infiltration has improved.
- Because of "The System" (Combination of Zero-till and Controlled Traffic) our yields have improved 40%-50% in above average seasons and 30% in below average seasons and our cropping frequency has dramatically increased.
- Compacted tramlines allow earlier access of spray rigs and planters after rain.
- Operator convenience and less fatigue.
- Efficiencies in overlaps and misses in all operations.

The future of Controlled Traffic

- definitely here to stay
- aim to cut % of tracks in field
- 3 metres or 120 inch will be the width of the future
- wider swath widths (e.g. 40 ft) will also cut down compacted % of field.

"Controlled Traffic Farming at Brookstead"

Engelbert Krampl, 'Garryhunden Farming", Brookstead, Qld.

Introduction:

Having visited Australia in 1984, '85 and '86, the decision was made to purchase two properties, 'Garyhundon' and 'Mussenhof' in 1987. These adjoining farms, with a total area of 2700 acres, are located in the Brookstead area of Queensland on the floodplain of the Condamine River. The entire property produces irrigated crops using a 2000 Megalitre ring tank supplemented by a 1100 Megalitre underground water allocation. Initially, these properties were farmed using conventional methods, with high horsepower tractors and wide equipment.

Before coming to Australia, I farmed in Austria. Although the average farm size was only 40 to 50 acres, by leasing additional smaller farms, I produced corn, wheat and barley on 200 acres. These crops were used as feed to fatten pigs in our 1000 head piggery. During the early 1970's, the traditional European farming method used the mouldboard plough, where the measure of a good farmer was the total absence of any crop residue on the soil surface and a smooth even field finish. Later, the practice moved away from total soil inversion, in an effort to eliminate layers and speed stubble decomposition.

At this time, planting and spraying operations were performed using a system of controlled traffic or tramlining. In Austria, we used 4WD tractors with linkage mounted, 3 metre planters, and a 15 metre boomspray. A mechanical device on the planter, would shut off the seed to particular rows on every fifth pass to mark the spray tracks.

Since the early days of my farming in Australia with a 400 HP tractor and a New Holland Trashfarmer, I have been investigating ways of improving my farming operation. The obvious change was to move towards a system of controlled traffic, which had proven successful in Austria. It was encouraging that a neighbour, John Woods, was also farming using 3 metre beds at 'Dunbar'. The decision was made to use a controlled traffic system, and produce all crops on 30 inch rows, with the wheels spaced at 120 inches.

1989 was the year that I would identify as the 'turning point' in our farming system at 'Garryhunden'. That year it was necessary to use a contractor to assist with planting 1000 acres of soybeans. The crop was planted using our Becker planter, based on 30 inch rows, and in 40 inch rows by the contractor. Yield tests revealed that the crop planted under the controlled traffic system produced 3.5 ton per hectare while that planted on 40 inch rows yielded 2.5 ton per hectare. The main reasons for this variation were:

- the plants in the wheel tracks were stunted and approximately half the height of the others resulting in reduced yields
- losses at harvest due to unevenness of the crop and different stages of ripening

Now, under the system of permanent wheel tracks our soybeans can be harvested using a contractor with a MacDon draper front. This harvesting contractor, from Pittsworth, has the facility to change the harvesters' wheel spacing to suit our requirements.

Cropping Program:

The cropping rotation at Garyhunden Farming is quite flexible and is determined by:-

- Water availability

- Crop prices
- Weed problems
- Chemical residuals
- Soil fertility
- Seasonal conditions

After a cautious venture into cotton from the traditional summer crops of sorghum and corn, we now plant 1000 to 1500 acres of cotton each year, plus around 500 acres of corn. Soybeans are also grown for seed production. During winter our cropping options include oats, canary or wheat which is usually double cropped into cotton stubble.

Currently, we base the rotation around a cotton crop, doubled into cereal after pulling, raking and applying urea with a spreader. Additional nitrogen and phosphorus is applied and incorporated prior to planting. This is usually followed by corn or sorghum and then back into cotton. In some seasons, high levels of corn crop residue can difficult to work with. One option it to leave the trash for as long as possible and if necessary rake and burn, prior to planting.

For the current season, we have planted 400 acres of canary. This will be complimented with 1200 acres of cotton, 400 acres of corn and 300 acres of corn.

Machinery:

All my machinery is designed or modified to suit 120 inch beds, with widths in multiples of the bed size.

Tractors:

Fiat 180-90 with spacers added to the front axle to achieve 120 inch wheel spacing.

Fiat 1880 with extended front axle

G210 Fiatagri with the same front axle modification.

Planters:

Monosem linkage planter is used to plant corn and cotton. This machine is set up to plant 12 - 30 inch rows.

