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A review of deep tillage research in Western Australia

M W. Perry
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A REVIEW OF DEEP TILLAGE RESEARCH IN WESTERN AUSTRALIA

Edited by M.W. Perry

Western Australian Department of Agriculture

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Edited by

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INTRODUCTION

Deep tillage to disrupt compacted soil layers on sandy surfaced soils appears to be one of the most promising methods of increasing crop productivity. From chance observation by farmers and researchers in the late 1970's came the largely unsuccessful trials of 1979 and 1980 and finally the very large wheat yield increases seen in 1981. From this time onward, the scientific investigation of deep tillage and its effects on soil structure and crop production has broadened enormously.

This workshop, held in March 1985, was an attempt to draw together the many pieces of research being conducted within the Western Australian Department of Agriculture. It provided an opportunity to consider results, discuss progress and decide on future directions for research.

Dr A. Ellington of the Rutherglen Research Institute, Victorian Department of Agriculture and Rural Affairs kindly attended the workshop and presented a comprehensive paper on deep tillage in eastern Australia. My thanks for contributing to the workshop go to him, to all other contributors, and to those who participated and made it a useful and successful workshop.

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August 1986.

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THE HISTORY OF DEEP TILLAGE RESEARCH IN WESTERN AUSTRALIA

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Researchers in Western Australia have been evaluating deep tillage for forty years but it is only in the last few years that benefits have been demonstrated.

In 1947-49 G.H. Burvill and E.R. Watson conducted trials on the property of R. Whitehead at Hines Hill comparing a disc plough, scarifier and chisel plough in fallow and non-fallow situations. Generally the chisel plough, worked at 15-20 cm, performed poorly and this result often led to very heated debate at field days. The trials were on fluffy morrel and gimlet clay loam soils and results really reflected the weed control ability of the different machines.

In the mid 1950's H.M. Fisher's trials at Avondale Research Station on loam soil over three years showed reduced yields from chisel ploughing at 20 cm, again due to worse weed control.

Fisher also conducted trials at Chapman, Wongan Hills, Avondale and Esperance in the early 1960's looking at speeds of cultivation and depths with chisel ploughs, scarifiers and disc and mouldboard ploughs. Weed control measurements were not often taken, however it was concluded "The effect of various machines under clover ley conditions is almost entirely due to level of efficiency in controlling annual weed growth" (Fisher 1962).

However, one trial within this series appears to have been the first trial to show a positive significant ($p < 0.01$) response to deep working light land. Fleming sand at Esperance Downs Research Station ploughed to 20 cm depth yielded 968 kg/ha compared to 780 kg/ha from a 10 cm deep ploughing in the absence of weeds (Fisher pers. comm.).

T.C. Stoneman included deep ripping in several of his gypsum trials on clays in the late 1960's-early 1970's but did not obtain crop yield responses. lHamblin and Tennant (1979) showed wheat root deformation below the cultivated layer in a yellow loamy sand and a severe reduction of root numbers at 20 cm in comparison with the numbers above and below.

At the same time a few farmers were talking about the need for deeper cultivation of light land, probably from observing the slower early growth of direct drilled crops. Others were still claiming responses from deep cultivation of clays and clay loams.

Deep ripping trials in 1979 and 1980 by Fenwick, Poole, Jarvis, Sweeny and Richardson failed to produce crop responses above those obtained from "conventional" cultivation.

The enormous wheat yield responses achieved in 1981 (Table 1, Jarvis 1983) from ripping light land was the commencement of the large research effort which has followed and is listed in the Appendix.

Table 1: Wheat responses from deep ripping trials 1981 (Jarvis 1983) - sands and loamy sands

Site	Cult./seeding method	Grain yield (kg/ha) No rip	Grain yield (kg/ha) rip	Yield increase (%)
Wongan Hills	Conventional	2040	2648	30
	Direct Drill	1881	2545	35
Yorkrakine	Conventional	353	678	92
	Direct Drill	354	682	93
Yorkrakine (Ripped May 1980)	Direct Drill	1203	1793	49
Watheroo*				
(15 cm deep)	Conventional	865	958	11
(30 cm deep)	Conventional	865	1155	34

* Data provided by R. Burnett, Crop Protection Consultant.

Aspects of deep ripping which have been or are currently being researched are:

- Soil types — white and yellow sands and loamy sands: acid loamy sand; loams; clay loams; duplex sand/gravel and sand/clay; gravels.
- Species response — wheat, oats, barley, triticale, cereal rye, lupins, peas, pastures; rotations.
- Mechanisms — root growth; water and nutrient relations; root disease interactions.
- Hard pan — artificial compaction; site variations; strengths at moisture contents, and bulk density effects on yield.
- Operational variables — draft and fuel use; depth; shank spacing; machines; time of ripping.
- Residual effects — longevity; artificial recompaction; longevity in rotations with varying cultivation techniques.

Fisher H.M. (1962) The effect of tillage implements on cereal yields. Journal of Agriculture W. Aust. Vol. 3 4th. Series 524-537

Hamblin, A.P., Tennant, D. (1979) Interactions between soil type and tillage level in a dryland situation. Aust. J. Soil Res. 17 177-89

Jarvis, R.J. (1983) Deep ripping produces wheat yield responses. Australasian Field Crops Newsletter. 18 104-106

APPENDIX

DEEP RIPPING RESEARCH BY THE DEPARTMENT OF AGRICULTURE, WESTERN AUSTRALIA 1979-1984

Trials are listed under sub headings of the year in which they were first cropped.

Each trial shows the following details:

* Trial number
* Research officers responsible
* Soil type (white, yellow etc.)
* Treatments included (direct drill, cultivated, deep rip, etc.)
* Trials sown to wheat except where otherwise mentioned (1st year only)
* Duration of trial. 'c' indicates continuing into 1985.

CROPPED 1979

79ES42 Fenwick - sand/clay - DD cult DR - 1979.

CROPPED 1980

80A44 Poole, Jarvis - sandy loam - DD cult DR - 1980-84.

