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Grape and Wine Research and Development Corporation

Soil Improvement Technologies for Established Vineyards



FINAL REPORT to

GRAPE AND WINE RESEARCH & DEVELOPMENT CORPORATION

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Research Organisation:
Agricultural Machinery Research Design Centre, University Of South Australia

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Executive Summary

Project Number: USA00/01
Organisation: AMRDC, University of South Australia
Location: Adelaide
Supervisor: Dr Jack Desbiolles.
Time Span: 2000 - 2005

This project was part of a multi funded research program that aimed to provide the technology to better tackle several vineyard specific problems. The research was carried out in stages; the first stage (machinery development) was funded by SENRAC, the University of SA and industry partners. The second stage was co-funded by GWRDC, the University and industry partners and investigated the performance of this newly developed technology against the industry equipment and practices currently available. The conventional approach of machinery use and machinery management was compared to some novel machinery and site management strategies aiming to provide better and longer lasting removal of subsoil constraint problems.

The research has lead to a new technology that not only has the potential to loosen greater volumes of soil within the vine row for the given power available from vineyard tractors but also apply soil ameliorant in a liquid form to the soil throughout the loosened profile. This report covers all aspects of the research and then focuses on where the technology fits into the industry with the ability of providing improved loosening capabilities and amelioration application as a complete system. The University of SA through AMDRC has recently been successfully included in a joint project with the CSIRO and SARDI into soil management for yield and quality. The technology and practices developed are now being utilized to satisfy the requirements of current and ongoing projects in the viticulture industry.

Objectives:

- Identification of advances in subsoil tillage machinery, with the design and manufacture of a high efficiency subsoil loosening machine, including soil amendment incorporating ability suitable for use with vineyard tractors.
- Investigation into the relative performance of the developed machinery compared with currently available technologies as the benchmark.
- Evaluation and demonstration of the benefits of energy efficient, quality subsoiling compared to current equipment available, in terms of subsoil improvements
- Evaluation of subsoil management strategies for a selection of problem soils in established vineyards.
- Dissemination of knowledge on best practices for achieving effective and efficient subsoil physical environment, along with maintaining that improved environment for as long as possible.

Industry significance:

The South Australian viticultural industry in 1997-98 represented 50% of the national production and 64% of the industry's national export value. The Australian industry comprises 7,000 winegrape growers (2,600 in SA) and a vineyard area of more than 100,000ha. The South Australian export share in value amounted to more than $630 million in 1998-99 (Source: Australian Bureau of Statistics). The soil research community estimates that a 60-80% proportion of existing vineyards are significantly affected by subsoil compaction (Cass, 1999).

Newly developed more efficient machinery will offer opportunities for improving the consistency in grape quality and productivity across vineyards and between vintages. This represents very significant benefits for the viticultural industry in South Australia, as well as the orchard and farming industries in general where this improved technology can also be applied. The ability to deep loosen vineyard subsoils through a more effective use of the available tractor power, will allow operations such as deep incorporation of soil amendments to simultaneously be carried out in problem soils which also impose

great limitations on crop quality and productivity. Deeper soil loosening means a greater soil volume exploration by roots for better access to stored water and nutrients. Deeper root systems give direct benefits, decrease reliance on irrigation water and improve consistency in both grape yield and quality across vineyards and between vintages. With the viticulture industry in South Australia being a large proportion of Australia's wine production area, the project outcomes can most directly improve the sustainability and profitability of the Australian viticultural industry.

Summary of experiments:

Identifying the vibratory parameters to optimise ripper performance. (Ex1)

The evaluation of a range of vibratory ripper parameters such as tine vibration angle, amplitude, frequency of vibration and velocity ratio was conducted to determine the optimum. Preferred settings enabled a 38% reduction in draft force compared to a rigid machine. Higher velocity ratios increased the PTO power required and also the 3D seat vibrations

Evaluation of dual depth, dual pass and winged tine technologies (Exp2)

Using the best performance setting from (Exp1) and a rigid equivalent, dual depth, dual pass and winged tine techniques were used to investigate strategies for maximising the soil loosening capacity and depth of the ripper. Fitting wing produced a slight reduction in depth but increased the soil loosened area by up to 20%. Dual depth tillage increased loosened area by up to 55% with an additional 20% from a dual pass approach.

Comparison of performance for a range of tine designs (Exp3)

Comparing the rigid and vibrating version of the new technology against a range of commercial rippers all operated with two tines (Red Rhino, Agrowplow, Paraplow and Grizzly-Michel). As all treatments were operated at the same depth a comparison was able to be made of the energy requirements of each tine design.

Comparison of maximum capacity of new technology and commercial subsoilers (Exp4)

A comparison of the maximum subsoiling capacity/depth of each subsoiler was made with the new technology set up as a dual depth system and the commercial units as a two tine and their preferred arrangements. This gave an indication of the subsoiling capacity of each ripping technology.

Technology to increase output and capacity (Exp5)

A range of ripper technologies with varying subsoiling capacity were selected for vineyard application. The experiment compared the soil and vine response to the different levels of subsoil loosening and the different strategies selected. The subsoiling capacity was greatest with the dual depth dual pass vibrating ripper technology and approx. 150 mm deeper that a commercial ripper. Ideally the economic, long term vine response for the subsoil loosening input level would provide valuable planning knowledge to maximizing the vineyard output.

Post ripping management and traffic control (Exp6)

A vineyard site was used to investigate the influence of the timing of subsoiling and management of wheel traffic on vine performance and subsoil re-compaction. Monitoring the resettling or re-compaction of the loosened subsoil showed that typical vineyard traffic could readily return the loosened soil close to its pre-loosened density within 3 months of ripping. Highlighting the potential for yield gains where traffic is minimized following the subsoiling operation to allow sufficient opportunity for root growth to advance into the loosened subsoil.

Design and development of a liquid amelioration system

Ongoing work on this project by AMRDC has funded and developed equipment to be fitted to the ripper that enables liquid soil ameliorants such as gypsum, lime and nutrients to be added to subsoils. The ability of this technology to place these materials at depths up to 600 mm in the soil profile. This depth is much greater than current equipment allows whilst being able to fit between the narrow rows of vines, using a vineyard tractor. This technology is available to be utilized for current and future vineyard projects.

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Description of Units and Terminology:

Due to the high amount of technical terminology, abbreviations and acronyms used in this report it was considered appropriate to include the following definitions.

Draft Reduction – The reduction in the draft force required for a vibrating tine system compared to an equivalent rigid system operating at the same speed and depth.

Drawbar Power – Pulling (draft) force developed by the tractor via the traction of the wheels and available to pull the implement multiplied by tractor ground speed.

Drawbar + PTO power ratio – The ratio of the sum of the drawbar and PTO power required to power the vibrating ripper compared to drawbar power required for equivalent rigid tillage.

Engine Power – Power required at engine flywheel (In this case based on transmission efficiencies of 92.5% and the calculated traction efficiency).

PTO Power – Power required at the tractor power take off (PTO) shaft to drive the ripper (PTO torque x speed).

Soil Loosening Energy (SLE) - This parameter was developed in this study and is a value that represents the energy to loosen the soil above a given depth, based on the Cone Index profile (indication of soil strength) and the area loosened to each depth across the loosened soil profile.

Specific Engine Power – This is the calculated engine power used divided by the cross sectional area of soil loosened, an indication of energy used per unit of soil loosened.

Tractive Efficiency (TE) – The efficiency of power transfer from that available at the tractor axle to that available at the drawbar. Tractive efficiency depends on tractor tyres, ballasting, soil condition, wheel slip and tractor drive configuration.

Velocity ratio – is an accepted means of combining the vibrating parameters of amplitude, frequency and forward speed. The ratio is the product of the vibrating amplitude and frequency divided by the forward ground speed of the ripper. This is equivalent to the ratio of the maximum tine tip speed to that of the ground speed.

Wheel Slip – Is the difference in travel of the tractor wheel on a hard surface with no pulling load to that operating with a pull load.

Effective Rigid Draft – (ERD) – Is the theoretical amount of equivalent draft needed if a rigid tine had been operated to the same depth as the vibratory subsoiler.

Preface:

Throughout this project several aspects of subsoil constraints and deep loosening of soil in vineyards have been investigated. The work can be broken into several sections with two main stages encompassing the main areas of the research. The first stage consists of the investment of technology from the University of South Australia, (AMRDC), SENRAC and industry partners to develop an improved solution to subsoil constraints issues in vineyards.

This was followed up by stage two of the project co-funded by the GWRDC, the University of SA and the industry partners to evaluate the technology against the currently available market equipment and practices and to provide the industry with some justification for using the improved technology and working practices through benefits on both grape yield and quality.

Abstract:

Using technology developed to enable deeper and more energy efficient loosening of subsoil in vineyards the project investigated the benefits of the new technology over currently available methods for reducing subsoil compaction between vine rows. This investigation encompassed many areas of comparison

1. Optimising vibration settings
2. Maximise the capacity and Efficiency
3. Comparison of different tine designs
4. Comparison of capacity and efficiency of different ripper designs
5. Using technology to increase output and capacity
6. Managing post ripping traffic and machinery usage
7. Development of an ameliorant applicator.

The influence of ripper technology and capacity on the subsoil constraints of vineyards was considered for the quality of soil loosening, its influence on re-compaction and vine response. Consideration was then turned to the timing of subsoiling and vineyard inter-row management of subsoil compaction in vineyards. Factors such as the amount of soil loosening, soil disturbance, re-settling and re-compaction were investigated. This included the traffic management of vineyards to reduce and minimise the re-compaction of the vine mid-row.

As part of tackling subsoil constraints soil chemical modification was considered an important area, so a liquid amelioration system has been designed and built and is ready for testing which will be carried out in subsequent seasons. Finally the dissemination of the information to the industry and the end user of the machinery and the vineyards have been kept up by conference presentations local field days and also the addition of a section in the CRC for Viticulture, Online Viti-Notes.

Background:

General Background

Competing demands for irrigation water and land degradation (salinity) threats are placing increasing pressure on the Australian wine industry to justify its current use of water and to make real savings. Part of these savings must come through the industry adoption of management practices aimed at saving irrigation water and maximising the impact of natural rainfall. Successful adoption of water saving measures requires, i) creating and ii) maintaining - a hospitable subsoil environment which:

- allows the development of an optimum root system within the subsoil profile to minimise the likelihood of water stress effects on vines between rainfall events and decrease the risk of nutrient deficiency impacting on the productivity and disease resistance of vines (grape yield and quality produced in vineyards are directly correlated to the depth of the root system),
- optimises infiltration and transportation of water into the profile stored as plant available water following rainfall or irrigation events, with reduced waterlogging risks and surface run-off losses, and enhanced soil aeration,
- allows a greater pool of stored soil water to be manipulated by partial root zone drying and other irrigation practices aimed at saving water.

These requirements are determined by the size distribution of pore spaces in soil and the soil strength or mechanical impedance. Myburgh et al. (1998) found through extensive survey of vineyards that between 60 and 80% of sites suffered some forms of compaction (reduced soil porosity and increased soil strength), with many layers compacted beyond 2 MPa at field capacity. As these soil layers dry, they harden beyond 3-4 MPa preventing adequate root development and access to plant available water stored at greater depths.

The buffer capacity between too much soil water (waterlogging) and too little soil water (drought) is strongly dependent on the extent of soil compaction. Mechanically induced compaction through trafficking has been shown to be a major factor reducing vine performance through reduced root system development (Myburgh et al., 1998). Additional symptoms of a poor root system in vineyards are poor water use efficiency and reduced fruit quality, increased sensitivity to diseases, particularly root rotting diseases, and potential soil waterlogging.

Reduced soil porosity and increased soil density can also occur as a result of high sodium content (sodicity) causing soil structure to collapse on wetting, hardsetting on drying and fine particles move to accumulate and block soil pore channels (Rengasami and Olsson, 1991). Other subsoil limitations to deep root development include acidity in higher rainfall areas, and salinity exacerbated by increasing industry reliance on saline bore water and reclaimed water for irrigation. The extent of subsoil impediments to grapevine root growth is widespread and acknowledged in the industry by an increasing number of grapegrowers. Results of a soil information survey compiled by the Primary Industries and Resources South Australia (Grieger, 1999) showed that a great majority among approximately 2000 viticulturists surveyed at workshops (Research to Practice seminar series) perceive their 3 main soil problems to be: compaction, salinity and waterlogging, followed next by hardsetting and erosion.

Table 1 below summarises a range of limiting subsoil conditions where tillage based remedial treatments are required. The report of Myburgh et al. (1998) lists benchmarks for soil physical fertility and recommended a series of remedial and maintenance measures for managing subsoil compaction. The ability to implement the remedies and achieve optimum vine response is fully dependent upon the availability of effective and versatile machinery, and on the post-ripping management practices to control re-compaction.

Table 1 Soil Problems and recommended tillage action

Soil problem situations*	Identified recommendations
Soft rock/saprolite	Low disturbance deep ripping
Hard calcareous clays (fine lime to hard sheet boulders / hard fine sandy clay)	Deep ripping (high disturbance in fine texture soils only)
Compact subsoil clays (duplex soils)	Deep ripping / incorporate gypsum - organic matter
Bleached subsurface sandy layers	High disturbance deep rip/mix with top soil/incorporate organic matter. ripping by itself is often ineffective
Compact sands	Deep ripping / add organic matter
Compacted traffic lanes	Deep ripping to 600mm / limit and time trafficking operations
Subsoil chemical toxicity (eg. acidity)	Incorporate/mix lime

(Source: Myburgh et al. (1998) and Cass (1998) Soil Limitations to Vine Growth and Managing Soils Structure in Research to PracticeTM workshop manual, CRC for Viticulture and CRC for Soil and Land Management.

Preliminary and Previous Research

History of related R&D

Cass and Maschmedt (1998) highlighted the important role of soil physical properties in regulating the supply of many of the fundamental requirements for the healthy functioning of plants such as available water, essential nutrients and oxygen, and their accessibility by root exploration. Soil physical quality is itself dominantly influenced by the pore size range, affecting the balance of water, available nutrients and oxygen.

Inhospitable subsoil environment to plant root development is often the result of either naturally, mechanically or chemically induced soil compaction. Myburgh et al. (1998) identified soil compaction as a major limitation to achieving optimal soil physical fertility in vineyards, and set a benchmark for resistance of soil to penetration by roots of 2 MPa at field capacity. Much research work on the mechanics of soil compaction has been documented, in particular on mechanically induced compaction (in the context of an intensifying broadacre agriculture), as well as on the mechanics of the associated remedial tillage operations. Below is an extended review of tillage based investigations which have addressed machinery aspects of soil manipulation, tillage efficiency and technological solutions, developed to implement physical and chemical changes within problem subsoils which are of relevance to the Australian vineyard context. This review highlights the potential for applying and combining previous research outcomes into a form directly suitable for the specificity of vineyard environment.

Subsoil loosening is a deep tillage operation aimed at re-establishing soil porosity and soil bulk density to levels optimum for root growth, and is an integral part of agricultural production where subsoil compaction is a problem. The lasting benefits of deep ripping are typically a function of the follow-up management strategies (Soane et al., 1986). Varying degrees of success have been measured following deep ripping operations conducted in row crops such as vineyards (eg. Myburgh et al., 1998). The effectiveness of the ripping operation is strongly influenced by the soil state (eg. soil compactibility, function of moisture content) at the time of ripping, the correct use of well designed implements (depth, configuration), and the timing with respect to active root growth period. In particular instances, use of unsuitable ripping implements can easily result in subsoil smear and compaction at depth, demand higher power requirements and increase tractor slippage (and hence surface damage) due to unfavourable tool critical depths (Spoor and Godwin, 1978).

Techniques to improve tillage efficiency (eg. soil loosening), tillage effectiveness at depth and to reduce pulling requirements have been developed in the broadacre farming context. These include job specific tine layout and tine design, and power driven vibratory implements (where the optimum vibratory mode, amplitude and frequency suited to the natural frequency of soil shear and to the tractor

forward speed can achieve very high efficiencies, with up to 93% draft reduction quoted - Blight, 1971 ; Szabo et al. 1998). A recent review (Myburgh et al. 1998) has highlighted the requirement for deep soil tillage in existing vineyards and the urgent need for specific machinery development to enable the improvement of problem subsoil conditions.

Subsoil amendment incorporation: Previous research work in this area has mainly focussed on lime injection into acidic subsoils, which are a major limiting factor to crop production. Due to the low mobility of lime correctors in most soils, the prospect of subsoil incorporation/mixing of lime represents a great potential for quick and effective improvement in subsoil acidity.

Ripping tines equipped with injecting boots (injector tines) coupled with an air conveying system have successfully been used in broadacre research contexts at the University of New England, NSW (Murray, 1995), also showing potentially favourable economics of the operation. Further work by the Department of Natural Resources in Queensland (Aitken and Kingston, 1997) moved away from this vertical slot incorporation concept and adapted it to a horizontal banding arrangement, with specifically designed horizontal boots fitted behind the tine wings. Data to date has confirmed the great yield improvements obtained with lime injection into acidic subsoils (Aitken, 1999), however the overall efficacy of the lime injection operation relies on i) the reliable metering and conveying of the powdered amendments and ii) its thorough incorporation and mixing (ie. pressure blowing and simultaneous soil stirring).

Commercial machinery currently available (eg. Gessner Industries, Hodge Industries, Fabro-Weld) consists of hopper and metering units delivering products by gravity behind ripping tines and typically lack versatility in their ability to loosen the soil profile and therefore have limited applications and variable efficacies in treating subsoil structure, acidity and sodicity, particularly in restricted environments such as vineyards.

An alternative option was followed at the CSIRO in Griffith, NSW along the concept of segmental/partial lime mixing using a rotary slotting machine (Blackwell et al. 1989). Trials in acidic vineyards of the Hastings river showed very favourable yield responses and low risk of subsequent re-compaction while trafficking onto the undisturbed soil portions adjacent to the slots (Kirchoff et al., 1995). Although a lower work rate, higher wear and higher power operation compared to the injection approach, lime slotting offers the best potential for thorough mixing of lime and soil into a slot environment.

Good responses to surface gypsum application (because of its high solubility) is often obtained on sodic soils in vineyard contexts (Adam, 1999), however, the relevance of the deep incorporation/slotting option is likely to be influenced by the extent of the imperviousness of the sodic sub-layer to water infiltration. Similar incorporation technology has been used in research projects across Australia (Hamza and Anderson, 1998 ; Aitken and Kingston 1997, Desbiolles et al. 1997, Jayawardane and Blackwell, 1986) to improve structureless sodic subsoils. Other current research applications requiring such technologies include incorporation of organic matter in nutrient deficient and structureless soils, such as in the form of organic fertiliser, wood chips, industrial compost or dried pig effluent (eg. Shrale, 1999 ; Williams 1999). In similar context, work at the AMRDC successfully used multiple tillage depth tine layout to control soil clod size and improve fertiliser/soil mixing following incorporation (eg. Ascher et al. 1997).

The above examples of subsoil amelioration research have mainly focussed on broadacre farming rather than on row cropping, and are mostly suited to high tractor power. The vineyard context, with row spacings of 7 to 12 feet, limited power availability and where root pruning can have a major effect on crop response/recovery, offers limited scope for directly applying these same techniques. Also, the lack of hard data on the economics of deep incorporation and on the effectiveness of soil/amendment mixing are likely reasons limiting its widespread adoption, even in broadacre farming at present. However, the previous research outlined above provides significant avenues for developing new machinery applications that are suited to vineyard environments.

Specific Background:

Investigating the optimum vibratory settings (Exp 1)

There are many variables known to influence vibratory tillage performance. These are based on the favourable results of work from Sakai et al (1993) who found power ratios close to 1 when large amplitudes and lower frequencies were used. Also much promise was shown with draft reductions (up to 75%) and engine power savings (up to 28%) in the early trials (Slattery & Desbiolles, 2002a). However the most favourable settings found in initial trials suffered greatly from unsustainable vibration levels transferred from the ripper to the tractor and operator. A number of strategies were implemented to overcome this, by converting the prototype ripper to a trailed unit, higher PTO speeds, using a flywheel and a rolling tractor drawbar. This experiment was implemented to optimise the vibration settings for improved potential ripping capacity and efficiencies in two soil conditions, whilst minimising the vibration levels of the tractor/operator. Oscillation frequencies were chosen such that high and low velocity ratios were tested, at either end of the range 1.5 to 3.3 as recommended by Sakai etal (1993) and Venter (1989).

Strategies to maximise prototype ripper capacity and efficiency (Exp 2)

This second experiment looked further at techniques to improve subsoiling capacity and efficiencies. Techniques such as dual depth tillage, either in a single pass or in two passes, can increase the cross sectional area of soil loosened for similar draft force demands, while adding wings also increases the area loosened for draft force applied (Spoor & Godwin, 1978). Testing with the first prototype (Slattery & Desbiolles, 2002a) found dual depth compared to single depth tillage increased the area loosened by 19% and SLE by 8% with a similar fuel to SLE efficiency; however tine arrangements were limited by the three-point linkage frame layout. Comparatively, using the multi-pass multi-depth strategy saw gains in soil area loosened of up to 119% and SLE of 134%. Experiment 2 aimed to investigate whether similar gains could be made with the new trailed ripper configuration, using optimised vibratory parameter selection for low tractor-operator vibration levels.

Comparison of the characteristics of different ripper tine designs (Exp 3)

To gain an understanding of the performance characteristics of different ripper tine design it is necessary to compare them side-by-side under similar performance conditions. By operating all the ripper tines at the same depth in the same soil it is possible to compare the influence of different tine shank, tip and mode of operation functions on the performance characteristics. An understanding of these characteristics can then lead to aid in selecting a particular ripper design to suit the subsoiling conditions and requirements that are at hand.

Comparison of subsoiling capacity and energy efficiency of a range of ripper designs (Exp 4)

To effectively and economically correct vineyard subsoil constraints by ripping, vineyard managers will require comparative performance information on available subsoiler designs. While not all rippers available on the market were tested, a range were selected with different tine and point designs. It was intended that information from this testing would aid vineyard operators in selecting an appropriate ripper to create the desired subsoil loosening that best suits their vineyard requirements. The results would also compare efficiencies and capacities of a typical vineyard tractor with each ripper.

Ripping Technology and Capacity on vine response (Exp 5)

Having developed new technology with the potential of increased capacity and improved benefits it was necessary to investigate the influence of the level of compacted subsoil loosening attributed to a

range of subsoiling technologies when operated with a 70kW vineyard tractor, on the quality of soil loosening and its influence on soil re-compaction and vine performance.

Management of post ripping Traffic (Exp 6)

It is well understood and documented that mid-row traffic is a major cause of compaction of soils. This is increasingly the case where the soil is freshly loosened or disturbed. In the viticulture situation where frequent traffic between the vine rows is a very important and major part of the activity that is carried out it is important to investigate the influence of the timing of the subsoiling operation combined with post ripping vine mid-row traffic management on subsoil re-compaction and vine performance. There are machinery technologies and solutions available that allow the vineyard manager or owner to carry out all necessary tasks whilst not travelling every row of the vineyard.

Development of an ameliorant application system

The remedy to many subsoil constraints that have chemical imbalance that attributes to their compaction problems is the process of deep ripping the soil between the rows of vines to a depth greater than 600 mm and applying soil ameliorants and/or nutrients through the soil profile so that the soil structural improvements effects last for several years. Unfortunately for vineyard owners, machinery that can work to the required depths that can fit down the vineyard rows and the existence of knowledge and appropriate equipment to inject soil ameliorants to depths was not currently available. The most common form of ameliorant is the bulk lime or gypsum, which is spread on the surface (often with some kind of shallow tillage for mixing purposes and takes time to move down through the soil profile where it is needed. Recently the use of liquids in the broadacre application for fertilizer and nutrients has increased the knowledge, understanding and development of the suitable equipment to handle a wide range of chemical.

Consideration for an amelioration applicator suitable for vineyards

- Review current soil ameliorant application technologies that are used for shallow depths.
- Apply soil dynamics theories and machine design to develop technology which will deliver and distribute the correct qualities of soil ameliorants in the soil profile.
- Consider designs for the construction of the soil amelioration equipment to be fitted to ripper machinery.
- Seek further industry / university support for the construction and evaluation of the soil amelioration technology.

Objectives:

Vine productivity and reliance on irrigation water are directly related to the ability of the root system to develop at depth and of the soil to harvest and store rain water within the profile. Subsurface compaction (eg. cone index > 2Mpa at field capacity) within a depth of 1 m restricts winegrapes from establishing an optimum root system. It is estimated that 60% to 80% of viticultural soils contain compacted layers or hard pans, either natural and/or due to trafficking.

Underlying objectives of this project include

- Improve vineyard water use efficiency through getting water stored outside the current root zone available to the vine and relying less on irrigation water.
- Improve uniformity of grape quality through allowing the roots to access nutrients in the soil that are inaccessible to the plant due to compaction and chemical limitations.
- Extend the effects of deep ripping for several years, thus adding to the cost effectiveness of the operation.

Specific project objectives.

- Identification of advances in subsoil tillage machinery, with the design and manufacture of a high efficiency subsoil loosening machine suited to use in established vineyards with 60-80HP tractors, including soil amendment incorporating ability.
- Investigation into the relative performance of the developed machinery compared with currently available technologies as the benchmark.
- Evaluation and demonstration in selected problem vineyards the benefits of energy efficient, quality subsoiling compared to current equipment available, in terms of subsoil improvements that directly effect grape production quality, yield and sustainability.
- Development and promotion within the industry of strategies for high efficiency subsoiling techniques that combine (i) appropriate subsoil management in the context of yield and grape quality considerations, and (ii) on-site management to maximise consistency across the vineyard and minimise re-compaction risks over time.
- Dissemination of knowledge on best practices for achieving effective and efficient subsoil physical environment, along with maintaining that improved environment for as long as possible.

To suitably cover these objectives in accordance with types of funding available a two stage project was conducted

- Stage 1 (funded outside GWRDC) aimed to increase the depth and versatility of subsoil tillage operations through a better use of available tractor power in the context of established vineyards, traditionally limited by the narrow vineyard row spacings, low machine efficiency and low available tractor size.

- Stage 2 of the project (co-funded by GWRDC) aimed to evaluate the benefits of applying the improved technology in established vineyards compared to controls and benchmark technologies. The parameters assessed included power requirement, soil physical changes achieved, grape yield and grape quality responses.

Some sections of the research will be carried through both stage 1 and stage 2, these include the ability to incorporate soil amendments with any technology that is developed and to monitor the effect of

subsoil amelioration strategies through out the machinery evaluation and comparison stages, this ability will lead to enhanced subsoil environments for the viticulture industry.

Specific objectives of an amelioration application system include.

- To develop a system that can effectively be used to apply required amounts of lime or gypsum into the subsoil profile in a viticulture scenario.
- Determine if root, vine and soil response can be improved by strategically ripping in ameliorants (ie lime, gypsum.) to the affected subsoil zones, compared to no application or surface application.

The other activities that will be carried out though both stages of the research is the dissemination of knowledge and the extension activities such as reports, articles, papers, conferences and demonstrations. This will also include future collaborative link building with both the machinery and the viticulture industries.

Technical information including issues addressed in the project:

This section concentrates on the second stage of the project, which was the investigation into the ability of the technology to improve vineyard soils.

Subsoil loosening experiments at Orlando's Klugge site Rowland Flat

Two experiments were conducted one looking at the effect of ripping technology performance and the other investigating rip timing and traffic management scenarios these were used to investigate a number of factors.

Ripper technology trial (Experiment 5)

Issues/Questions being addressed:

In this experiment the degree and quality of soil loosening and its influence on re-compaction, root and vine performance, were looked at.

How much loosening is required to make how much difference to root growth and vine performance. The quantity of soil loosening with a vineyard tractor and standard rigid tine ripper is limited in depth and volume.
To address the following:

- Does mid-row ripping improve the soil from a vine point of view?
- How does the soil resettle after loosening, how long is our remedy effective for?
- Does the degree of mid-row subsoil loosening (ripping technology) have an effect on vine performance? Does it influence soil settling?
- Can we equate vine/soil improvements to improved roots, water and nutrient access?
- Economics short term/ long term?

Variables used throughout the experiment:

1. Nil (no mid-row ripping)
2. Vibratory ripping one pass
3. Vibratory ripping two passes
4. Standard ripper one pass.

All ripping operations were performed in autumn to try and obtain the most beneficial soil conditions for the ripping operation whilst having minimum effect on the vines growth stages.
Experimental design to be used Latin square (to account for soil variations in two directions).

In this experiment traffic will also be minimised in the ripped mid-rows

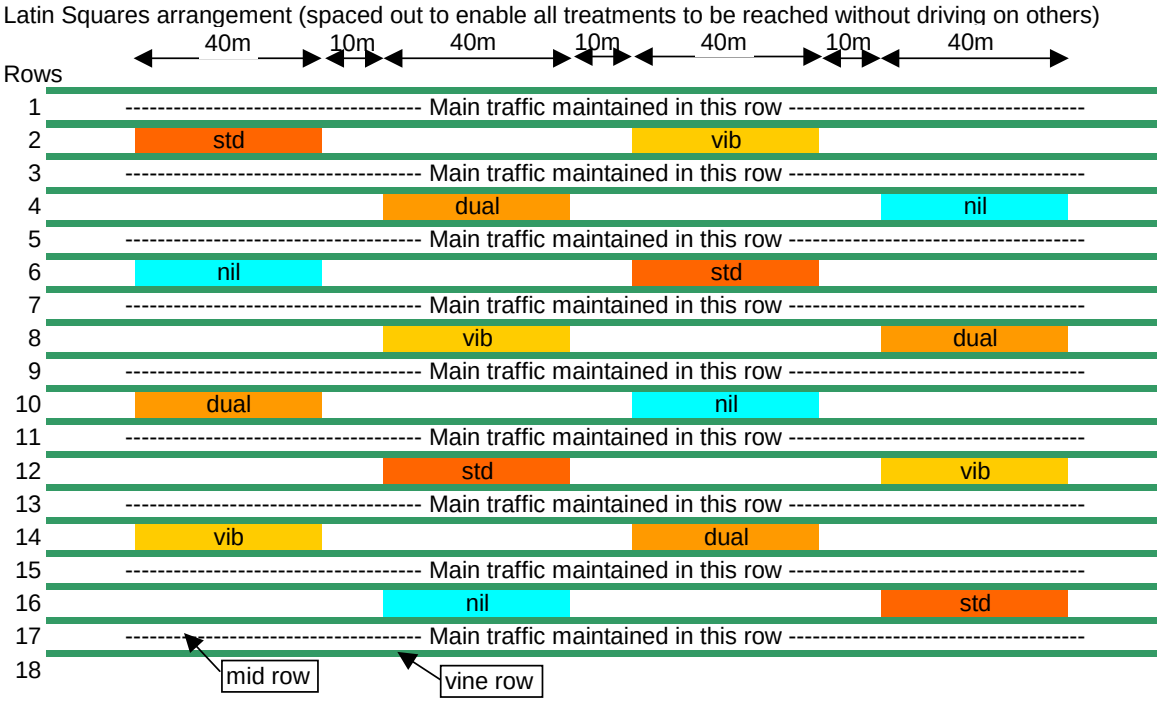


Figure 1 Latin Squares experimental layout.

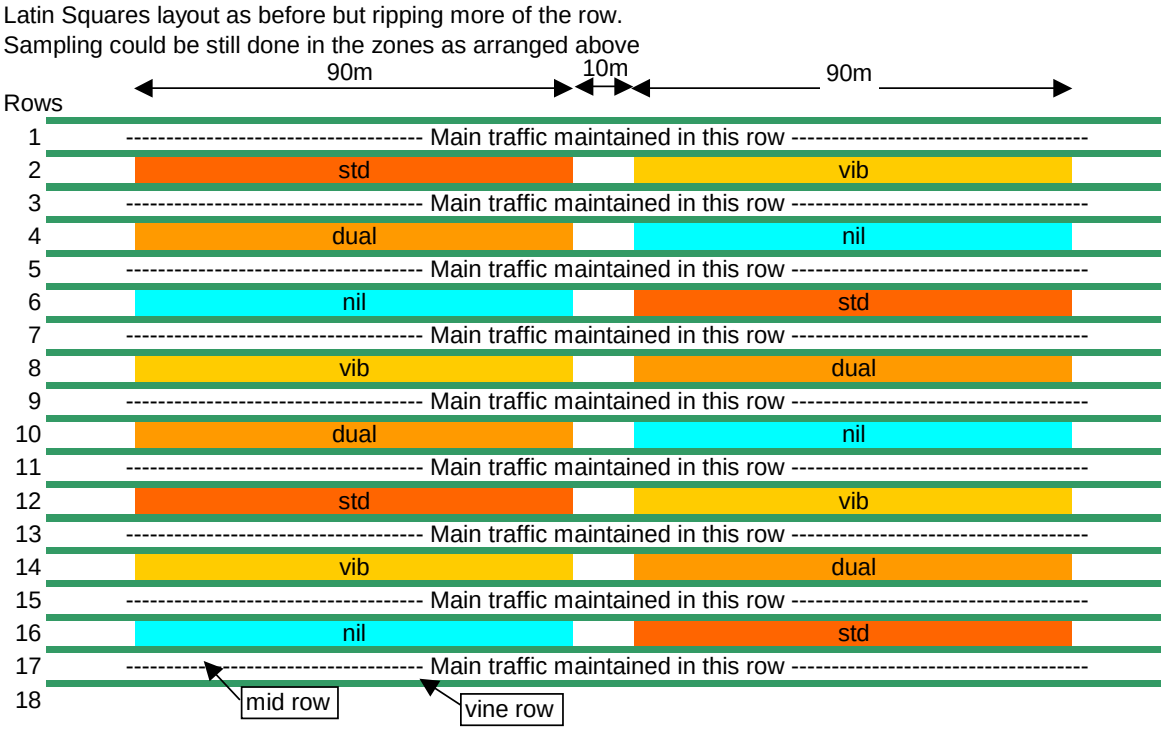


Figure 2 Alternative way of conducting Latin squares experimental design

How the performance of the ripper technology was measured

1. Re-compaction/resettlement - extensive penetrometer probing, less extensive bulk density (comparison), less extensive surface profile settlement.
2. Infiltration -
3. Moisture content -
4. Root growth - visual assessment before, after first season, after second season, minimised.
5. Vine growth - Light penetration, pruning weights. (Vineyard to measure)
6. Grape yield - total weight, quality, bunch weight. (vineyard to measure)
7. Keep track of rainfall and traffic operations and dates also compare to overall vineyard moisture measurement (logged by vineyard)

Further issues:

Do vine roots get into the inter row in one season?
Does re-compaction beat them?
If they do get into inter-row does re-compaction eventually stifle them?
Do the different scenarios investigated affect the level of above?

Timing/traffic management (Experiment 6)

Issues/Questions being addressed:

Timing:

- Root/Vine performance - What is the timing influence on root growth/performance and vine growth/yield?
    - Roots going into dormancy in autumn compared to becoming active in spring?
    - Is all the stored energy in the roots pruned similarly whether pruned in autumn or spring?
- Infiltration - Does autumn ripping allow better infiltration of winter rainfall and is this a benefit (likely to depend on season)?
- Soil settling re-compaction –
    - Effects traffic options: Does Autumn ripping lead to traffic minimisation problems (pruning, under-vine spraying, cover crop?) which would be conducted on the soil in higher moisture content conditions (typically) whereas with spring ripping, traffic can be removed until harvest when the soil is much drier.
    - Natural re-compaction of soil due to winter rainfall etc before root growth of vine begins that may minimise benefits to root development.

Traffic Management:
What impact does minimising traffic on mid-row of ripped soil have on:

- Re-compaction expected to depend on time of ripping and what traffic and moisture conditions occur at time of traffic,
- Is this bad enough to reduce root development at budburst?
- Cover cropping (requires several passes of tractor and spraying equipment) can be beneficial to holding open loosened soil.