Cereal crops are planted with a Simplicity Airseeder mounted to the hitch of a 30 foot AFM Scarichisel. The 36 planting tynes, fitted with narrow sowing points, are spaced at approximately 9 inches. To reduce problems with lodging, the tynes adjacent to the wheel tracks are positioned so that the seed is actually placed in the edge of the wheel depression. A Janke vertically adjustable tyne is used in these locations to provide improved seed placement.

Fertilizer Spreader:

Our fertilizer spreader can be adjusted to spread over an area of 18 or 24 metres.

Boomspray:

A 24 metre tractor mounted boomspray is used.

Harvester:

To harvest all cereal crops and corn, we use a Claas 106 header. This machine has been simply modified by repositioning the wheel centres within the front rims to achieve the desired wheel spacing. The adjustment, provided by the manufacturer, enabled the rear wheels to be shifted into alignment.

Using spacers available from John Deere, the front wheels of our cotton pickers were moved out to match the rest of our equipment, and a local engineering works extended the rear axle. Another minor modification was the addition of deflectors to prevent crop being run over by the wheels.

Additional Machinery:

Other equipment used, particularly for the production of cotton, includes:-

4 row stalk puller

12 row interrow cultivator

12 row shielded sprayer

and a 12 row spot sprayer

Difficulties:

- Crop lodging in wheel tracks. This was addressed by planting as close as possible to the wheel track and if necessary at harvest, using crop lifters in those rows.
- The control of weeds in the wheel tracks did present a problem. With the use of improved spray technology this has been controlled. To supplement chemical weed control, we also use an Alabamah sweep which also helps maintain the track evenness.
- Manufacturers will not warrant the extended front axle on our tractors. Some early breakages have been overcome by increasing maintenance and attention to specific areas. As an example, the ball joints on the front axles are regularly checked and adjusted to specification.
- It was necessary to strengthen hubs and housings on the front final drives of the older tractors.

Changes resulting from Controlled Traffic:

- The number of permanent staff reduced from 4 to 3.
- Fuel bill decreased by 1/3.
- Allowed a wider range of cropping opportunities.
- After a couple of years it became obvious that the soil structure improved.
- With this improved soil structure, yields increased by 10 - 15%
- Only under extreme circumstances is it necessary to use aerial spraying.

The Future:

In the future, I would like to see progress in standardisation of row spacing and wheel track spacing,

improvements in guidance systems to assist in precision farming,

improved flexibility from equipment manufacturers,

and advances in band spraying technology.

Controlled Traffic Farming
A Grower's Perspective

prepared by Pete Mailler
August 1998

Until last year I was farming with my parents, Michael and Barbara, and older brother, David, and his wife, Clare. I left the family operation to start sharefarming in my own right. I have however been involved with the evolution of our family's farming operation for many years. The two operations farm approximately 11 000 acres under a controlled traffic system. The land we farm is quite variable from gentle slopes to flood plain. Although we do not have to deal with contour banks, erosion is an issue on some of our lighter country.

The beginning of our shift to controlled traffic farming came when we started to farm up and down our paddocks instead of round and round. We made our boomspray match the planter width and left out marker rows at planting to give the ground rig lines to follow both in the crop and through the subsequent zero-till fallow. We struggled on for some time with this system which I liken to the farming system in the UK. This is a semi controlled traffic system, where all the traffic for each crop is on one set of wheel tracks which are laid down at planting and are then lost when the field is ploughed. The next time the field is planted there is a new set of wheel tracks.

There were several things we began to notice in this system. We could spray wet paddocks if we stayed on existing tracks. We could also clearly see the effects of compaction from the previous year's tracks in our crops. We could identify the problems associated with compaction and saw a need to get our tracks to line up year after year. The system still caused us several other problems. The main problem was that our lapping errors were only as good as the planter lap lines. The next problem arose when we worked country and then wanted to spray, usually herbicides at night during summer to improve efficacy. What we needed was a way of guiding our machinery without a physical mark.

This is when we began looking at GPS guidance equipment. We were unimpressed with the accuracy and reliability, or lack thereof, of the systems that were available. At this point we decided to develop our own system. Fortunately I have a brother called Robert who is an electrical engineer. So after a lot of time, research and trial work we come up with the Beeline GPS Navigator, which is the first and currently only commercial agricultural GPS guidance system to guide and steer tractors to sub 10cm accuracy. This breakthrough eliminated all the mechanical problems with moving to a true controlled traffic system. We are able to lay out our paddocks accurately while spraying, ploughing or planting and return to the same wheel tracks without any visible marks, day or night if need be. The accuracy of the system meant that we have also minimised our overlap, saving approximately 10% of our variable input costs.

The only dilemma facing us now is the same problem faced by nearly all farmers looking at controlled traffic. What configuration should we set our farms up on? I don't believe there is a correct answer to this question at this stage and this poses a new problem. If I set up a system for the time being what happens if and when I have to change?