80WH52 Poole, Jarvis - sandy/gravel - DD cult DR - 1980.

80ES50 Richardson - sand/gravel - DD cult DR - barley - 1980.

80NO46 Sweeny, Jarvis - Y loamy sand - DD DR - 1980 C. (failed)

CROPPED 1981

77WH17 Jarvis - Y loamy sand - DD cult DR 1981 C.

79MO19 Sawkins, Jarvis - clay loam - cult DR times - 1981 C.

80NO46 Sweeny, Jarvis - Y loamy sand - DD DR - 1981 C.

81NO3 Jarvis, Sweeny - Y loamy sand - DD DR time- 1981 C.

81NO4 Jarvis, Sweeney - Y loamy sand - cult DR time - 1981 C.

81NO2 Jarvis, Sweeney - clay loam - cult DR times - 1981-82.

81M45 Jarvis - clay loam - cult DR machines - 1981-84

81NA10 Negus, Jarvis - grey clay - DD cult DR machines 1981.

81NA11 Negus, Jarvis - shallow gravel - DD cult DR machines - 1981.

81MO39 Sawkins, Jarvis - clay loam - cult DR - 1981.

81ES55 Young, Jarvis - shallow gravel - DD cult DR - barley - 1981.

CROPPED 1982

81M53 Jarvis - Y loamy sand - DD cult DR times - 1982 C.

82M25 Ferguson, Jarvis - Y loamy sand - DD cult DR spacing times - lupin - 1982-83.

82M34 Jarvis - clay loam - DD cult DR - 1982 C.

82M35 Jarvis, Ewing - loamy sand - DD cult machines DR - 1982 C.

82M46 Jarvis, Ferguson - Y loamy sand - DD cult DR - 1982 C.

82ME38 Jarvis, Ferguson - Y loamy sand - DD cult DR times nitrogen spacing - 1982 C.

82GE37 Jarvis, Nelson - Y sand - DD cult DR - lupin - 1982 C.

82GE38 Jarvis, Nelson - Y sand - DD cult DR - 1982 C.

82NO48 Jarvis, Sweeny - Y sand - DD cult DR times machines N - 1982 C.

82NO49 Jarvis, Sweeny - Y sand - DD cult DR times machines - lupin - 1982 C.

82NO50 Jarvis, Sweeney - W sand - DD cult DR times machines N - 1982-83.

82NO51 Jarvis, Sweeny - W sand - DD cult DR times machines - lupin - 1982-83.

82MO35 Sawkins, Jarvis - red sand - cult DR N - oats - 1982.

82MO36 Sawkins, Jarvis - buckshot gravel - DD cult DR N - 1982.

82M31 Jarvis - clay loam - DD cult depths DR - 1982-83.

82M32 Jarvis - sandy loam - DD cult depths DR - 1982-83.

81LG3 Jarvis, Porritt - grey clay - DD cult DR machines depths times - 1982-83.

82N32 Jarvis - sand/clay - DD cult machines DR machines depths - 1982-84.

82N34 Jarvis - soil types - DD DR - barley - 1982-83.

82M61 Jarvis - sandy loam - DD cult DR machines - 1982-83.

76WH9 Bowden, Jarvis - Y loamy sand - compactions - 1982 C.

82WH2 Bowden, Tennant - Y loamy sand - cult DR N - 1982 C.

82WH36 Tennant - Y loamy sand - DD cult DR depths - 1982-83

81M52 Tennant - clay loam - cult DR times - 1982-83.

81M54 Porter - Y loamy sand - cult DR depths - 1982-84.

CROPPED 1983

82WH49 Jarvis - Y loamy sand - DD mod C cult DR depths times - 1983 C.

83NO69 Jarvis, Sweeny - Y loamy sand - cult DR N - 1983 C.

83JE26 Rees, Jarvis - W sand/gravel - DD cult DR depths N - 1983 C.

83NA37[a] Rowley, Jarvis - Y sand - DD cult DR N - 1983.

83NA37[b] Rowley, Jarvis - S C/clay - DD cult DR N - 1983.

83NA38	Jarvis, Negus - sandy loam/clay - DD cult DR - 1983.
83NO72	Sweeny, Jarvis - gravel - cult DR depths - 1983.
83TS42	Jarvis, Blake - clay loam - DD cult DR - 1983.
83ME63A	Sullivan - clay loam - cult DR gypsum - 1983-84.
83WH28	Tennant - Y loamy sand - cult DR lupin and wheat - 1983-84.
82WH35	Bowden, Delroy - Y loamy sand - DD DR N after spp. - 1983-84.
83WH31	Bowden - Y and W loamy sand - cult DR N - 1983-84.
83C24	J. Hamblin - Y sand - DD cult DR fungicide - 1983.

CROPPED 1984

84C42	Jarvis, Haagensen - Y sand - cult DR - 1984.
84C43	Jarvis, Haagensen - Y sand - cult DR - 1984.
84C44	Jarvis, Haagensen - Y sand - cult DR - lupin - 1984.
84C45	Jarvis, Haagensen - Y sand - cult DR - 1984.
84WH2	Jarvis - Y loamy sand - cult DR spp. - 1984 C.
84WH3	Jarvis - Y loamy sand - DD cult DR recompaction - 1984 C.
84WH39	Jarvis - Y loamy sand - cult DR speeds machines - 1984 C.
84M38	Jarvis - Y acid loamy sand - cult DR spp. - 1984 C.
84LG37	Jarvis, Porritt - W sand - DD compactions - 1984 C.
84NO58	Sweeny, Jarvis - sand/clay - cult DR machines - 1984.
82MO30	Sawkins, Jarvis - Y loamy sand - cult DR after W and after lupin N - wheat and barley - 1984 C.
84JE43	Jarvis, Rees - W sand/clay - DD cult DR depths - 1984 C.
84JE44	Jarvis, Rees - gravelly sand/clay - DD cult DR depths - barley - 1984 C.
84E23	Jarvis, Brennan - s/grav. - DD cult machines times DR depths - 1984 C.
84E24	Jarvis, Brennan - w sand - DD cult machines times DR depths - 1984 C.
83M62	Riethmuller, Jarvis - clay loam - cult DR depths - 1984.
84ES47	Richardson, Jarvis - W sand - DD DR - lupin 1984 C.
84ES48	Richardson, Jarvis - sand/clay - cult DR - barley - 1984 C.
84GE45	Henderson - Y sand - compactions - spp. - 1984 C.
84GE46	Henderson - Y sand - compactions - wheat - 1984 C.
84C15	Wilson, Brown - Y sand - DD DR fungicide after W and after L - 1984.