All compared to doing nothing
How do the different scenarios compare to doing nothing can we quantify the benefits.

Experimental variables.

1.	no rip		typical traffic	(control)
2.	ripping	in autumn	typical traffic	
3.	ripping	in autumn	minimum traffic	
4.	ripping	in spring	typical traffic	
5.	ripping	in spring	minimum traffic	

Repeated 4 times in a randomised block design? Alternative is to use a Latin square design without a no-rip treatment.

Minimum traffic is an approach where traffic is minimised as much as is practical in every second mid-row to minimise re-compaction of loosened soil. This will ideally have traffic for under vine weed control and one wheel of harvester. Practically we may need to accommodate pruning traffic (can this be done prior to autumn ripping?), cover crop traffic can this be minimised with light weight equipment? Should a cover crop be planted in the ripped mid-row???

Typical traffic is where typical vineyard traffic is allowed in the mid-rows, if a cover crop is used it should be planted into both traffic conditions.

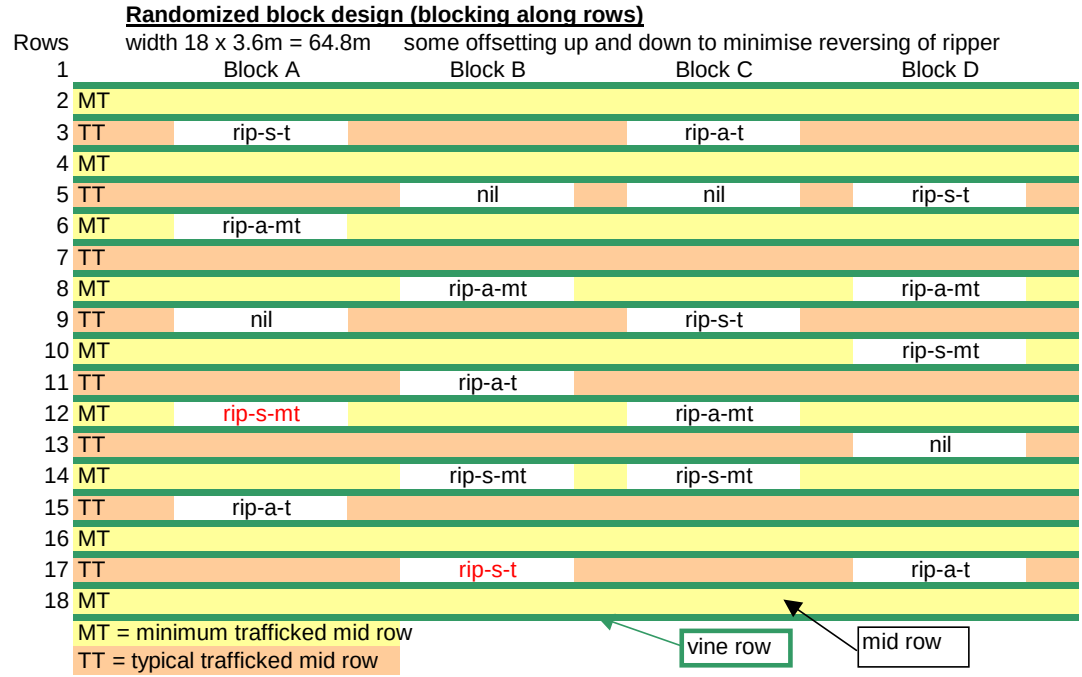


Figure 3 Proposed randomised block experimental layout

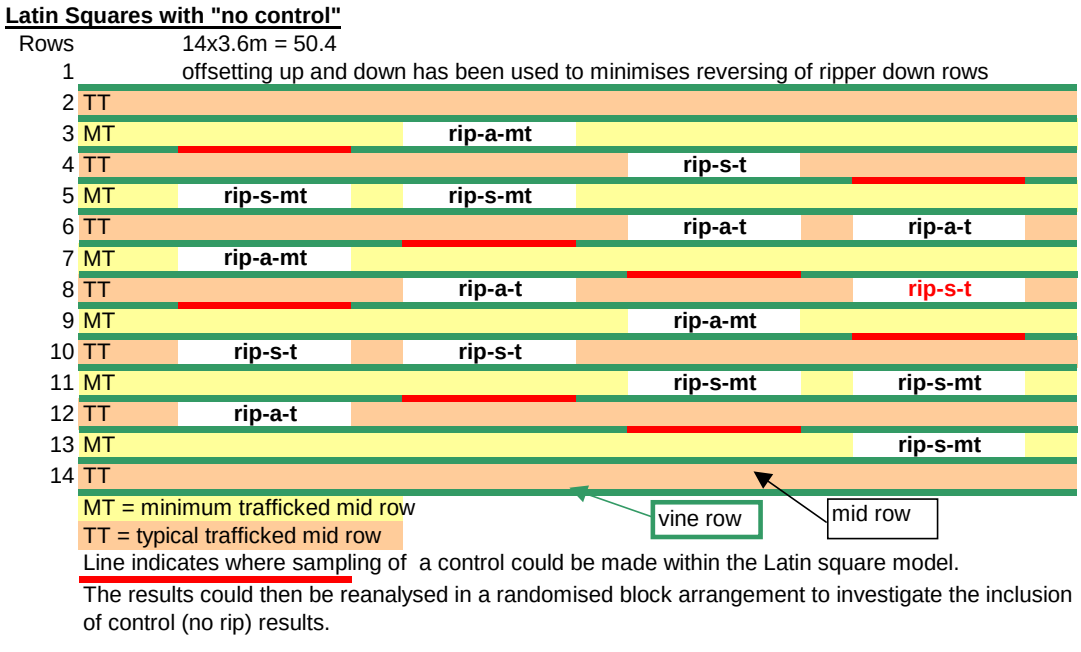


Figure 4 Alternative proposed Latin square experimental layout

Issues and strategies for developing an ameliorant applicator

Current strategies typically used:

- Surface application, and in some cases followed by ripping otherwise relies on leaching to the desired zone.
- In some cases ameliorant applied into pre-planting rip lines with light soil re-opener and belt screw feed system.
- Typically surface applications are of powdered material
- Some soluble forms can be applied through the irrigation system

Expected Advantages of applying ameliorant in subsoil zones to be corrected

- Compared to surface application no need to wait for leaching that could take a couple of years.
- Can improve inhospitable subsoil zones almost immediately.

Organise sites in vineyards

- Find preferably an acidic and a sodic site
- Depending on type of constraint and where in the profile plan a suitable experiment and analysis strategy to be developed.
- Types of variables:
    - Typical surface application
    - Nothing
    - Ripping only
    - Ripping + levels of application + different zoning of application.

Development of Equipment

Looked at using a pneumatic applicator in conjunction with powdered gypsum or lime.

- Advantages powdered product is slow release, longer lasting effects, more readily available
- Disadvantages (compared to soluble product) higher rates required, increased transport/storage and hopper capacity, products do not flow, meter easily requiring either expensive positive displacement blower and air lock pneumatic system or a robust conveyor/screw type system.

Considering a soluble liquid type applicator.

- Advantages: lower rates required smaller tank/hopper capacity, easily controlled with off the shelf sprayer pump, valve and plumbing systems, better suited to fitting in with our tractor and ripper arrangement. Need to find out requirements, specifications.

Issues with a liquid system approach.

- How to get an equivalent application rate as granular systems
- Problems with system blockages due to the suspended nature of the liquid product
- The distribution of the liquid through nozzles or outlet pipes which are likely to be below the soil surface.

Details and justification of methodology used

Development of technology

Initial Concept

The approach was to review, adapt and combine a range of subsoil improvement techniques previously developed in the broadacre farming context and combine them into a more efficient purpose-designed machine suited to the smaller low power vineyard tractor. The development of the higher efficiency subsoiler was funded by SENRAC and the University of SA, with the machine manufacture completed by industry partners Kubpower and De Mill Engineering. The new technology provides a versatile subsoiler machine that encompasses the following technologies: 1) multi-depth tillage, to increase soil loosening at depth at no draft penalty, 2) multi-pass operations, successive strategic loosening passes by a lower power tractor and 3) vibratory tillage, where the tines are mechanically oscillated drastically reducing draft and increasing subsoil loosening efficiencies.

The main machine features are: variable dual depth tillage, variable tine spacing and patterns, additional tine wings, 750mm long vibratory tines with variable frequency, amplitude and direction of oscillation all suited to mount on 60-70kW vineyard tractor for operation within 2.5 to 3.6m vine row spacings.

Performance evaluation

In 2001 SENRAC co-funded the performance evaluation of the ripper in a representative vineyard soil at Orlando Wyndham's Langhorne Creek property (clay subsoil site). Characteristics of machine settings and tine arrangement parameters of the vibrating, dual depth and multi-pass technologies were evaluated in terms of tractor power use, energy efficiency and soil loosening capacity. In addition energy efficiencies and subsoiling performance of the new technology were also compared with commercial subsoiler technologies from Grizzly, Red Rhino, Agrowplow and Howard Australia.

This investigation produced some promising results, such as excellent power savings and power use efficiencies, but the observed machine and tractor dynamic stability was unsustainable at these settings (large amplitude vibrations giving rise to "rocking" instability to tractor). Redesign of the prototype was required to achieve acceptable machine stability while operating under best performance settings.

Redesign and evaluation of prototype ripper

Redsign was seen as essential to overcome the prototype induced tractor dynamic instability when operating at settings identified for maximised power use efficiencies and tractor subsoiling capacity. The redesign and modify of the subsoiler technology was from three-point linkage mounted to a trailed version (funded by industry partners Kubpower and De Mill). These changes expected to greatly reduce the transfer of the rocking vibration from the operating ripper to the tractor and to overcome weight balance and stability issues found in transport with a vineyard tractor. Critical to the commercialisation success of this technology was the evaluation of the modified prototype to ensure energy savings and transfer of engine power to subsoil tillage can be maximised in a manner not detrimental to the tractor and operator.

The above work was seen as a key foundation upon which additional related research has been built which is of high relevance to the vineyard and orchards industries in South Australia, where the field and vineyard research took place.

Optimising the technology

Vibration optimisation. (Exp1)

The aim of this first experiment was to determine the best parameter settings of the vibratory ripper as determined from the following performance factors.

1. Maximising the potential loosening capacity
2. Minimising vibration and undesirable shaking of both tractor and operator
3. Minimising engine power requirements
4. Maximising draft reduction
5. Most efficient use of tractor power for subsoil loosening

Maximise capacity and efficiency through dual depth and dual pass. (Exp2)

To investigate the subsoiling capacity and efficiency of different subsoiling strategies such as the effect of wings on subsoiling tines; vibratory vs. rigid, single vs. dual depth and single vs dual pass, suitable for the selected vineyard tractor the strategies for soil loosening were assessed using a number of factors:

1. The extent of soil loosening required to alleviate the particular subsoil constraint such as:
   a. Traffic induced compaction
   b. Combined soil chemical limitations (ie. Sodicity)
   c. Tillage induced hardpan layers
   d. Natural subsoil compaction layers
2. Capacity in terms of maximum depth achieved, cross-sectional area loosened and Soil Loosening Energy (SLE) parameter.
3. Efficiencies, comparing the area and SLE to the engine power required, and SLE to fuel use rate.

Characteristics of different tine designs available. (Exp3)

As there are many different rippers available and these all have a variation of tine design, number and configuration, an investigation where machines were set-up to operate with only two tines all operating at the same depth would thus compare draft and power requirements along with loosening efficiencies that directly relate to the tine design and mode of operation. This would give the possibility of choosing a tine design to suit the soil and constraints issues faced in particular locations or viticulture areas to best optimise power and loosening capacity.

Capacity and energy efficiencies of a range of ripping technologies (Exp4)

To justify the new technology against what was currently available to the viticulture industry a comparison of the maximum subsoiling capacity/depth of each subsoiler was made with the new technology set up as a dual depth system and the commercial units as a two tine and their preferred arrangements. This gave an indication of the subsoiling capacity of each ripping technology. Typically the Red Rhino and Agrowplow rippers are five-tine single depth arrangements. The Paraplow system used a two-tine arrangement while the Grizzly-michel tine could be used as two single tines or two pairs of tines where the shanks of the paired tines are aligned.

Finally evaluating the revised new technology in the context of established vineyards and to quantify the in field trials of soil improvement and efficiency benefits obtainable from applying the newly developed technology was essential in proving the technology to both the industry and the commercial partners.

Applying the technology to determine the capacity (Exp5)

The approach was to select an established vineyard with existing subsoil compaction issues. The subsoil was then investigated with the aid of cone penetrometer to establish varying soil strength (and compaction zones), vineyard soil maps and soil pits. After establishing that a response to subsoil loosening could be expected and the location of the compacted zones a Latin Square experimental design was applied to investigate four levels of subsoil loosening:

1. A control that was not subsoiled.
2. Traditional subsoiling approach with a single depth 5-tine commercially available ripper (Agrowplow), where the whole vine mid-row is loosened to the same depth.
3. UniSA vibratory ripper in a dual-depth arrangement with 2 rigid shallow leading tines set outside of the 2 deeper wingless vibrating tines spaced 1250mm apart. In this case the subsoil loosening tines were aimed at maximizing the wheeled traffic induced compaction zone of the vine mid-row.
4. A dual-pass approach that utilized the UniSA vibratory ripper in a shallow 3 rigid-tine arrangement in the first pass with a central tine and two outer tines spaced wider than those in the above arrangement. The second pass was then followed with the same arrangement as used in treatment 3. The strategy in this case was to further loosen the soil between the wheel trafficked zone and the vine to encourage better root growth towards the vine mid-row.

The Latin Square design was employed to minimize the two directional variation in soil and slope on the experimental results. The ripping was conducted in June 2002. In order to provide the best opportunity for the vine root system to access the loosened subsoil and minimize recompaction all ripping experimental treatments were applied to every second mid-row with vineyard equipment traffic constrained to the unripped between mid-rows until harvest.

Measurements

Soil conditions were monitored by mid-row transects from vine row to vine row with a cone penetrometer and surface profile meter. Cone penetrometer readings were taken every 200mm along the transect prior to ripping and later in September 2002. Soil surface profiles were also measured prior to ripping and immediately after and again in September to determine soil loosening and settling. Additional profiles were also made to determine the below surface soil profile loosened. When the first profile transect was made stakes were driven into the soil adjacent the vine each side of the mid-row to provide a permanent height position reference point for subsequent profile measurements

Vine performance was established in terms of hand harvesting 4 randomly selected vines from each plot for bunch number, vine yield weight and Brix. Cordon length of the selected vines was determined to minimize the variation in vine size in this 39 year old Riesling vineyard. Pruning weight and cane numbers were also determined for each of the selected vines as an indicator of vine and vine root growth.

Issues that arose

The trial was originally intended to be implemented in 2001, however due to a delay in the manufacture and testing of the UniSA vibratory ripper the seasonal timing was missed and with GWRDC it was agreed to delay these trials to the following season. The plan was to rip the treatments in autumn once the profile had been wet up to almost the plastic limit at depth in the profile. At the time of ripping in June 2002 the surface soil was wet with some rain showers that resulted in sticking of the loosened surface soil to the roller, thus the roller was removed for the test and depth control was thus provided by the transport wheels. The positioning of these wheels was such that they were close to the abrupt height change in the mid-row soil surface profile. This height difference was present in almost all mid-rows brought about by years of tillage and wheeled traffic lowering the soil in the centre of the row below that adjacent the vine row. Depth control of the ripper was thus varied by where these wheels travelled on the mid-row soil profile.

The results obtained with the penetrometer were compromised to some extent by the soil compaction variations influencing the moisture profile through the mid-row cross-section, where the measurement may have corresponded with soil moisture content rather than soil strength. It was difficult to find times when the whole profile was of a similar moisture content to facilitate cone index measurement.

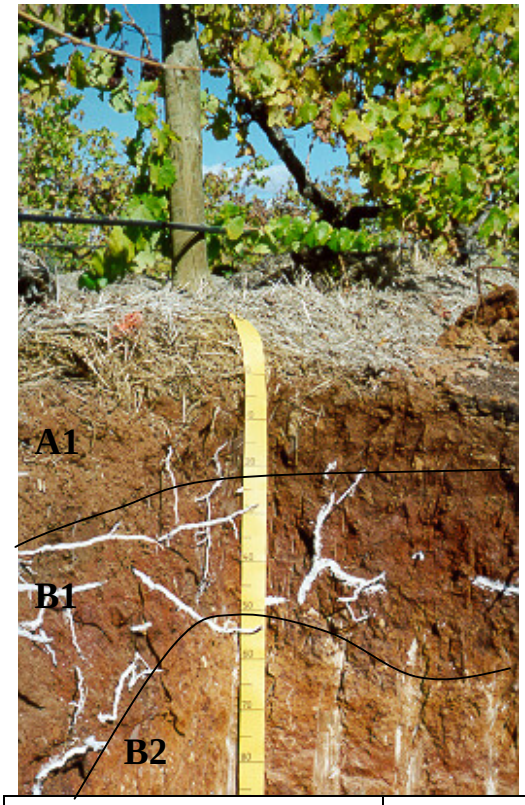
This was especially so in the wheel track zone where water tended to run off and enter the adjacent looser soil. The varied profile between the vines and the vegetation cover also tended to influence the moisture content profile. The drought conditions in spring of 2002 also resulted in minimal moisture content in the soil profile that was also influenced by the varying weed density between the vines.

Unfortunately the irrigation system of the vineyard failed at the main risers that couple to the dripper lines in about 40% of the vine rows contained within the experimental area. These failures occurred in the spring-summer irrigation period of late 2002. It is not known when and for how long these failures occurred but indication of water movement down some of the mid-rows was clearly observed. These failures can thus be expected to have resulted in less pressure and flow in what dripper lines remained connected whilst also depriving some rows of any irrigation and tending to flood the mid-row of others. Thus the outcomes of the experiment following this irrigation period are expected to have been seriously effected. Therefore any harvest and pruning yield results considered with great care.

Site Assessment of soil profiles prior to deep ripping (Jeanette Chapman):
Root development was most prolific undervine, as would be expected. Abundant root development, >200 roots/10 cm^2, was due to branching up to 4 main orders which resulted in 4^{th} order roots being spaced within 10 mm, with visible prolific root hairs. Two-three sets of these roots were found per 10 cm^2. Many roots, 20-200 roots/ 10 cm^2, were associated with reduced branching and/or fewer primary roots. Root exploration within the soil would be good.

Compaction under, the wheel track, and natural compaction within massive subsoil layers quickly reduced root density to a few larger diameter roots. Occasionally roots found natural planes of weakness and were able to branch, however at least 60% of soil volume would not

Klugges South Vineyard



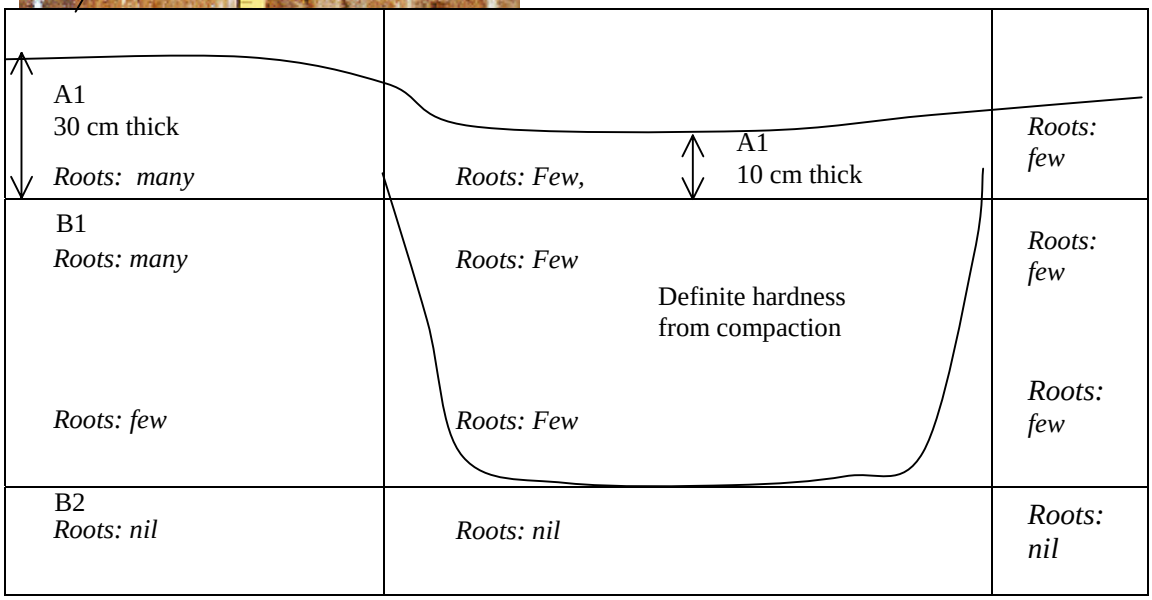
Railroad end North, Vine 17

A1
Dark brown sandy clay loam
Granular shaped aggregates,
Weak structure (<30% aggregated)

B1
25 cm dark reddish brown, medium clay with signs of both stickiness and plasticity
Blocky shaped aggregates
Strong structure (>60% aggregated)

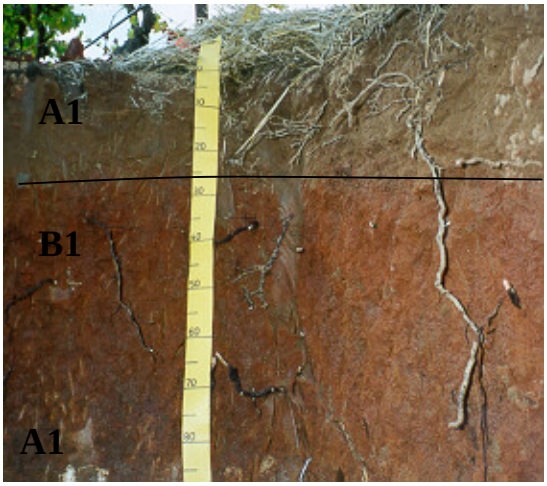
B2
50 cm calcareous, dark brown, sandy clay with massive structure

B3 not pictured
110 cm dark greyish brown, light clay, massive structure



The figure above comments: Less undervine root development compared with row 7, massive structure of the B2 was too hard for root penetration and common for clay impregnated with fine sand. Vines in this area will be dependent on root exploration within the A1 and B1 layers hence ripping should have a greater beneficial effect. The greyish hue of the B3 is a sign of poorer drainage.

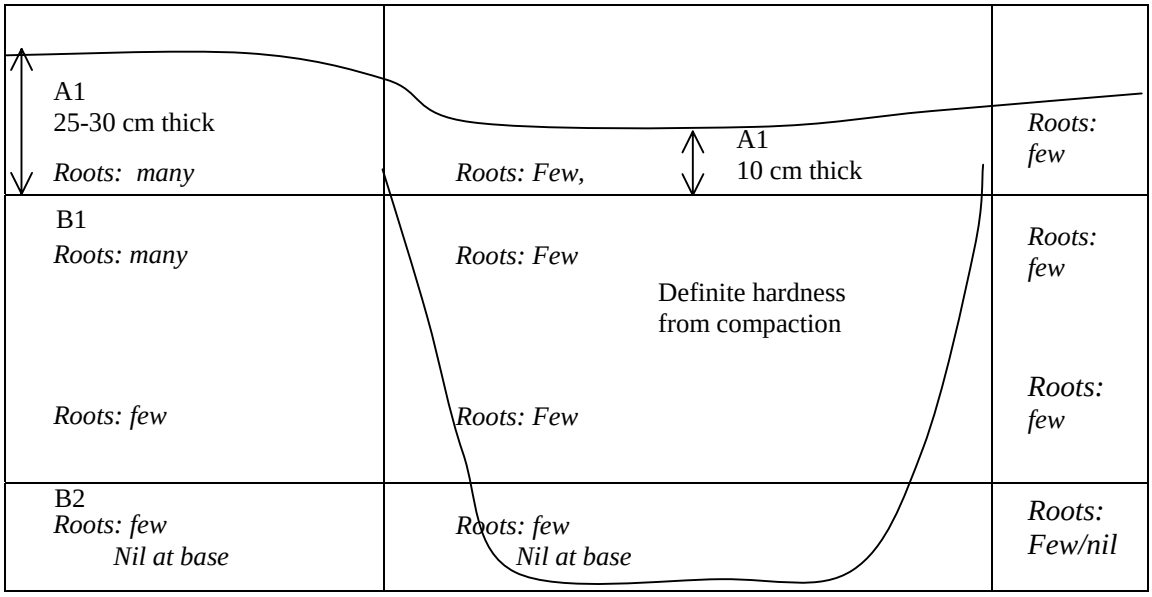
Kluges South Vineyard **Railroad end South, Vine 17 from end**



A1
Dark brown loam
Granular shaped aggregates,
Weak structure (<30% aggregated)

B1
25 cm reddish brown, medium clay with signs of both stickiness and plasticity
Blocky shaped aggregates
Strong structure (>60% aggregated)

B2, not shown
70-80 cm transitional, mottled, dark brown/greyish brown, medium clay with massive structure



The figure above comments: again vine root development was poorer in comparison to row 7, with root growth restricted to the upper 10 cm of the B2 layer. Mottled B2 sign of poorer drainage.

have roots within 10 cm, and thus soil water extraction would be inefficient. Soil water extracted from this region would be almost entirely rainfed.

Recovery of root density was noted within the mid-row region, outside compaction zones, however branching was generally not extensive, particularly along the downgradient row closer to the west. Subsoil drainage within these downgradient soils was also poorer, primarily due to the impregnation of fine sand within the clay forming massive clumps.

Vines closer to the west of the vineyard (Figure 2 & 3) would be reliant on extracting nutrients and water from the upper A1 and B1 layers with root development mostly absent beyond 50-60 cm. Thus ripping the wheel track to loosen the B1 should have a favourable effect. Orlando staff mentioned that canopy growth could be better; hence deep ripping the wheel track might have this desired effect.

Post ripping management and traffic control (Exp6)

Two main windows of opportunity typically exist for subsoiling in the vineyard where soil conditions are best suited to maximizing the subsoiling benefits. In both cases it is desirable to have a soil profile that is wet to just below the plastic limit. In the autumn period following vintage the soil is typically "wetup" by opening rainfalls that will suit subsoiling until winter, when due to additional rain the soil may become too wet. In spring the soil dries out from the top and may reach a suitable moisture content for ripping prior to vine budburst and spring flush of root growth beyond which ripping may hamper the vines performance for that season.

Once again an established vineyard with known subsoil compaction issues was chosen. The subsoil was then investigated with the aid of cone penetrometer to establish varying soil strength (and compaction zones), vineyard soil maps and soil pits. After the establishing an expected response to subsoil loosening and the location of the compacted zones a Latin Square experimental design (Figure 5) was applied to investigate two times of ripping and two levels of mid-row trafficking:

Ripping in autumn with minimal mid-row traffic except harvest. (RAM)
Ripping in autumn with typical vineyard traffic applied (RAT)
Ripping in spring with minimum mid-row traffic except at harvest (RSM)
Ripping in spring with typical vineyard traffic maintained (RST)

The ripping was conducted in June "autumn" and September "spring" 2002. A true Latin Square design was not possible due to the practicality required of having minimum traffic applied to every second mid-row and typical vineyard traffic to the between mid-rows. In addition certain vine rows were also selected to be used as a control that had no ripping to either side of them, to be analysed as a separate randomized block design. All ripping was conducted with the UniSA vibratory ripper operating to the maximum depth as limited by the Lamborghini 990 Agile vineyard tractor used throughout the testing. The ripper was arranged with a dual depth setup using 2 rigid shallow leading tines set outside of the 2 deeper wingless vibrating tines spaced 1250mm apart. The subsoil loosening tines were aimed at maximizing the wheeled traffic induced compaction zone of the vine mid-row. Autumn and spring ripping were conducted without the ripper's crumbling roller, however in spring additional treatments were also added that included the roller.

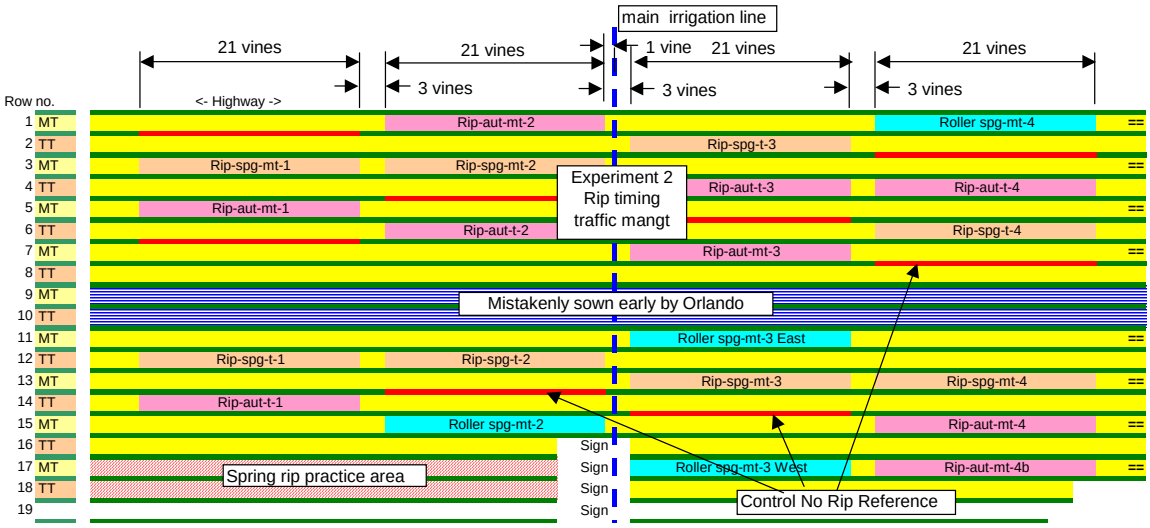


Figure 5 Experimental layout of a Latin Square design limited by every second laneway being used for typical vineyard traffic.

MT = Minimum traffic, TT = Typical traffic. The redlined vine rows were used as control vines for reference data.

Measurements

Soil conditions were monitored by mid-row transects from vine row to vine row with a cone penetrometer and surface profile meter. Cone penetrometer readings were taken every 200mm along the transect prior to ripping and later in September 2002. Soil surface profiles were also measured

prior to ripping and immediately after and again in September to monitor soil loosening and settling. Additional profiles were also made to determine the below surface soil profile loosened. When the first profile transect was made stakes were driven into the soil adjacent the vine each side of the mid-row to provide a permanent height position reference point for subsequent profile measurements

Vine performance was established in terms of hand harvesting 3 randomly selected vines from each plot for bunch number, vine yield weight and Brix. Cordon length of the selected vines (5 in each plot) was determined to minimize the variation in vine size in this 39-year-old Riesling vineyard. Pruning weight and cane numbers were also determined for each of the selected vines (5 in each plot) as an indicator of vine and vine root growth.

Issues that arose

The trial was originally intended to be implemented in 2001, however due to a delay in the manufacture and testing of the UniSA vibratory ripper the seasonal timing was missed and with GWRDC it was agreed to delay these trials to the following season. The plan was to rip the treatments in autumn once the profile had been "wet up" to almost the plastic limit at depth within the profile and at a point when the profile had dried to a similar moisture content in spring. At the time of ripping in June 2002 the surface soil was wet with some rain showers that resulted in sticking of the loosened surface soil to the roller, thus the roller was removed for the test and depth control was thus provided by the transport wheels. The positioning of these wheels was such that they were close to the abrupt height change in the mid-row soil surface profile. This height difference was present in almost all mid-rows brought about by years of tillage and wheeled traffic lowering the soil in the centre of the row below that adjacent the vine row. Depth control of the ripper was thus varied by where these wheels travelled on the mid-row soil profile. In spring soil conditions at ripping were dryer and the ripper crumbing roller could be used, thus additional treatments were added such that with and without roller treatments could be included.

The results obtained with the penetrometer were compromised to some extent by the soil compaction variations influencing the moisture profile through the mid-row cross-section, where the measurement may have corresponded with soil moisture content rather than soil strength. It was difficult to find times when the whole profile was of a similar moisture content to facilitate cone index measurement. This was especially so in the wheel track zone where water tended to run off and enter the adjacent looser soil. The varied soil surface profile between the vines and the vegetation cover also tended to influence the water dispersion and hence the moisture content profile. The drought conditions in spring of 2002 also resulted in minimal moisture content in the soil profile that was also influenced by the varying weed density between the vines.

Unfortunately the irrigation system of the vineyard failed at the main risers that couple to the dripper lines in about 40% of the vine rows contained within the experimental area. These failures occurred in the spring-summer irrigation period of late 2002. It was not known when and for how long and in what order these failures occurred but indication of water movement down some of the mid-rows was clearly observed. These failures thus could be expected to result in less pressure and flow in what dripper lines remained connected whilst also depriving some rows of any irrigation and tending to flood the mid-row of others. Thus the outcomes of the experiment following this irrigation period were expected to have been seriously effected. Therefore any harvest and pruning yield results were considered with great care.

Site Assessment of soil profiles prior to deep ripping

Site assessment provided by Dr Jeanette Chapman

Root development was most prolific undervine, as would be expected. Abundant root development, >200 roots/10 cm^2, was due to branching up to 4 main orders which resulted in 4^{th} order roots being spaced within 10 mm, with visible prolific root hairs. Two-three sets of these roots were found per 10 cm^2. Many roots, 20-200 roots/ 10 cm^2, were associated with reduced branching and/or fewer primary roots. Root exploration within the soil would be good.

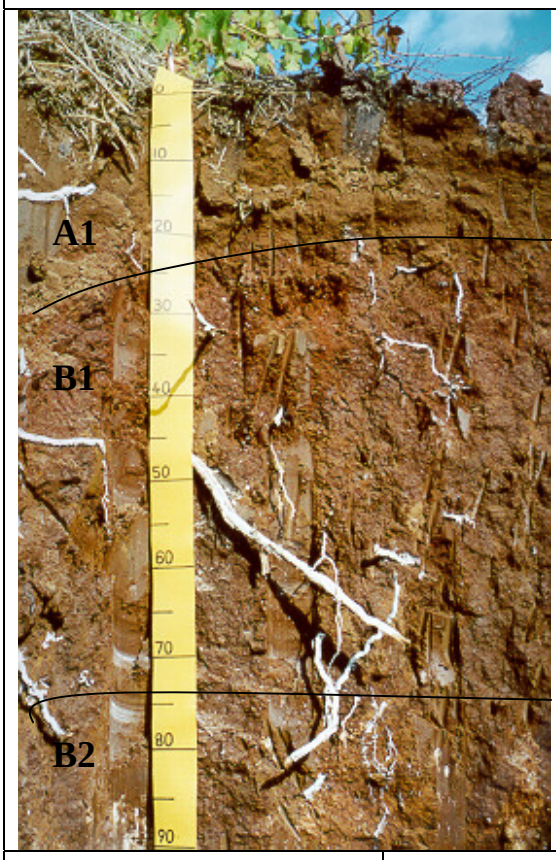
Compaction under, the wheel track and natural compaction within massive subsoil layers quickly reduced root density to a few larger diameter roots. Occasionally roots found natural planes of weakness and were able to branch, however at least 60% of soil volume would not have roots within 10 cm, and thus soil water extraction would be inefficient. Soil water extracted from this region would be almost entirely rainfed.