I have elected to set up on an eight metre base width with two metre centres on my tractor. I plant and plough on an eight metre width and spray with a tractor mounted 24 metre boom. There are a few reasons for this configuration:

1. Allows maximum utilisation of the tractor through all operations
2. Allows reduced size, weight and cost of the tractor as it suits FWA models
3. Stays in line with the current cotton industry standard used by so many contractors
4. Allows flexibility in summer and winter cropping rotations and row crop options
5. Allows trucks into the paddock on traffic lines at harvest if necessary
6. Through rotations and controlled traffic one unit should be able to cover 4000 acres per year comfortably.

The only major drawback is that the header tracks do not suit the system, but I am playing the odds here in that eight out of ten harvests are dry in my region. The problem I see with trying to incorporate the headers in the system is the wide variation of tyre gauges within and between all the makes and models. Until there is some standardisation of headers I can't see a safe way to incorporate them in the long term. I am often amused and annoyed by the catch cry of three metre centres when a large proportion of headers are not on three metres anyway.

In conclusion the results of the shift to controlled traffic have been dramatic, with an amazing increase in infiltration rates and reduction in run off. This season the improvement in soil structure has enabled our crops to cope far better than we could have hoped. While these benefits are hard to quantify, I feel it is essential to encourage farmers to do what they can to adapt the way they farm as quickly as possible. It is mind numbing to think of what it has cost us to date by not adopting the principles of controlled traffic sooner. If you can only reduce compaction by 10 % it will bring its own reward. I am frequently asked questions about how to get into controlled traffic and what it costs. I believe the real question is, "What is it costing to not get into it?". We must make some decisions about which configuration is most suitable and or adaptable down the track. I strongly believe that it would be a serious error to sit on the fence and not commit to controlled traffic in the hope of a universal answer to configuration problems being just around the corner.

Controlled Traffic Pays off

Aaron Sanderson
"Kulawin"
Clermont, QLD.

In 1995 after we had trialed a paddock in a basic controlled traffic regime, it struck us as to why we hadn't thought of this sooner.

My parents, my wife and myself operate a grain growing property north of Clermont in Central Queensland. It was originally brigalow scrub country and is characterised by soft black soil and being relatively level, although approximately half the place is contoured. Coupled together with long gradual slopes (often 1km+) and a summer storm rainfall pattern, we find we can often stretch the friendship between contour banks and runoff water.

Before moving into controlled traffic farming, we generally farmed on the contour and around the paddock. We were gradually increasing chemical weed control but were still putting a lot of hours on tractors. In regards to equipment, we were using two 4WD tractors and due to probably more good luck than anything, most of our tillage equipment was somewhere near 40ft wide. The only real change we made was from a 60ft to an 80ft boomspray.

I would like to spend a moment on some of the points that lured us into controlled traffic farming.

- *Spray Guidance* - Trying to figure out where you had been and conversely where you were going next was a constant aggravation. The life span of foam blobs in a Central Queensland summer is about the same as snowflakes in hell and equally as useful. The best you could do was to pick a row of crop or stubble that you liked the look of and follow it. That was fine until you looked behind because when you looked back all rows looked the same.

  For Controlled Traffic, we pulled a row out of each tractor wheel track in winter and closed up the middle pair of rows on the summer crop planter and now we almost treat spraying as rest time.

  This last summer we sprayed almost entirely at night and found we were getting much better results.

- *Reduced wheel track emergence* - There are two parts to this. For years we have been using different points and digging tynes deeper in order to improve emergence behind the tractor. It never occurred to us to just stop trying and don't plant there. The other half of the problem was that after planting, the prior spray wheel tracks were still with us because nothing germinated in the depressed wheel tracks.

  These last two points tie together somewhat. By keeping everything on track we now eliminate the guidance problem and missed strips. As well as keeping all wheel tracks common we don't have any extras heading somewhere else.

- *Erosion rills between contour banks* - Just before the first Controlled Traffic farming conference in 1995, I had the pleasure of harvesting some of our wheat which yielded about a bag per acre. My high speed operation became quite difficult in the contoured country as I bounced from one wash to the next. At the time I was wondering how effective these contour banks were as there were a multitude of rills coming across the contour bay before spreading out in a silt fan in the bottom of the contour. It looked to me as if we were still doing a pretty good job of moving dirt downhill!

  After returning from that first conference we decided to turn some workings down the hill and across the contour banks. We had to reshape some of our banks a little but the difference has been amazing. Now when water starts to runoff, it simply leaves the soil behind.

- *Overlap or a lack of it* - This is probably one of the most important aspects of controlled traffic farming. We fitted our planters with marker arms and now look all day at a line extending out from the tractor bonnet instead of peering over at the last worked edge. In one paddock that we used to work as separate contour bays, we now work up and down and an effective 18% less area. That figure is also what we save on fuel, seed, chemical etc. What you pick up however is the yield on the part of the crop that would normally be double planted and suffering because of that. The Queensland DPI state that average overlap is approximately 7%. A 7% reduction in costs across the board adds up to some real dollars.