BIOLOGY OF ROOT GROWTH IN CEREALS

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In common with other grasses, the temperate cereals posess two distinct root systems: the seminal roots which develop from primordia present within the grain, and adventitious or nodal roots which develop in association with tiller buds from the nodes of the crown.

SEMINAL ROOTS

In the mature grain the embryo consist of a short axis with a terminal plumule enclosed within the coleoptile, the scutellum which is attached to the back of the axis below the coleoptile attachment, and the terminal primary root enclosed within the coleorhiza (Fig. 1).

From a consideration of the vascular anatomy of the seedling McCall (1934) identified the vascular structures at the root-stem plate, and at the points of attachment of the scutellum and coleoptile as homologous to the nodes of the stem and thus the points of origin of the 'seminal' roots.

The radicle or primary seminal root is an extension of the embryonic axis below the root-stem vascular plexus. Also present in the embryo, but less well developed are the primordia of the first pair of lateral seminal roots originating at the root-stem vascular plate or first node. The primordia of one or two of the second pair of lateral seminal roots may also be present at the scutellar node (Fig. 2).

The appearance of the primary seminal root is the first outward sign of germination and this is followed by the first pair of lateral seminal roots which originate at the root-stem vascular plate. These roots grow rapidly probably due to their well developed vascular connections to the scutellum. Seminal root primordia are also present at the scutellar node of the embryo and normally a second pair of lateral seminal roots appear from this node 3-4 days after germination. In poorly developed seeds one or both of these primordia may be absent, whilst in well developed seeds a third root may appear at the scutellar node. Later still, 1-3 roots may appear from the coleoptile node although they usually grow only slowly. Thus a minimum of three and a maximum of nine 'seminal' roots may be attached below the sub-crown internode of the plant.

NODAL ROOTS

Klepper, Belford and Rickman (1984) have described in detail the development of roots in the wheat seedling. Their paper highlights the close association of root and shoot growth, particularly for the nodal roots, and the predictability of root appearance at least in constant environments.

The adventitious, crown or nodal roots originate from the nodes of the crown and develop in association with the tiller buds formed in the axils of the leaves. The nodal roots are first apparent at the time of appearance of the first tiller from the sheath of its subtending leaf as a pair of roots appearing at 90 degrees to the attachment of the leaf (and tiller). A third root may appear opposite the tiller, and a further root attached to the tiller appears through the leaf sheath about one phyllochron later.

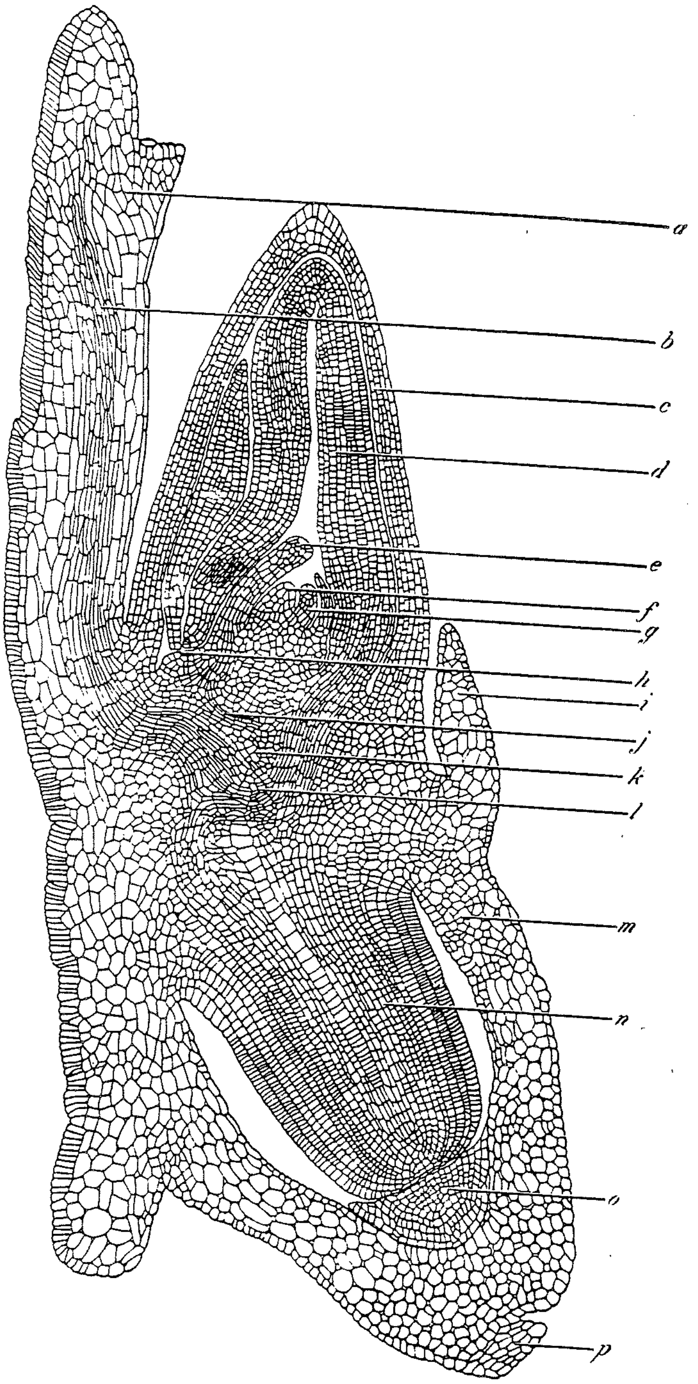

Fig. 1. Section of a mature wheat embryo. Structures are
a) Scutellum, c) Coleoptile, d) First leaf, g) shoot apex
n) Radicle. After Weaver (1926).