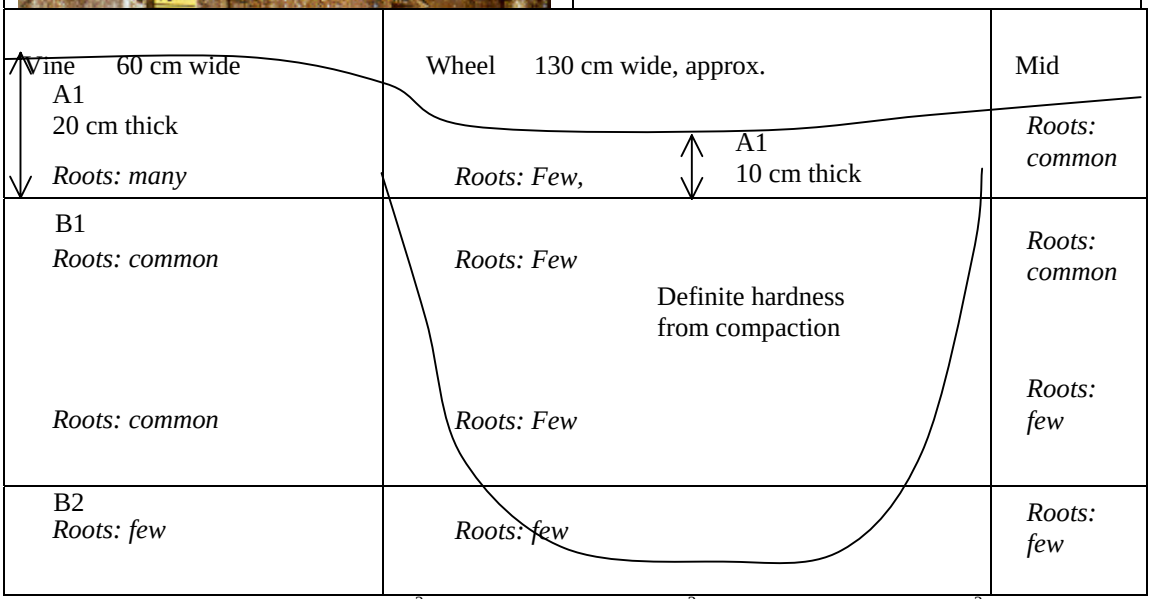
Recovery of root density was noted within the mid-row region, outside compaction zones, however branching was generally not extensive, particularly along the downgradient row closer to the west. Subsoil drainage within these downgradient soils was also poorer, primarily due to the impregnation of fine sand within the clay forming massive clumps.

Vines in this experiment have the 'luxury' of accessing soil to around 100 cm, albeit inefficiently at depth. Thus ripping the wheel track to loosen the B1 should have a favourable effect. Vineyard staff mentioned that canopy growth could be better; hence deep ripping the wheel track might have this desired effect.

Soil moisture conditions

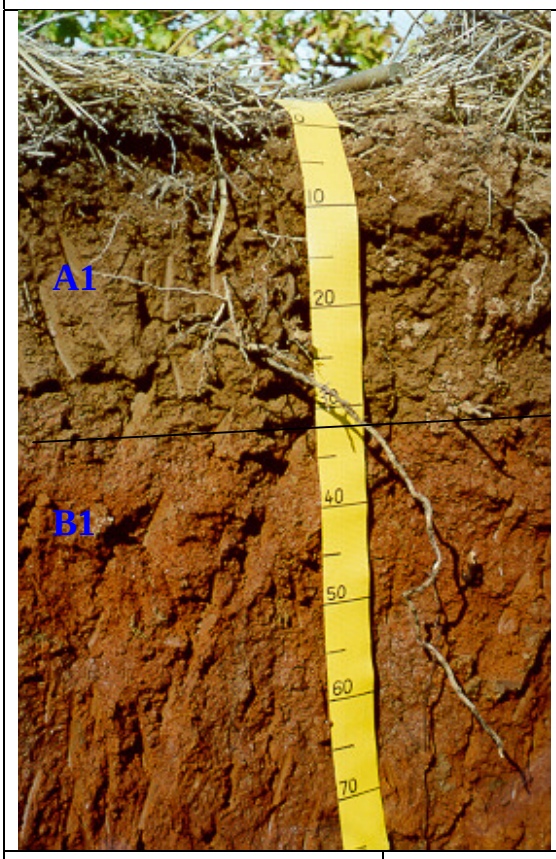
The plastic limit of the subsoil of this part of the vineyard was determined at 24-25% water content (d.b.) whilst the liquid limit was in the range 64-65% water content (d.b.). At ripping in June the soil moisture content varied between 15.9 and 28% for the top 600mm of soil whilst the spring rip was conducted with moisture contents ranging from 7.6 to 26.1% (d.b.)

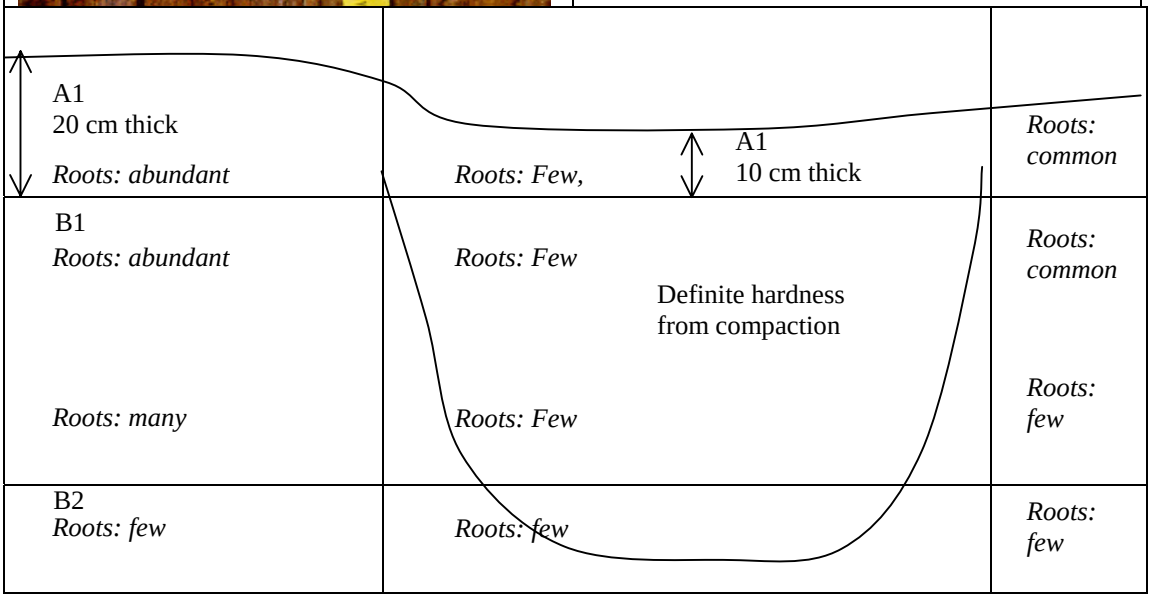
Klugges South Vineyard	**Rows 7/8 North, Vine 17**
	**A1** Dark brown, sandy clay loam Granular shaped aggregates, Weak structure (<30% aggregated)
	B1 25 cm, dark reddish brown, medium clay with signs of both stickiness and plasticity Blocky shaped aggregates Strong structure (>60% aggregated)
	B2 Dark brown, calcareous, medium clay with signs of both stickiness and plasticity (higher amounts of sand-sized particles) Massive Structure



Note: Roots abundant, >200/100 mm^2, many, 25-200/ 100 mm^2, common 10-25/ 100 mm^2, few, <10/ 100 mm^2

Comments regarding the figure above: Root growth mostly restricted to undervine; wheel track compaction preventing even 'common' root exploration, although modest recovery of root density exhibited at mid-row outside compaction zone. Vines would not be accessing all the soil stored water within the wheel track and parts of the mid-row areas.

Klugges South Vineyard	**Rows 7/8 South Vine 16** (from end)
	**A1** Dark brown, sandy clay loam Granular shaped aggregates, Weak structure (<30% aggregated) **B1** 30 cm, dark reddish brown medium clay with signs of both stickiness and plasticity Blocky shaped aggregates Strong structure (>60% aggregated) **B2** not shown on photograph 80 cm, calcareous, dark brown, medium clay with signs of both stickiness and plasticity (higher amounts of sand-sized particles) Massive Structure



Comments on figure: Root growth adjacent to the vines was by far the most prolific, however quickly declined within the compacted zone.

Development of an ameliorant applicator

After investigation the possible solutions to applying soil chemical modification that would satisfy both current and future requirements for the viticulture industry it was decided to opt for a liquid system due to both the advantages and the flexibility of such a system. The type of liquid system chosen was similar in principal to the liquid fertilizer systems currently being used successfully in the broadacre industries as the components are readily available, robust and familiar. This means that the liquid product is mixed proportionally into a stream of water than acts as a carried for the chemical. This allows the rate of application to be varied easily for a fixed number of nozzles in a system.

Advantages

The advantages of a liquid system include, a reduced amount of bulk material has to be carried to obtain the equivalent application rates with technical grade liquid lime or gypsum than with a granular product. It was found that approximately 20 l of liquid product would provide the same amount of chemical modification as 1 ton of the granular product. With potential application rates of 10t/ha the logistics of carrying this amount of bulk product on a vineyard tractor would be difficult. The liquid option leads to a more compact system and reduced weight of product and bulk trailer/hopper to carry around the vineyard. Even thought a tank of clean water will need to be carried in addition to the concentrate chemical this will still be significantly less than an equivalent bulk system.

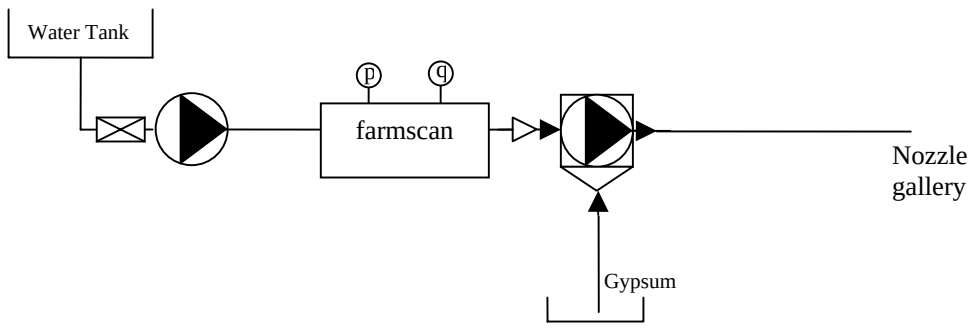
Using a liquid product also allows easier direction and transport of the chemical to more remote parts of the ripper such as down the back of the tines. This would not be possible with a granular product due to the size limitations of any transfer hoses causing the possibility of blockages. Using a liquid product also allows for increased coverage of the soil profile through a spraying effect, whether this is across the soil surface or down the soil profile.

Potential Issues

The nozzles required for controlling the application rate and directing the liquid into the required section of the profile may have to be placed deep in the soil profile behind the ripper tine, this puts the nozzle in contact with the soil and therefore could be subject to wear or blocking. The concentrate chemical is of a suspended form and will settle in water over time, therefore the system must be flushed after use to ensure blockages do not build up.

System specification and layout

<u>Layout of the system:</u>



System Components:

1. 200 Litre water tank
2. System Filter
3. Hydraulic driven pump
4. FARMSCAN flow meter
5. FARMSCAN flow control valve
6. FARMSCAN pressure meter
7. Oneway Valve
8. Mixrite proportioning pump
9. Concentrate Chemical container
10. Nozzle gallery (mounted on ripper)

- Mixing percentage of 3-10%
- Max. pump flow of 72 l/min
- Max. pump pressure is 20 bar

The 200 l water take was designed to fit to the front of the tractor to reduce the weight on the ripper. This also transfers the weight of the water to the front of the tractor where it can be useful in terms of improving the tractive ability of the lightweight vineyard tractors. Between the clean water tank and the pump, a filter was placed, this ensure the system especially the pump are protected form foreign objects that may enter the tank and be harmful to the system. The Hydraulic driven water pump was positioned at the front of the ripper, this location is close to the hydraulic supply on the back of the tractor and also close to the location of the Mixrite unit. The Mixrite unit is also located on the ripper and this needed to be close to the nozzles, so that there is a minimum amount of pipe work and system components subjected to the mixed chemical solution.

The control of the system is supplied by the "FARM SCAN" components; these include the flow meter, the pressure sensor and the control valve. These components are fundamental to the control of the application rate and the operation of the system. The flow rate of the system can be controlled by entering the value into the "Farm Scan" control panel; this monitors the flow rate of the pump and therefore the input side to the Mixrite unit. The flow is controlled by restricting the output of the pump and increasing the pressure and when necessary causing the excess flow to be returned to the clean water tank. There was a one way valve located in the system between the farm scan controlled and the Mixrite unit, this eliminated the possibility of the mixed chemical solution getting back to the control valve and causing possible blockages.

The nozzles used on the system are straight orifice stainless steel, which can be of various diameters depending upon the calibration that determined the application rate and the number of nozzles to be used. As this type of system has not been used for the injection of a suspended liquid both the Mixrite proportioning unit and the nozzles needed calibration to determine there functionality.

Results

Investigating the optimum vibratory ripper settings (Exp 1)

The approach used a randomised block experimental design in an open field near Langhorne Creek on the vineyard property managed by FABALs. The experiment was implemented at either end of the field in two differing soil conditions where soil composition varied in soil strength and moisture content. A 63kW Lamborghini 990 Agile, front wheel assist (4WD), vineyard tractor, weighing 3.28t with 1.64t on both the front and rear axles was used throughout the tests.

Soil conditions

Soil A - Top 100-200mm is a loamy clay to clay loam over a light to medium clay to silty clay in the top 600mm (northern end of field)

Soil B - Top 100-150mm: light sandy clay loam to light clay.
From 100-150 down to 300-350mm a light medium clay to a medium clay.
Below 300-350mm from north to south of this plot was a transition from medium clay to a sand.

Soil density was determined by using sampling cylinders while moisture content was gained from augered soil samples. An indication of soil strength was also found by conducting cone index probes across each block of each experiment. The cone index measure of soil strength is shown in Figure 6 along with the corresponding soil density, and moisture contents. The cone index values for soil B were largely underestimated below 150mm as a large portion of sites could not be penetrated below this depth. This greater soil strength limited the rigid tillage to 390mm depth in soil B compared to 410mm in soil A.

Vibratory ripper parameters

The experiment investigated the influence of the following settings:

1. Nominal ground travel speeds of 2.5 and 4km/h
2. Tine vibration angles of 0 and 30°
3. Amplitude of oscillation (three for each tine type ranging from 45 to 81mm)
4. Frequency of oscillation this was set such that a high (HVR) and low (LVR) velocity ratio could be achieved for each of the above combinations. The velocity ratio is the ratio of maximum tine tip speed to the forward travel speed. A higher velocity ratio implies smaller bite length in the cyclical tillage process, for a given amplitude.

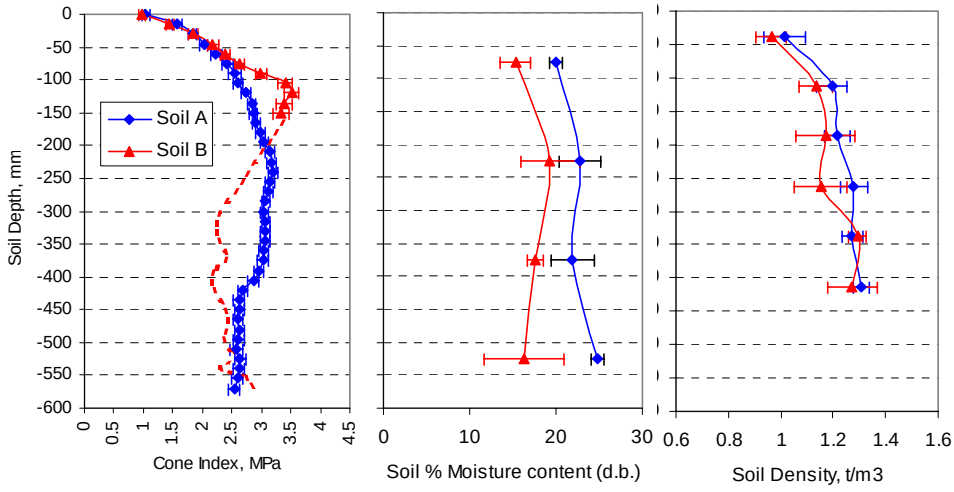


Figure 6 Physical soil Characteristics for Experiment 1

Measurements used to determine vibratory ripper performance

A shear-pin was fitted in the ripper hitch to determine draft forces, while a torque transducer was placed in the PTO driveline to measure PTO torque and speed. Forward speed was determined with ground speed radar, which also provided wheel slip data when compared to the tractor rear axle speed, monitored by an optical sensor. The methods used to calculate tractive efficiency and tractor engine power use are described in Slattery & Desbiolles (2002b). Operator comfort levels were determined with accelerometers by measuring the 3D acceleration of the tractor seat beneath the operator. The 3D acceleration data was filtered to Australian Standards AS2670.1 such that they could be related to operator comfort levels. Tractor chassis roll was compared to cabin roll by comparing the angular velocity output of two gyroscopes fitted to each respective part. All data was logged at 500Hz through a DAT card and analysed with Labview™ software.

An ANOVA type analysis was performed on all data to assess treatment differences, while a multiple linear regression was performed to look at the significance of settings on performance indicators.

Engine power and power savings

To perform rigid tillage, drawbar power is required to pull the ripper forward through the soil. However to develop drawbar power the tractor must secure additional engine power (ie. DB Pwr losses) to overcome losses through the transmission and wheel slip. To operate the vibratory ripper, PTO power is required, with some corresponding transmission losses (ie. PTO Pwr losses). Figure 7 shows the proportioning of engine power use, as measured in the trials with the height of the columns estimating the total engine power required.

It is easily seen in Figure 7 that, for the vibratory case the portion of power required to develop the required drawbar power is always lower than for the equivalent rigid case. However, in some cases, the PTO power input to achieve this can require greater total engine power from the tractor. This scenario may still be an advantage if tractor weight and traction are limited compared to the available power of the engine, where the tillage capacity (depth of loosening) under vibratory tillage could be increased. However at the lower speed and lower velocity ratios (lower frequencies), data showed that, a saving in engine power of up to 20% can be achieved when operated at the same depth as the rigid tine. It appears that, as forward speed is increased, engine power savings also diminish. In practical terms, this means that the greatest depth benefits of vibratory tillage are best realised when able to operate at a lower speed.

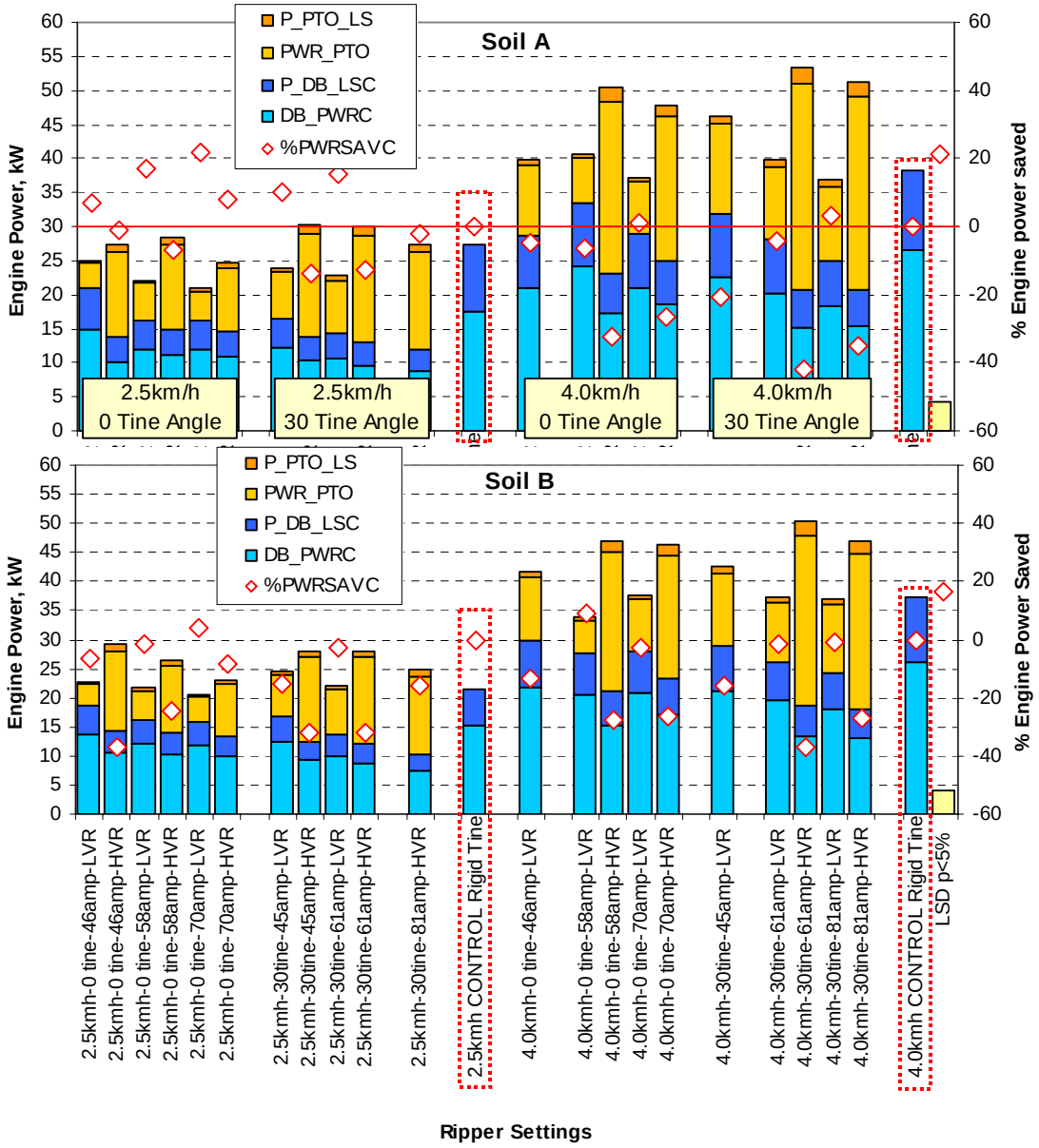


Figure 7. Distribution of engine power required for subsoiling and engine power savings.

Engine power saving is the percentage difference in the engine power required for vibratory tillage compared to that required for rigid tillage at the same depth and speed. Variation was high as can be seen by the large statistical least significant difference (LSD) value for both soil types of between 17 and 21%. The engine power calculation is based on the drawbar power and PTO power including power lost through the transmission and traction efficiencies. Positive values indicate that the vibratory settings used required less engine power than the rigid equivalent. While a similar trend was observed in both soil types for engine power savings, significant positive power savings were only found at the lower ground speed in soil A. Smaller drawbar power losses were measured in soil B at this speed thus making the efficiency gains of vibratory tillage smaller. Therefore at higher levels of slippage greater power savings will be realised for the vibratory case. Multiple linear regression showed a strong link of increased power savings with lower frequencies of oscillation. This is mostly due to the increase in pto power requirements with increases oscillation frequency. The regression also indicated a small possible benefit by using the 0° vibration angle tine, smaller amplitudes and the slower forward speed.

Ripper driveline efficiencies

Ideally to determine efficiency we would compare the power input with the power output. However it is difficult to measure the power output at the tine when it is operating in the soil. An indication of driveline efficiencies can be gained by considering the power to drive the ripper at the chosen settings in operating out of the ground compared to operating at depth in the soil. However this may be misleading as power input whilst out of the ground is mostly constant while power required in the soil varies with depth and soil conditions. As shown in Figure 8, out of ground power requirements increase with frequency of oscillation from 1 to about 5kW over the frequency range of 2.8 to 9.5Hz. Figure 8 shows the rapid increase in PTO power required while ripping with increasing frequency and amplitude (ie. a bigger stroke moving more rapidly against the soil is typically going to increase energy requirements). If out of ground PTO power is compared to in ground ripping PTO power to determine efficiency then the efficiency would increase with higher PTO power demands.

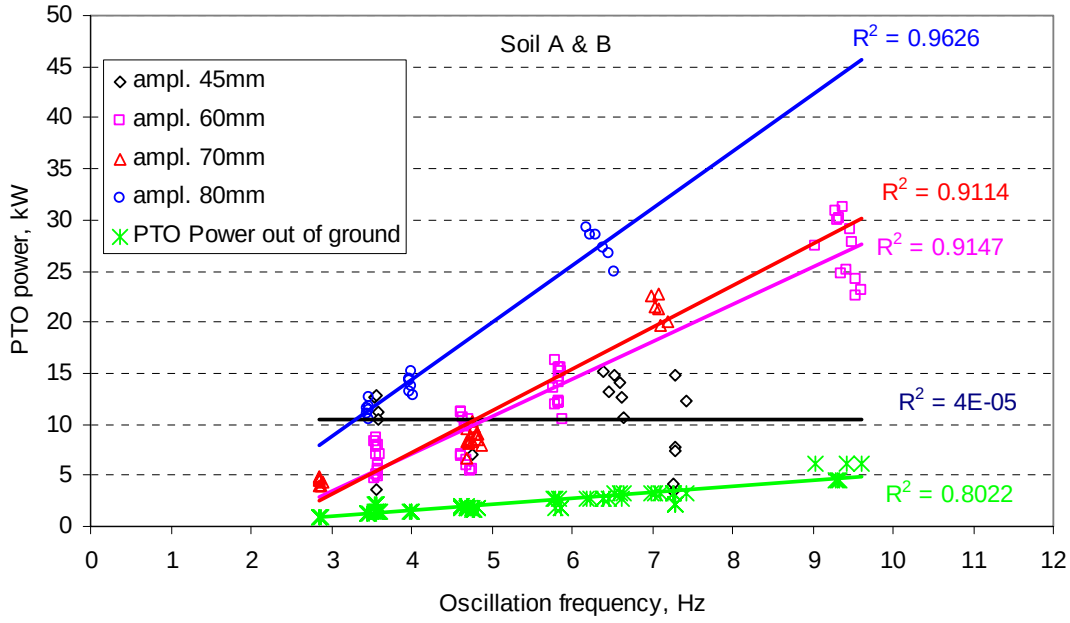


Figure 8. PTO power requirements for varying amplitudes and frequencies.

Draft reduction and Power Ratio

Draft reduction is the reduction in draft achieved by vibratory tillage compared to rigid tillage of a similar tine at the same depth. The total power ratio is the ratio of (PTO and drawbar) power of the vibrating tine over the drawbar power of an equivalent rigid tine operating at the same depth. Vibratory tine settings that maximise draft reduction and hence potentially the subsoiling capacity of the tractor, also increase the total power ratio, which needs to be minimised to make the best use of the tractor engine power.

A multiple linear regression analysis of both % draft reduction and total power ratio found that both increased significantly with an increase in tine oscillation frequency and amplitude. The 30° angle of vibration also increased draft reduction and total power ratio, as did a reduction in tractor forward speed. These parameters can be combined by considering the velocity ratio which is the ratio of the maximum tip speed of the tine (ie. amplitude x frequency) over forward travel speed. Figure 9 shows that increasing the velocity ratio maximises both the draft reduction and total power ratio. This is thought to occur as increasing the velocity ratio increases the portion of subsoil loosening done by the oscillation motion of the tines compared to that achieved by the overall forward movement of the tine through the soil, thus increasing draft reduction. Researcher's (Verma, 1971) have attributed the phenomena of draft reduction due to vibration to increases in soil failure frequency above the natural failure frequency of the rigid tine, thus reducing the soil force that can develop against the tine. In addition less soil contact when the tine is oscillating may also reduce soil-tine frictional forces thus reducing draft requirements. However the additional energy required to oscillate the tines faster and

over a greater stroke increases the demand on PTO power from the tractor. Results in Figure 9 show that only a few vibratory treatments could be operated with total power ratios less than or equal to one. Performance gains in tractor engine power however can still be made using vibratory tines due to the very efficient transfer of engine power to the PTO compared to the transfer of engine power to the drawbar which typically is no greater than 70%. Performance gains can also be made in subsoiling capacity by travelling slower and leaving more engine power for oscillating the tines.

Increased subsoiling capacity by more effective use of engine power

By employing favourable vibratory tillage settings more effective use of the vineyard tractor's engine power can be made, thereby increasing it's subsoiling capacity. Vibratory tillage can potentially increase subsoiling capacity over that of an equivalent rigid tillage system where the vibration of the tines:

- Reduces the draft requirement (thereby increasing the draft reduction), thus less draft is required to do the same tillage work leaving draft capacity in reserve.
- Increases the effective power saving at the engine, thus leaving power reserves available for increased tillage (ie. Increased depth)
- Lowers the drawbar demand increasing the tractive efficiency and thus leaving drawbar power capacity in reserve that can be used to increase the level of tillage.

However it is difficult to ascertain the most optimum settings when the performance parameters are considered independently, where for example the best draft reduction and power ratio values have contradicting vibratory ripper settings. Thus the concept of a predicted Equivalent Rigid Draft (ERD) value was developed. This theory used an equation that accounts for the effects of: draft reduction, power ratio, tractive efficiency, transmission efficiency, ground speed and available tractor engine power to predict a draft force that theoretically would be required by an equivalent rigid tine ripper to do the same level of tillage as the vibratory settings. A bigger heavier tractor of course would be required to deliver this predicted ERD with a rigid tine system. The data used to predict the ERD is based on the measurement of the above variables for a range of vibratory setting where the ripper was operated to the maximum depth limit of an equivalent rigid tine. Thus this ERD value can be used to compare the maximum subsoiling capacity of the tractor/ripper combination for a given set of vibratory settings and to identify the optimum settings.

The ERD theory can be summarised as follows: by vibrating the tine, draft is reduced compared to an equivalent rigid tine at the same depth. A tractor in given conditions can develop a maximum draft at a particular slip (tractive efficiency), where for the rigid tine this would result in a maximum depth (d1). Theoretically, by vibrating the tine a greater depth (d2) can be reached until the tractor is again limited by the maximum draft at the particular slip. Thus, the equivalent draft if the tine had been rigid and operated to this same increased depth (d2) is defined as the Equivalent Rigid Draft (ERD). The delivery of this ERD, however, can additionally be limited by the available tractor power to achieve the above at the given ground speed (which is usually the case for higher tractor forward speeds). As a result, the slower the targeted operating speed, the more applicable is this ERD concept, to quantify the improvement in tractor subsoiling capacity. In the calculation of ERD it is assumed that:

1. the measured rigid ripper data was where depth d1 was at the tractor's tractive efficiency capacity where slip was not excessive.
2. the same ground speed and slip can be maintained when vibrating at depth d2 as for the rigid ripper limit at depth d1.
3. the traffic efficiency for vibratory tillage at d2 will be equivalent to that of the rigid ripper at d1.
4. That the power ratio measured at d1 will be maintained at depth d2
5. That the soil is homogeneous with increase in depth.

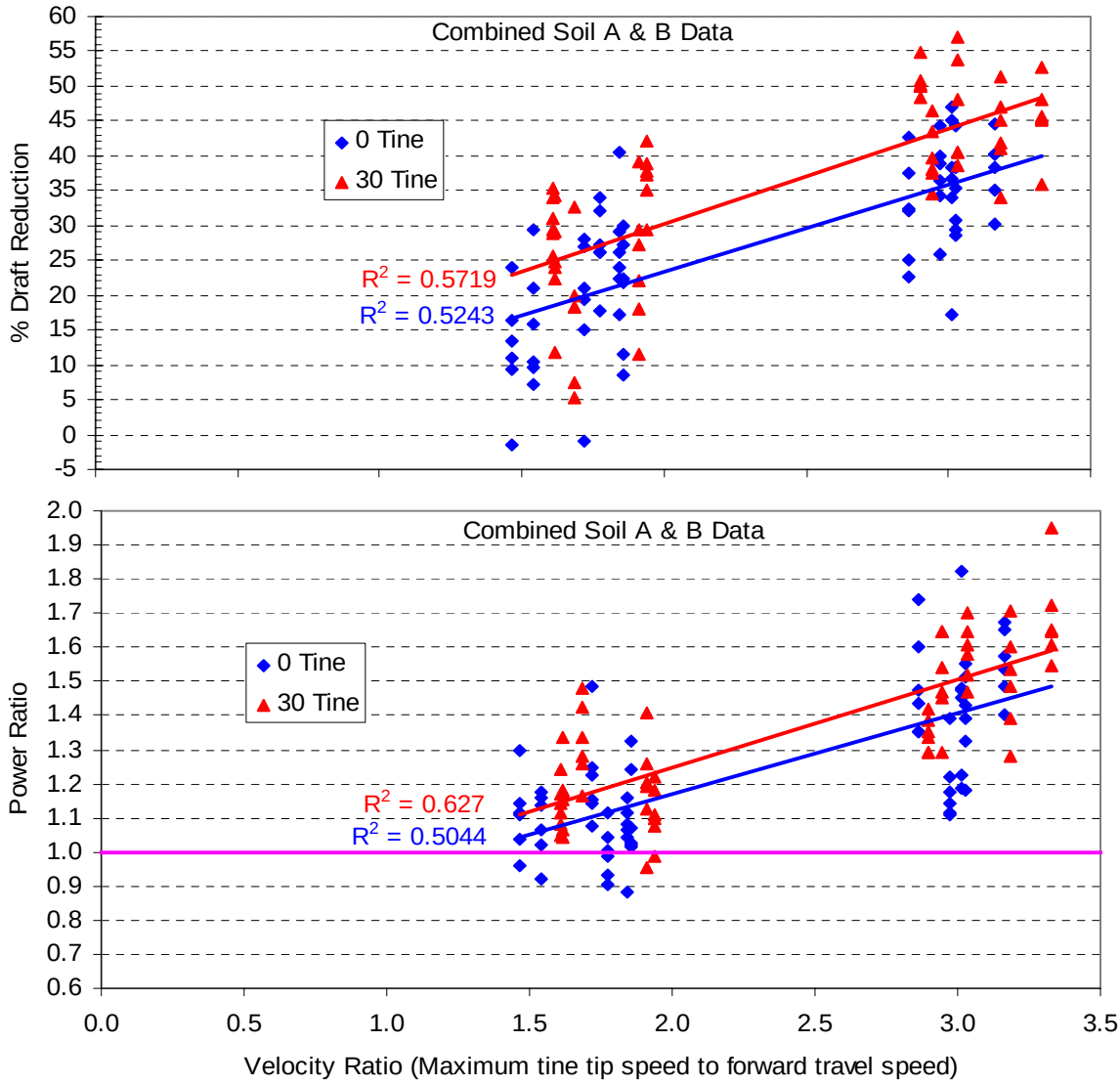


Figure 9. Draft reduction and power ratio relationships with tine vibration angle and velocity ratio.

The following should be considered when comparing ERD to the rigid tillage results (of depth d1). Rigid tine tillage is entirely dependent on draft force from the tractor to induce soil disturbance. For a given tine design and a homogeneous soil an increase in soil, disturbance typically requires greater draft up to a point where the critical depth is reached, and further increasing the depth does not increase but can rather drastically decrease the volume of soil loosened. Draft typically increases in relation to the square of the operating depth. In practical terms, to deliver the Equivalent Rigid Draft at the improved depth, a tractor with a proportional increase in weight, tyres and size would be required. This increase in tractor size may not be appropriate in the vineyard due to physical limitations and the increased compaction effects that would be applied to the soil.

With a rigid tine, draft is limited by tractor weight, traction efficiency and speed of operation by the tractor power available. So to make best use of the available engine power the tractor speed is increase until the tractor power is almost fully used thus the equivalent rigid tillage operation compared in this experiment could be conducted at a higher speed. Thus if a sufficient level of tillage can be performed by a rigid ripper with the tractor available the gains by using vibrating tillage may not be useful. Increasing speed will also increase slightly the draft but typically increasing speed also improves tractive efficiency and thus may not result in any change in capacity, especially at speeds less than

4.5km/h (Godwin, 2003.) The most fuel efficient tractor engine performance typically occurs at 90% of maximum power, Witney, 1996. Thus using 90% of the 63kW engine power and allowing for transmission and tractive efficiency losses, in soil A, with an average rigid draft of 28.7kN, a maximum rigid tine speed of 4.8km/h could be used. While in soil B, where average draft was 25.8kN the speed could be increased to 5.6km/h due to the lower draft and greater tractive efficiency measured.