The points just mentioned were what got us initially interested in controlled traffic. As the system evolves, constant adjustments are being made. Our 12 metre wide, 2m wheel centres and 1m row crop systems work perfectly until you want to bring the header into the system. This has become our next challenge. The point was recently hammered home when we wanted to plant sorghum immediately behind the header harvesting corn. The header wheel tracks were just simply in the wrong places. It meant that 2 rows out of 11 or 18% of plants were going to have a fairly unhappy life.

As a solution we have decided to return to a 30ft header front and extend everything to fit a 3 metre wheelbase. Our header is the most indivisible article and since it is relatively easy to change the other equipment, we will do just that. We currently have front wheel assist tractors and a spra-coupe, all of which we can adapt to a 3 metre wheelbase to follow the header.

In the near future we have plans to make possible some alternative operations such as sidedressing fertiliser on all crops including wheat and to do some more work on long slope management by using furrowing techniques similar to the flood irrigation industry.

As our system has evolved, possibilities are always emerging which previously seemed unfeasible. I look forward to the time ahead when we will start to see some of the current new technologies mature, especially in the areas of spray application and guidance.

CONCLUSIONS FROM AN EROSION STUDY
RAINFALL EVENT - FEBRUARY 1997

R.S. Cannon, Extension Officer
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Department Of Natural Resources

Introduction

Controlled Traffic Farming (CTF) might be expected to reduce soil erosion because:

- Permanent wheeltracks and implement furrows can be used to prevent concentration of overland flow, and to channel runoff rapidly to safe disposal areas, and
- Soil infiltration capacity will be improved, and runoff reduced with zero compaction and zero tillage.

The first of these mechanisms has aroused substantially controversy because it entails "downslope" rather than "contour " orientation of all farming operations. Disagreement occurs largely because the contour bank/contour operation philosophy applied in soil conservation extension for the past 50 years is apparently in conflict with the "downslope" systems used in CTF, where permanent wheeltracks and all farming operations are oriented generally parallel to the slope direction.

Severe storm activity occurred in February 1997 in areas of the Central Highlands of Queensland where some farmers were using CTF. The aerial survey and followup ground work reported here were carried out following discussion of interesting land management system effects on erosion in the Bauhinia/Moura and Biloela districts of the Dawson Callide, and in the Kilcummin/Clermont areas after these events.

Methods

During the aerial survey, large numbers of still photographs were taken of obvious erosion damage and management system response, and over 2 hours of video footage was recorded. Team members completed the subsequent on-ground measurements at several sites identified from the air, in order to quantify soil movement in relation to the photographic record. A snapshot of farmer rainfall records was obtained to supplement results from official gauging stations.

Soil movement was estimated using 100 m horizontal transects, recording width and depth for each rill. Early in the investigation soil loss calculations were based on a triangular rill shape, but rills were observed to be rectangular in most situations, so soil loss calculation was subsequently carried out on this basis, using transects midway down the slope length.

Results and Discussion

The aerial survey technique enabled rapid inspection of large areas of farm and pasture lands, and identification of major damage. The photographic record was particularly useful, although we also studied specific sites on the advice of growers. The record assisted in discussion of causal relationships between erosion damage and processes involved. This damage, which was observed on paddock after paddock, and on many farms, was caused largely by rilling, contour bank breakage and watercourse problems. Some of the results are summarized in Table 1.

Table 1: Summary of results -- rainfall events and return periods, management systems and soil movement:

RAINFALL	SITE	DISTRICT	ESTIMATED SOIL MOVED	
>400mm/ 6hrs 1:100 = 75mm/hr	Alluvial Stripping	Bauhinia	2000 ton/ha	up to 2500 ha
	Conventional	Bauhinia	<30% stubble cover	196 ton/ha 35 000ha
	Zero Till	Bauhinia	>70% stubble cover	80 ton/ha
>150 mm/1.1hr 1:100 = 75mm/hr 1:10 = 40mm/hr	Conventional	Kilcummin	>30% cover	60 ton/ha
	Controlled Traffic	Kilcummin	>30% cover	< 5 ton/ha
100 mm	Zero Till	Jambin	>70% cover	< no evidence of loss
	Controlled Traffic	Jambin	>70% cover	< 5 ton/ha

Rilling

This was clearly identified as the dominant process of in-paddock soil loss. Rilling occurred on all conventional (ie non-CTF) farming properties which received more than 100 mm rain, regardless of cover level. Rill frequency and width was probably greater on bare cultivated paddocks than on uncultivated paddocks (eg. 1996 wheat paddocks with over 70% cover), but rilling was severe even on these paddocks. Of the paddocks surveyed, 60% included contour banks which did not stop rilling, but prevented rills accumulating into gullies.