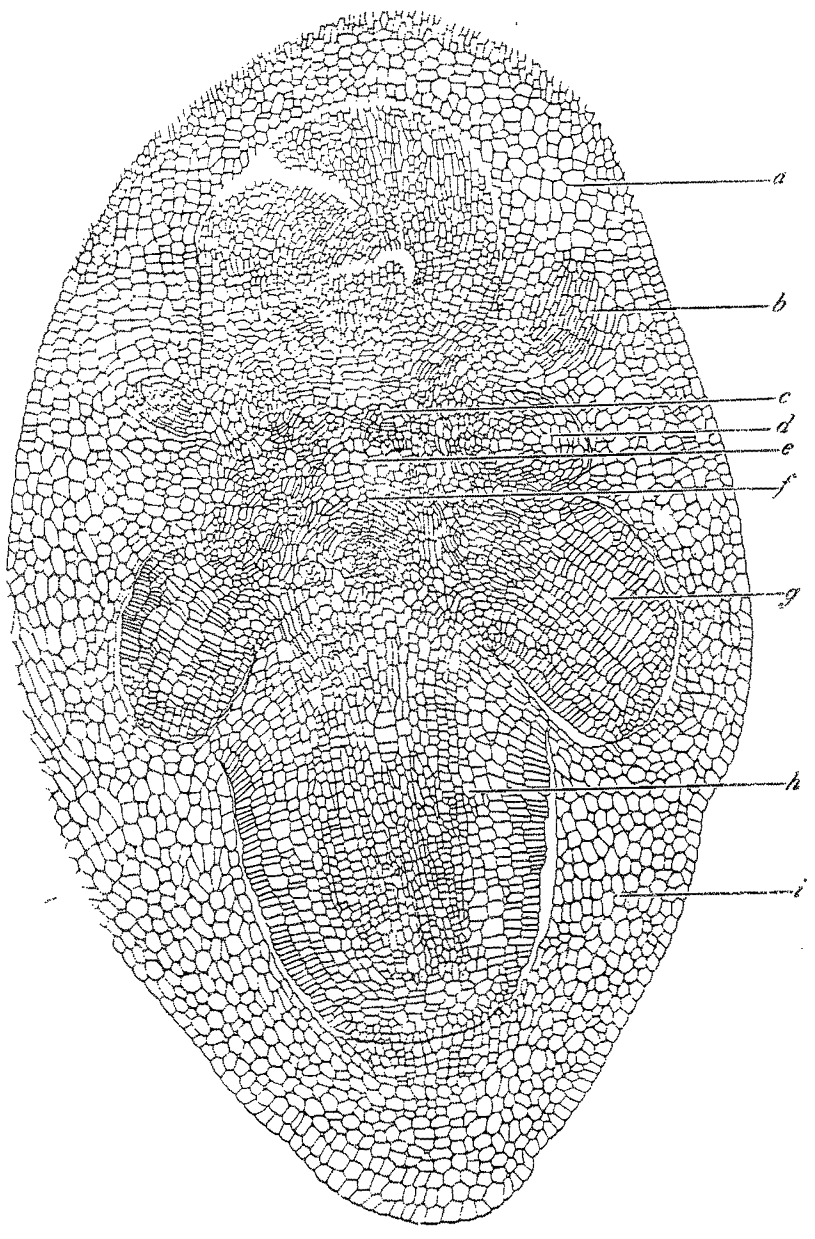

Fig. 2. Longitudinal section of a wheat embryo showing the radicle (first seminal root) and the primordia of the first and second pairs of lateral seminal roots.

ANATOMY

Despite the great variation in form, all root systems share the common characteristic that their continued elongation depends on cell division and subsequent expansion of cells in the apical meristem. In cereals, the root attains maximum diameter within 0.5 - 1.0 cm of the apex when the cells are fully expanded and tissue differentiation has occured, the older root parts remaining as a cylinder of approximately uniform diameter. The main tap root of dicotyledons, in contrast, increases in diameter as a result of cell divisions in the vascular cambium tangential to the root axis.

The general structure of the root apex is similar in all flowering plants. Cell division in the apical meristem occurs in both directions along the axis of the root creating both the new root cells and a protective root cap. A zone of cell elongation and differentiation follows the apical meristem to form the two major structures of the mature root: the cortex and the vascular stele (Fig. 3).

The cortex

The innermost layer of the cortex develops into the endodermis which encases the vascular stele. A 'casparian strip' first develops on the radial walls of the cells forming a barrier to the movement of water and solutes through the cell walls into radial walls to form a water tight barrier penetrated only by plasmodesmata which constitute a cytoplasmic link between the endodermal cells and the pericycle. Outside the endodermis the cells of the cortex are thin walled with large intercellular spaces. The outer epidermis bears the root hairs which are protuberances from the epidermal cells. They arise 0.5-1.0 cm behind the apex and may be up to one millimeter in length. Frequently they persist for only a few days. When root extension is limited by mechanical forces root hairs form very close to the apex and may function to anchor the root thus increasing the effective pressure at the root tip.

The vascular stele

The root tissue within the endodermis is called the stele. It contains relatively undifferentiated tissue, the pericycle, within which are embedded the dual transport systems of the xylem and phloem.

CEREAL ROOT SYSTEMS IN THE FIELD

Weaver (1926) has provided elegant descriptions of unrestricted cereal root systems in the field. Figure 4 is one example of his painstaking work. However, for many purposes we require more quantitative measures of the performance of the root system.

Branching

Laterals originate on the unbranched segment of the root. Primordia may be present within 2 cm of the apex, but laterals seldom appear until the apex has extended a further 6-10 cm. Lateral primordia develop within the pericycle and are thus protected from dessication in dry soil conditions. Their appearance is also altered by environmental conditions and localised proliferation can occur due to favourable soil conditions.