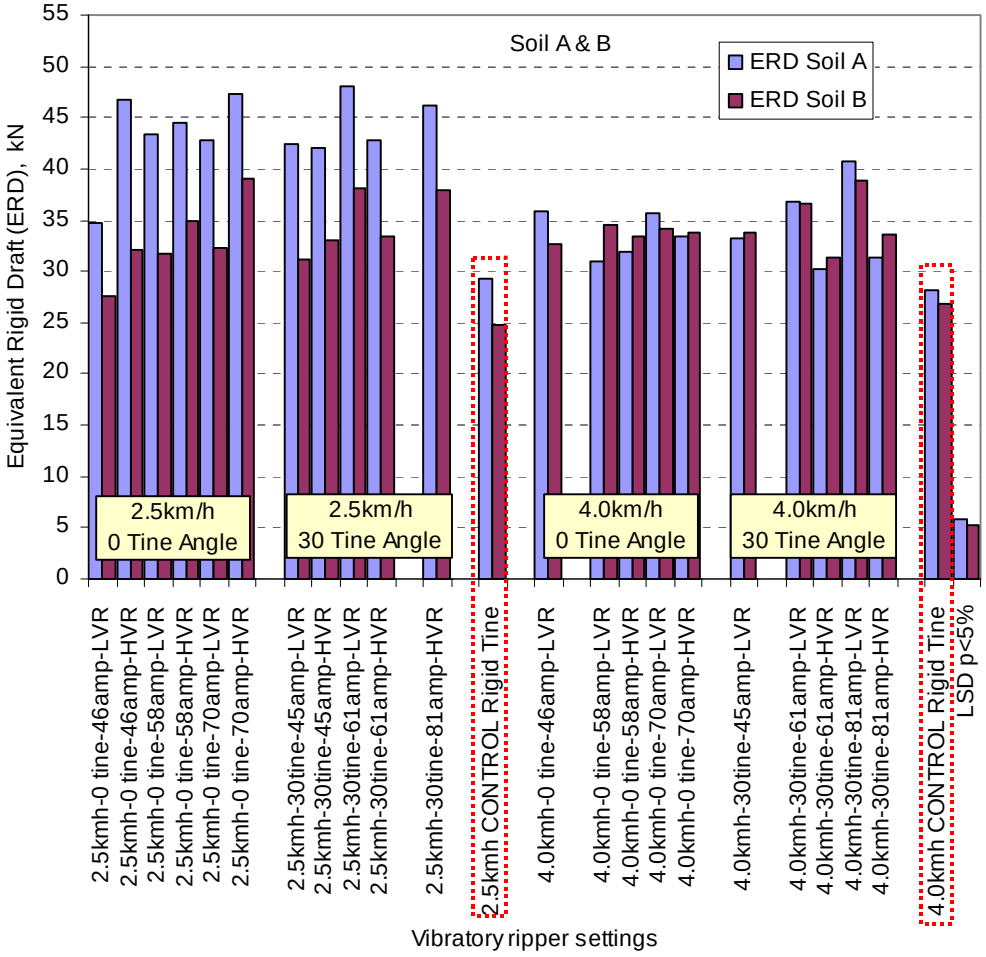


Figure 10. Equivalent Rigid Draft (ERD) predictions for vibratory ripper settings relative to the control (rigid tined ripper)

Equivalent Rigid Draft results are shown in Figure 10 for soil conditions A and B. A 48% and 36% higher ERD was predicted at the nominal 2.5km/h speed in soil A and B respectively, whilst at 4km/h this increase was only 21% and 28%. These speed induce differences are due to the greater engine power required for ripping at higher speeds reducing the engine power available for vibrating the tines and thus reducing the potential subsoiling capacity as the speed is increased. At the lower speed, the data suggests greater ERD are obtainable under the higher velocity ratio (HVR), this is because this is because under these conditions, the maximum tractor draft is the main limiting factor and thus ERD is maximised where draft reduction is greatest, that is at higher velocity ratios. Conversely, at the higher speed, engine power is the main limiting factor and the lower velocity ratios corresponding to lower PTO power demands tends to result in a maximising ERD at 4km/h. A multiple linear regression analysis of the ERD variable to amplitude, speed, tine angle and frequency parameters confirmed speed as a significant factor in soil A only.

In summary to maximise the subsoiling capacity, a low operating speed should be used along with a high velocity ratio and frequency. However at higher ground speeds, lower velocity ratios should be selected to promote efficient transfer of power to soil loosening. These effects should only be considered within the range of settings used in this study.

Tractor and operator vibration/comfort levels

The operation of the vibratory ripper results in the transfer of some vibration to the tractor and then to the operator positioned within the cabin on the operator's seat. It is desirable to minimise the risk of injury and fatigue that both the tractor and operator are subject to when operating the ripper. Thus the accelerations of the tractor seat when operating was measured along 3D axis and analysed according to Australian Standards AS 2670.1-2001 to determine a weighted acceleration value. For an 8 hour daily continuous exposure, this value should not exceed about $0.8m/s^2$ and ideally be less than $0.5m/s^2$. In reality the exposure would not be continuous at the levels measured due to lunch breaks and the time turning at the end of each vineyard row (ie. no load)

Due to equipment limitations three-dimensional seat vibration data was recorded in soil A, while chassis and cabin angular velocities were recorded in soil B. The results shown in Figure 6 show that four vibratory ripper treatments produced weighted acceleration values that were not significantly greater than the rigid ripping at 4km/h. All four treatments included the horizontally vibrated tine angle operating at the lower speed. There is no obvious relationship between the velocity ratio, frequency or amplitude of these treatments compared to the other treatments that can be attributed to these lower acceleration values.

In Figure 11 an indication of the influence of tine angle, speed and amplitude on seat vibration values can be gained. The 30° angle of tine vibration tended to increase the seat vibration with increase in amplitude for both speeds, while the 0° tine was not influenced by amplitude as shown in Figure 12. The lower operating speed with the 0° degree tine angle also reduced the seat vibration value.

Components of seat vibration

If we consider the components of vibration vertical, longitudinal (in direction of travel) and lateral at right angles to the travel direction we can isolate the influence of different parameters on these different directions of vibration.

The longitudinal (travel direction) and lateral (side to side) are of most interest as the transfer of vibration from the ripper is expected to have minimal direct influence on the vertical acceleration (also dampened by seat design features). Longitudinal acceleration is excited by the back and forth motion of the tines while the lateral acceleration is influenced by the oscillating moment of the out of phase motion of the two vibrating tines, along with torque peaks through the PTO requiring a resisting torque from the tractor. With the 30° tine angle, some torque may also be applied through the hitch as there is some vertical movement of the tine tips that is 180° out of phase.

Use of a rolling drawbar was implemented to minimise the severity of the oscillating moment to the tractor while the use of a flywheel was employed to minimise the magnitude of the PTO torque peaks. Multiple linear regression of frequency, amplitude, tine angle and speed with lateral acceleration showed some significant vibration reduction at increased frequency and under smaller amplitudes, while speed and tine angle had no significant effect.

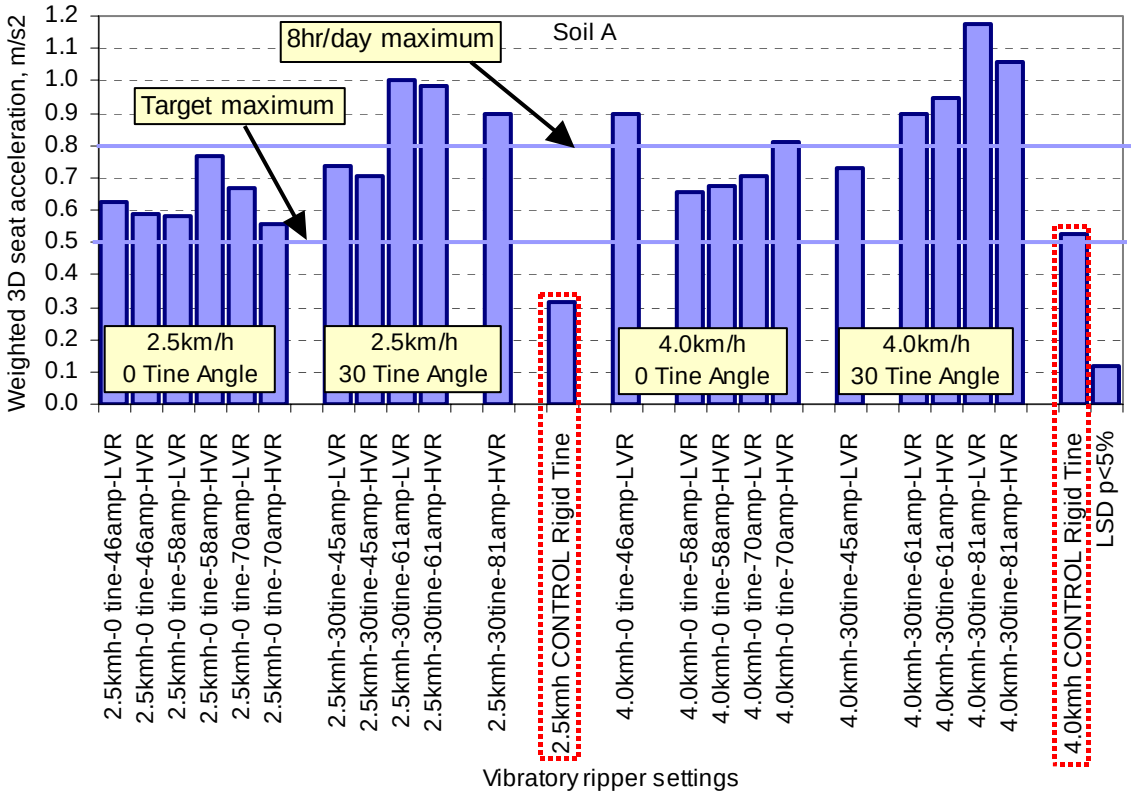


Figure 11. Weighted 3D seat vibration values (AS 2670.1-2001) for the range of vibratory setting relative to control (rigid) riper.

The AS2670.1 requires the filtering of the longitudinal and lateral acceleration to bias towards lower frequencies in the range 0.5 to 2Hz while for the vertical direction; frequencies retained are biased in the range of 3 to 12.5Hz due to their effect on operator comfort and fatigue. The lateral and longitudinal values are also given a 1.4 times greater weighting than the vertical direction. Thus the response of vertical acceleration values increasing with velocity ratio (H or increasing frequency) are almost the opposite to the longitudinal and lateral acceleration value response of decreasing with an increase in velocity ratio (or frequency). A frequency of around 5Hz appears to be a good compromise at minimising the weighted acceleration contributions of each direction to give a lower overall 3D weighted acceleration. There was some tendency for lower 3D seat vibration associated with the combined frequency of around 5Hz and the maximum PTO speed of 1000rpm.

Tine vibration also has a significant effect on 3D weighted seat acceleration as shown in Figure 12 where overall the 0 angle tine has lower values than the 30° angle tine vibration. The 30° angle tine vibration also was found to increase the seat vibration as the amplitude was increased while the other tine seat vibration response was not influenced by the amplitude magnitude.

Selection of most optimal vibratory settings

Choosing the most desirable settings should be a balance of low seat acceleration and high ERD. The vibratory ripper settings that best fit this criteria across both soils were a 2.5km/h speed, 0 tine vibration angle, 70mm amplitude and the higher velocity ratio. This setting had the equal highest ERD in both soils potentially giving a 57-61% increase (beyond measured rigid tillage) in subsoiling capacity. This setting also minimised the 3D weighted seat vibration that was the equal lowest of any of the vibratory settings at 0.56 m/s^2 fitting within the acceptable levels of the standard.

The best setting at the higher operating speed of 4km/h also used the 0 tine vibration angle and 70mm amplitude while potentially only increasing the subsoiling capacity by 26-27% the 3D seat acceleration was still within the acceptable range of 0.70m/s^2. While increased capacities of up to 45% could be

achieved with the 30° at this higher speed the seat vibration was unsustainable with a value of 1.18m/s^2.

To deliver with a larger tractor and rigid ripper system the optimum ERD predicted for the vineyard tractor and vibrating tractor at 2.5km/h, the larger tractor would have to weigh in the order of 60% more.

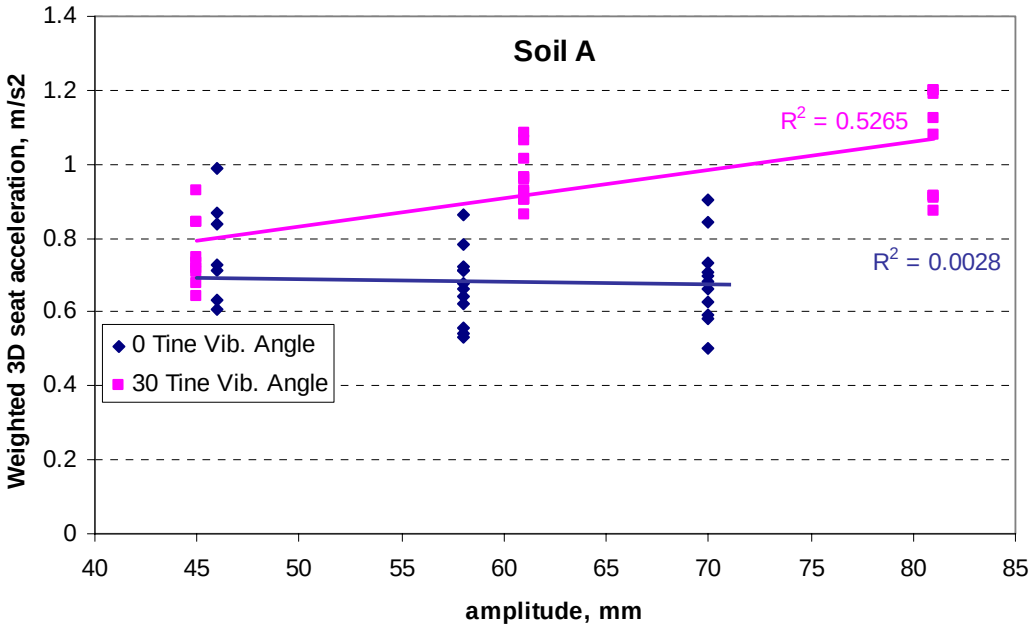


Figure 12. Weighted 3D seat acceleration for tine vibration angle and amplitude.

Strategies to maximise prototype ripper capacity and efficiency (Exp 2)

Soil conditions

The two soil types used were of similar make up to soils A and B as described in Experiment 1. The soil strength (Figure 13), density and moisture content profiles however varied and are as shown in Figure 14. It can be seen that in soil B, while density was reasonably consistent with depth, reduced moisture content at depth correlated with increased soil strength.

Subsoiling strategies investigated

The following strategies were investigated, each operated at a nominal 2.5km/h to a depth that produced 12-15% wheel slip:

- One-pass to full depth using the two main tines (spaced 1250mm apart).
- One-pass - dual-depths using 4 rigid shallow leading tines operating at 40% of the full depth of the same two main tines (the positioning of the 4 shallow tines was such as to maximise the area of soil loosened).
- Two-pass - dual-depth - The first pass used three shallow rigid tines to (centre and at 1090mm to either side). The second pass used the two main tines to full depth.

All three strategies were conducted for combinations of rigid and vibrating tines, winged/wingless tips on the two main tines. Point width was 50mm while wing width was 300mm and positioned 50mm above the lowest part of the point and 200mm behind the leading tip.

The vibratory tine parameters used were 0° vibration angle, a 70mm amplitude, high velocity ratio and an oscillation frequency of 4.8Hz (1000rpm PTO).

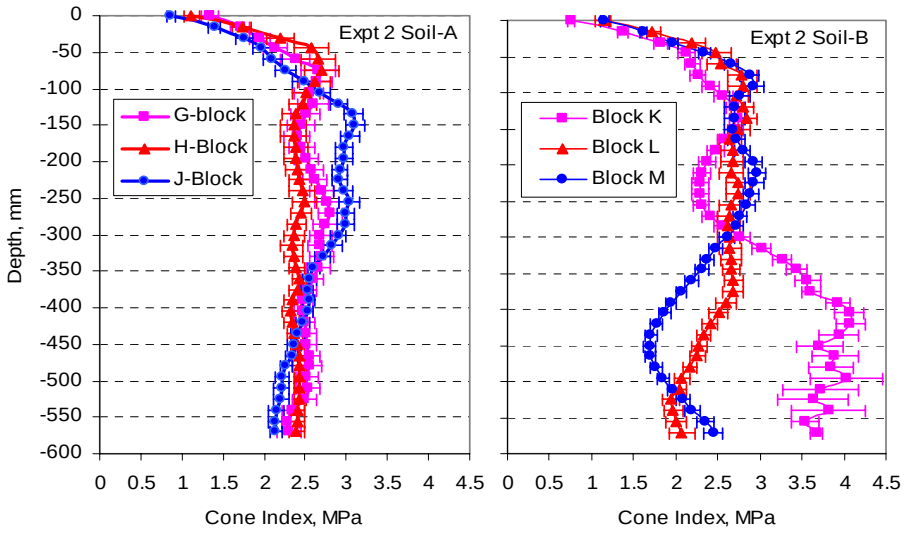


Figure 13 Soil strength (cone index) in soils A and B used in experiment 2

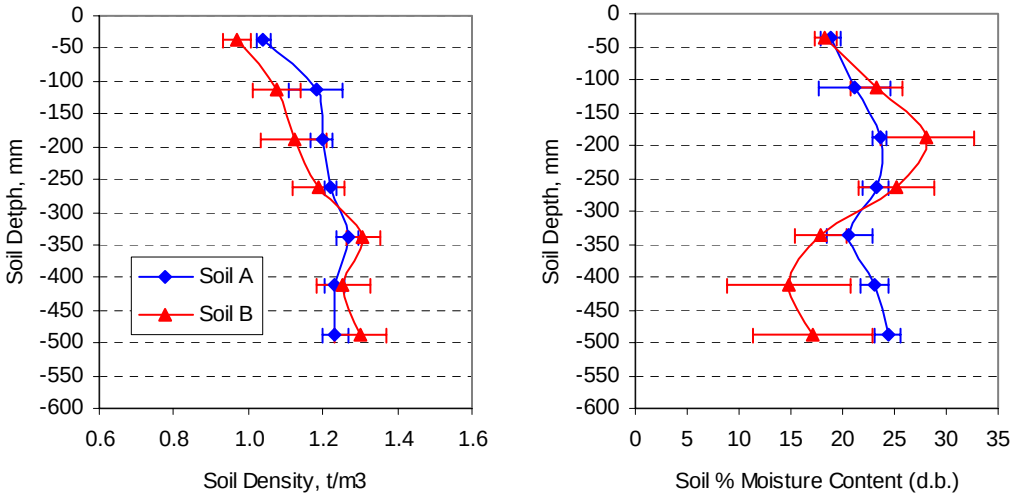


Figure 14 Soil density and moisture content soils A and B

Determining the loosened area/surface profile and Soil Loosening Energy parameter

Soil loosened area and surface profiles were determined in one of the three experimental blocks at each soil site, the loosened area surface boundary and surface profile were plotted using a profile meter (repeated 3 times). To achieve this, the loosened soil was carefully excavated to reveal the shape and extent of the loosened profile. In all one-pass treatments, only the left side was excavated assuming symmetry about the centre. For the first pass of the two-pass treatment the two outside tine loosened zones were excavated to produce and average profile. The second of the two pass treatments and the dual depth treatments were fully excavated and profiled.

In this component of Experiment 2, the subsoil loosening capacity of vibrating and rigid tines were compared for various combinations of wing, dual depth, and multi-pass scenarios. As soil strength increases with depth, loosening the same soil area at a shallow depth requires considerably less effort than the equivalent area loosened to a greater depth. On this basis, comparing soil-loosening capacity in terms of loosened area alone can be misleading, as ripper arrangements which loosen large shallow areas may appear to have a greater loosening capacity and better efficiencies than those that loosen to a greater depth. Thus in this study, a new Soil Loosening Energy (SLE) parameter was developed in order to effectively relate the soil loosening energy to the loosened area above a given depth. Thus a better representation of the loosening work for various depths, areas, profile shapes and varying soil strength can be achieved. This SLE parameter is based on the Cone Index profile (indication of soil strength) expressed as specific cone penetration energy, (area under the Cone Index - depth curve as used by Desbiolles et al (1999)) for a given depth and is multiplied by the area to that same depth in the loosened soil profile. Summing all these for each depth interval across the loosened soil profile gives the value of the SLE parameter. The SLE is an energy parameter and as such can be used when compared to engine power and fuel use as an indication of the efficiency at loosening the soil of the particular tine arrangement.

Tractor capacity

The approach used to determine the maximum capacity for each ripper configuration was to increase the subsoiling depth until the tractor reached a similar level of slip (approximately 12-15%). However, in practice, it was very difficult to achieve a constant draft or wheel slip between treatments due to soil variation (ie. practice area settings did not always give a good indication of plot ripping conditions). The variation of draft over all the treatments and blocks was found to vary by ±10% about an average 26.2kN.

In addition the following difficulties were encountered:

- The front of the tractor had a tendency to rise up before maximum traction was developed when conducting the first shallow tine pass. This was due to the component of vertical force exerted by shallow tines and contributed to a more difficult control over depth/slip parameters.
- Accuracy of driving in the second pass of the two-pass treatment was difficult to maintain due to operating close to the slip capacity of the tractor. If tractor direction of travel deviated from alignment with the first pass the drawbar requirements would increase thus increasing wheel slip reducing controllability of tractor direction.

Subsoiling Capacity

The subsoiling capacity of the various ripper configurations evaluated were assessed in terms of three indicators; maximum depth, area of soil loosened and the SLE parameter. Figure 15 shows a similar trend in both soil types where maximum depth of tillage is reduced by 10-20% by adding wings to the main tines. This reduction occurred for both rigid and vibratory systems. Whilst the depth capacity was reduced the area loosened and SLE remained similar or increased by up to 20%. Vibrating the wingless tines increased the depth by about 45mm in both soils from rigid depths of 430 and 405mm. Vibrating the winged tines increased the depth by 120mm to 460mm in soil A and by 30mm to 360mm in soil B. The rigid system whether winged or wingless was found to loosen a similar area and SLE, however, when vibration was used the increased depth increased the SLE by 42-59% while the corresponding increase in loosened area was only 20-30%. This showed that using the SLE and accounting for the varying soil strength can give a fuller picture of the soil loosening demands, overcome by ripper configurations that have varying depth and soil disturbance characteristics. See Table 2 & Table 3

Performance indicators	1Pass 1Depth	1Pass 2Depth	2Pass 1Depth	P>0.05
Soil A	1.Depth	2.Depth	1.Depth	LSD
Work Depth/ mm	417	421	423	ns
Fuel consumption/ ml·hm⁻²	0.249	0.263	0.268	0.0021
SLE/ %	24.9	31.1	33.9	3
Engine Power Peak/ kW	26.1	22.2	22.4	1.4
Fuel consumption/ h	11.1	13.3	14.1	0.9
Engine Power Loss/ kW·m⁻²	7.1	4.7	3.6	2.1
Engine Power/SLE/ kW	0.197	0.166	0.149	0.004
Fuel consumption/SLE/ kW·h	0.068	0.044	0.035	0.001
3D weighted operation/ m²·s⁻¹	1.544	1.469	1.534	0.045
Work weighted operation/ m²·s⁻¹	1.393	1.345	1.371	ns
Speed weighted operation/ m²·s⁻¹	1.228	1.234	1.233	0.019
Long weighted operation/ m²·s⁻¹	1.248	1.269	1.244	0.022

Performance indicators	Rotary tine		Vibrating tine		P>0.05
Soil A	Point	Wing	Point	Wing	LSD
Work Depth/ mm	426	438	427	449	6
Fuel consumption/ ml·hm⁻²	0.429	0.439	0.388	0.377	0.0
SLE/ %	26.5	27.1	37.8	41.9	5
Engine Power Peak/ kW	21.0	19.9	20.2	20.9	1.3
Fuel consumption/ h	13.1	12.5	14.7	15.9	0.9
Engine Power Loss/ kW·m⁻²	6.2	6.2	6.7	6.2	0.3
Engine Power/SLE/ kW	0.165	0.154	0.133	0.115	ns
Fuel consumption/SLE/ kW·h	0.058	0.057	0.052	0.049	0.00
3D weighted operation/ m²·s⁻¹	0.321	0.312	0.338	0.309	0.01
Work weighted operation/ m²·s⁻¹	0.276	0.267	0.442	0.382	0.02
Speed weighted operation/ m²·s⁻¹	0.151	0.139	0.175	0.162	ns
Long weighted operation/ m²·s⁻¹	0.271	0.254	0.301	0.245	0.01

Performance indicators	1Pass- 1Depth		1Pass- 2Depth		2Pass- 2Depth		P>0.05
Soil A	Rotary tine	Vibrating tine	Rotary tine	Vibrating tine	Rotary tine	Vibrating tine	LSD
	Point	Wing	Point	Wing	Point	Wing	Point	Wing	
Work Depth/ mm	430	340	473	456	400	323	520	440	397	417	467	440	14
Fuel consumption/ ml·hm⁻²	0.343	0.257	0.406	0.306	0.549	0.388	0.580	0.650	0.427	0.368	0.588	0.671	0.040
SLE/ %	27.5	15.2	31.6	24.4	33.3	19.1	44.7	47.5	22.2	47.0	37.3	49.1	9
Engine Power Peak/ kW	22.3	21.3	17.3	31.4	19.1	17.7	28.3	25.6	21.5	19.8	31.0	29.4	2.2
Fuel consumption/ h	13.4	13.1	11.5	15.4	12.5	12.0	14.3	14.2	13.2	12.7	15.2	14.4	ns
Engine Power Loss/ kW·m⁻²	6.9	6.4	6.3	7.5	3.9	4.0	4.6	3.4	8.7	5.4	8.5	6.8	0.6
Engine Power/SLE/ kW	0.095	0.149	0.087	0.077	0.057	0.092	0.057	0.054	0.157	0.079	0.145	0.094	0.009
Fuel consumption/SLE/ kW·h	0.057	0.060	0.046	0.052	0.033	0.045	0.032	0.030	0.110	0.052	0.074	0.054	0.002
3D weighted operation/ m²·s⁻¹	0.322	0.308	0.603	0.357	0.317	0.333	0.510	0.376	0.349	0.329	0.670	0.708	ns
Work weighted operation/ m²·s⁻¹	0.197	0.135	0.443	0.327	0.210	0.227	0.357	0.297	0.228	0.168	0.527	0.553	0.057
Speed weighted operation/ m²·s⁻¹	0.151	0.105	0.202	0.203	0.143	0.149	0.214	0.202	0.168	0.155	0.234	0.270	ns
Long weighted operation/ m²·s⁻¹	0.214	0.167	0.324	0.300	0.166	0.205	0.270	0.370	0.202	0.228	0.339	0.478	ns

Table 2 Results of Analysis of variance on the experiment 2 subsoiling capacity, efficiency and vibration performance indicators.

Performance indicators	1Pass-1Dem		1Pass-2Dem		2Pass-2Dem				P>0.05
	Rigid tire		Vibrating tire		Rigid tire		Vibrating tire		
SoilB	Plain	Wing	Plain	Wing	Plain	Wing	Plain	Wing	LSD
Max. Depth/mm	-404	-327	-451	-357	-408	-323	-472	-415	-337	-307	-497	-382	9
Area/m²·m⁻¹	0.245	0.245	0.282	0.228	0.149	0.265	0.149	0.208	0.144	0.204	0.266	0.234	0.020
SE/kJ	168	203	284	233	285	212	333	284	191	326	375	356	9
Engine Power/kW	203	172	265	170	199	163	255	214	196	160	264	167	35
Fuel consumption/kg·h⁻¹	12.8	11.8	14.3	11.7	12.7	11.8	14.1	13.8	10.1	11.4	14.9	11.6	1.1
Engine Power/Area/kW·m⁻²	82.1	48.9	67.8	46.7	43.5	46.1	57.1	42.5	67.2	49.6	73.8	53.4	9.5
Engine Power/SE/kW·J⁻¹	0.138	0.085	0.094	0.073	0.068	0.080	0.077	0.062	0.145	0.087	0.118	0.087	0.015
Fuel consumption/SE/(kg·J⁻¹)	0.088	0.058	0.051	0.050	0.045	0.056	0.042	0.050	0.110	0.065	0.069	0.062	0.005
3D weighted sear.m³													
Ver. weighted sear.m²	not a complete data set												
Lateral weighted sear.m²													
Long. weighted sear.m²													

Performance indicators	1Pass-1Dem				1Pass-2Dem				2Pass-2Dem				P>0.05
	Rigid tire		Vibrating tire		Rigid tire		Vibrating tire		Rigid tire		Vibrating tire		
SoilB	Plain	Wing	Plain	Wing	Plain	Wing	Plain	Wing	Plain	Wing	Plain	Wing	LSD
Max. Depth/mm	-404	-327	-451	-357	-408	-323	-472	-415	-337	-307	-497	-382	9
Area/m²·m⁻¹	0.245	0.245	0.282	0.228	0.149	0.265	0.149	0.208	0.144	0.204	0.266	0.234	0.020
SE/kJ	168	203	284	233	285	212	333	284	191	326	375	356	9
Engine Power/kW	203	172	265	170	199	163	255	214	196	160	264	167	35
Fuel consumption/kg·h⁻¹	12.8	11.8	14.3	11.7	12.7	11.8	14.1	13.8	10.1	11.4	14.9	11.6	1.1
Engine Power/Area/kW·m⁻²	82.1	48.9	67.8	46.7	43.5	46.1	57.1	42.5	67.2	49.6	73.8	53.4	9.5
Engine Power/SE/kW·J⁻¹	0.138	0.085	0.094	0.073	0.068	0.080	0.077	0.062	0.145	0.087	0.118	0.087	0.015
Fuel consumption/SE/(kg·J⁻¹)	0.088	0.058	0.051	0.050	0.045	0.056	0.042	0.050	0.110	0.065	0.069	0.062	0.005
3D weighted sear.m³	0.145	0.119											
Ver. weighted sear.m²	0.225	0.164											
Lateral weighted sear.m²	0.223	0.235											
Long. weighted sear.m²	0.234	0.149											

Table 3 Results of Analysis of variance on the experiment 2 subsoiling capacity, efficiency and vibration performance indicators.

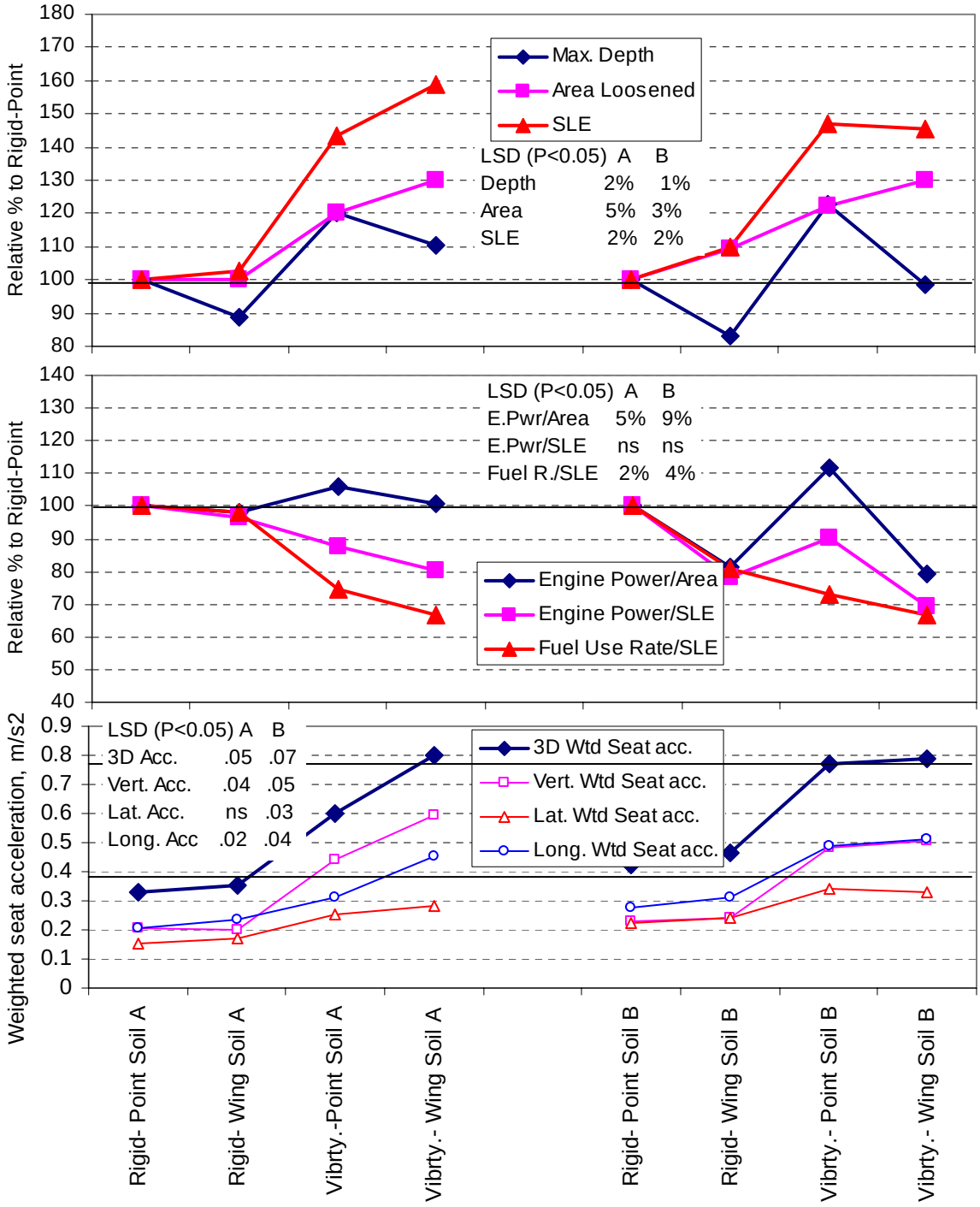


Figure 15. Relative comparison of subsoiling capacity (depth, area, SLE), efficiency (Power and fuel compared to area and SLE) and weighted 3D seat acceleration of implement combinations.

The overall effect of dual tine depth layout and twin passing strategies is shown in Figure 19. It is observed that while the maximum depth of tillage remained similar, using dual tine depth layouts saw significant increases in area loosened and SLE in the order of 35-45% compared to a single pass with deep tines only. Using two loosening passes instead, increased the area loosened by an additional 15-20%. It is expected that this might have been even greater had the full draft capacity of the tractor of around 26kN, been applied rather than 13kN to the first pass. In a practical application of this approach, it would be expected that a separate (simpler conventional) ripper on a separate tractor would

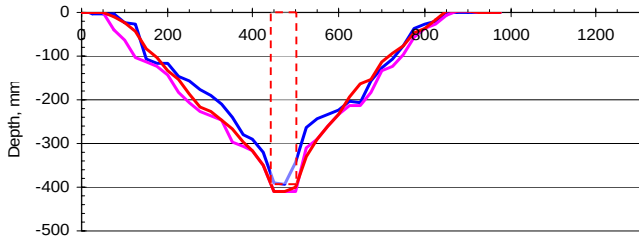
be used to conduct the first pass such that the issues described above could be overcome. The first pass of the two-pass approach has limited tine-positioning options, as firm wheel tracks zones need to be retained between the loosened zones to deliver the traction needed for the second pass. It was found that both winged arrangements benefited most from the first pass as soil failure from the wing tips (wider disturbance) could easily break through to the soil loosened by the first pass giving much greater soil disturbance. Comparatively the wingless arrangements almost operated independently within the soil loosened by the first pass such that only minimal break through occurred and mostly close to the surface.