Rills are caused by runoff following implement marks or wheeltracks, and moving across slope to concentrate in the rill line. This process was clearly encouraged by contour cultivation, planting and harvesting. Contributing area is the key parameter. Most rills were shallow, occurring only to the depth of an apparent compacted layer. They were wider in bare cultivated soils, but strict comparisons were not possible due to the lack of rainfall data. Zero tillage appeared to have removed the compacted layer in the case of one paddock which had been in zero till for three years, and helped to convert overland flow into stream flow. Although the rills in this paddock were infrequent, they were up to 450 mm deep and more than 1m wide, making it almost unfarmable. In C.T.F. paddocks, no runoff concentrations occurred.

Broken Contour Banks

Contour breakage creates major gullies in paddocks which usually cannot be fully removed, particularly where the cascade effect of a broken top bank causes failures on an increasing scale down the slope. Bank failure often occurred at the point where the contour channel was restricted by the silt fan introduced by a rill. Where banks didn't break, the silt fans and their attendant pondage areas caused continuing difficulties with timeliness of subsequent operations.

The following considerations, and critical values of contour bank design parameters, have been written to incorporate the lessons learnt from this observation of bank performance in a situation where the rainfall event substantially exceeded those used in contour bank system design:

1. Water/Silt must be delivered uniformly along the full length of the bank - not by concentrated rills.
2. Contour banks need to be resurveyed and maintained to remove zero and reverse grades.
3. Contour banks must be up to specification and compacted to full design height.
4. Contour banks discharge ends must be clear of obstruction and have positive grade.
5. Systems must be protected from run on water, including that from houses, sheds, yards etc..
6. All system elements must drain positively, ie. rows to a safe discharge, contour banks to a waterway.
7. Bank maximum spacing (for rain fed systems)
   - 0 - 0.5% banks at landscape faults
   - 0.5- 1% banks at less than 1000 metres
   - 1 - 1.5% banks at 600 metres or less

1.5 - 2% banks at 400 meters or less
2.0+ % banks at major slope changes or less than 200m

It should again be noted that the Bauhinia rainfall event exceeded the one in a hundred return period every hour for 6 hours and the Kilcummin event was twice the one in a hundred return period.

Ineffective Waterways:

Constructed Waterways:
Waterways must have adequate depth. Seasonal events leading up to the event meant that shallow waterways were carrying large bodies of grass. This along with silt deposition and flows exceeding the one-in-ten design capacity caused many waterways to overtop and prevented contour banks being able to discharge freely. Soil loss from this process was very large, but impossible to quantify using this survey method.

Natural Waterways:
Follow up surveys found that natural depressions used for waterways were often not adequate to run water at design depth and this effect was compounded by grass and vegetation. In the Bauhinia area particularly, natural water course capacity was often exceeded, and alluvial topsoil stripping was estimated to have occurred on over 2,500 ha. at a rate of 2,000 tons per hectare. Landholders have seen this occur 5 times in the last 20 years (*McDonald per comm*) and are now questioning the sustainability of cropping on these highly productive areas.

C.T.F. and Down Slope System Performance:

The survey covered a number of CTF and conventional properties using downslope systems, allowing comparisons between neighbouring properties with the full support of most producers.

The results and differences were clear, unambiguous and observed repeatedly across all CTF properties. There was no accumulation of rills into gullies, contour channels were clear and there was no restriction to access or other effect on operational timeliness where CTF was used. Contour bank overtopping and breakages did occur along with ineffective waterways, but timeliness was affected only on small areas.

The outcome in three CTF paddocks is described here to provide compelling evidence for use of this system in erosion control. Where sites were recorded from producers working downslope:

1 Birch - With paddocks furrowed downslope, runoff was delivered to contour banks from defined elements (ie each furrow). The contour banks ran at or near capacity, but silt deposition occurred only at the leading edge of the channel leaving the full depth of the channel available to carry water. Soil movement was < 12t/ha.

2 Sanderson - Downslope layout, with no defined elements, but water moved downslope between crop rows and a little deeper in the wheel tracks. Soil movement was not measurable.

3 Durkin - Downslope lengths up to 650 m showed no significant soil loss - cover levels exceeded 70 percent.

4 Swifts - Downslope system; soil movement was less than 10 tons per hectare and contour bank channels free of silt fans, cover less than 30 percent.

5 Mathieson - This was an across the slope (contour) layout. Wheeltracks and rows carried water for about 300 m until these were over-topped, but soil loss was less than 10 tons on a per bay basis.

The conclusion that a design that prevents surface water concentration, particularly where furrows behave like a corrugated roof, appears to be sound. The CTF system was effective in preventing rill development and delivereed very little soil to contour structures, while maintaining trafficability.