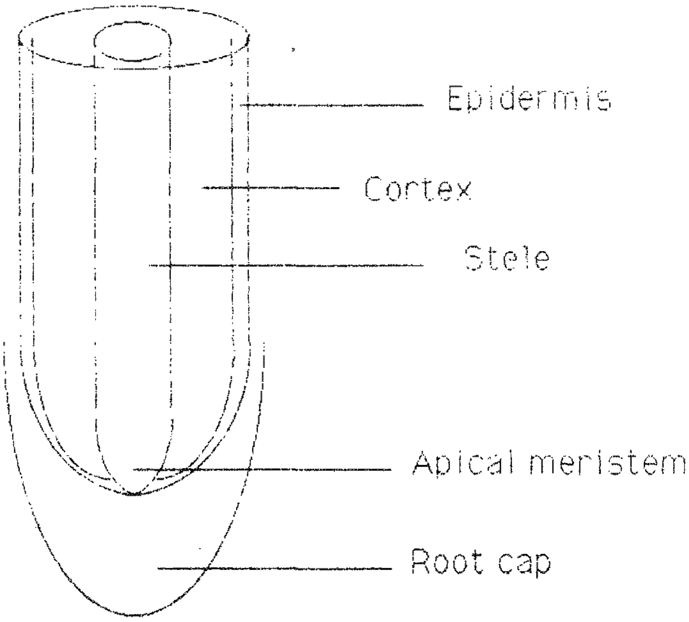

Fig. 3. Structure of a root tip

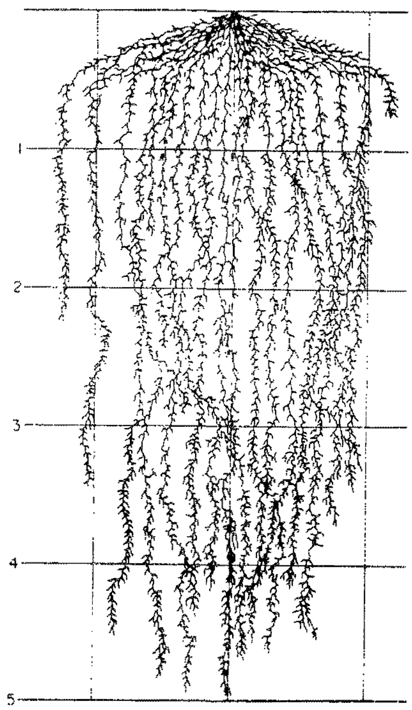

Fig. 4. Root system of rye grown in a dry sandy soil. Weaver (1926)

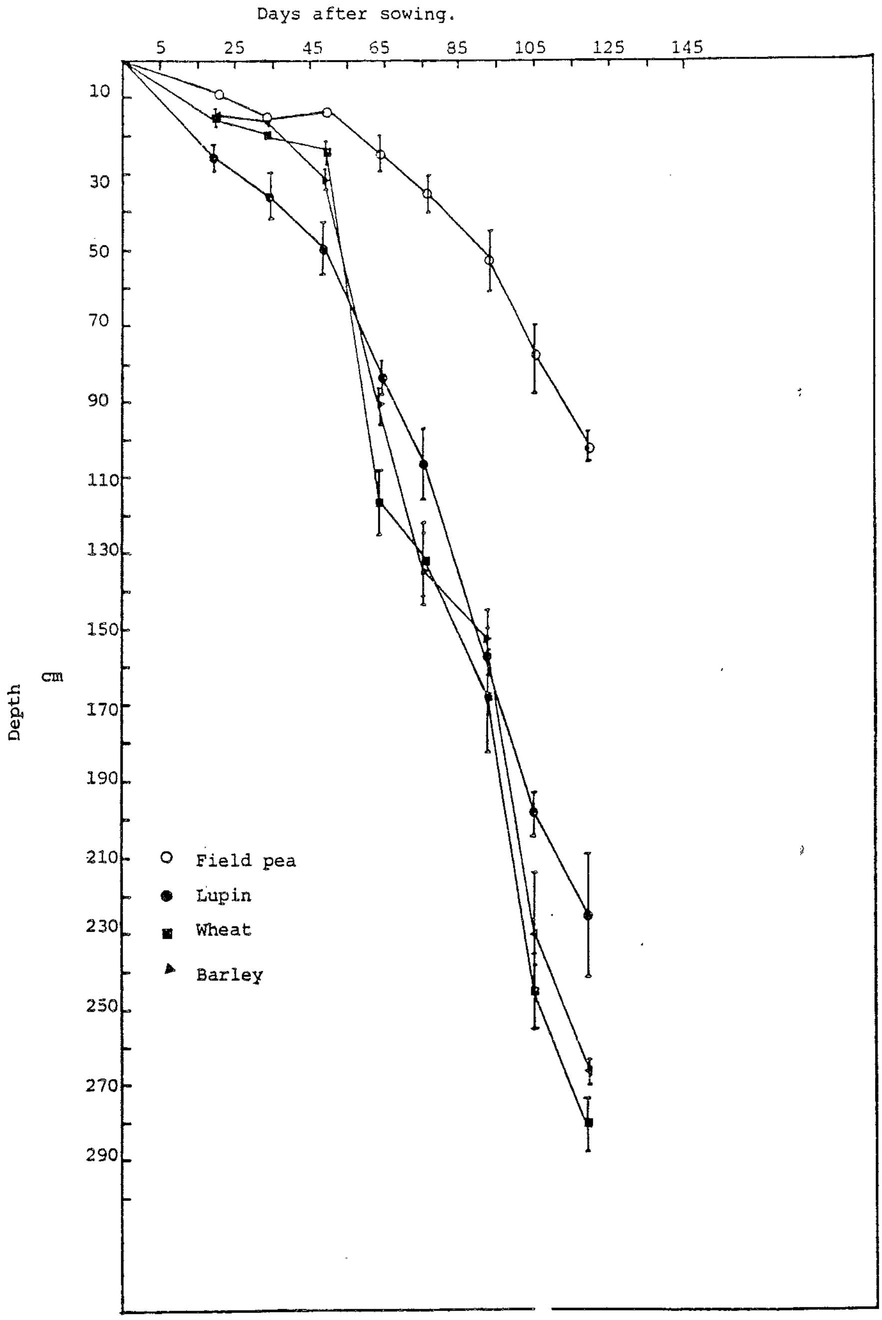

Fig. 5. Root extension rates for wheat, barley, lupins and peas in a deep loamy sand. Wongan Hills 1983.