Subsoiling efficiency.

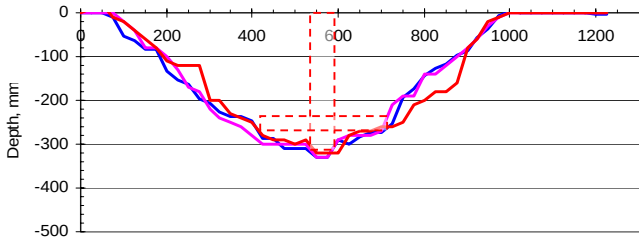
Whilst the subsoiling capacity maybe increased by wings, vibration, dual depth or dual pass configurations, the cost in efficiency of transferring tractor engine power to the subsoil loosening needs to be considered. Traditionally, subsoiling efficiency may be compared in terms of draft force required to loosen the cross-sectional area, this would be appropriate if the soil was homogenous and draft (or drawbar power) was the only transfer of tractor output to the soil loosening operation. However where tines are oscillated and power is also taken from the PTO, it is more representative to consider overall power input to the ripper. However, as transfer of power through the PTO and tyre/soil interaction have varying efficiencies, the power to conduct the operation at the engine flywheel was the basis considered, which is the maximum power, the operator has as a resource. In Figure 10 a comparison of this power to both area loosened and the SLE parameter have been made. In soil A, engine power to area loosened was similar for all four configurations whilst in soil B gains of 20-30% were made when the wings were added. In both soils gains of about 10% in efficiency (power/SLE) were made with vibrating wingless tines, when wings were added this efficiency improved by a further 10-20%. If fuel use was compared to SLE efficiencies increased further, due to fuel use becoming more economical as more of the tractor available power is used. As vibrating the tines at the 2.5km/h speed used more of the available engine power, fuel use efficiency looked more favourable. In reality, operating the rigid configurations at higher speed (also using more of the available engine power) could effectively improve the engine's fuels use economy to a similar level.

Implementing the one pass dual depth configuration achieved gains of 20-40% in tractor output use compared to two single tines used in one pass. The reason is that the strategically placed shallow tines improve the loosening capacity (cross-sectional area) and efficiency (draft) at depth of the deep tines. Without shallow leading tines, soil failure at depth can be constrained by critical depth where the soil tends to be compacted to either side of the tine rather than failed upwards. Similar gains should be expected using the dual pass approach, however the strategic placement of the tines is more difficult to achieve successfully. The graph of Figure 19 shows the performance averaged for both wingless and winged arrangements. However, considered gains in efficiency are made with both winged arrangements compared to a single pass single depth approach as the placement of the first pass tines suits the wings best (which is not reflected in the averaged data). The wingless tines in the second pass, however, do not effectively interact, failing soil across to the first pass loosened soil zone, but almost operating independently thus reducing their potential efficiency Figure 16 & Figure 17 & Figure 18. The differences in the three efficiency indicators is small as effectively on average all configurations operated to a similar depth.

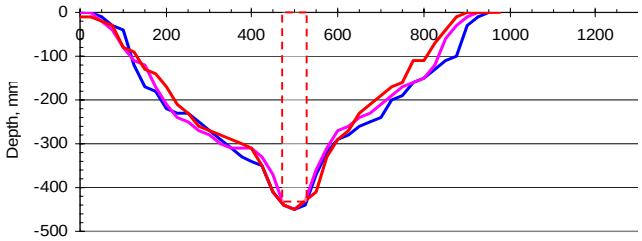
1Pass-1Depth
Rigid Point



1Pass-1Depth
Rigid Wing



1Pass-1Depth
Vibratory Point



1Pass-1Depth
Vibratory Wing

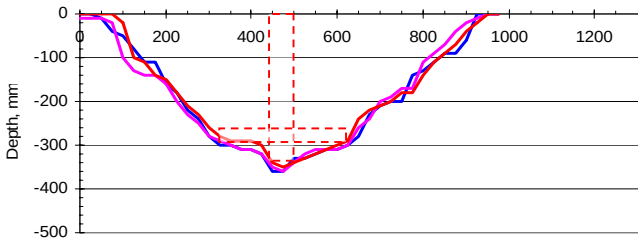
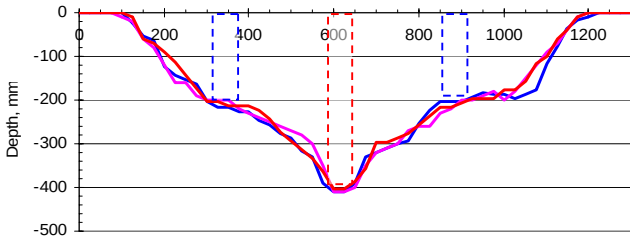
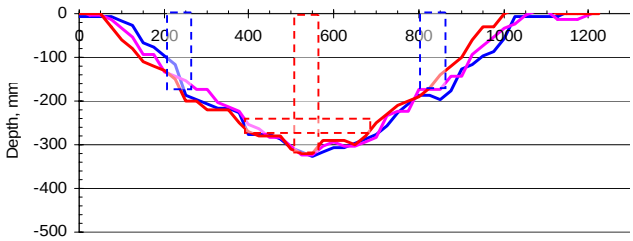


Figure 16 Experiment 2 Loosened soil profile shapes for Soil B

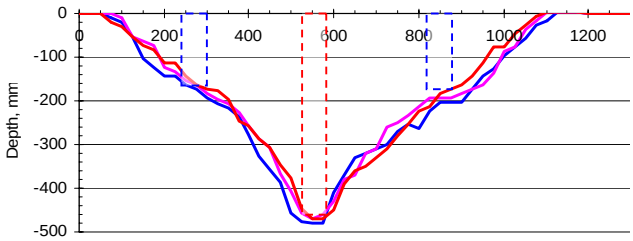
1Pass-2Depth
Rigid Point



1Pass-2Depth
Rigid Wing



1Pass-2Depth
Vibratory Point



1Pass-2Depth
Vibratory Wing

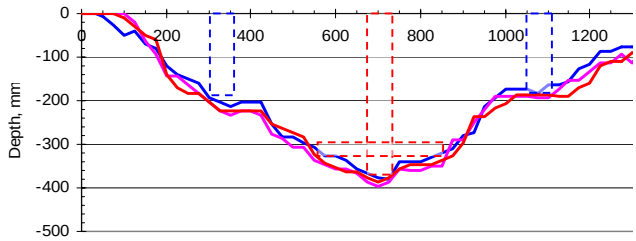


Figure 17 Experiment 2 Loosened soil profile shapes for Soil B

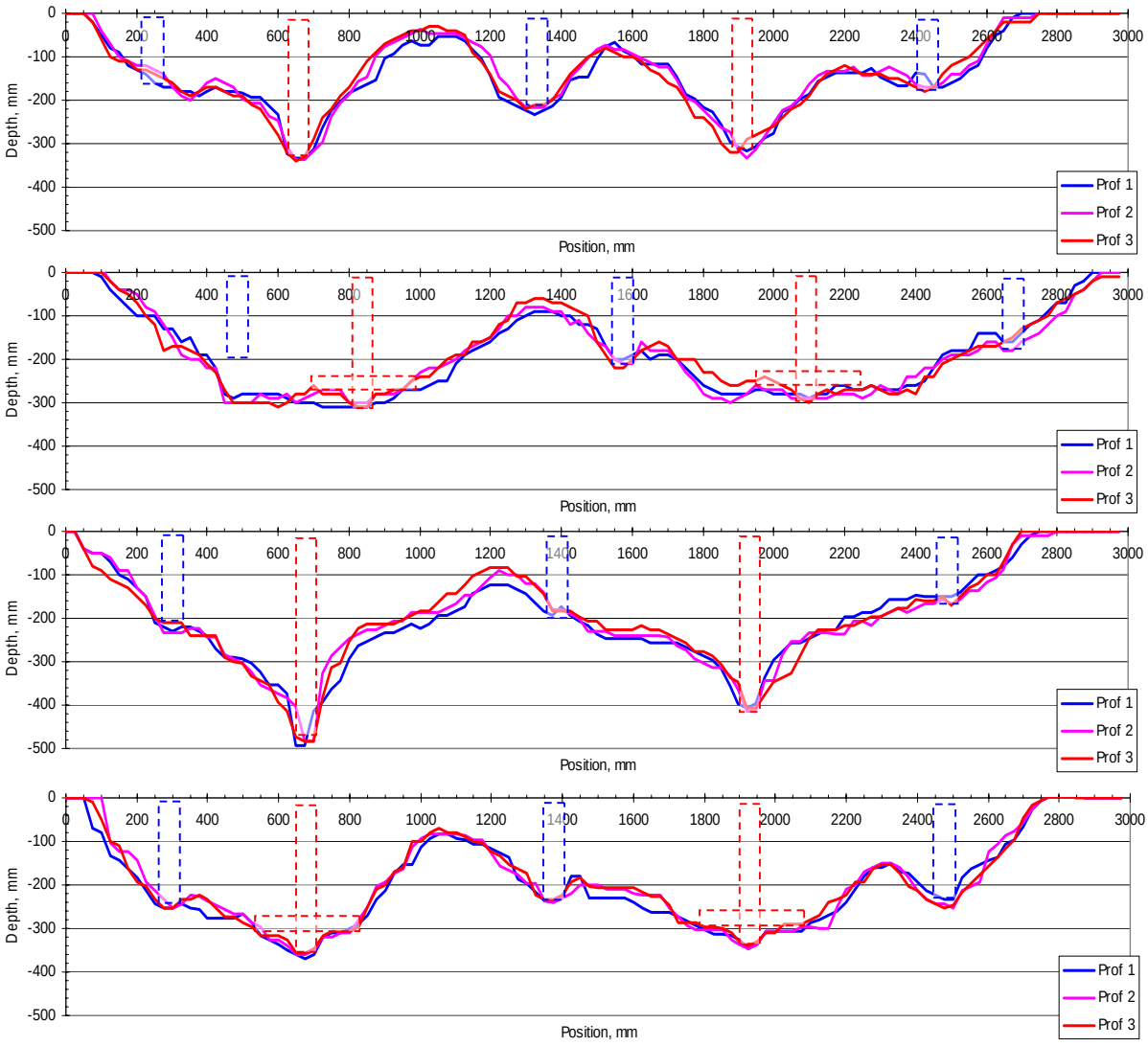


Figure 18 Experiment 2 Loosened soil profile shapes for Soil B

The soil profiles are of the following configurations, from Top to Bottom

2Pass-2Depth
Rigid Points

2Pass-2Depth
Rigid Wings

2Pass-2Depth
Vibratory Points

2Pass-2Depth
Vibratory Wings

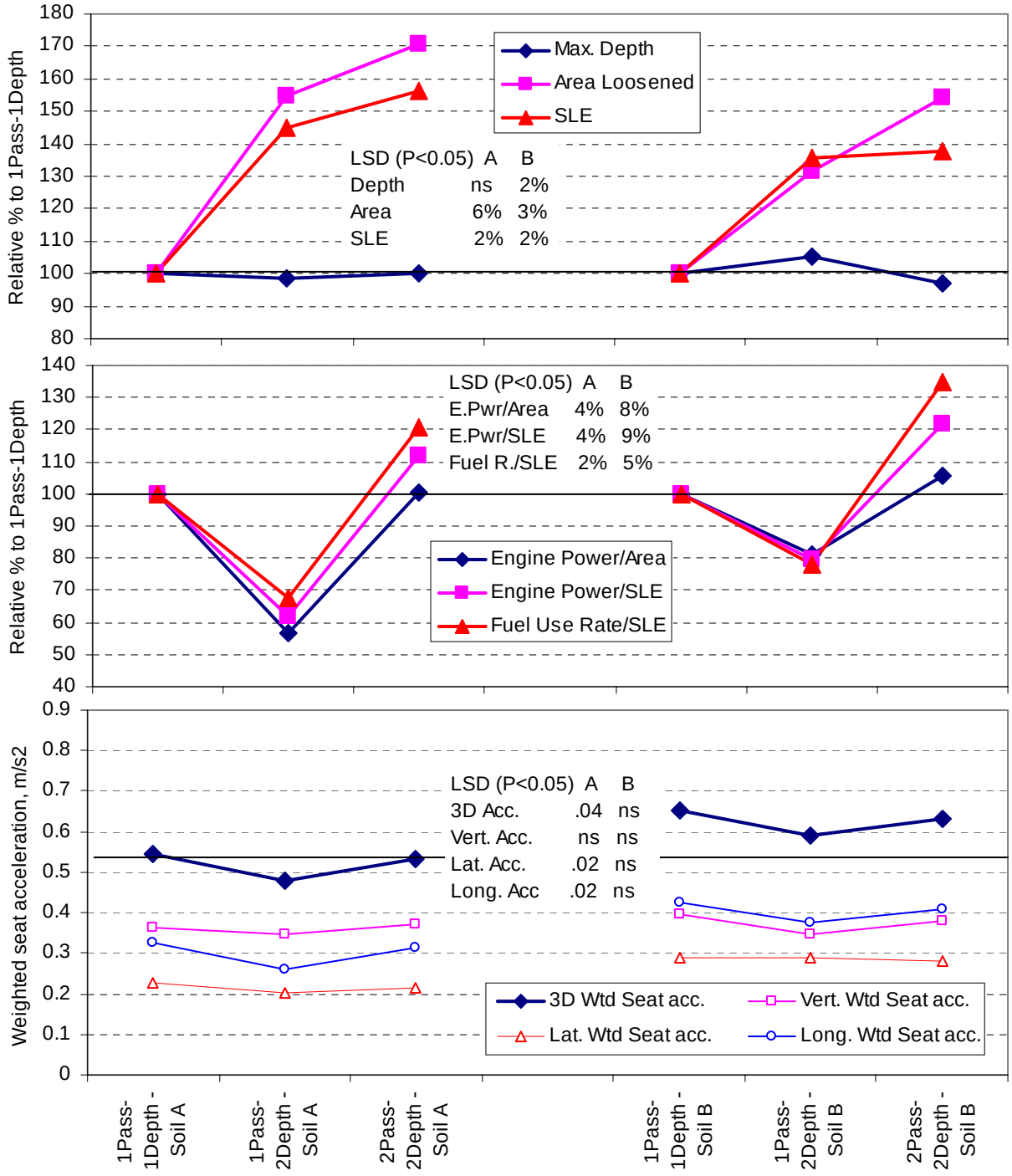


Figure 19. Relative comparison of subsoiling capacity, efficiency and weighted 3D seat acceleration of three loosening strategies.

Driver and tractor comfort levels

Vibrations at the seat affecting operator fatigue and comfort were determined according to AS 2670.1-2003 as weighted acceleration values. Operating the oscillating tines increased the level of seat vibration, by a considerable level over that of a similar rigid tine system operated at 2.5km/h. Adding wings to the oscillating tines was found to increase the seat vibration levels in soil A but not in soil B. In soil B the higher strength drier soil at depth may have resulted in large reaction forces and greater

vibrations for both point and wing configurations. Winged configurations generate larger reaction forces as the wings interact with a greater volume of soil at almost the full stroke length of the oscillation. This increase in soil A showed a marked increase the vertical and longitudinal acceleration components rather than lateral acceleration, indicating that the rolling drawbar modification was effective at minimising that component. A small reduction in seat vibration was observed when shallow rigid tines are used ahead of the oscillating tines as in the 1-pass-2-depth scenario. This is brought about by the stabilising and damping effect of these tines thus reducing the size of the excitation forces transferred to the tractor that are responsible for vibration of tractor and operator. This effect mostly influenced the vertical and longitudinal acceleration components. It was observed when using the vibrating tines with the wings that the tractor and operator were subject to quite severe vibrations as the wings entered the soil, but gradually settled down to a more acceptable level on approaching the operating depth.

Benefits to vineyard subsoil management

The results of this experiment can be used to plan any vine inter-row subsoil loosening strategy. The approach taken is dependent on the subsoil constraints present. If depth is to be maximised to ensure breaking through deep compaction layers (within 500mm) then wingless vibrating tines would be used. However, if the area disturbed is to be maximised with the highest efficiency a dual depth approach should be used with wings fitted to the deep tines. The loosening depth and area can be further increased if the deep tines are oscillated. Oscillating the tines however tends to increase operator/seat vibration levels. These are at acceptable levels (as per AS 2670.1 2003) when no wings are used but tend to approach unacceptable levels where wings are used. The dual pass approach would have a greater potential than was realised in this trial due to practical issues specific to this heavy ripper prototype (ie. avoidable with lighter conventional technology used for the first pass). To the two-pass option, wings need to be used on the deep tines or alternatively, strategically positioned leading shallow tines could be included on the second pass.

Comparison of the characteristics of different ripper tine designs (Exp 3)

Soil conditions

The two soil types used were of similar make up to soils A and B as described in Experiment 1 and more details of the properties are given in that section. The soil strength, density and moisture content however where the same as that of Experiment 4 and can be seen in Figure 28 and Figure 28. Once again the soil density was determined by using sampling cylinders while moisture content was gained from augered soil samples. An indication of soil strength was also found by conducting cone index probes across each block of each experiment.

Subsoilers investigated

The following subsoilers (Figure 20 & Figure 21.) were used in the tests with commercial units loaned for the testing from the participating manufacturers. In Experiment 3, each unit was operated with two tines:

1. Vibratory ripper University of SA (UniSA) prototype rigid configuration, wingless tines fitted only.
2. Vibratory ripper UniSA prototype vibratory configuration, same wingless tines fitted. The vibratory settings used were 0° tine angle of vibration, a 70mm amplitude, high velocity ratio (3.0) and an oscillating frequency of 4.8Hz (1000rpm PTO)
3. Agrowplow three-point linkage (3PL) mounted ripper with depth wheels: common subsoiler tine design with 50mm wide point shallow rake angle and almost vertical tine shank.
4. Red Rhino 3PL ripper: ripper had 50mm wide tips fitted to parabolic shaped tines shanks (side view) with a knife like leading edge. A smooth levelling roller was fitted to the rear of the ripper which also provided depth control.
5. Paraplow trash clearance tines: these were fitted to the university designed 3PL ripper frame with adjustable rear depth wheels. Due to the size of these tines and mounting arrangement, their mounting was restricted to the outsides of the ripper frame, such that they operated in

soil outside the tractor wheel tracks unlike the other rippers. These tine shanks were very long (1000mm clearance below the frame to tip) the lower part of the shank was angled to the side at about 45° to the vertical this design is used such that the shank passes close to the natural failure line produced by the tip. This in effect should reduce the draft compared to a vertical shank that is required to fail or push loosened soil and clods to either side. The very low rake angle of the lower part of the shank would also tend to lower draft compared to a more vertical shank as loosened soil is more easily lifted against air than pushed ahead into loosened soil.

6. Grizzly, Michel tines, these were also fitted to the university designed 3PL frame fitted with the same rear depth wheels. These tines were shaped where the shank curved to the side (parabolic) such that the shank approximately follows the natural failure zone created by the tip, that should lower draft similarly to the paraplow tine. The rake angle of the shank however was much higher than that of the paraplow tine.



Figure 20. Rippers used in these experiments.



Figure 21. Photographs showing approximate relative size, shape and operating orientation of the commercial ripper tines (left to right - Paraplow, Michel, RedRhino and Agrowplow designs

Determination of tine type performance characteristics

To enable performance comparisons of the various tine designs and modes of operation all tines were operated to the same depth. Control of the set depth was maintained either with depth wheels or a trailing roller. This depth (325mm and 300mm in soil A and B respectively) was determined as the maximum capacity of the two-tine Agrowplow configuration. Due to small variations in actual measured depths, a less biased, corrected draft and power value was used in the comparison. This

correction was based on the assumption that draft is proportional to the square of the ripping depth. However in comparing efficiencies the actual measured draft, power and fuel use were compared to the measured loosened area and SLE values. In addition tractor power was corrected for minor variations in ground speed.

The determination of depth, loosened area and SLE were similar to that used in Experiment 4, with the profiles found for the soil disturbed by both left and right tines. In this experiment) while the draft force of the UniSA prototype ripper was measured with a hitch mounted shear pin, this could not be used with the 3PL mounted commercial rippers. To overcome this, a second larger tractor was used to tow the vineyard tractor and ripper combination with a draft force transducer mounted in the tow cable. A rolling resistance factor obtained by towing the tractor with the ripper raised was then subtracted from the value obtained when ripping. To obtain wheel slip an additional run was conducted where the tractor was not towed. The other measurements were determined as for Experiment 1.
A breakdown in the instrumentation resulted in a delaying the experiment during which time a 30mm rainfall event occurred before the UniSA prototype ripper treatments could be completed. Unfortunately this resulted in much wetter soil conditions that inturn influenced the soil physical characteristics and performance of the UniSA ripper configurations. Thus a true comparison between the UniSA and commercial rippers could not be made.

Draft results

The ranking of draft force requirements (Figure 22) was found to be in the main similar in both soil types for the range of tine designs investigated. Overall the draft in Soil A was 33% greater than in Soil B. This difference was due to the variation in soil strength in Soil B, where the depth selection was based in the higher strength soil. In both soils the lowest draft was achieved with the UniSA vibratory ripper and the Paraplow tines, which was 18 to 27% less than the next lowest draft of the Grizzly Michel tine. However compared to the Agrowplow tine with a design similar to a number of commercial rippers the UniSA vibratory and Paraplow ripper were found to require 43% less draft in Soil A and 36% less in Soil B

In both soil types the greatest draft was required for the Agrowplow tines; in Soil A this draft at 20.3kN was significantly greater than all other tine designs. However in Soil B where a draft of 13.6kN was obtained, a similar draft was also found necessary to operate the RedRhino, Grizzly-Michel and UniSA prototype in the Rigid ripper configuration.

Overall there were found to be significant reductions in draft requirements by using either the UniSA Vibratory or Paraplow ripper in both soils compared to all the other ripper designs and configurations. In Soil B the variability of soil strength across the plots and the high strength at depth may have resulted in the tine tip forces dominating the draft measurements while minimising beneficial draft reduction influence of the tine shank shape. It is thought that the very low rake angle and side inclined shank of the Paraplow combined to give the very low draft performance. These tines were also very long and thus the shank rake angle was very low over the full operating depth used, compared to the near vertical rake angle of the other tines close to the soil surface. In Soil A the tine design (and particularly the shank shape) appears to have had a greater influence on the draft requirements. This is thought to be a result of the greater operating depth and more uniform soil strength throughout this depth. Under soil B conditions the Agrowplow ripper required the greatest draft whilst the RedRhino and UniSA rigid ripper performed similarly, however in Soil A they required 12 and 17% lower draft than that of the Agrowplow ripper respectively.

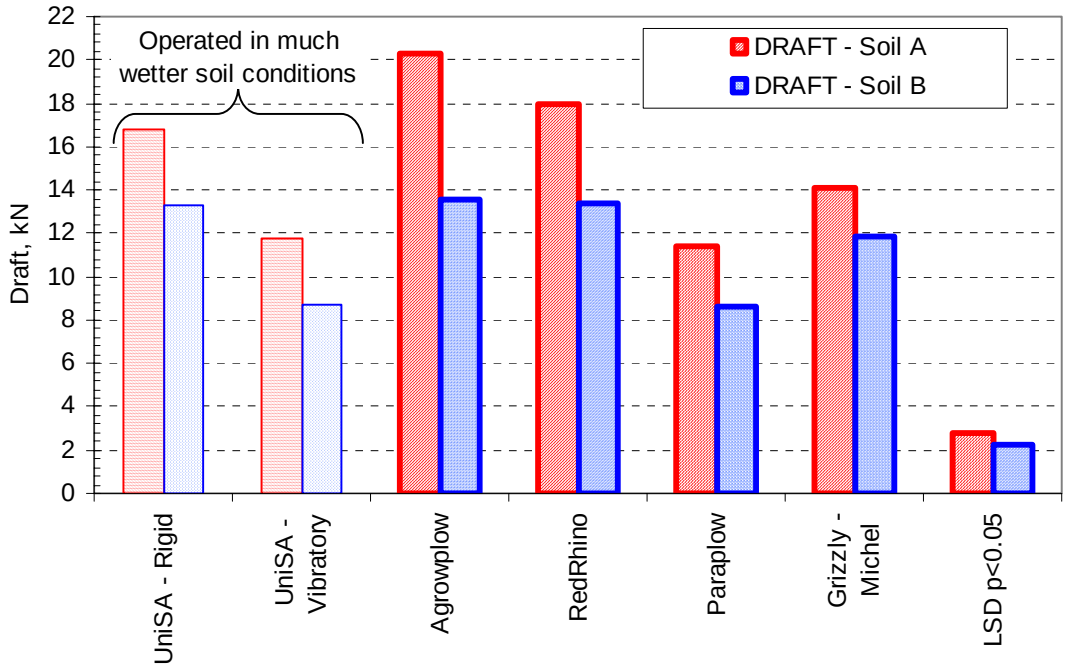


Figure 22. Draft force measured and adjusted for depth variation in soil A and B Fabals 2003. Note: Treatments where the difference is greater than the LSD are considered to be statistically different.

Specific draft (draft/area loosened) Results.

The specific draft results Figure 23, do not show quite the same response in tine type ranking in both soils. Specific draft is based on actual measured draft required to loosen the measured area. Specific draft gives an indication of the ripper design's efficiency at soil loosening with lower specific draft resulting in lower draft requirements to loosen a similar cross-section of subsoil.

In soil A the specific draft was found to be considerably lower for the UniSA vibratory, Red Rhino and Paraplow tines compared to the UniSA Rigid, Agrowplow and Michel tines. In soil B the paraplow tine had the lowest specific draft, followed by the Agrowplow and UniSA vibratory tines, with the UniSA rigid and Red Rhino significantly greater than these while the Michel tine was ranked between these two groups of tines..

The Paraplow and UniSA Vibratory ripper had the lowest specific draft in Soil A at 54.6 and 57kN/m2 that were significantly lower (24-35%) than the similarly ranked Michel, Agrowplow and UniSA rigid rippers. While a slightly higher specific draft was measured for the RedRhino ripper design it was not found to be significantly greater than the Paraplow and Vibratory ripper configurations when operating in Soil A. In Soil B the Paraplow again performed the best with a specific draft of only 33.6kN/m2 that was 30 to 35% better than the next lowest Agrowplow and Vibratory tine designs whilst requiring around half the specific draft of the Michel, RedRhino and UniSA rigid rippers. In terms of specific draft the Michel tine is ranked more poorly than when comparing draft this is due to the sharp tip used compared to the 50mm wide chisel type point used on all the other tines, resulting in less soil loosened when operated to the same maximum depth. In Soil B the specific draft of the RedRhino tine is high and does not follow the apparent trend of the other rippers with a lower specific draft in Soil B than in Soil A. There is no clear reason for this difference.

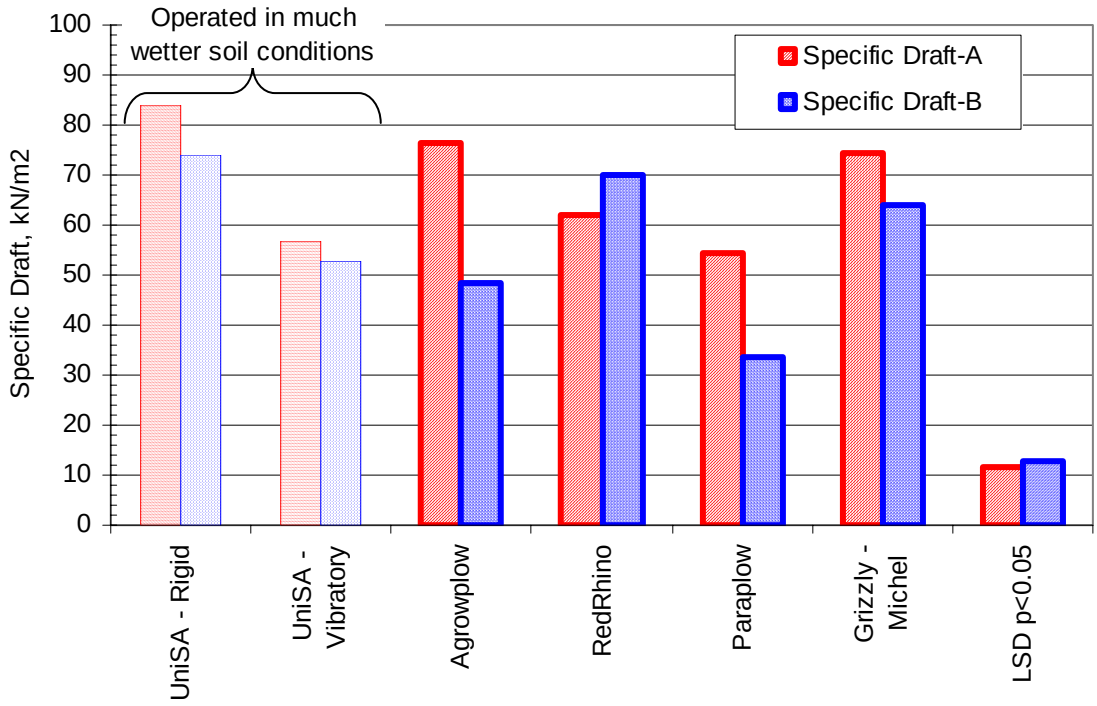


Figure 23. Specific draft data from both Soil A and B.

Ripper related engine power requirements

As expected the engine power response (Figure 24) is very similar to the draft (variations in ranking occur due to small differences in tractive efficiency and the PTO power requirements of the vibratory ripper). Thus in terms of engine power use the vibratory tine was the most demanding in soil B. In Soil A the Agrowplow ripper required the largest engine power use that was not significantly greater than the vibratory ripper. It should be remembered that where tractor power is not limiting but traction is, this higher power demand with low draft of the UniSA vibratory ripper, may not necessarily be a limitation.

Energy efficiency in loosening the subsoil results

Whilst we can compare the draft and power used by each ripper to operate at about the same depth, it is also important to consider the amount of subsoiling work done by the ripper. Had all tine types operated at the same depth (exactly) and loosened the same area to the same shape, this would have little effect as to just comparing engine power or draft. Thus we can better equate efficiencies of soil loosening for the inputs required.

As the area and shape of loosened soil varied then so also did the energy requirements to loosen that soil. The changes in soil strength with depth will influence the ripper effort required in loosening this soil. By using the Cone Index as a measure of this and combining with the area and shape of soil loosened, a Soil Loosening Energy (SLE) parameter was established for each ripper.

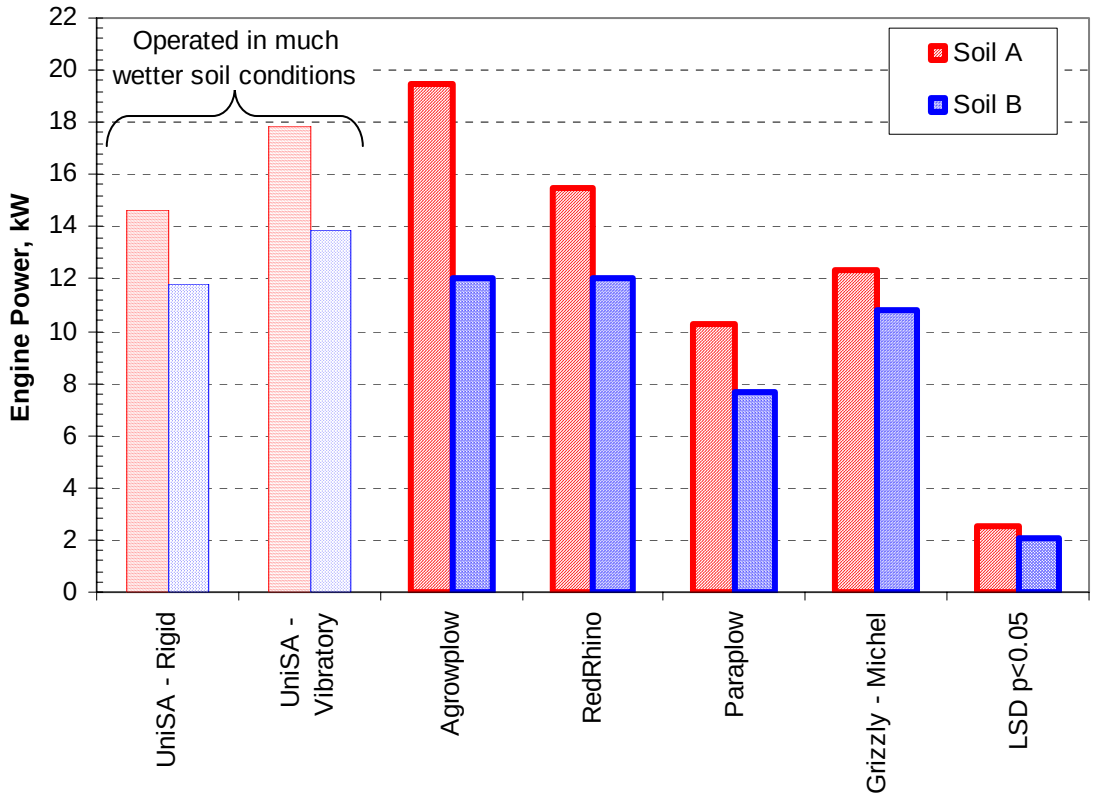


Figure 24. Calculated engine power required to operate each ripper.

The Paraplow made the most efficient use of tractor fuel (Figure 25) to loosen the subsoil in both soils conditions, however in Soil A this was not significantly better than the RedRhino ripper. In Soil A these two rippers were 11 to 15% more efficient than the Agrowplow ripper and 29 to 30% more efficient than the Michel type ripper. However the UniSA rigid and vibrating rippers had similar poor efficiencies that were 40% behind that of the Paraplow and RedRhino rippers in Soil A. The Paraplow ripper was 27% more efficient than the Agrowplow and 49 to 53% better than the group of RedRhino, Michel and UniSA Rigid that were all ranked together in Soil B. The UniSA vibrating ripper was found to be the least efficient being 62% less efficient than the Paraplow ripper in this soil type. The poor efficiency of the UniSA rigid and vibratory rippers can be explained in part by operating in wetter soil conditions where lower soil strength would have tended to reduce the fracturing and hence cross section of soil loosened.

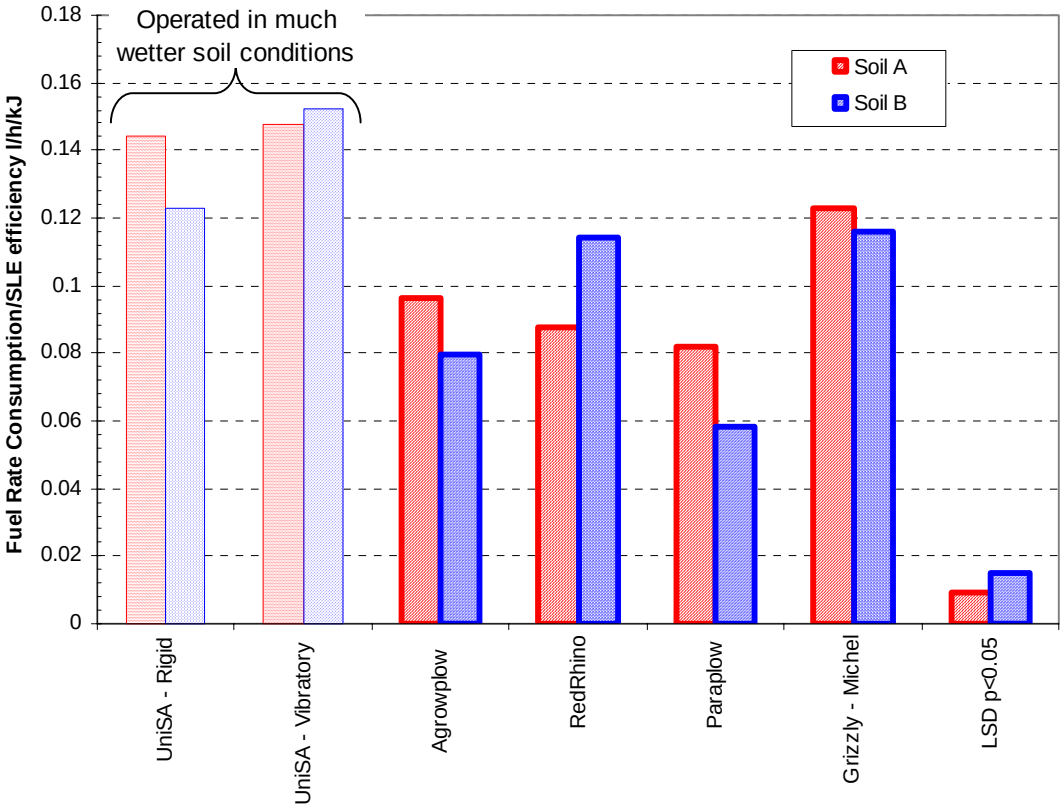


Figure 25. Efficiency of the rippers at using tractor fuel to provide Soil Loosening Energy.