Erosion Measurement:

The aerial survey technique is effective in the rapid assessment of damage from severe (over-design) rainfall events, where rilling is the major mechanism of damage in paddocks with adequate residue cover. In the Central Highlands of Queensland, these infrequent but catastrophic erosion events are arguably responsible for the major proportion of damage to crop lands. In this environment rilling is likely to become a key performance indicator for erosion control programmes, and of the downstream effects of agriculture.

We propose the use of aerial photographs to allow measurement of rill frequency and broken/silted contour banks, followed by ground truthing for rill depth and width as the basis for realistic performance indicators to explain the problems and potential solutions to individuals and groups of growers.

This aerial survey technique does not take account of all erosion processes, because sheet erosion, for instance, cannot be seen from the air. Soil deposition is also not easily detected from the air or from quick land traverses, and no attempt has been made to assess movement in terms of suspended and bedloads. The repeatability of soil loss estimation from ground traverses might be questionable, but the alternative estimation process of scaling-up soil loss measurement from instrumented bays to real life also involves many assumptions.

Conclusions:

The aerial survey technique was highly effective in providing a rapid assessment of erosion damage caused by over-design rainfall events in terms of data and photographic evidence that would be difficult to observe from the ground. The visual impression of erosion damage has also had a substantial and long-lasting impact on the work ethic of those involved. Data from the survey has demonstrated that:

1) The installation of CTF across the affected areas would have reduced in-paddock soil movement by at least 90 percent.

2) Contour bank damage would have been less of a problem in CTF. The other major benefits of better channel performance include access, trafficability and timeliness of operations.

The support of other team members, Don and Wayne, plus other Soil Conservation Officers is gratefully acknowledged. The support of landholders who helped with the survey despite recent experience of catastrophic damage to their properties and enterprises, was particularly gratifying.

A more extensive report on this material is contained in "Performance of Controlled Traffic Farming Systems in an Episodic Rainfall Event February 1997" (in print).

Conservation Tillage Research for Dryland Grain Production in China

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ABSTRACT

ACIAR research project 9209 has investigated a range of conservation tillage options for maize and wheat production in China. Zero till planters were developed using combinations of Chinese and Australian technology, and research plots established to assess tillage effects in terms of soil properties, water use, and crop yield. The results show that conservation tillage can improve yield, economic viability and sustainability, so the extension prospects for this technology are very good. Preliminary experiments have also demonstrated the negative effects of wheel traffic in terms of tillage energy and inflation of rainfall in China. The work is continuing under ACIAR 96143, which is investigating the relative contribution of residue, soil disturbance and traffic to soil/crop performance

1. INTRODUCTION AND BACKGROUND

Rainfed agriculture occurs over nearly half the total cultivated land in China, and much of this area (approximately 35Mha) is located in the northern 16 provinces. Limited annual rainfall and frequent drought result in poor and unreliable yield, while extensive soil degradation reduces sustainability. Annual soil erosion in the areas surrounding the Yellow River, for instance, are estimated at > 15t/ha and the resulting rills and gullies reduce the area of productive land. Shanxi, where this research is carried out, is a typical dryland province in the northern loess plateau area. A broadly similar program has been carried out in both maize and wheat, but only selected are presented and discussed here.

2. MATERIALS AND METHODS

The traditional production system in this area involves two mouldboard plough operations prior to planting, and recent attempts to improve productivity and included ridging, subsoiling, furrow planting, sand mulching and the use of plastic or residue mulch. Because there are no large tractors (above 75 kW) in China, and most production occurs in small fields, medium-sized, 3 point linkage, mounted planters are required. This constrains the use of wide tine spacing to achieve zero tillage planting.

A 4 row, 3 point linkage, mounted zero till planter has been developed over several years work. This unit can effectively cut the straw, divide the residue and assist its passage through the machine. Field trials have shown that this planter can work with occasional blockages in unchopped maize residue. Its performance is significantly improved with working in chopped residue providing < 60% cover (Li, 1998).

Table 1 shows the range of tillage/residue cover treatments used to test conservation tillage effects. Two treatments -- zero tillage/standing residue and subsoiling/rolled residue – which gave a poor initial yield response, were replaced by zero tillage/chopped residue cover/disk harrow and subsoiling/chopped residue cover/disk harrowing treatments in 1996. Each treatment was replicated four times.

Table 1. Treatments applied in maize production.