Rate of root extension

Rates of root extension of up to 8 cm/day have been measured in maize, but typical values for the small grain cereals under favourable conditions are (Lungley 1973):

Root axes: 2.0 cm/day
Primary laterals: 0.5 cm/day
Secondary laterals: 0.1 cm/day

Figure 5 shows the extension to depth of the roots of four species on a deep yellow loamy sand in the Western Australian wheatbelt. For the wheat, barley and lupin, the rate of root extension from about day 45 onward approaches 3.5 cm/day almost double the rates quoted for temperate cereals by Lungley (1973).

Root distribution

Depth: The volume of soil the root system can explore is determined largely by the depth of root penetration. This depends on both plant species and growing conditions, but, given an extension rate of 2-4 cm/day, the root system of annual crops will seldom extend to beyond 3.0 metres.

Table 1: Measured maximum root depths (cm) for crops and pastures in Western Australia.

Location:	WHRS	Chapman	Northam'n	Merredin	Merredin	Merredin
Soil:	YE	YE	YE	HL	TL	LL
Year:	1983	1982	1982	1984	1984	1984
Source*:	2	1	1	2	2	2
Wheat	280	138	100	116	140/150	175
Barley	265	-	-	100	125/150	103
Lupin	230	198	182	85	135/140	163
Pea	102	70	60	76	84/140	95
Rye	-	-	-	-	-	245
Clover	-	-	80	-	-	-
Medic	-	77	102	-	-	-

Source: 1. Hamblin and Hamblin (1985)
2. Hamblin, Tennant and Perry (unpublished)

On fine textured soils in low rainfall regions, root depth is often limited to 1.2 - 1.5 m by the depth of rainfall penetration, whilst in well watered temperate climates maximum depth is often only 1.5 m despite a lack of obvious restriction. Deepest root penetration appears to occur on coarse textured soils with low to moderate seasonally concentrated rainfall where water drains to depth and the surface soil dries during the later part of the crop's life cycle. Table 1 lists some measured root depths for crops in Western Australia.

Root length

Root length present in the soil beneath a cereal crop can be prodigious. Length measurements may be presented as root length per unit soil volume (Lv), or as root length per unit ground area (La). Table 2 gives some values for La and Lv recorded for maize in the USA and for barley and wheat in the United Kingdom.

Of the two measurements, La, the root length per unit area, represents an integrated measure of the total root length below unit area of the surface. For the cereals, La may be as high as 400 cm/cm^2 (Walter and Barley 1971) although values of 100-200 cm/cm^2 are more common in European cereal crops at anthesis (Nye and Tinker 1984). (To put these figures in better perspective, 100 cm/cm^2 is equivalent to 10.0 km of root per square meter of surface).

Table 2. Measurements of root length per unit volume (Lv) and per unit surface area (La).

Species	Age days	Depth cm	Lv cm/cm^3	La cm/cm^2
Zea maize	100	0- 15	7.7	170
		15- 30	2.7	
		30- 60	0.6	
		60- 90	0.1	
Hordeum vulgare		0- 5	4.2	96
		5- 10	1.6	
		10- 20	1.1	
		20- 60	0.7	
		60-140	0.3	
Triticum aestivum		0- 15	3.3	111
		15- 30	1.1	
		30- 60	1.1	
		60-100	0.3	

In Western Australia, measured root lengths are much lower than those commonly quoted for cereals in Europe (compare Tables 2 and 3). Lengths measured for grain legume crops are much lower again, but the pasture legumes appear to have overall root densities as high or higher than the cereals.

Table 3. Root length per unit area (La) for crops and pastures in Western Australia.

Species	Age (days)	La (cm/cm2)	Source*
Triticum aestivum	110	23 (22)	1
Triticum aestivum	110	26 (59)	1
Triticum aestivum	109	42	2
Triticum aestivum	104	76	2
Lupinus angustifolius	110	10 (12)	1
Lupinus angustifolius	109	9	2
Lupinus angustifolius	104	15	2
Hordeum vulgare	109	38	2
Hordeum vulgare	104	50	2
Pisum sativum	110	11 (13)	1
Pisum sativum	109	15	2
Pisum sativum	104	10	2
Trifolium subterraneum	110	62 (85)	1
Medicago polyumorpha	110	75 (85)	1

* Sources 1. Hamblin and Hamblin (1985)
2. Hamblin, Tennant and Perry (Unpublished)

Figures in brackets refer to the rainfall site of Hamblin and Hamblin 1985.

Root lengths per unit area alone, however, are only one aspect of root distribution. Plant communities with equal La may have very different root density distribution (lv) with depth in the profile with important consequences for growth and water extraction. Lv may approach 10 cm/cm^3 in the surface 15 cm but usually decreases very rapidly to about 1.0 cm/cm^3 below 20 cm and to values of 0.5 - 0.1 cm/cm^3 at depth. Figure 6 illustrates the distribution of roots down the profile for three contrasting crop species on a yellow loamy sand.

The decline in Lv with depth is approximately logarithmic and can be described by:

$$Pz = 100 \ (1-e \ (fz) \ )$$

where Pz is the percentage of root between the surface and any depth z, and f is a constant. It follows that 1/f is the depth of soil containing 63% of the roots and this depth is less than 30 cm for most crop plants (Gerwitz and Page 1974).