A tabulated summary of the results from which the graphs in the section were produced can be found in Table 4

Experiment 3 Soils A and B FABALS 2003

Ripper tyne type rankings

DRAFT Soil-A (corrected)		5%	10%
Paraplow	11.4	14.2 a	13.6 a
Vibrtry	11.8	14.5 a	14.0 a
Michel	14.1	16.9 ab	16.4 b
Rigid	16.8	19.6 b	19.1 c
RealRhino ...	17.9	20.7 bc	20.2 c
Agrowplo	20.3	23.1 c	22.6 d
LSD p<0.05	2.8		
LSD p<0.1	2.3		
kN			

Spec Draft Soil-A		5%	10%
Paraplow	54.6	66.1 a	63.9 a
Vibrtry	57.0	68.5 a	66.3 a
RealRhino ...	62.0	73.5 a	71.3 a
Michel	74.4	85.0 b	83.7 b
Agrowplo	76.4	87.9 b	85.8 bc
Rigid	83.9	95.4 b	93.3 c
LSD p<0.05	11.5		
LSD p<0.1	9.3		
kN/m^2			

Eng Power Soil-A (corr.)		5%	10%
Paraplow	10.2	12.8 a	12.3 a
Michel	12.4	14.9 ab	14.4 b
Rigid	14.6	17.2 bc	16.7 c
RealRhino ...	15.5	18.0 cd	17.6 c
Vibrtry	17.9	20.4 de	19.9 d
Agrowplo	19.5	22.0 e	21.6 d
LSD p<0.05	2.5		
LSD p<0.1	2.1		
kW			

Fuel Rate/S.I.E Soil-A		5%	10%
Paraplow	0.0821	0.0912 a	0.0895 a
RealRhino ...	0.0874	0.0955 a	0.0948 a
Agrowplo	0.0964	0.1055 b	0.1038 b
Michel	0.1228	0.1319 c	0.1302 c
Rigid	0.1439	0.1530 d	0.1513 d
Vibrtry	0.1479	0.1570 d	0.1553 d
LSD p<0.05	0.0091		
LSD p<0.1	0.0074		
l/hr/J			

DRAFT Soil-B (corrected)		5%	10%
Paraplow	8.6	10.9 a	10.4 a
Vibrtry	8.7	11.0 a	10.6 a
Michel	11.8	14.1 b	13.7 b
Rigid	13.3	15.6 b	15.1 b
RealRhino ...	13.3	15.6 b	15.2 b
Agrowplo	13.6	15.8 b	15.4 b
LSD p<0.05	2.3		
LSD p<0.1	1.9		
kN			

Spec Draft Soil-B		5%	10%
Paraplow	33.6	46.3 a	43.9 a
Agrowplo	48.4	61.1 b	58.8 b
Vibrtry	52.7	65.5 bc	63.1 b
Michel	63.9	76.6 cd	74.2 c
RealRhino ...	70.2	82.9 d	80.5 c
Rigid	73.9	86.7 d	84.3 c
LSD p<0.05	12.7		
LSD p<0.1	10.3		
kN/m^2			

Eng Power Soil-B (corr.)		5%	10%
Paraplow	7.7	9.8 a	9.4 a
Michel	10.8	12.9 b	12.6 b
Rigid	11.8	13.9 bc	13.5 b
RealRhino ...	12.0	14.1 bc	13.7 b
Agrowplo	12.1	14.2 bc	13.8 b
Vibrtry	13.9	16.0 c	15.6 c
LSD p<0.05	2.1		
LSD p<0.1	1.7		
kW			

Fuel Rate/S.I.E Soil-B		5%	10%
Paraplow	0.0583	0.0734 a	0.0706 a
Agrowplo	0.0797	0.0949 b	0.0921 b
RealRhino ...	0.1145	0.1296 c	0.1268 c
Michel	0.1161	0.1312 c	0.1284 c
Rigid	0.1229	0.1381 c	0.1352 c
Vibrtry	0.1525	0.1676 d	0.1648 d
LSD p<0.05	0.0152		
LSD p<0.1	0.0123		
l/hr/J			

Note: 5% and 10% indicate statistical levels of confidence, same letters indicate that the rippers (treatments) are no different whereas differing letters indicate significant differences

Table 4 Tine type and rankings for Draft, Specific Draft, Engine Power and Fuel used

Comparison of subsoiling capacity and energy efficiency of a range of ripper designs (Exp 4)

Soil conditions

The testing was conducted in two different soil types with the same properties as the rest of the experiments, a profile of which can be seen in Figure 26:



Figure 26 Soil profiles - left is soil condition A and right Soil condition B.

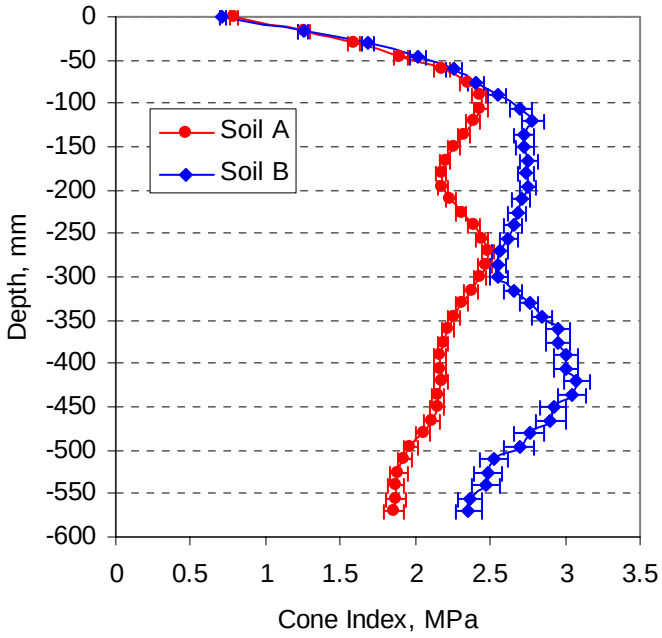


Figure 27 Soil strength profile as determined by a cone penetrometer for the two soil conditions.

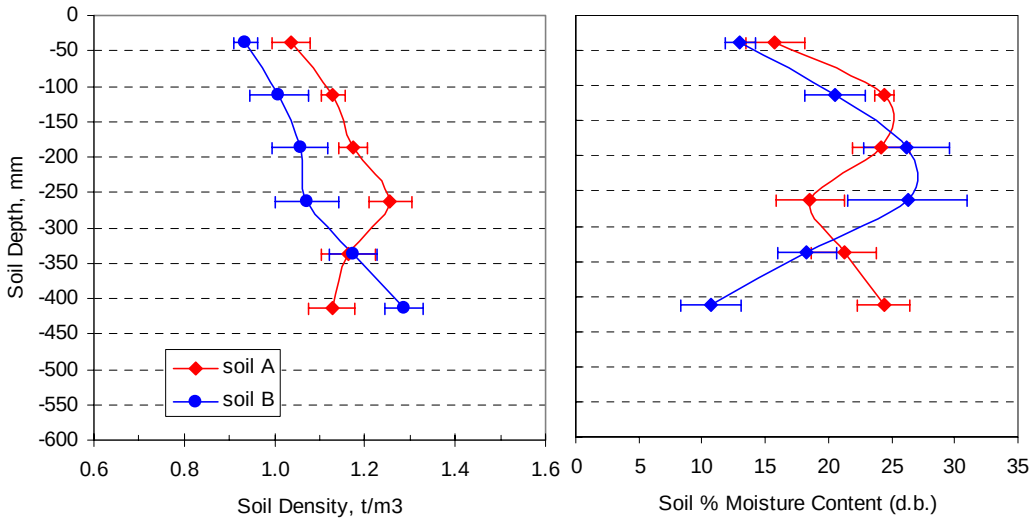


Figure 28 Soil density and moisture contents of soil conditions A and B.

Soil density was determined by using sampling cylinders while moisture content was gained from augered soil samples. An indication of soil strength was also found by conducting cone index probes across each block of each experiment. The cone index measure of soil strength is shown in Figure 27 along with the corresponding soil density, and moisture contents Figure 28. In soil B at the change in soil type to sand an increased cone index value, increased density and lower moisture content can be observed.

Subsoilers investigated

The following subsoilers (Figure 29) were used in the tests with commercial units loaned for the testing from the participating manufacturers.

1. Vibratory ripper University of SA (UniSA) prototype rigid dual depth configuration, with a pair of shallow leading rigid tines positioned to each side and ahead of each of the two deep wingless tines that were spaced 1250mm apart.

2. Vibratory ripper UniSA prototype in vibratory dual depth configuration, arranged similar to the rigid configuration but with the deep tines vibrated. The spacing of the shallow rigid leading tines was adjusted to suit the extra depth that was achieved with the vibratory function. The vibratory settings used were 0° tine angle of vibration, a 70mm amplitude, high velocity ratio (3.0) and an oscillating frequency of 4.8Hz (1000rpm PTO)

3. Agrowplow three-point linkage (3PL) mounted ripper with depth wheels: a common subsoiler tine design with 50mm wide point shallow rake angle and almost vertical tine shank. A 2 and 5-tine variation were evaluated in this experiment.

4. Red Rhino 3PL ripper: ripper had 50mm wide tips fitted to parabolic shaped tines shanks (side view) with a knife like leading edge. A smooth levelling roller was fitted to the rear of the ripper which also provided depth control. Two and 5-tine variants of this ripper were also evaluated.

5. Paraplow trash clearance tines: these were fitted to the university designed 3PL ripper frame with adjustable rear depth wheels. Due to the size of these tines and mounting arrangement, their mounting was restricted to the outsides of the ripper frame, such that they operated in soil outside the tractor wheel tracks unlike the other rippers. These tine shanks were very long (1000mm clearance below the frame to tip) the lower part of the shank was angled to the side at about 45° to the vertical this design is used such that the shank passes close to the natural failure line produced by the tip. This in effect should reduce the draft compared to a vertical shank that is required to fail or push loosened soil and clods to either side. The very low rake

angle of the lower part of the shank would also tend to lower draft compared to a more vertical shank as loosened soil is more easily uplifted against air than pushed ahead into loosened soil.

6. Grizzly, Michel tines, these were also fitted to the university designed 3PL frame fitted with the same rear depth wheels. These tines were shaped where the shank curved to the side (parabolic) such that the shank approximately follows the natural failure zone created by the tip, that should lower draft similarly to the Paraplow tine. The rake angle of the shank however was much higher than that of the Paraplow tine.

Determination of tractor-ripper type capacity

The approach used to determine the maximum capacity for each ripper configuration was to increase the subsoiling depth until the tractor reached a similar level of slip (approximately 12-15%). However, in practice, it was very difficult to achieve a constant draft or wheel slip between treatments due to soil variation (ie. practice area settings did not always give a good indication of plot ripping conditions).

It should be noted that all the 3PL rippers were operated with a floating hitch arrangement with depth controlled by depth wheels or roller. In practice the draft control of the 3PL system could be used to transfer some of the ripper down force (generated by the tine tips pulling into the soil) to the tractor thus effectively increasing the tractor's dynamic weight. This additional weight would increase the tractor's traction and thus generate higher draft that could then potentially increase the subsoil loosening capacity of these 3PL-mounted rippers. Use of the 3PL system to increase the draft was avoided due to the difficulty in keeping this constant throughout the tests and between rippers.

The determination of depth, loosened area and SLE were similar to that used in Experiment 2, with the profiles found for the soil disturbed by both left and right tines. In this experiment while the draft force of the UniSA prototype ripper was measured with a hitch mounted shear pin, this could not be used with the 3PL mounted commercial rippers. To overcome this, a second larger tractor was used to tow the vineyard tractor and ripper combination with a draft force transducer mounted in the tow cable



Figure 29 Photographs showing approximate relative size, shape and operating orientation of the commercial ripper tines (left to right - Paraplow, Michel, RedRhino and Agrowplow designs) and the prototype below.

A rolling resistance factor obtained by towing the tractor with the ripper raised was then subtracted from the value obtained when ripping. To obtain wheel slip an additional run was conducted where the tractor was not towed. The other measurements were determined as for Experiment 1.
A breakdown in the instrumentation resulted in a delaying of the experiment during which time a 30mm rainfall event occurred before the UniSA prototype ripper treatments could be completed.

Unfortunately this resulted in much wetter soil conditions that inturn influenced the soil physical characteristics and performance of the UniSA ripper configurations. Thus a true comparison between the UniSA and commercial rippers could not be made. To provide a comparison data was used from equivalent treatments from Experiment 2. Experiment 2 was conducted adjacent this experiment in a similar soil and immediately prior to this experiment.

Subsoil loosening capacity

One of the main objectives of this investigation was to establish the subsoil loosening capacity of the various ripper designs and configurations when operated behind a 63kW vineyard tractor. As described in Experiment 2, the SLE value is the preferred means of comparing subsoiling capacity of rippers that loosen to differing depths and loosen the subsoil to differing shapes. In Figure 6 the graphs show the rippers ranked by their subsoil loosening capacity for the two soil conditions.

It should be noted that in these results the data used for the rigid and vibratory prototype rippers is taken from a separate experiment and thus should not be analysed statistically with the data of this experiment. However the experiment from which the rigid and vibratory ripper data was taken from was immediately adjacent to the experiment described here and conducted immediately prior to it. Thus the data is expected to be quite close to that which could have been obtained in this experiment had there not been a rain interruption, and has been included in the following comparisons.

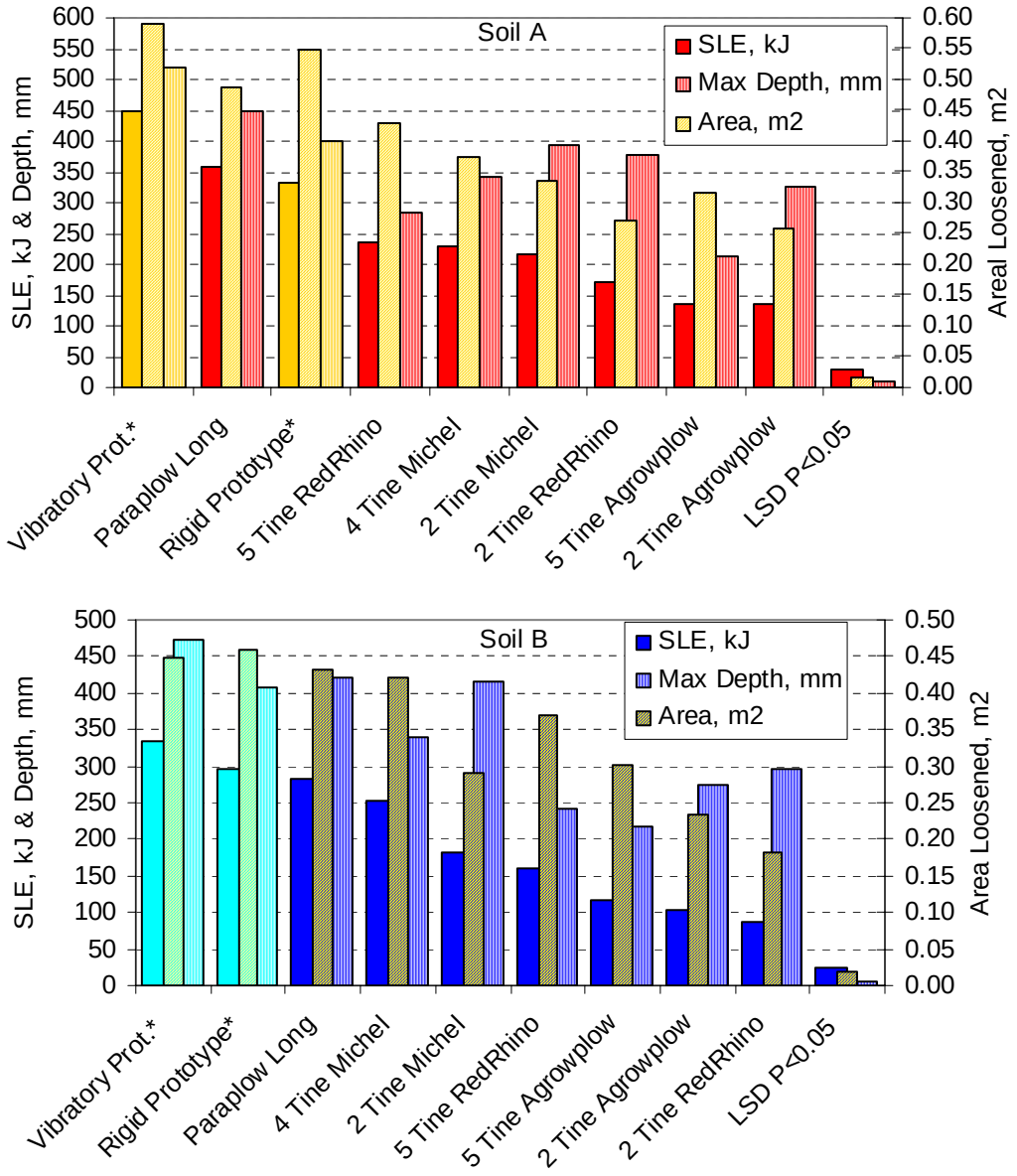


Figure 30. The subsoil loosening capacity of the various ripper configurations, ranked in terms of SLE parameter from left to right for soil conditions A and B. *indicates data from an adjacent experiment. Note: Treatments where the difference is greater than the LSD are considered to be statistically different.

In both soil A and B the greatest subsoiling capacity in terms of SLE was achieved with the dual depth prototype vibratory ripper. The next best were the dual depth rigid prototype and the Paraplow ripper that were both similarly ranked at 74 to 80% in soil A and 85 to 89% in soil B behind that of the vibratory ripper capacity. In soil A the 5-tine RedRhino ripper was ranked similarly with the 2 and 4-tine configurations of the Michel ripper that had a loosening capacity of only 48 to 53% of that of the vibratory ripper. The 2-tine RedRhino ripper was ranked next in loosening capacity in soil A behind these three ripper configurations with a capacity of 38% of the vibratory ripper while the 2 and 5-tine Agrowplow configurations were found to have a capacity of only 31% of the vibratory ripper. While in soil B, after the Paraplow and rigid prototype rippers the next highest capacity was achieved with the 4-tine Michel ripper at 76% of the vibratory ripper. Following this, similar capacities of 48 to 55% of that achieved with the vibratory ripper, were achieved with the 2-tine Michel and 5-tine RedRhino ripper configurations. With a lower capacity again of 31 to 35% of the vibratory ripper were ranked the 5 and 2-tined Agrowplow rippers. Whilst having a slightly lower loosening capacity than the 5-tine

Agrowplow ripper the 2-tine RedRhino ripper was not significantly less than that of the 2-tine Agrowplow configuration.

In both soil conditions the maximum depth achieved was with the vibratory ripper with a depth of 520mm in soil A and 472mm in soil B with the next deepest the Paraplow at 87 to 89% of the vibratory ripper. Very close to this were the depths achieved by the rigid prototype and 2-tine Michel configurations at 76 to 77% less than the vibratory ripper in soil A and 86 to 88% less in soil B. Typically the 2-tined configurations achieved greater depths than the 4 or 5-tine configurations of the same tine as would be expected. However the multi-tine configurations tended to loosen a greater area and achieve higher SLE values. This is expected as the tines benefit by interacting to achieve greater loosening than when two tines spaced far enough apart to act as two individual tines.

These results indicate that the combined benefits of dual depth and vibratory tillage were best able to maximise the subsoil loosening capacity of the 70kW vineyard tractor. However at 80 to 85% less and 75 to 89% less the Paraplow and Dual depth rigid prototype configurations were only a short way behind. The vibratory, dual depth and Paraplow technologies all tended to have considerably greater subsoiling capacity than the more conventional ripper designs of the RedRhino and Agrowplow rippers.

Energy efficiency in subsoil loosening results

The efficiency of the tractor ripper combination at transferring energy into subsoil loosening was considered via the following three methods (Figure 31). Both the power required at the tractor engine and the calculated fuel use were compared to the SLE parameter while the engine power was also compared to the cross sectional area of soil loosened. Fuel use rate was calculated from a generalized formula based on the proportion of engine power used compared to the maximum available from the tractor. This calculation tends to give more efficient fuel use to systems utilizing close to all the available tractor power. As all testing was conducted at a speed of 2.5km/h, wheel slip was the limitation to tillage capacity rather than a power limitation thus the best comparison of efficiency was considered the ratio of engine power used to the SLE parameter.

In soil A the Paraplow, Rigid and Vibratory prototypes were similarly ranked as the most efficient users of engine power for subsoil loosening. The next most efficient ripper configurations were the 2 and 4-tine Michel and the 5-tine RedRhino but these required 2.2 to 2.4 times the engine power to SLE of the Paraplow. Unfortunately in soil A the draft instrumentation was found to have gone off scale for both the RedRhino configurations this would have thus resulted in a lower power and efficiency value being recorded than was actually the case. The next most efficient were then the 5-tine Agrowplow and 2-tine RedRhino at 2.9 and 3.1 times the power to SLE requirements of the Paraplow ripper, followed by the 2-tine Agrowplow configuration.

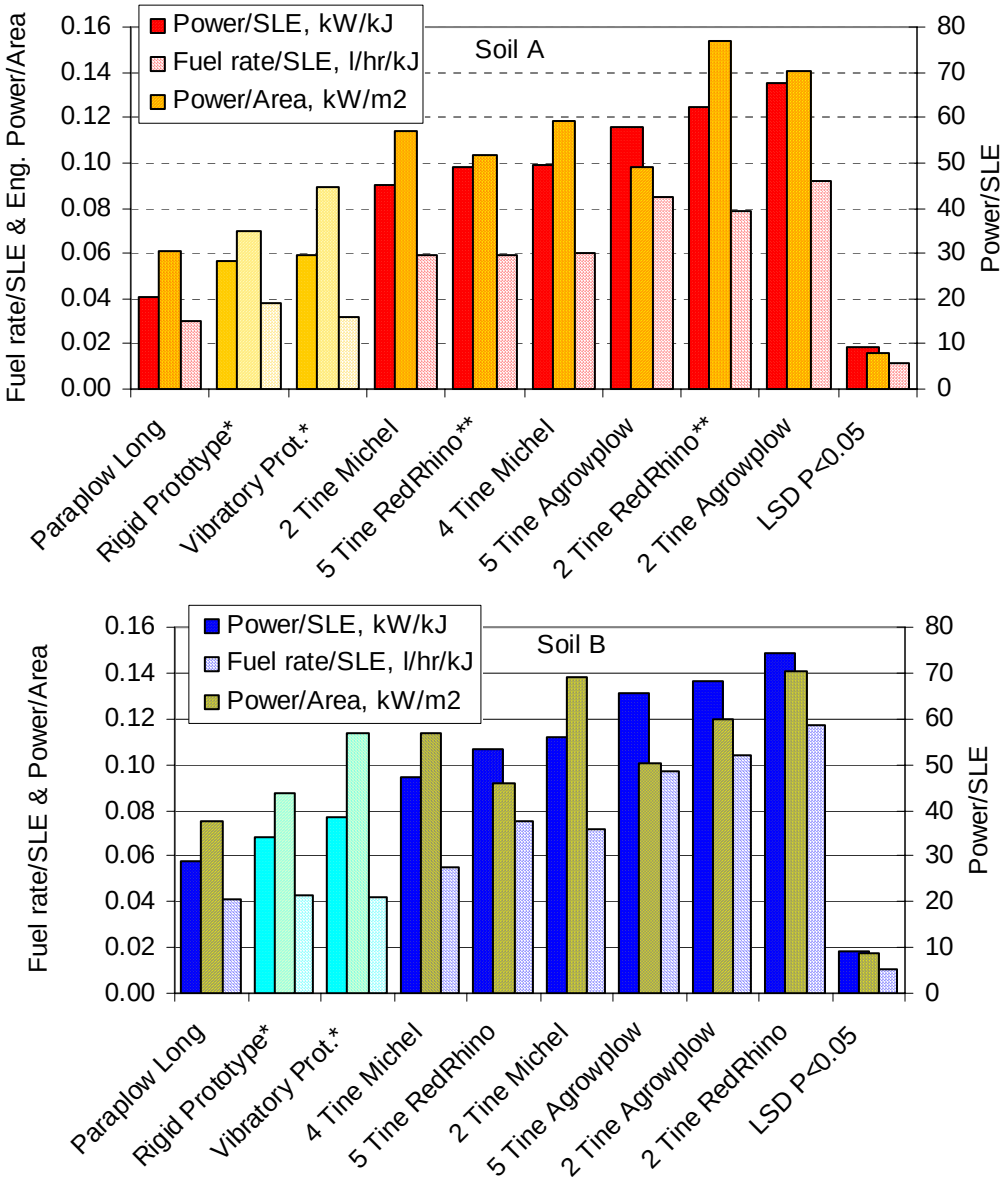


Figure 31. The tractor –ripper subsoil loosening efficiency in use of energy for the various ripper configurations, ranked in terms of Engine Power/SLE parameter from left to right for soil conditions A and B. *indicates data from an adjacent experiment and **where draft and hence power measurements went off the instrumentation scale.

The best ranking in terms of power used to achieve a level of SLE was for the Paraplow and rigid prototype rippers in soil B. Marginally less efficient was the Vibratory prototype requiring an additional 34% of engine power for SLE achieved compared to the Paraplow. Next and similarly ranked were the 4-tine Michel, 5-tine RedRhino and 2-tine Michel requiring in the range of 65% to 95% more engine power to achieve each unit of SLE than the Paraplow ripper. The least efficient ripping systems in Soil B were the 5-tine Agrowplow, 2-tine Agrowplow and 2-tine RedRhino rippers that consumed 2.3 to 2.6 times the engine power for each unit of SLE achieved when compared to the Paraplow ripper.

Overall the rippers having the greatest soil loosening capacity (SLE), depth, and area loosened were also those systems that were the most efficient at using the tractor engine power to loosen the subsoil. The better performing ripper configurations across the two soil conditions were the two UniSA

prototypes with dual depth arrangements and either vibrating or rigid ripper excitation along with the long-tined Paraplow ripper.

Soil loosening and disturbance

Provided below are observations on the soil loosening and disturbance characteristics of the rippers investigated.

University Prototype Dual Depth - Vibratory and Rigid configurations	The soil loosening shape, upheaval and soil surface left by the dual depth prototype ripper in both vibratory and rigid settings was very similar. The dual depth approach left wide loosening of the subsoil close to the surface and ensured good width of disturbance at the maximum depth of the deep tines. Soil surface was left relatively smooth with clods broken down within the width of the trailing crumbling roller. Outside the area broken down by the roller there appeared to be a less rough surface with smaller aggregates where the vibratory function was used.
Paraplow ripper	Subsoil failure shape is triangular from the ripping tip. Soil failure is wider to the side away from the shank, possibly the shank as it passes behind the tip causing this increased soil failure away from it. While the soil is upheaved over the full loosened width the surface soil disturbance is concentrated around where the shank interacts with it.
Grizzly Michel tine ripper	When this ripper was operating with two single tines the shape of soil loosening, disturbance and upheaval was typically similar to that produced by the Paraplow ripper. Using the tines in two pairs provided good loosening between each pair tip. The pairing of the tines such that the upper part of the shanks were aligned resulted in keeping the surface disturbance to a similar level as if only one shank had been used but greatly increasing the width of soil disturbance. The ripping tip at maximum depth was pointed such that a V-shape was left compared to the chisel type tips of all the other rippers.
RedRhino ripper	The design of the RedRhino tine shanks with leading tips and knife like leading edges resulted when coupled to the trailing roller in very even, low soil surface upheaval and disturbance. This was the case for both 2 and 5-tine variants. In the vineyard this would provide a good surface for following operations such as sowing cover crops, spraying and mowing. In the 5-tine configuration good between tine soil failure was observed providing good width of soil failure at the maximum depth reached.
Agrowplow ripper	The Agrowplow tines were found to disturb the soil right through the profile resulting in considerable disturbance at the surface, however the soil was very loose throughout the soil failed zone. In the 5-tine arrangement good interaction between adjacent shanks resulted in good width of soil failure at the maximum tip depth.

Once again a ranking of the ripper technologies investigated is included in a tabular form that can be seen in Table 5.

Note: LSD $P<0.05$ indicates statistical confidence levels are greater than 95%. The same letters following different treatments indicate no significant differences while different letters indicate statistically that the values are significantly different.

Max Depth, mm			Area, m^2			SLE, kJ			Power/Area, kW/m^2			Power/SLE, W/J			Fuel rate/SLE, l/hr/kJ		
Ripper	Soil-A		Ripper	Soil-A		Ripper	Soil-A		Ripper	Soil-A		Ripper	Soil-A		Ripper	Soil-A	
Vibratory	-520	a	Vibratory	0.590	a	Vibratory	447.0	a	Paraplow	30.6	a	Paraplow	0.041	a	Paraplow	0.030	a
Paraplow	-450	b	Rigid Prot.	0.549	b	Paraplow	357.8	b	Rigid Prot.	34.9	a	Rigid Prot.	0.057	a	Vibratory	0.032	a
Rigid Prot.	-400	c	Paraplow	0.488	c	Rigid Prot.	333.0	b	Vibratory	44.6	b	Vibratory	0.059	a	Rigid Prot.	0.038	a
2T Michel	-395	c	5T RedR.	0.429	d	5T RedR.	235.9	c	5T Agrop.	49.0	b	2T Michel	0.090	b	5T RedR.	0.059	b
2T RedR.	-377	d	4T Michel	0.375	e	4T Michel	230.4	c	5T RedR.	51.9	bc	5T RedR.	0.098	bc	2T Michel	0.060	b
4T Michel	-342	e	2T Michel	0.335	f	2T Michel	215.7	c	2T Michel	57.2	c	4T Michel	0.099	bc	4T Michel	0.060	b
2T Agrop.	-327	f	5T Agrop.	0.317	f	2T RedR.	170.6	d	4T Michel	59.2	c	5T Agrop.	0.116	cd	2T RedR.	0.078	c
5T RedR.	-285	g	2T RedR.	0.272	g	5T Agrop.	137.1	e	2T Agrop.	70.1	d	2T RedR.	0.125	de	5T Agrop.	0.084	cd
5T Agrop.	-212	h	2T Agrop.	0.259	g	2T Agrop.	136.6	e	2T RedR.	77.0	d	2T Agrop.	0.135	e	2T Agrop.	0.092	d
LSD P<.05	-9			0.015			28.0			7.9			0.018			0.011	

Max Depth, mm			Area, m^2			SLE, kJ			Power/Area, kW/m^2			Power/SLE, W/J			Fuel rate/SLE, l/hr/kJ		
Ripper	Soil-B		Ripper	Soil-B		Ripper	Soil-B		Ripper	Soil-B		Ripper	Soil-B		Ripper	Soil-B	
Vibratory	-472	a	Rigid Prot.	0.459	a	Vibratory	333.0	a	Paraplow	37.8	a	Paraplow	0.057	a	Paraplow	0.041	a
Paraplow	-420	b	Vibratory	0.448	b	Rigid Prot.	295.0	b	Rigid Prot.	43.5	ab	Rigid Prot.	0.068	ab	Vibratory	0.042	a
2T Michel	-417	b	Paraplow	0.431	bc	Paraplow	283.4	b	5T RedR.	45.9	ab	Vibratory	0.077	bc	Rigid Prot.	0.043	a
Rigid Prot.	-408	c	4T Michel	0.421	c	4T Michel	252.8	c	5T Agrop.	50.2	bc	4T Michel	0.094	cd	4T Michel	0.055	b
4T Michel	-338	d	5T RedR.	0.369	d	2T Michel	182.2	d	Vibratory	57.0	cd	5T RedR.	0.107	d	2T Michel	0.072	c
2T RedR.	-295	e	5T Agrop.	0.302	e	5T RedR.	159.7	d	4T Michel	57.0	cd	2T Michel	0.112	d	5T RedR.	0.075	c
2T Agrop.	-273	f	2T Michel	0.291	e	5T Agrop.	115.7	e	2T Agrop.	59.9	d	5T Agrop.	0.131	e	5T Agrop.	0.097	d
5T RedR.	-243	g	2T Agrop.	0.233	f	2T Agrop.	102.3	ef	2T Michel	68.9	e	2T Agrop.	0.136	e	2T Agrop.	0.104	d
5T Agrop.	-218	h	2T RedR.	0.182	g	2T RedR.	86.3	f	2T RedR.	70.3	e	2T RedR.	0.148	e	2T RedR.	0.117	e
LSD P<.05	-7			0.018			24.1			8.6			0.018			0.011	

Table 5 Ranking of rippers according to capacity and energy efficiency in Soil A and B.

Technology to increase output and capacity (Exp 5)

Level of subsoil loosening

Significant differences in ***depths*** and area of subsoil loosened were measured between the three different ripping technologies. The Agrowplow had the shallowest average depth of 213mm, the next was the dual pass vibratory treatment at 333mm followed by the single pass vibratory treatment at 359mm. The Agrowplow was expected to be the shallowest due to the use of the five rigid tines arrangement. However it was expected that the second pass of the vibratory ripper should have achieved a greater depth than that achievable in a single pass, due to the loosening of the upper subsoil with the first pass. This is in part in due to the difficulty in maintaining the desired depth with the transport wheels rather than the roller as planned.

The ***area of soil disturbance*** trend was as expected with the Agrowplow producing the least followed by the single-pass vibratory ripper then the dual pass system. However while the difference between the Agrowplow and one pass vibratory ripper was not significant the single-pass vibratory ripper treatment was operated to a greater depth in the more compacted wheel trafficked zone of the vine mid-row that could be expected to require greater draft and energy inputs. The greater loosening of the dual-pass treatment 44% more than the single-pass was expected due to the benefits of this arrangement. The maximum benefits of the dual pass may not have been realized due to the tracking and depth control issues with the transport wheels.

The ***% reduction in soil bulk density*** determined from the change in the loosened area to the sum of the loosened and upheaved area was not found to vary significantly between ripping treatments. Within and across all the treatments there was great variation ie from about 7.5% to about 34.5% that accounts for the lack of measurable differences. Blocking across the three treatments did however show that some of these variations maybe attributed to position and soil type. On average the % reduction in bulk density was 18.9%

The ***area of upheaval*** was also highly varied and would have contributed to the high variation in % of bulk density reduction. The variation was high within and across treatments with no significant differences being associated with ripper types, however on average the area upheaved was about 0.034m2. Blocking across the experiment for this variable also showed that position and soil type may have had an influence.