Tillage	Zero	Zero	Zero	Zero	Subsoil	Subsoil	Subsoil	Mould
Residue	Standing	Rolled	Chopped	Chopped	Rolled	Chopped	Chopped	Board
Disk harrow	No	No	No	Harrow	No	No	Harrow	Plough
Treatments	ZT/SDRS	ZT/RLRS	ZT/CPRS	ZT/CPRS/HR	SB/RLRS	SB/CPRS	SB/CPRS/HR	Control

A preliminary exploration of controlled traffic effects was carried out using a pair of instrumented tines on the same toolbar to evaluate wheeltrack energy effects, and a rainfall simulator to assess crop residue and wheel compaction effects on inflation of rain. Field-scale experiments to evaluate controlled traffic effects in crop to production have since been established with the treatments shown in Table 2. All the treatments are set out in a controlled traffic pattern with wheeltracks on 1.5m centres. Results are available for the first year's work in wheat only, where the wheel compaction treatment was carried out using a small (13 kW, 1t mass) tractor.

Table 2. Treatments applied in controlled traffic experiments.

Tillage	Zero	Zero	Shallow	Shallow
Residue	Cover	Cover	Cover	No Cover
Compaction	Non Compaction	Compaction	Non Compaction	Non Compaction

3. RESULTS

1). Conservation Tillage Yields and Benefits

Figure 1 shows the mean maize yield over the years for years 95, 96 and 97. Most conservation tillage treatments provide greater yields in most years, although effects were not significant ($P<0.05$) in all years. Crop yields were greater where residue was chopped, or after harrowing. It is suggested that this occurred because the soil surface was more level, optimizing planting conditions and improving the soil temperature. This aspect needs to be validated with more experiments (Gao *et al.*, 1997).

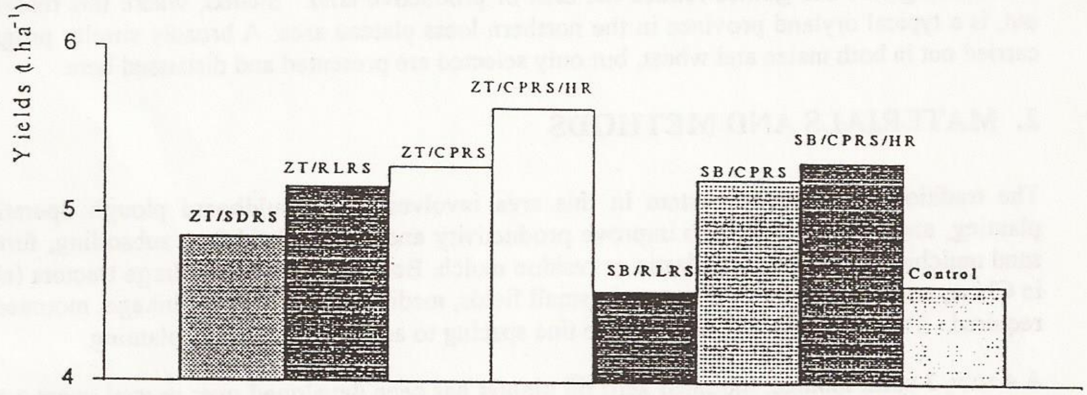

Figure 1. The yields for maize conservation tillage

Table 3 sets out the economic benefits of conservation cropping, based on an examination of cropping inputs and outputs, including seed, chemical, labour, cattle, and machinery operation. The value of crop residue was not considered. Conservation tillage can increase net income by more than 50% compared with conventional tillage through increased yields and reduced cost.

Table 3. Economic benefit of maize conservation tillage[1]: RMB Yuan/ha

Tillage	Zero	Zero	Subsoiling	Zero	Subsoiling	Mould
Residue	Rolled	Chopped	Chopped	Chopped	Chopped	Board
Disk Harrow				Harrow	Harrow	Plough
Input	2100.3	2160.3	2340.3	2250.3	2379.3	2775.6
Gross output[2]	5477.44	5595.53	5537.86	5974.16	5639.2	4870.30
Net income[3]	3377.14	3435.23	3197.56	3723.86	3208.90	2094.70
Response to CK(%)	61.2	63.9	52.6	77.7	53.2	/

1. Two treatments: ZT/SDRS and SB/RLRS were omitted in 1996
2. The price is based on 1997, A$1.00=5 RMB Yuan
3. Net income = Gross output – input

2). Preliminary Results –Controlled Traffic

Tillage energy requirements were assessed by measuring tine draft in wheeled and non-wheeled soil at four tillage depths, following different overall tillage treatments. These results are set out in in Figure 2 as tine draft/depth characteristics, and demonstrate that the average tillage energy requirement of wheeled soil is approximately 80% greater than that of the non-wheeled soil. The data also shows that surface tillage in zero tilled soil requires more energy than conventional tillage. At depths below 7cm, however, the energy for zero tillage is less than that for conventional tillage.