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PHYSICS OF SOIL COMPACTION AND ROOT GROWTH IN COMPACTED MEDIA

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SOIL COMPACTION

Soil compaction describes reductions in soil pore volume which occur as the result of applied stresses. These stresses may include raindrop impact, overburden pressure, compression by plant roots, pressure of vehicle wheels, tillage blades or animal hooves. All result in a loss of pore volume and an increase in particle to particle contact of the soil matrix. The result is that the cohesive forces in the soil increase, and in the case of angular particles, the angle of internal friction also increases. The soil develops higher shear, compressive and tensile strength as a result. Shear strenth (T) of a normally loaded soil depends upon the cohesive (C) and frictional (ϕ) forces of the material as follows:

$$T = C + E_n \tan \phi$$

Coulombic or cohesion forces depend upon the number of adsorbed water layers and surface area of the soil matrix. C therefore increases with clay content and with surface area (which also increases with clay content). If the water content increases to a value where water, not mineral particles form a continuous lattice, then cohesion once more declines. Soils with 30% clay have clay particles forming a continuous matrix. They generally show bulk shrinkage and swelling with changes in water content, and their high cohesive value of the dry matrix is offset by tensile failure of the bulk material. Soils with less than 8% clay have very little cohesive strength at any water content, but develop high angular friction as particle interlocks with particle when water is progressively withdrawn. In sands which have surface coatings of metal-hydrous oxides dry strength is much enhanced by secondary cementation. Fragipans and plinthites are examples of soil types which are soft when wet, hard when dry. Conversely materials which increase intra-aggregates (organic matter and live are the best known) reduce the angle or internal friction, so that the soil shears at a lower stress value.

When the soil is compressed the volume change causes a reduction principally in the gas filled void space, (water being virtually uncompressible). The void ratio (e = volume of voids/volume of solids) depends logarithmically on the applied load and its rate of application.

$$e = \frac{de}{d \ln P} \ln P - K \qquad \text{where K is a constant}$$

When soils are compressed at low pressures particles simply reorient in relation to each other. In high pressure consolidation the colloidal "packages" or micelles are squeezed together as well. Then when the load is removed the soil "rebounds" to some extent through the re-absorption of water in the diffuse double layer around clay micelles.

The amount of rebound depends not only on the clay content, but on the clay and cation composition, with greater compressibility and rebound of monevalent than divalent cations and of three layer to two layer clays.

When a wheel or animals' hoof presses on the soil the resultant forces are distributed over a pear-shaped vector in what is described as arch-action, with decreasing reduction or void ratio outwards across the vector. Maximum compaction occurs directly below the applied pressure, but the soil is compressed laterally either side as well. When soils are compressed while wet, by wheel tracks, the slippage of tyres also puddles and shears the immediate contact zone.

The depth and degree of compaction in any soil will depend on both traffic and soil factors. The load per unit area of surface contact is the most significant aspect of the traffic, unless the vehicle is drawing a tillage implement. Then a double compaction feature develops, with shearing and blocking of transmission pores beneath the compaction zone. Load for load a narrow wheel causes greater compaction than a wide one, and a wheel more than a caterpillars track. The dilemma for the farmer is that any draw-bar pull requires a certain load per unit contact area to avoid excess wheel slip. Wheel-slip is wasteful of fuel and just as damaging as compaction to the surface soil. All loads large enough to reduce wheelslip are liable to cause compaction when the ground is wet or loose. Ideally traffic and tillage would be restricted to times when the soul is friable enough to shear without being wet enough to deform plastically. Sadly the water content range over which most soils are capable of brittle fracture is small, and becomes smaller when organic matter content is low.

Identification of compaction is made by using a hand-held penetrometer which has a fine cone-topped probe linked to a pressure sensor. Characteristically the force required to compress and shear the soil increases then decreases as the penetrometer moves through the compacted zone. If the surface has not been tilled or loosened since compaction occurred the highest strengths will be nearest to the surface, but generally the surface soil is loose after tillage and the compaction appears as a "pan" at the base of the tilled top-soil.

It is not always easy to distinguish compacted layers from pedalogical layers of inherently varying mechanical strength. Many Australian soils have a "textural B" horizon of higher clay content than the A horizon, which offers more resistance to penetration, especially at low water contents. Equally, the slower wetting-up of clay profiles may confuse idenfication of textural layering from compacted soils. Compaction is most readily identified in soils of less than 30% clay, and traffic pans form particularly easily in soils of high silt and fine sand content, such as silt and sandy loams, loamy sands, and fine sands. In finer textured soils identification is possibly by observing changes in ped-structure in parts of a paddock which have had different levels of traffic (gate areas, headlands, fence-lines, etc.). Compaction typically gives rise to platey ped - structures with tell-tale traces of mottling indicative of impeded water movement, in many wetter locations.

ROOT GROWTH IN COMPACTED MEDIA

The pressure applied by growing root tips to the soil is approximately radial, which is why the penetrometer may be considered to simulate the force-field, though the scale dimensions are quite different. Root elongation rate is related exponentially to penetrometer resistance across a wide range of soil types. In any one soil an increase in bulk density (decreased void ratio) a suite of functional curves develops for root elongation rate closer and closer to the intercept. Root growth is also highly dependent on soil aeration, water potential and temperature. As these are all altered by reduction of void ratio and the disruption of continuous pore channels in compacted soils, root growth in compacted soils can only be understood in terms of the interactions between soil physical properties.

Considering the pore geometry aspect first we note that:

(i) Roots cannot grow into rigid pores narrower than their own diameters.

(ii) Root tips can exert pressures up to 10 MPa to expand non-rigid pores in deformable (plastic or friable) soils.

(iii) Critical values at which root growth ceases in compact soils vary from < 1 to > 4 MPa depending on the soil composition, plant species and pore water potential. In other words the penetrometer only poorly simulates the root.

(iv) Roots growing through apedal sands must expand pores or be deflected, but roots growing in coarse-structured fine textured clays are inevitably restricted to regions of lowest resistance (major crack planes).