Table 6 Ripper technology depth and loosened area performance

Ripper Technology	Max Depth, mm	Area Loosened, m^2
Agrowplow	213	0.222
Vibratory Ripper, Dual Depth Single-Pass	359	0.272
Vibratory Ripper, Dual Depth Dual-Pass	333	0.392
LSD ($p<0.05$)	40	0.070

Soil Settling results

The area of soil upheaval one week after ripping was determined, as the vertical cross-sectional area between the original soil surface profile and that measured after ripping. The settling of the loosened soil from the time of ripping until September 2002 was then found by again measuring the surface profile and determining the area that had not yet settled back to the pre-rip soil level. The settling rate was such that by September the upheaved area had reduced to 67% of that area measured directly following ripping. The percentage of upheaved soil settling rate was similar for all ripper technologies.

Cone penetrometer results

It was intended to compare relative changes in the cone index cross-sectional profile before ripping, in spring and in autumn and spring of the following years of the trial. Changes in soil strength were going to be determined by changes in the area of the cone index profile that had a value less than 2Mpa. The cone index values were measured in September but the dryness of the soil during this period of the year meant the soil moisture varied considerably through the profile and was also influenced by the mulch under the vine row and the varying density of weeds in the mid-row. Where weed density was high

soil moisture was low and cone index values high. Due to these difficulties this data was considered an unreliable comparison. A non-replicated sample of soil moisture contents over two depth ranges to 400mm was taken at each end of the experimental area in the vineyard. At each site samples were collected in adjacent heavily grassed and bare soil areas that for the centre of the mid-row and under the wheel tracked zone. In all cases the soil moisture content was considerably less under the heavily grassed area as shown in Table 2.

Table 7 Soil moisture content variation under bare and grassed soil, September 2002.

Position	Depth range, mm	Centre of mid-row		Wheeled zone	
		Grassed	Bare soil	Grassed	Bare soil
North	0-200	15.2	12.5	17.5	14.7
North	200-400	20.4	14.4	24.9	22.7
South	0-200	12.1	3.8	12.3	12.7
South	200-400	15.6	6.5	21.2	15.7

Grape yield results

Grape vine yield was compared in terms of bunch number/vine, yield weight/vine, bunch weight, and weight/cordon length. All these yield variables were found to be statistically similar for all treatments with averages of 133 bunches/vine, 6.7kg grapes/vine, 50.7g/bunch and 2.98kg/m of vine. In terms of yield a slight difference was measured with the non-ripped control treatment having a Brix value of 21.03 that was significantly lower than all the ripped treatments. Typically lower Brix values are found to correspond to higher yields and vice versa. The similar measured yield response of all the treatments is likely to be due to; 1) the drought conditions and uneven weed growth in the mid-row that would not have encourage root growth into the dry mid-row zone, 2) the result of the irrigation system failures contributing to very uneven water application during the spring/summer period of vine growth and grape development and 3) the large variation in vine size and structure of the 39 year old vineyard. In addition it is possible the benefits of root growth into a loosened vine mid-row may not be fully realized until the second season.

Pruning weights

Vine and vine root growth can be related to pruning cane weight and number. While number of pruned canes and their weight were related to both each vine and cordon length no statistical differences were established between the treatments. The average pruning results were 570g/vine, 44.3 canes/vine, 266g of canes/m, and 20.3 canes/m. The points listed above for the grape yield would also have significantly influenced the outcome of these growth results.

Management of post ripping Traffic (Exp 6)

Loosening

The average maximum depth of subsoiling was 375mm in June and 365mm in September. The slightly greater depth achieved in June resulted in a greater area of soil loosened of 0.281m^2 compared to the 0.253m^2 achieved in September. The greater tillage achieved in June is thought to be due to the wetter soil and thus lower soil strength that is thus required to be overcome by the subsoiling machinery. Interestingly a slightly greater average area of soil was upheaved with the September ripping of 0.111m2 compared to the 0.090m2 achieved in June, this resulting in a larger calculated percentage reduction in bulk density of 30.5% compared to 24.3%. Figures 3 and 4 below show an example of the subsoil loosening and surface upheaval profiles that were measured following the ripping in September. These figures show the different surface profile left when the roller is used or not.

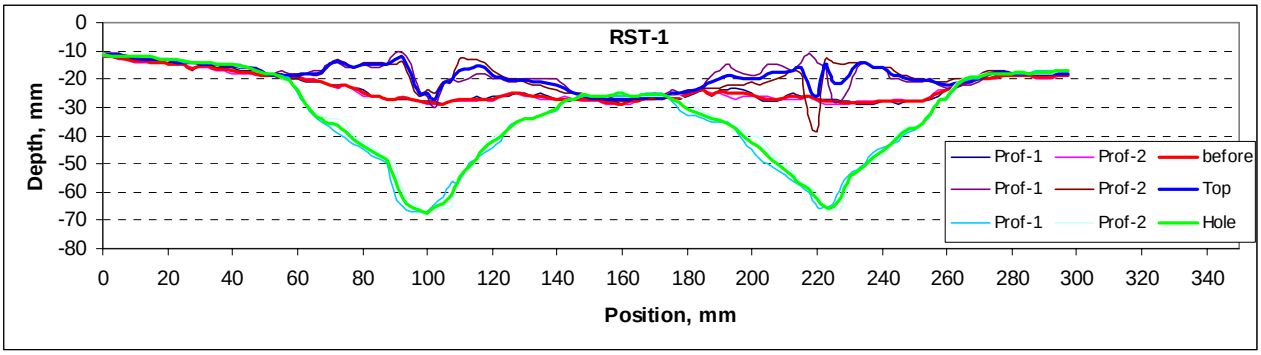


Figure 32 Example of subsoil and surface soil profile after ripping with out a crumbling roller.

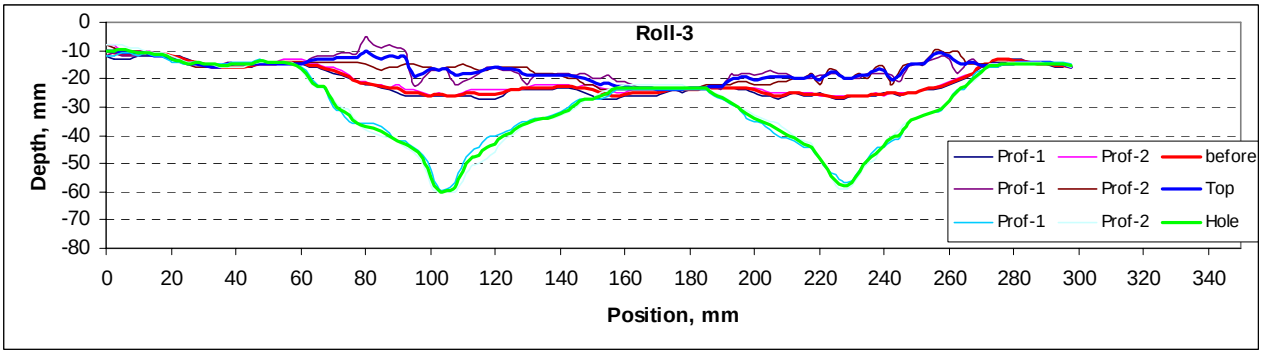


Figure 33 An example of surface subsoil profiles after ripping with a trailing crumbling roller

Soil Settling results

The area of soil upheaval one week after ripping was determined, as the vertical cross-sectional area between the original soil surface profile and that measured after ripping. The settling of this upheaved loosened soil from the time of ripping until September 2002 was then found by again measuring the surface profile and determining the area that had not yet settled back to the pre-rip soil level. These settling results were thus determined for the treatments that were ripped in June. It was found that the soil had settled such that the area remaining up heaved in September was 69.4% where traffic was minimized but significantly reduced to 14.1% where typical vineyard traffic was allowed to continue. If we relate this to the average bulk density measured in the ripped area of 1.52t/m3, the subsoil area loosened and the original area up heaved we can predict the resulting effect on the bulk density in the ripped zone. These results are shown in Table 1 where minimizing wheel traffic in the mid-row can be shown to provide a lower soil bulk density that is more hospitable to root growth for a longer period. It is expected that thus minimizing traffic will provide a greater opportunity for root growth to take advantage of this loosened soil whereas where typical traffic is continued it can be observed that the soil bulk density is quickly returned to close to that found prior to ripping. Much of the settling or re-compaction of the typical traffic treatment is expected to have occurred when soon after ripping a tractor mounted pruner was used requiring two passes in each mid-row one in each direction. The result of this is that as the tractor is offset from the centre of the mid-row a large portion of the mid-row is wheeled by the tractor with this operation. An example of better mid-row water penetration and reduced runoff is shown in Figure 3 with water clearly running to a low point and gathering in the mid-row that was not ripped compared to the adjacent autumn ripped minimum traffic treatment.



Figure 34 Left mid-row was ripped in autumn with traffic minimized while the adjacent mid-row to the right has not been ripped. Water has run down the non-ripped mid-row to pool at a low point after a winter rain.

Table 8 Changes in subsoil density from ripping and soil settling.

Ripping/Traffic Management	Area remaining upheaved, %	% Reduction in bulk density	Estimated ripped zone bulk density t/m^3
Prior to ripping		0	1.52
1 week post ripping	100	24.3	1.15
By September			
Minimum Traffic	69.4	18.2	1.24
Typical Traffic	14.1	4.3	1.45

Cone penetrometer results

It was intended to compare relative changes in the cone index cross-sectional profile before ripping, in spring and in autumn and spring of the following years of the trial. Changes in soil strength were going to be determined by changes in the area of the cone index profile that had a value less than 2MPa. The cone index values were measured in September but the dryness of the soil during this period of the year meant the soil moisture varied considerably through the profile and was also influenced by the mulch under the vine row and the varying density of weeds in the mid-row. Where weed density was high soil moisture was low and cone index values high. Due to these difficulties this data was considered an unreliable comparison.

Grape yield and pruning results

Whilst the yield and pruning results are expected to have been influenced by the failures of the irrigation system the data was analysed assuming this had no bearing on the outcomes. The results of this analysis are shown in Table 2 for the Latin Squares design with control data given for a reference point. If the data is assumed not to be adversely effected by the irrigation problems then there appears to be significant yield gains due to the autumn ripping followed with a minimized traffic regime to avoid re-compaction this is especially in contrast to the autumn rip with typical traffic retained. This was also the inverse with the Brix value which typically is the case of high yields associated with low Brix. Overall there appeared to be a stronger yield performance with the minimum traffic autumn rip to all the other treatments. Although pruning weights and cane numbers showed no strong differences there were a greater number of canes found on those vines of the autumn rip with minimum trafficking. Although the data may not be reliable there appears to be some indication of benefits of minimizing traffic on ripped mid-rows, especially when winter traffic will typically be at high moisture conditions that would lead more readily to re-compaction. It is quite possible that the spring rip treatments have not had sufficient time to influence the vine performance, especially with the drought conditions dominating the latter part of the year that would have left a dry mid-row that would not be encouraging to root development. As initially intended it would be interesting to follow into following years the performance of vines growing in the various treatments but the irregular irrigation due to pipe failures is likely to override the effects of the ripping and traffic treatments.

Table 9 Pruning and yield data

Treatment	Pruning Canes/vine	Yield bunches/m	Yield kg/m	Yield/pruning kg/kg	Brix
Ripped Autumn - Min. Traffic	55.8 a	81.4 a	4.21 a	18.8 a	19.5 a
Ripped Autumn - Typical Traffic	50.6 ab	57.5 b	2.92 b	12.1 b	23.4 c
Ripped Spring - Min. Traffic	46.4 b	67.6 b	3.53 ab	16.3 a	21.8 b
Ripped Spring - Typical Traffic	48.6 b	66.3 b	3.24 b	17.2 a	19.7 a
Least Sig. Dif. ($p<0.01$)	6.2	12.9	0.70	4.0	1.13
No rip control (for reference)	52.9	63.2	3.69	15.1	21.5

Note: treatments followed by the same letter in the same column are not significantly different. This data maybe unreliable due to the adverse influence of a failed irrigation system.

Calibration of the liquid amelioration system

As much of the equipment being used for the liquid system had not been used for the specific application before it was necessary to test and provide some kind of calibration to the components that could effect the operation of the system and most importantly the application rates that were possible. It was important to know that when the system was required to deliver a certain application rate that it was able to do this. The main areas of concern where (1) the output of the pump, (2) the ability of the "Mixrite" proportioning unit to deliver the required proportions and (3) the nozzle operation, both for the output possible with certain diameters so that the number required could be decided, but also the potential not to deliver the chemical due to its highly viscose consistency.

There was an iterative process that took place to develop the system between the pump capacity and the output of the nozzles, these components had to be match together with the proportioning pump to give the desired output and therefore application rate.

Calibrating the pump

The initial pump choice was a 12v DC with stated output of 15l/min at 4 bar pressure. This was chosen due to the portable nature of the DV powered pump and the spec's suggested that this would be adequate. This was used for the initial testing of the Mixrite with out nozzles, and then later with nozzles. The initial testing showed that the pump could not deliver the characteristics that it was stated to and this was a concern. The reduction in flow rate with an open system resulted in a slight drop in the required mixing proportions of the Mixrite unit. When a range of nozzles were fitted to the system the pressure increased causing the flow and therefore the proportions to drop to unacceptable levels.

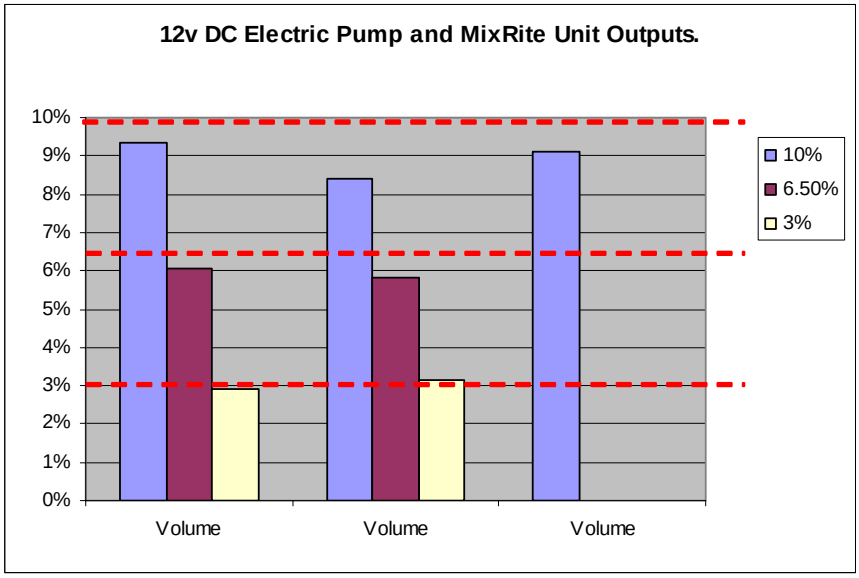


Figure 35, Mixrite calibration with Small Electric Pump.

Figure 35 shows that the results of the tests as being unsatisfactory. The main problem is the flow of the pump, when a higher pressure is required from the pump the flow rate drops and this affected the proportion of chemical added. When a mix percentage of 3% is required this is achieved because the flow of the pump is high enough, but when the Mixrite is increased to 6.5% proportion and 10% the desired value is not reached due to a insufficient flow. This can be see to decrease in

The best solution was to change the pump for a higher capacity unit, which had increased flow and pressure characteristics. The choice was made to go for a hydraulic pump with the following specifications

Hydraulic Pump Specification		
Max. Flow:	72	[l/min]
Max. Pressure:	20	[bar]
Max. R.P.M.:	550	
Max. Temperature:	60	[°C]
Weight:	9.5	[kg]

Table 10. Hydraulic pump Specification

This pump had plenty of capacity in reserve and the choice of nozzles and application rates where increased so the system specification would be restricted more by the number and size of the nozzles used.

Testing the Mixrite unit for correct proportioning

As the Mixrite unit had not been used for high viscosity suspended liquid before the manufacture, even though being confident that it would work, could not guarantee the output would be exactly what the required percentage was set to. Therefore it was necessary to test the Mixrite unit in the system with a chemical product flowing through it. Once the Mixrite had been tested with the original 12v pump and found to reduce in capacity due to the flow of the pump, it was necessary to test the Mixrite unit with the increased pump. As the lower mix percentages were not a problem only two higher percentages were tested with the higher capacity pump.

Calculated mixing percentage of the Mixrite [%]			
		Desired percentage	
Test	**Calculation with**	**9%**	**6%**
#1	Mixed Volume	-	6.40%
	Nozzle Output Volume	-	6.08%
#2	Mixed Volume	9.76%	-
	Nozzle Output Volume	9.27%	-

Table 11 Comparison of Mixed percentages from mixrite unit.

This data can be shown as a graphical format in Figure 36, now it can be seen that the percentage required is achieved at the 6% and 9 % mixing value. The differences seen in the table and on the graph are due to differences in the control valve setting and the actual flow given.

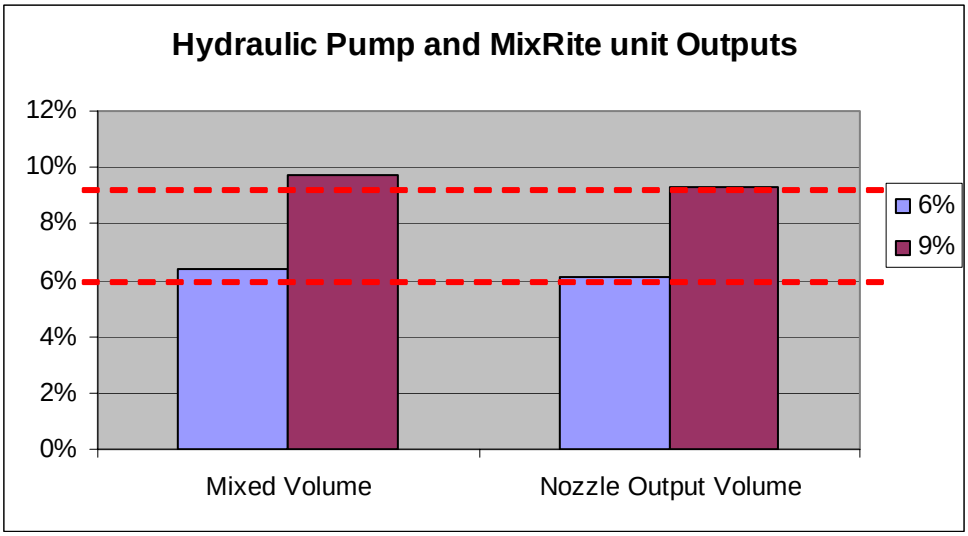


Figure 36 Mixrite percentage calibration with hydraulic pump.

Now that it was know that the pump and the Mixrite unit would deliver the required flow rates that were selected it was possible to finish the system component selection and specification. The system was tested in two ways in order to check that the flow rate from the Farm Scan controller was correct.

Firstly, by using the mixed volume added by the Mixrite unit. The time taken to deliver a known volume into the system by the Mixrite gave the flow rate into the system, knowing that the Farmscan controller was set to deliver 20l/min the percentage of mixing could be obtained.

The second method was to measure the total volume of liquid output from the nozzles in a given period of time to determine what actual flow the pump was delivering and also determine the percentage mixing as a proportion of this actual pump flow.

Calibrating the nozzles

The nozzles where selected by using the nozzle manufactures guide information to the output flows at given system pressures and by determining the likely number of nozzles that was required on the ripper to get an even coverage of the soil profile. It was decided that the nozzles would be spread between the front and the back tines of the dual depth setup of the new ripper. In addition to this the nozzles needed to go down into the profile to achieve application of the chemical at depth so this meat that more than one nozzle would be needed on the deeper tines.

With the ripper setup up in the four shallow and two deep tine configuration the minimum number of nozzles would be 8 and this could go up to approximately 20, limited by space on the deep tines.

The nozzles only came in a limited range of sizes that was from 0.9mm through to 1.5mm. The initial procedure was to get the manufacturer to provide the output of these nozzles at a range of pressures with water to determine their outputs. The results of these tests are in Table 12

Theoretical	**[l/min]**						
Nozzles DIA[mm]	*0.5 bar*	*1 bar*	*1.5 bar*	*2 bar*	*2.5 bar*	*3 bar*	*4 bar*
0.9	0.25	0.36	0.44	0.51	0.57	0.62	0.72
1.1	0.37	0.53	0.64	0.74	0.83	0.91	1.05
1.5	0.70	0.99	1.21	1.4	1.56	1.71	1.98

Table 12, Nozzles flow rates for a range of pressures

Knowing the equivalent rates of the liquid product to a similar granular one allowed the estimation of how much product is likely to be needed. Using Gypsum as an example Table 13 shows the comparison.

Gyp-Flo [ton/ha]	Gyp-Flo [l/ha]
0	0
2	40
4	80
6	120
8	160
10	200

Table 13 Equivalent amounts of liquid Gypflow to Granular product

By considering different numbers of nozzles that the system would likely need to achieve good chemical coverage, with the nozzle sizes available it was found that the 1.5mm nozzle was the most suitable. This kept the system pressure to a relatively low value, but high enough to produce the required results. Using the largest nozzle also provided the easiest nozzle for the chemical to flow thought reducing complication in nozzle blockages.

Once the 1.5mm nozzle had been chosen, it was possible to check the actual output of these against the manufactures stated values; this calibration can be seen in Table 14.

	[l/min]						
Diameter nozzles [mm]	*0.5 bar*	*1 bar*	*1.5 bar*	*2 bar*	*2.5 bar*	*3 bar*	*4 bar*
1.5	0.86	1.21	1.48	1.71	1.91	2.09	2.42

Table 14 Actual 1.5mm nozzle output.

By estimating an appropriate forward speed of operation and knowing the width of application it is possible to determine the flow rate of the pump at the various mixing percentages that give the required application rates. See Table 15

Flow of pump [l/min]									
		Mixing percentage							
Gyp-Flo [ton/ha]	**Gyp-Flo [l/ha]**	**3%**	**4%**	**5%**	**6%**	**7%**	**8%**	**9%**	**10 %**
0	0	0	0	0	0	0	0	0	0
2	40	**20**	15	12	10	8.57	7.5	6.67	6
4	80	40	30	24	**20**	17.14	15	13.33	12
6	120	60	45	36	30	25.71	22.5	**20**	18
8	160	80	60	48	40	34.29	30	26.67	24
10	200	100	75	60	50	42.86	37.5	33.33	30

Table 15 Pump flow rate required for different Mixrite setting and application rates

Knowing the system flow required for the application rates it was possible to test the system with the 1.5mm nozzles to determine the actual number of nozzles needed to obtain the application rates at different operating pressures. Table 16 shows the number of nozzles required at a system pressure of 1.5 bar.

Number of nozzles with a pressure of 1.5 bar									
		Mixing percentage							
Gyp-Flo [ton/ha]	**Gyp-Flo [l/ha]**	**3%**	**4%**	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**
0	0	0	0	0	0	0	0	0	0
2	40	**14**	11	9	7	6	5	5	4
4	80	28	21	17	**14**	12	11	10	9
6	120	42	32	26	21	19	16	**15**	13
8	160	56	42	34	29	25	22	20	18
10	200	70	53	43	36	31	27	25	22

Table 16 Number of 1.5mm nozzles required at 1.5 bar System pressure.

It is also possible to determine required pump flow of the system in litres per hectare as this value is used to control the Farm Scan unit and the mixed chemical is a percentage of the water flow thought the system, seen in Table 17

Flow of pump [l/ha]									
		Mixing percentage							
Gyp-Flo [ton/ha]	**Gyp-Flo [l/ha]**	**3%**	**4%**	**5%**	**6%**	**7%**	**8%**	**9%**	**10%**
0	0	0	0	0	0	0	0	0	0
2	40	1333.3	1000	800	666.6	571.4	500	444.4	400
4	80	2666.6	2000	1600	1333.3	1142.8	1000	888	800
6	120	4000	3000	2400	2000	1714.2	1500	1333.3	1200
8	160	5333.3	4000	3200	2666.6	2285.7	2000	1777.7	1600
10	200	6666.6	5000	4000	3333.3	2857.1	2500	2222.2	2000

Table 17 Total flow through the system per hectare

Figure 37, shows the layout of the nozzles on the ripper, with 6 nozzles placed down the back of each of the deep vibrating tines and one nozzle on each of the leading shallow tines.

Nozzle Layout on ripper

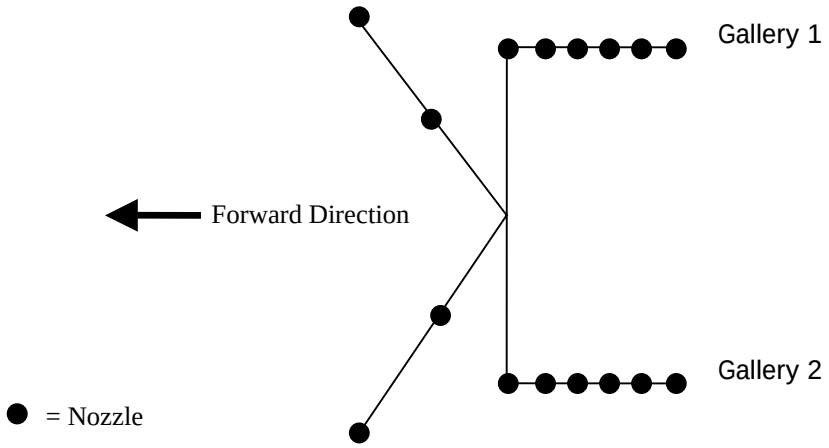


Figure 37, Layout of the nozzles on the ripper tines

Discussion of results

With a review of the currently available technology (mainly for the broadacre industry) it was found that there were several ways in which the capacity and efficiency of a conventional rigid leg sub-soiler could be improved. This included such technology as the vibration of the tines, especially the use of high amplitude and low frequency rather than the conventional high frequency vibration that has been used on other tillage machinery. This was combined with the ability to adjust both the amplitude and frequency to obtain the most beneficial setting for power saving and soil loosening. In addition to vibration of the tines, wings could be added and the spacing could be changed, this allowed for the adjustment of soil loosening capacity depending upon the depth of the subsoil constraints and the situation requirement.

Along with this an amelioration system has been developed specifically and integrates into the technology, allowing variable amounts of soil amendment chemical to be added to the soil profile during the ripping process. This uses similar technology to the liquid fertilizer equipment used in the broadacre industries which has been adapted and modified to suit the ripping equipment. The system allows for the chemical to be distributed throughout the profile by access to the soil slot behind the ripping tine, this is considered to be more beneficial than spreading a product on the surface as conventionally done. The system has not currently been used for any vineyard trials, but it is due to be operated this season as part of the "soil management for yield and quality" project. This will allow the root and vine response to be monitored to determine if strategic ripping and ameliorant application can provide an improvement.

In relation to the new technology and its performance against what is currently available, this was carried out on different occasions using different methods. Firstly in terms of the draft force, engine power and fuel used, which were the primarily measured values, but also in terms of the specific draft and soil loosening energy (SLE). Not all of the primary measured values were found to be directly improved with the new ripper technology when comparing as a standard two tine arrangement. Additional trials where the new technology was arranged in a more beneficial configuration showed an increase in depth and soil loosening was achieved with the use of the optimum settings. There was a significant increase in the depth of operation for all the tests and also the amount of soil loosening.

When the new vibrating dual depth technology was tested in a vineyard situation along with a conventional deep ripping machine the depth achieved was again significantly greater for all the plots. This gives the potential for increased root volume to the lower soil profile along with access to stored water. As there were irrigation problems in the vineyard during the trials there was no conclusive pruning or yield results obtained from these trials.

From trials within vineyards it was possible to determine that there were beneficial management practices that can reduce compaction in vineyards and more importantly reduce the rate and severity of re-compaction that occurs from trafficking after subsoil loosening. It was found that common vineyard traffic could return the bulk density of the soil to its original value within 2-3 months. Management of traffic in a vineyard is very hard to enforce due to the limitations of other machinery required to carry out essential operations, such as pruning, spraying and harvesting. A potential method of informing the industry of the effects of traffic and the better management of this could be an addition to the CRC viti-notes series

The Viti-notes series being developed by the CRC for Viticulture is a useful way of disseminating the knowledge and expertise gained during this project to the industry. Current Viti-notes that have been produced include the "characterisation of compacted subsoils" and also the "physical solution to these constraints". As well as the Viti-notes parts of the project have been presented at conferences. The technology has been demonstrated to the industry and knowledge of the new technology has spread around the industry and as far as New Zealand.

Implications and recommendations of the project and the benefits to the Australian wine industry, recommendations for future research needs

Conclusions for all the research carried out

Optimising vibratory ripper settings (Exp 1)

A number of factors must be assessed when choosing the optimum settings and maximising the benefits of vibratory subsoiling compared to rigid tine subsoiling. By oscillating the tines, a reduction in draft is found compared to an equivalent rigid tine at the same depth. Draft reduction was maximised by operating with a higher velocity ratio (increased frequency and amplitude and reduced forward speed) and by using the 30° angle of vibration tine with a maximum draft reduction of 52% achieved. These greater velocity ratios and 30° tine vibration angle, however increased the pto power required and thus increased the power ratio (vibratory PTO and drawbar power compared to rigid drawbar power) to values in the order of 1.8 while ideally it is desirable to obtain values close to or less than 1.0. Therefore a balance is required to compromise between maximising draft reduction and minimising power ratio to get the best gains in efficient power use and increased subsoiling capacity.

A theoretical approach was developed where by an Equivalent Rigid Draft (ERD) was predicted to provide an indication of increased subsoiling capacity of the vineyard tractor. This approach amalgamated issues of draft reduction, power ratio, tractive efficiency, transmission power losses and available tractor engine power. At 2.5km/h the ERD was limited by the available tractor draft and thus maximised through higher draft reductions and velocity ratios with a potential ERD 63% greater than the max rigid draft measured. While at 4km/h, the ERD was limited by maximum available tractor power and was maximised at lower velocity ratios with a 44% increase over the maximum rigid draft force.

In maximising the tractor subsoiling capacity, careful consideration to unsustainable tractor and operator vibration needs to be given. Weighted 3D seat acceleration values were compared to AS 2670.1-2003 acceptable operator comfort levels. Acceptable low seat vibration levels below 0.6m/s^2 were obtained with the 0° angle of vibration tine at 2.5km/h that were comparable to those found with the rigid ripping scenario at 4m/h. While slightly higher 0.7m/s^2, acceptable vibration levels were also found at 4km/h with the 0° angle of vibration tine. The 30° angle of tine vibration tended to increase seat vibration levels beyond the acceptable range of 0.8m/s2, especially for the settings that maximised the draft reduction. A four tine machine however, with balanced motion would potentially cancel the 30° tine angle limitations.

Thus, the optimum settings found, with maximising ERD across both soils and minimising the seat vibration level, are as follows: 2.5km/h, 0° vibration angle, 2.5km/h, 70mm amplitude, high velocity ratio (of approximately 3) and an oscillation frequency of 4.8Hz (1000rpm pto). These gave a draft reduction of 36-38%, power ratio of 1.16-1.23, 3D seat acceleration of 0.56m/s^2 and ERD 57-61% greater than the maximum rigid draft. At the higher speed of 4km/h the preferred parameters were 0° vibration angle, 70mm amplitude, low velocity ratio (approximately 1.75) and an oscillation frequency of 4.8Hz with pto speed of 1000 rpm. This resulted in a 26-27% draft reduction, 1.04-1.09 power ratio, 0.70m/s^2 3D seat acceleration and 26-27% increase in predicted ERD over maximum rigid draft. To deliver the predicted ERD with a rigid ripper a larger tractor would be needed scaled up with a weight increase prorate of the ERD benefits.

Strategies to maximise ripper capacity & efficiency (Exp 2)

At full tractive capacity the use of wings was found to reduce the tillage depth by 10-20% but the resulting area loosened and SLE were upto 0- 20% greater. Fitting wings generally increased the efficiency in the use of engine power by 2-20%. While, in soil B, seat acceleration was similar for vibrating tines with and without wings, in soil A operating without wings significantly reduced the seat

acceleration. Vibration of the tractor and operator was very high as the winged vibrating tines entered the soil but reduced as the operating depth was reached.

Vibrating wingless tines increased the subsoiling depth by 45mm to depths of 470 and 450mm in soil A and B respectively. When wings were added, increases of up to 120mm were measured to maximum depths of 360 and 460mm. Vibratory tillage increased the tractor-ripper subsoiling capacity in terms of SLE on average by 42-59%, while the corresponding area loosened increased only by 20-30%. This demonstrates that the area loosened does not necessarily give a true indication of the energy put into the subsoil loosening which can be better represented by the soil loosening energy (SLE) parameter. Soil loosening efficiency (in terms of engine power use to transmit SLE) was improved by 10-18% by vibrating the tines. Seat acceleration levels were greatly increased with the vibration of tines, whereby the upper limits of the acceptable level were reached, especially where wings were used.

Large increases in soil loosening capacity (30-55%) in area and SLE were gained by using a dual depth tillage approach compared to single depth tillage, which also saw efficiency gains of 20-38%. In addition to this gains of 15-20% in loosened area and SLE capacity were obtained by using a two-pass tillage strategy with best efficiency achieved when using wings. A slight reduction in tractor seat vibration was achieved where shallow tines were positioned ahead of the vibrating tines, thus damping the transfer of vibration to the tractor.

Experiment 3 – Conclusions of ripper tine characteristics
Six ripper designs were all operated at set depths of 325mm in Soil A and 300mm in Soil B. The Paraplow ripper with a very long shank, shallow rake angle and shank that is offset to the side performed very well in both soils. The Paraplow and UniSA Vibratory ripper both had very low draft requirements in both soil types that were from 18 to 43% less than the other ripper designs. Specific draft was also lowest in both soils although the vibratory and RedRhino rippers were found to be of a similar low figure in Soil A. Fuel use efficiency was also greatest in both soils when using the Paraplow ripper although a similar value was obtained in Soil A for the RedRhino ripper. The UniSA vibratory ripper, whilst having a low draft was found to require the highest engine power use and the poorest efficiency in fuel use for subsoil loosening. However, in cases where draft is limiting and engine power is not this may still provide an advantage to maximise subsoiling capacity of the tractor.

In both soils the highest draft was required by the Agrowplow ripper in Soil B however this was not significantly greater than the Michel, UniSA rigid and RedRhino rippers. In Soil B the specific draft of the Agrowplow was equal second lowest and fuel use efficiency the second best. Thus the high draft of the Agrowplow was quite efficiently converted to soil loosening, especially in Soil B. In Soil A the RedRhino had equal lowest specific draft and the equal best fuel use to soil loosening efficiency. The relative performance of the Agrowplow and RedRhino rippers was strongly influenced by the soil conditions. The Michel ripper was low in the rankings for both specific draft and fuel use to soil loosening energy efficiency.

To the vineyard operator low specific draft rippers that also have a high efficiency in the conversion of fuel use to soil loosening to maximise energy efficiency and tractor capacity. It should be noted that the results in this testing obtained for the two UniSA ripper configurations vibratory and rigid were unfortunately compromised due to the change in soil conditions during the testing and the above relative comparisons considered with this in mind.

Comparing ripper designs and capacities (Exp 4)

In this investigation a dual depth configuration of the University's prototype subsoiler in both the rigid and vibratory settings was compared to:
A three point linkage (3PL) 2-tine Paraplow ripper with long trash clearance tines.
A Grizzly 3PL ripper with a 2-Michel tine and 2 paired Michel tine arrangements.
A 5-tined 3PL RedRhino ripper in both a 5 and 2 tine configuration with trailing roller.
A 5-tined 3PL Agrowplow ripper in both a 5 and 2 tine configuration.

The subsoiling capacity was maximized in terms of soil loosening energy (SLE) with the dual depth vibratory ripper configuration with the capacities of the prototype dual depth rigid ripper and the Paraplow ripper ranging between 74% and 89% of that achieved with the vibratory ripper. Subsoiling capacity of the other ripper configurations however ranged between 31% and 55% of that of the

vibratory ripper capacity. The maximum depth of 520 and 470mm was achieved in the two soil conditions with the vibratory ripper configuration. Depths achieved by the Paraplow ripper were 88% of that of the vibratory ripper while the rigid prototype and 2-tine Michel configuration ranged between 75 to 80%. Efficiency at delivering tractor power to soil loosening was greatest for the Paraplow ripper that was just marginally better than that of the vibratory and rigid versions of the prototype ripper. The trailing roller and knife edged tine shanks of the RedRhino ripper provided the lowest surface disturbance characteristics of all the rippers leaving the smoothest surface for following vineyard inter row operations.