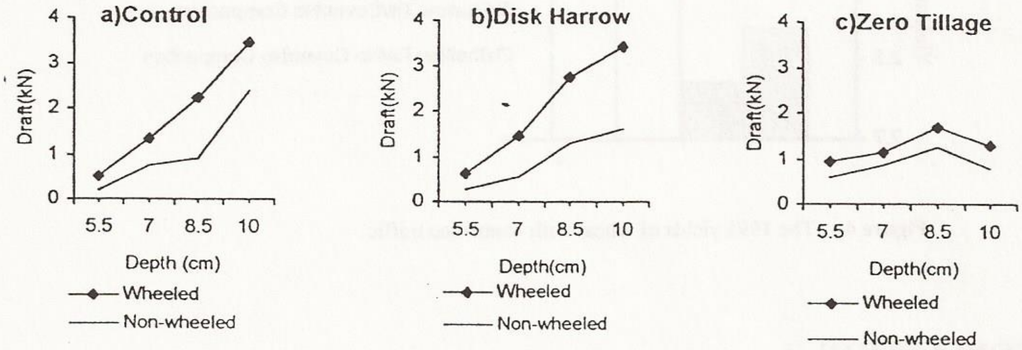

Figure 2 Energy requirement with different tillage for wheeled and non wheeled soil

Simulated rainfall at 80 mm/h was used to assess the effects of wheel traffic and crop residue on runoff. Rainfall/runoff data for maize is set out in Figure 3, and demonstrates that a single pass by the wheels of medium (30 kW) tractor had a greater impact on runoff than any residue treatment. Greater surface cover reduced runoff, and the minimum runoff occurred in non-wheeled situations with 100% residue cover, resulting from zero tillage.

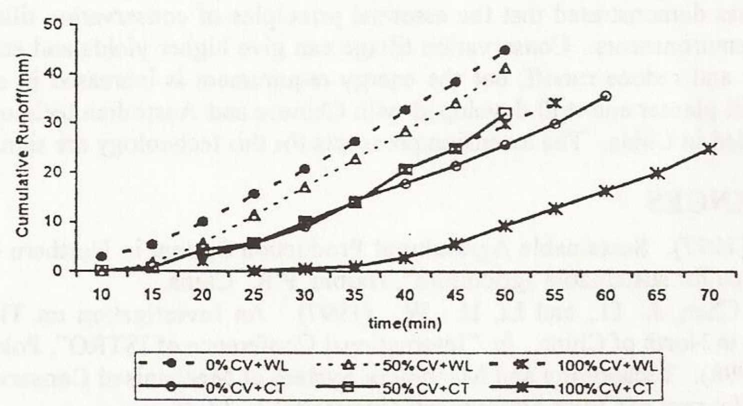

Figure 3 The effect of wheeling and ground cover level on runoff from zero till maize plots.

Controlled traffic effects on soil and crop performance of wheeled and non-wheeled treatments are currently being monitored, with the first complete crop cycle finishing in June 1998. Yield differences illustrated in Figure 4 suggest that wheeling might have reduced wheat yields slightly compared with non-wheeled treatments, while cover had no effect. The differences in wheat have just failed to meet the

5% test of significance, but this work will continue for at least two further years. The first maize harvest will occur in October, 1998.

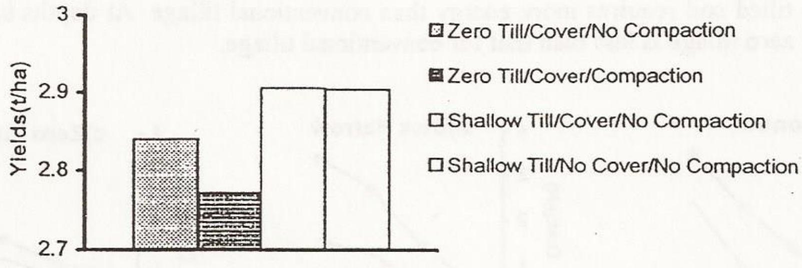

Figure 4. The 1998 yields of wheat with controlled traffic

4. CONCLUSION

After 5 years of research and 2 years of extension work, conservation tillage has been adopted in 12 counties of two Provinces, an area of about 1000 ha. In applying this technology, most farmers agreed that it is a good technology, but difficult to carry out, particularly if they can't afford feasible machinery. They need sprayers, no-till planters, subsoilers and choppers. Some farmers without feasible no-till planters have to chop the straw two or three times, so that they can use a heavy traditional planter. Regardless of the method used, yields tend to increase, while conserving soil and water.

Conservation tillage can conserve soil and rainfall, and also improve crop yield and farming income. Although there are many differences between the farming systems of Australia and NW China, ACIAR project 9209 has demonstrated that the essential principles of conservation tillage and controlled traffic apply in both environments. Conservation tillage can give higher yields and economic benefit, conserve soil and water and reduce runoff, but the energy requirement is increased in some operations. With a suitable zero till planter and drill developed with Chinese and Australian technology, conservation tillage is being extended in China. The extension prospects for this technology are significant.

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