Technology to increase Output and Capacity (Exp 5)

The investigation of a range of ripper technologies of varying subsoiling capacity was established in a 39 year old Riesling vineyard of Orlando, near Lyndoch. The subsoiling capacity was greatest with the dual depth dual pass vibrating ripper technology that loosened 44% more cross-sectional soil area than the single pass dual depth vibratory ripper configuration and 77% more than the 5-tined Agrowplow ripper. Maximum tillage depth of the two vibratory ripper configurations was similar at 330 and 360mm but were found to be much greater than the 215mm achieved with the Agrowplow ripper. These results show the increased subsoiling capacity of a small vineyard tractor using vibrating technology combined with dual depth and dual pass strategies over that of a more simple single depth multi rigid tine ripper configuration. The soil upheaved by the ripping operation above the original soil surface level was found to have settled to 67% of that original height three months post ripping. Cone penetrometer sampling can be severely affected by highly variable subsoil moisture contents. The grape Brix value was lower for the control non-ripped treatment than all the ripped treatments. The vine yield and pruning performance measurements were found to be similar for all ripped and the non-ripped control treatment. The lack of differences are in part attributed to difficulties that occurred with the drought conditions and then the part failure of the vineyard irrigation system along with lack of control of mid-row weed growth.

Management of post ripping Traffic (Exp 6)

A 39 year old Riesling vineyard of Orlando, near Lyndoch was used to investigate the influence of the timing of subsoiling and management of wheel traffic on vine performance and subsoil re-compaction. The University of SA's Vibratory ripper arranged in a dual depth configuration was found to achieve a depth of 375mm while loosening a cross-sectional area of 0.281m2 with a 70kW vineyard tractor. Monitoring of the resettling or re-compaction of the loosened subsoil showed that typical vineyard traffic could readily return the loosened soil close to its pre-loosened density within 3 months of ripping while minimizing traffic maintained a reduction from the pre-ripped soil bulk density of 18.2%. Whilst yield results are not conclusive due to doubts introduce with faults in the irrigation system, there appears to be potential for yield gains to be made where traffic is minimized following the subsoiling operation to allow sufficient opportunity for root growth to advance into the loosened subsoil.

Liquid amelioration system

Using known technology from the liquid fertilizer industry it was possible to build a system to apply liquid soil chemical amendment chemicals for viticulture usage. The system integrates into the deep loosening vibratory equipment developed at the University of SA. The system consists of a pump, a proportion mixing unit and 16 nozzles strategically placed on the ripper to provide a uniform application of chemical. Using a variety of setting for pump flow, systems pressure and mixing proportion it is possible to achieve theoretical equivalent application rates as granular product of up to 8 t/ha, based on a travel speed of not more than 3km/h. The settings can be seen in Table 18

Granular Gypsum	Liquid Gyp-Flow	Pump flow	Pump flow	Pressure at nozzle	Mixing	Min. number of nozzles
[ton/ha]	[l/ha]	[l/min]	[l/ha]	[bar]	%	
2	**40**	20	1333	1.5	3%	14
4	**80**	20	1333	1.5	6%	14
"	"	24	1600	2	5%	15
"	"	30	2000	2.5	4%	16
"	"	30	2000	3	4%	15
6	**120**	22.5	1500	1.5	8%	16
"	"	20	1333	1.5	9%	15
"	"	25.71	1714	2	7%	16
"	"	22.5	1500	2	8%	14
"	"	25.71	1714	2.5	7%	14
"	"	30	2000	3	6%	15
8	**160**	24	1600	2	10%	15
"	"	26.67	1778	2.5	9%	15
"	"	24	1600	2.5	10%	14
"	"	30	2000	3	8%	15
"	"	26.67	1778	3	9%	14

Table 18 Amelioration systems setting to achieve various application rates

Even thought the application rates are the equivalent given by the chemical manufactures, the effect of distribution, placement and incorporation into the soil profile has to be evaluated through vineyards trials.

Recommendations for ongoing and future work

Ongoing sections of this work include the involvement in the "Soil Management for yield and quality" project currently taking place with SARDI and the CSIRO. For this the ripper will be used to modify both the physical and chemical subsoil constraints under vineyard management and determine the vine response in terms of yield and quality against other soil management regimes. This will provide data of the effect on yield from both the modification of the physical and chemical constraints in vineyards.

For the participation in the project the University of SA have invested in longer tines for the ripper and some other modifications to enable even greater depth and capability. This work is in association with a current PhD Candidate that is working in the area of vibrational tillage and reducing the effects of vibration on the tractor and operator whilst maximising the vibrational effect on the soil and therefore reducing the draft force and increasing the loosening capacity.

Due to limitations and uncontrolled problems with irrigation systems and strategies in the vineyards trials that were carried out, there were fewer vineyard results than would have been liked especially the vine response and yield to ripping and traffic management strategies over a number of years It would be beneficial for decision making by vineyard managers to have an understanding of the economic and vineyard response to removing the subsoil constraints and managing those over the long term. Again, the potential to get more information about these factors during the activities associated with the soil management project with the potential to add input into the dissemination of this knowledge.

There is potential for future work with a similar type of experiment where soil and vine response to different subsoil loosening levels and strategies could be compared. Ideally the economic, long term vine response for the subsoil loosening input level would provide valuable planning knowledge to maximizing the vineyard output. This was not possible in the later stages of the current project once the problems had occurred with the irrigation system and a change of staff was made. The fact that ideally operations can only be done at one time per year and multiple years are needed to make long term decisions, this takes major vineyard co-operation.

As information has been provided for the Viti-note series, this would be a potential way of providing more information on a growing number of topics associated with machinery and technology to provide solutions in vineyards. Other areas of potential benefit are the management of machinery, especially a regime that enables the vineyard managers to control the re-compaction of the vine mid-row with the current machinery they have. It is very difficult to change the practices in vineyards when there are limiting factors such as expensive machinery changes to be made. It is also difficult to achieve minimum traffic in the vine mid-row due to activities such as vine checking, sampling, counting, cover cropping, weed spraying, and pruning. This project has gone some of the way to describing the potential for machinery operation that can reduce some of these effects but it is difficult to implicate in the vineyards.

In addition to the benefits from corrected subsoil constraints and management, the issues of machinery efficiency, work rates and machinery capacity to provide timely completion of each operation will become more important. This can include many other vineyard activities outside the soil engaging machinery, as the whole system can affect the timeliness of operation. With timeliness affecting the quality of the work carried out in subsoil physical modification as well as many other operations, this needs consideration.

In commercial terms there are still some small vibrational and also financial issues that need to be addressed before the industry partner is willing to commit to producing a number of the machines, which are being addressed by the University of SA with the hopeful outcome of this in the near future.

In addition to the PhD candidate working on the vibrational aspects such as reducing the peak accelerations at the driver seat making the machine more attractive for commercial users. The University of SA has a visiting postgraduate student from Italy for 6 months commencing at the end of 2005, who has worked on the vibration of dynamic machines. It is planned for this person to have involvement in the reduction of vibration of the ripper

Potential areas of export for this technology and capacity is New Zealand where we have had inquires about the ability to use vibration theory to increase the loosening capacity of compact vine rows and the type of machinery we have been using, in particular if this machinery is commercially available. This is a promising development and we are very interested to follow this up and find out more about the potential market in New Zealand.

On a more regional scale, there remains interest from vineyard managers that have known subsoil problems for this technology to be developed. This interest ranges from the potential of using the technology to gain extra capacity, where the constraints are below the depths of currently available equipment, to the possibility of reducing the energy required for the loosening operation and achieving maximum loosening capacity from the available tractor power.

Dissemination of the knowledge

General Activities

A paper was written for the SEAg conference in 2002 entitled “Energy use and soil loosening performance of a vibratory subsoiler”. This was accompanied by a presentation of this paper.

In February 2003 a presentation was made to the industry on “An energy efficient vibratory subsoiler for inter-row subsoil loosening in established vineyards” at the Australian Food & Wine Industries Conference 2003 in Mildura.

A post-vintage demonstration of the prototype subsoiler was made to key industry players at Langhorne Creek by industry partners Kubpower.

A presentation of the paper “Effect of vibrating tines, multi-depth and multi-pass subsoiling on soil loosening and tractor power use” was also made at the 16th Triennial International Soil and Tillage Research Organisations Conference in Brisbane July 2003.

A final report produced for the Sustainable Energy Research Advisory Board (SENRAC) in 2004 on the power and fuel savings possible with more efficient subsoiling machinery.

A conference paper was written for and presented at the biannual Society of Engineering for Agriculture (SEAg) conference in Dubbo in 2004 on the Soil Loosening Energy (SLE) concept; this is a method of determining the loosening capacity of different types of deep loosening machinery.

From the outcomes of this research it has been possible to produce information sheets on the characterisation of subsoil constraints and the technological solutions available to remove these constraints through the viti-notes system set up by the CRC for Viticulture, the two notes follow.

Viti-Notes

1. Characteristics of compacted subsoils

Limitations to grapevine root growth at depth in the soil profile are often called ‘subsoil constraints’ and can be physical or chemical in nature.

Physical constraints are due to an increase in soil density or ‘strength’. Increases in density with depth are common in many soils and can result from natural variations in soil texture (eg. clay content) or may be due to compaction by machinery. As the density of a soil increases, the total volume of pore spaces decreases, soils become drier and the force required by roots to push through the compacted soil increases.

Correct identification of compacted subsoil is the first step to overcoming the problem.

Determining soil compaction levels

Soil density is measured in megapascals (MPa) which indicates the level of penetration resistance. Grapevine root growth appears to become limited at 1MPa, and is severely retarded beyond 2MPa. Compaction can also be determined as soil bulk density, which is the weight (mass) of soil per unit volume normally expressed in g/cm3 (weight divided by volume).

Instruments such as penetrometers and bronzing rods are commercially available for measuring soil penetration resistance. These are used by pushing a rod downward from the surface into an undisturbed soil. They provide a non-destructive means of determining soil strength.

The best way to obtain a detailed and accurate understanding of soil compaction however, is by digging a soil pit. This allows both a visual inspection, and access to the lower layers of the soil at the vertical surface of the pit for collection of samples for bulk density measurements. Such pits obviously cannot be dug all over the vineyard, but 2-3 positioned in strategic places (depending upon the size of the area being considered and the soil variation at the site) should provide sufficient information to determine the degree and pattern of soil compaction in a vineyard.

Benefits of using deep cultivation techniques to remove compaction

Improved soil structure

Deep cultivation introduce fissures into the subsoil, opening up pathways of lower penetration resistance in the subsoil to access by vine roots, and improving the penetration of air and water to greater depths in the profile.

This ‘loosening up’ of subsoils by deep cultivation creates zones of weakness and deep fissures which can remain beneficial to the subsoil structure many years after cultivation. Often however, some areas of compacted subsoil can remain in the profile as a result of uneven application of the deep cultivation process, or due to re-compaction in the upper subsoil layers. The degree of improvement and the longevity of the improved soil condition after loosening are dependent upon soil type, drainage capability, the incidence of wet weather and subsequent traffic loadings. Vine roots are frequently unable to fully benefit from the attempted soil improvement process if results are patchy, or subsoil becomes re-compacted.

Improved vine health and yield

A study to determine the impact on yield and pruning assessments of deep cultivation made at different times in the season and followed by different levels of traffic showed that:

- Significant yield gains and some increase in pruning weights were made in sections of the vineyard which were cultivated in autumn and where subsequent traffic was kept to a minimum to avoid re-compaction. This increase in yield was not observed where normal traffic loads were maintained.

• Deep cultivation in spring may not provide sufficient time for vines to take advantage of the improved soil condition so as to show any yield improvement in the same season.

The study concluded that there appears to be a yield benefit from minimising traffic in the mid-row strip after deep cultivation to avoid re-compaction. This would especially apply on sites where soil moisture levels and traffic loads are high in winter.

Current topics in working with problem soils Vitinotes series include:

- Characteristics of compacted subsoils
- Deep cultivation as a practical solution to compacted subsoils

Further information

Product or service information is provided to inform the viticulture industry about available resources, and should not be interpreted as an endorsement.

A good general reference on soils topics is:

- Nicholas, P (Ed.) 2004 Soil, irrigation and nutrition, Grape Production Series 2, SARDI, Adelaide. Available from Winetitles, 08 8223 4700, or visit www.winetitles.com.au.

Water management for grapevine production: Research to Practice® and Grapevine nutrition: Research to Practice® are training programs whose delivery can be fine-tuned to suit each region. They include topics on soil management issues.

- Enquiries to Peter Mansfield at Winetac on (08) 8373 7090 or visit www.crcv.com.au for more information.

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The Cooperative Research Centre for Viticulture would like to acknowledge the assistance of Dr Chris Saunders in the production of this Vitinote.

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2. Working with problem soils

Deep cultivation as a practical solution to compacted subsoils

Once the type and severity of subsoil compaction at a site has been determined, one of the most practical solutions is to apply deep cultivation. Subsoils which receive the highest initial levels of disturbance to the greatest depth, using the correct spacing and type of tines on the cultivator (ripper), exhibit the most rapid root penetration and the greatest improvement in soil structural condition as a result of application of this technique.

Ground conditions required for an effective loosening operation

Soil strength varies with soil moisture content, among other factors, so the drier the soil the stronger it tends to be. This can limit the ability of the tractor and ripper combination to achieve the desired result in a deep cultivation operation.

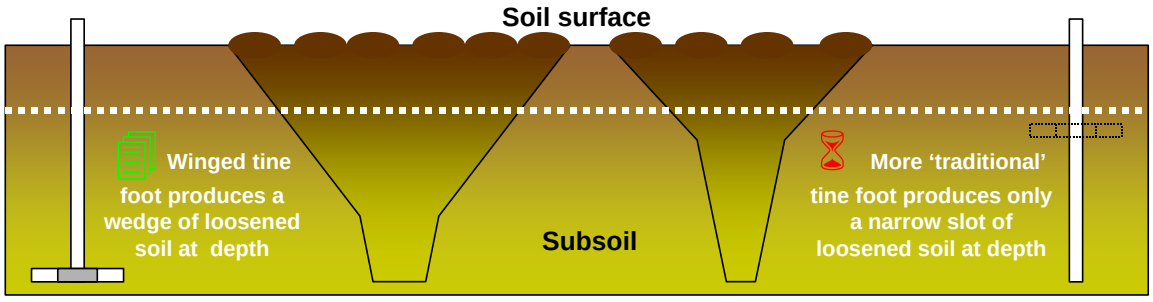
Soil moisture conditions are therefore critical in any loosening operation, particularly in the layers above the compacted soil; whilst it is advantageous for the compact layer itself to be as dry as possible, moisture content of compact layers tends to be relatively low anyway due to their high density. In order to avoid damaging soil structure in the looser upper soil layers when deep ripping, and to achieve good traction for machinery, the upper soils must be dry and friable.

The soil surface should be dry to achieve good traction, and in general the soil should be drier than the plastic limit down to the critical depth. The plastic limit is defined as the moisture content at which a thread of soil passing the 425 micron sieve can be rolled without breaking until it is only 3mm in diameter .[1]

Achieving sufficient loosening at the desired depth

The aim of subsoil cultivation is to create a wedge of loosened soil (wider at the surface) which causes fissures and cracks at depth, without compressing soil on either side of the wedge, or creating only a narrow slot of loosened soil.

The difference in the degree and ‘shape’ of loosened soil behind the cultivator is caused by using different types of tines. The Figure below shows two distinct types of soil disturbance which can be achieved in the same soil, at the same working depth, using different tines on the cultivator. Very significant loosening at depth is being achieved with the tines which cause a wedge of loosened soil, and hardly anything at all with the slot type.



The wedge shaped loosening is produced by a winged tine, with the wings fitted to the bottom of the leg, whereas the more traditional ripper tine, with no wings or wings part-way up the leg, produce the only a narrow slot of loosened soil.

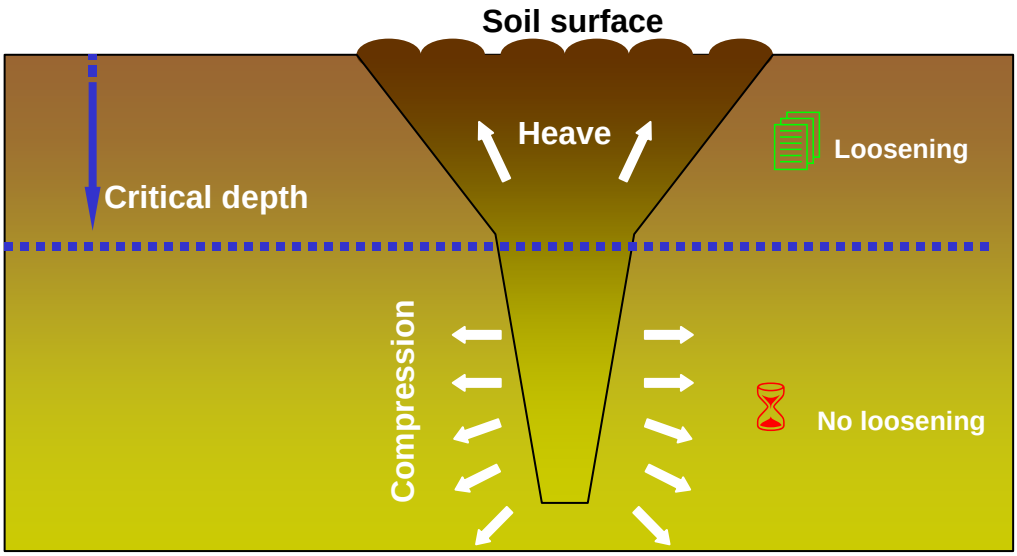
[1] The plastic limit is dependent upon both the type and amount of clay present. At the plastic limit sufficient water is present to wet all particle surfaces and reduce cohesion so that the particles can move past one another under stress, but maintain a new moulded position.

Different results can however occur using the winged tine when working under different conditions or at different depths:

- At shallower working depths the loosening is usually the desirable wedge-shaped.
- As working depth increases the trail of loosened soil changes to the slot type. When this happens, the tine cuts a slot and compacts the soil on either side rather than loosening it.

The working depth at which the transition from wedge to slot occurs is termed the 'critical depth' and defines the maximum useful working depth for that type of tine under those specific soil conditions

Subsoil loosening is therefore only effective if the tine foot is working above critical depth for the soil and producing a wedge of loosened soil behind the tine. The figure below shows the transition between wedge and slot, where above critical depth loosening occurs and below critical depth the soil is compressed to the side of the tine leg.



Critical depth for a type of tine varies between soil types, and with changing soil conditions for any given soil. In wet ground, the critical depth is often very shallow. Without complex measurements it is difficult to predict what the critical depth for a particular tine and soil condition will be. The only way to guarantee that tines are working above critical depth and creating a loosening effect is to dig a soil pit across the working area and check. If a slot-shaped loosening pattern is observed, the tine working depth should be raised until further soil pit examinations show a wedge-shaped pattern. If slotting is evident and soil pit examinations determined that the soil is wet, cultivation should be delayed until the soil is drier.

Choosing tines

Different models of tines have different characteristics:

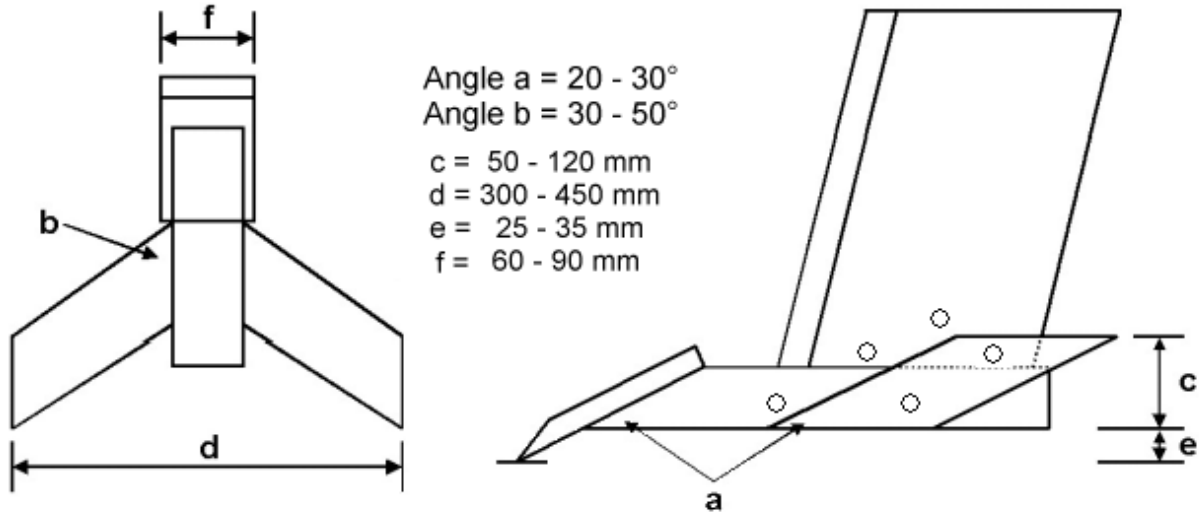
- The greatest increase in subsoil void capacity and thus improvement in soil condition and grapevine root penetration is generally produced by tines with wings located at the tine foot. This design creates the greatest level of soil disturbance and fissuring, and also allows the tine to be worked at a greater depth before critical depth is reached.
- Tines without wings do not always produce sufficient loosening at depth, especially if an effect at greater depths is required, however they tend to disturb the surface less.

Setting up the cultivator

Tine and wing angles

The lift height of the wings on winged tines gives some control over the degree of soil break-up and the amount of surface disturbance created (the wing lift height is a function of the wing length and angle). Generally wings are bolted onto the leg and often there will be a range of holes which can allow the wings to be bolted in different positions, permitting some adjustment by varying the position and angle of the wing in relation to the tine. An operator can select an appropriate wing setting and angle for the desired outcome, however effective settings for individual situations must generally be determined by trial and error and refined by experience. Generally the wings when fitted to the bottom of the leg should start flush with the leading edge of the tine leg. The wings should be angled back from the direction of travel at approx 30-40 degrees from perpendicular. The diagram below illustrates this [2]

Tines should have a low rake angle to aid penetration; therefore the tip of the tine should be approx. 20-25 degrees from the horizontal.



Tine spacing and leg length

To achieve complete soil disturbance across the working width of the machine, winged tines should be spaced at approx 0.6 times the depth of operation. The more tines that are fitted onto the tool frame the more draught, or horizontal force, will be required to pull the cultivator forwards through the soil. This is often the limiting factor for the width and depth of operation.

The table below indicates suitable lengths for tine legs to ensure sufficient ground clearance by the tool frame at different working depths. The dimensions of the legs are not critical, but tines should be strong and as narrow as possible to minimise draught.

Working depth (m)	Leg length (m)	Winged tine spacing (m)	Number of tines for track width	
			3.0 – 3.5m	1.8 – 2.5m
0.00 – 0.39	0.60	0.50	7 –8	5 – 6
0.40 – 0.54	0.75	0.55	6	5
0.55 – 0.69	0.90	0.60	6 – 7	-
0.70 – 1.00	1.20	0.75	5 - 6	-

[2] From Spoor, G and Godwin, RJ 1978 *An experimental investigation into the deep loosening of soil by rigid tines,* Journal of Agricultural Engineering Research 23, 3: 243-58.

Arranging tines on the tool frame and operating the cultivator

The number of tines required will vary and recommended numbers are given in the above table for different working depths and track widths. Tines which are spaced too widely will leave undisturbed and unloosened soil in between the tine slots, so it is important to generate a good overlap between the disturbance effects produced by each tine.

- Set the correct tine spacing for the working depth at which the tines will operate.
- A tine should be located directly behind each track or wheel and depending upon power available and the soil disturbance between the tines, additional tines should be spaced evenly in between, at the required tine spacing.
- Tines can be mounted on the tool frame in a V-shape or across two toolbars. This staggered arrangement between the tines in the direction of travel is necessary to allow free soil flow.

In some cases it is beneficial to carry out multi depth passes or even fit a shallow leading row of tines to a machine. In this case, the shallow depth tines or the first pass may use straight tines without wings if necessary or desired, but the deeper tines or subsequent passes should be fitted with wings to avoid the compaction caused by operating a wingless cultivator below the critical depth.

The supervisor / operator should keep to the following five step plan to ensure good loosening:

1. Open up a pit to look at the soil condition and rooting. Use this information to select an appropriate tine working depth and appropriate wing arrangement.
2. Ensure that the soil is dry and friable at the time of the loosening operation, particularly the soil above the compacted zone.
3. Use dual row or multi-pass tine configurations to utilise the power available and achieve the required depth.
4. Use winged tines, spaced correctly on the frame with sufficient ground clearance.
5. Perform checks at the commencement of the loosening operation to ensure that the:
    a. Tines are working above critical depth (ie. a wedge pattern of loosening is occurring rather than slotting). If not, raise working depth slightly or adopt the split parallel pass approach to achieve the desired depth.
    b. Cultivator is kept level during the operation.
    c. Working depth is correct, uniform and well-controlled (the working depth should always be measured from the original undisturbed soil surface and not from the top of the loosened soil heave).
    d. Forward speed is slow (about 2-3km/hr) and well-controlled.

In severely varying soil conditions the operator may have to accept a greater level of surface disturbance to ensure good subsoil loosening. Fitting cutting discs in front of the tines can help reduce surface disturbance a little, but this will not significantly reduce the heave caused by wings if they are set at a high lift angle. The cutting disc opens a clean path through any surface vegetation or turf for the following tine, reducing tearing and unwanted build-up of loose material in front of the tine. It also allows the tine slot to close neatly after the tine has passed, which will lead to a neater surface after settling. Alternatively a crumble roller may be fitted behind the cultivator - in bare soil or trashy conditions when the surface is friable, this can help break up large clods and level surface disturbance, but care should be taken not to transfer to much load to the roller and risk re-compacting the loosened soil.

After care of deep cultivated soils to reduce re-compaction

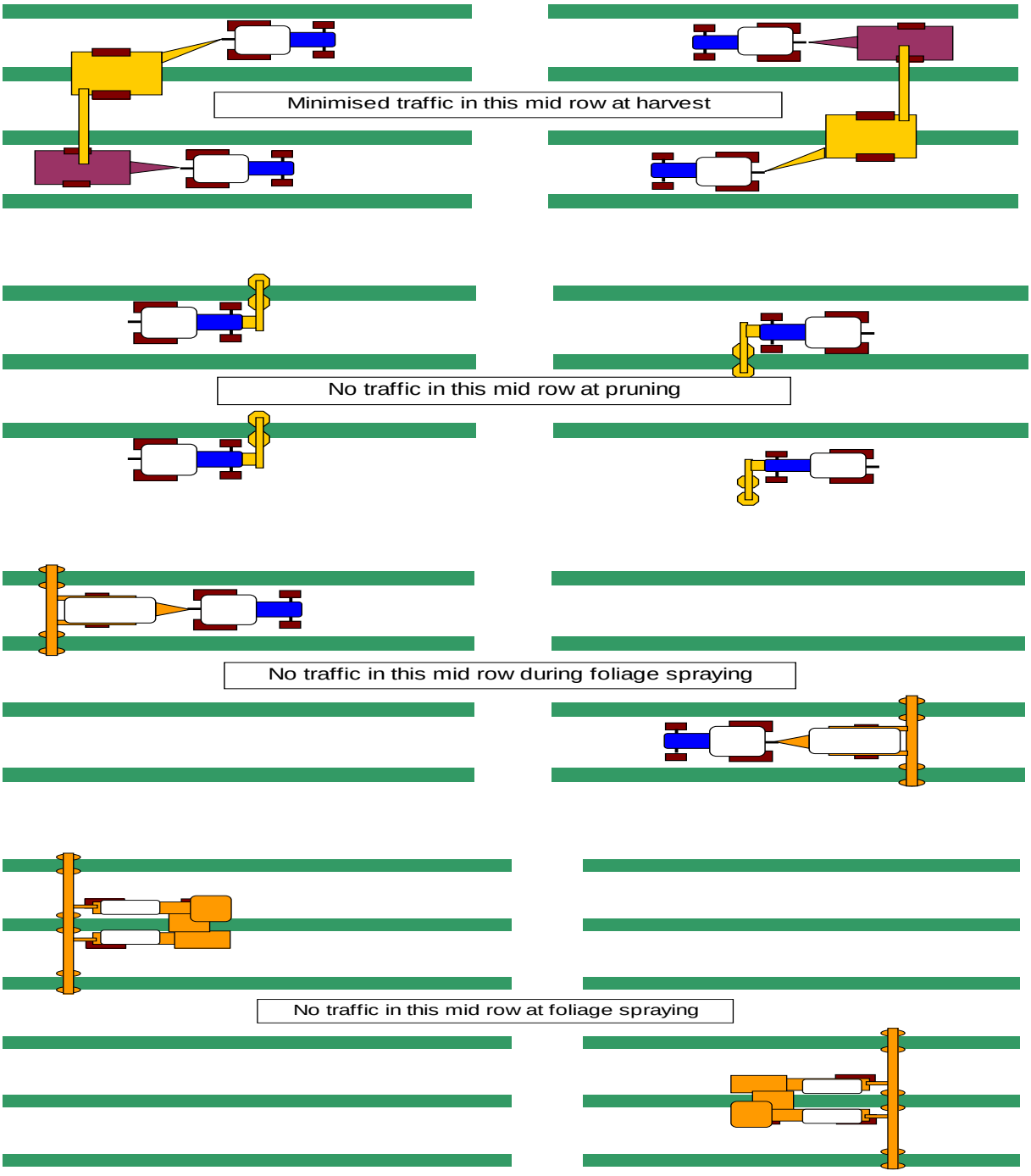
Most soil types subjected to deep cultivation benefit from shallow re-loosening operations at varying intervals throughout a 5 year period following the initial operation, particularly in high rainfall or poorly drained areas.

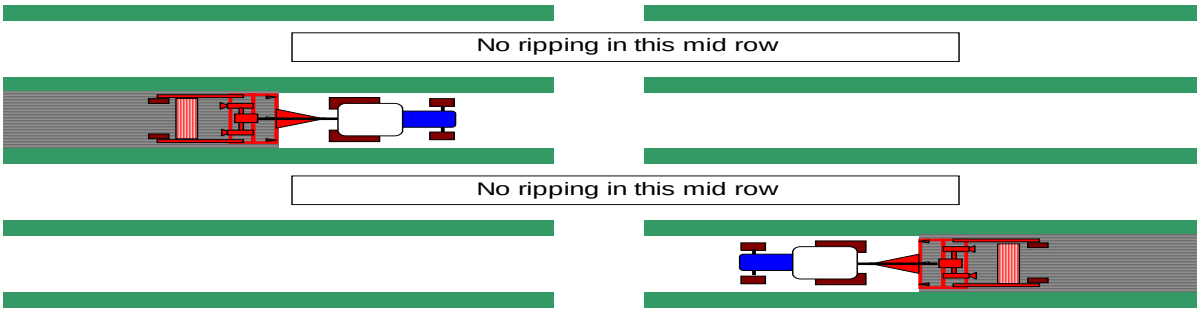
Soils with >35% clay content and some shrink-swell capability generally respond well to deep cultivation and require the lowest level of subsequent maintenance. Under drier conditions with careful surface management, these soils should required little further subsoil cultivation after an initial deep loosening operation, except for one shallower loosening 2-3 years later to re-open fissures in the upper subsoil.

An annual shallow loosening operations may help to maintain conditions for improved vine root penetration after an initial deep cultivation. At minimum, most soils will benefit from shallow loosening every two years

Managing the vineyard traffic subsequently to a loosening operation is very important as soils are most susceptible at this time to re-compaction. In some situations, the cultivated subsoils may re-compact worse than they were before cultivation, especially if deep tillage is applied in the upper of 15 – 35cm of the soil profile. Re-compaction is a particular risk if these soils are subjected to traffic with high axle loads and/or high inflation pressures, especially when the soil is wet.

The following diagrams show some typical scenario's of vineyard operations and how they can be carried out to minimise the trafficking in managed inter-rows to achieve maximum benefit from a ripper operation.





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Discussion of any IP derived from the project

There was no specific Intellectual property derived the GWRDC funded sections of this project, the technology was already developed by the University of South Australia and the Industry partners.

Details of Third Party IP rights

The IP rights for the technology developed in the first stage of this project and are shared between the University of South Australia and the industry partner.

Technical Summary

Vineyard and open field trials conducted by the University of South Australia have shown that a prototype dual-depth vibratory ripper can be used to maximise the subsoil loosening capacity of a 63kW narrow vineyard tractor. Vibrating the ripper tines has been found to reduce the draft or pulling effort required by these lightweight tractors by up to 38% compared to a similar rigid tine machine. The vibratory technology was found to increase the subsoil loosening capacity by up to 59% over equivalent rigid ripper configurations. Subsoiling capacity of a dual-depth ripper configuration was found to exceed that of a single depth arrangement by 30 to 50% whilst an additional pass preceding the dual-depth operation yielded a further 15 to 20% increase in capacity. The capacity and performance of a range of rippers with the small vineyard tractor were also evaluated. The greatest soil loosening capacity was achieved with the dual-depth vibratory ripper that was up to 3 times that of some commercial 3-point linkage rippers. A three-point linkage 2-tine Paraplow with long trash clearance tines also performed well with a subsoil loosening capacity of 80 to 85% of that achieved with the dual depth vibratory ripper.

Subsoiling capacity was greatest with the dual depth dual pass vibrating ripper technology that loosened 44% more cross-sectional soil area than the single pass dual depth vibratory ripper configuration and 77% more than the 5-tined Agrowplow ripper. Maximum tillage depth of the two vibratory ripper configurations was similar around 350mm but were found to be much greater than the 215mm achieved with the Agrowplow ripper. The vibratory ripper arranged in a dual depth configuration was found to achieve a depth of 375mm while loosening a cross-sectional area of 0.281m2 with a 70kW vineyard tractor. Vineyard trials investigating traffic management in the vine inter-row post ripping have found that within 3 months subsoil bulk density may return to that prior to the ripping operation when typical vineyard traffic is maintained. While minimising the inter-row traffic was found to have retained an 18% reduction in bulk density after 3 months. This provides greater opportunity for a more hospitable environment for vine root development into the previously compacted vine inter-row potentially increasing vine performance and economic viability.

Using liquid technology it is possible to provide the application of soil chemical modification, products such as Lime and Gypsum to the soil profile during the ripping process. This application can be made to the full depth of the ripping operation and distributed over the full width of the machine at the surface. The system has the potential to apply an equivalent amount of liquid as 2-8 tons/ha of granular product. The application of liquid lime or gypsum needs to be evaluated in the vineyard situation to determine any difference in rate of affect to the soil conditions and vine response

Statement of all receipts for expenditure in relation to the project

See Peter, need to ask Div ITEE finance dept.

Item	Funding allocated/approved 2003-04. This may be either total or **half invoice**	Actual expenditure for the period **Jan 04 to June 05**	Variance
1. Salaries	17,350.00	64,052.64	-46,702.64
2. Travel *Domestic* *International*	2,950.00	0	2,950.00
3. Operating	8,150.00	0	8,150.00
4. Capital			
TOTAL	28,450.00	64,052.64	-35,602.64
ADD GST	2,845.00	6,405.26	-3,560.26
TOTAL GWRDC	31,295.00	70,457.90	-39,162.90

Acknowledgements:

Many thanks to the funding of this project by GWRDC and the support provided by Orlando Wyndham staff, Kubpower, DeMill Engineering and Jeanette Chapman.