(v) Roots preferentially grow geotropically and root elongation rates are substantially reduced (to a half or less) if they are constrained to grow down channels at less than 45^{o} to vertical.

(vi) High levels of mechanical impedance cause tips to become buckled, with an expansion of the cross-sectional diameter and proliferation of root hairs behind the meristematic zone. Respiration rate increases but cell expansion is reduced.

Changes in mechanical strength, water and aeration occur consistently in compacted soils because all depend on the pore structure. As the soil is compressed there is a preferential loss of larger pores, together with shearing and deformation of continuous pathways leading to:

(i) Reduction in air filled pore space.

(ii) Reduction in hydraulic conductivity at high water contents.

(iii) Reduced soil water potential for the same water content.

(iv) Increased cohesion and shearing strength for each water potential.

(v) Decreased diffusivity for the same water content.

The effects on root elongation rate of say decreasing void ratio at the same time as soil water potential drops (soil water content unchanged) is synergistic. If a reduction from 90 to 40% of maximum root elongation rate occurs when void ratio is reduced from 1.63 to 1.43 then the same reduction is void ratio plus a change from -20 to -70 k Pa will result in a reduction in root extension rate from 90% to 10% of maximum.

Compaction of fine textured soils often leads to gas filled void space (X) of < 10% which is often considered a critical value for oxygen demands. However the necessary oxygen flux varies greatly with ambient and soil temperature and the combined respiration demand of the plat roots and microbial population. An oxygen flux of a seedling crop in winter at say $5^{o}C$ may be only 1×10^{8} mg m^{-2} S^{-1}, whereas the same soil growing a leafy crop in spring where soil temperature is nearer $20^{o}C$ would be of the order of 1.5×10^{-7} mg m^{-2} S^{-1}. Oxygen diffusion rates in moist soil are of this order of magnitude, whereas the diffusion rate in water is 1.8×10^{-9} mg m^{-2} S^{-1}.

Compaction of coarse-textured soils does not give rise to problems of anaerobiosis but it results in restricted root branching. This reduces the nutrient and water extraction from the compacted zone by increasing the pathlength from the mid-point between each root to the root surface. The half distance (b) between roots, each occupying a cylinder of soil is:

$$b = \frac{1}{\Pi L_v}$$

where L_v is the root length density per unit volume. In addition reduction in root elongation rate in coarse textured soils restricts the total depth of soil profile utilized. This has serious consequences for crop water status in soils of low available water capacity if the reproductive phase of the crop coinsides with spring and summer drought. A corollary of the extraction of water by plant roots is that they are themselves increasing the soil strength in the upper parts of the profile as they grow downard. The larger the canopy leaf area the faster this happens. Fine lateral root development may thus be restricted by increasing soil strength so that not all water can be extracted from all parts of the root-inhabited profile.

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EFFECTS OF DEEP TILLAGE ON ROOT GROWTH AND WATER USE OF WHEAT AND LUPINS

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INTRODUCTION

On light land, trial results have consistently shown higher yields with wheat (10 to 35%) after deep tillage to 35 cm than concentional cultivation to 10 cm (Jarvis 1982, 1983). These higher yields have been shown (Tennant 1983) to follow from disruption of traffic pans located between 15 and 25 cm from the soil surface. Disruption of these dense soil layers resulted in better plant water relations from faster root penetration to depth and greater final depths of root penetration. In contrast, lupins have generally failed to respond to deep tillage. Lupin yields after deep tillage have either been similar to those obtained after conventional cultivation or even been a little lower. Only in rare instances have yields of lupins been higher after deep tillage.

To better understand this differential species response to deep tillage, detailed root growth and water use data were obtained for wheat cv. Gamenya and lupin cv. Yandee under deep tilled and conventionally cultivated conditions on deep loamy sand at Wongan Hills.

MATERIAL AND METHODS

The trial was carried out at Wongan Hills on deep loamy sand - Uc 5.32 Northcote (1974) classification. The presence of ferruginous gravel at varying depths in the profile is characteristic of Wongan loamy sand. At the site used, this loose gravel occured at depths below 3.5 m. Clay content ranged from 10% in the surface 10 cm to 20% below 150 cm.

The site had been cropped to wheat in the previous year. A split plot design of 4 replications was used in which the wheat and lupins were randomised within alternatively deep tilled (DT) and conventionally cultivated (CON) blocks. Each treatment comprised two 5 m x 30 m plots; one of which was used for root and plant sampling, and soil water determination; and the other for machine harvesting. Deep tillage was carried out June 3, 1983, using an Agrowplow with two rows of offset tynes spaced 144 cm apart, to 35 cm depths. All treatments were sown on June 13 using 45 kg/ha wheat cv. Gamenya seed and 100 kg/ha lupin cv. Yandee seed. A basal dressing of 200 kg/ha superphosphate (CuZnMo No. 1) was applied at seeding. 45 kg/ha of N was applied as ammonium nitrate (Agran 34:0) to the wheat plots within three weeks of planting.

Soil strength data were obtained for all treatments at 3.5 cm intervals to 49 cm from the soil surface, at 4 locations in each plot of each replicate, using a Bush recording penetrometer (Anderson et al. 1980). Detailed dry matter, root growth and water profile data were obtained for all treatments. Soil water was measured at fortnightly intervals from planting with a CPN model 503 neutron moisture meter, using poly vinyl chloride lined access tubes to 400 cm, at 20 cm intervals down the profile, commencing at 30 cm from the soil surface. A single field calibration: - $Y = 0.32 + 3.26$ NCR, were Y = volumetric soil water; NCR = neutron count ratio was used for all depths of measurement. Dry matter data were obtained at the same time from two 0.5 m cuts (8 rows a 35.7 cm) from each end of each plot. Depth of rooting and root density data were obtained from 7.5 cm diameter cores, obtained over the crowns of single plants within rows, at 10 cm intervals down the profile to depths beyond which roots were observed. Sampling intensity varied from two cores per replicate during early sampling to 1 core per replicate at final samplings. Root length was measured using the root intercept method described by Tennant (1975).

RESULTS

Penetrometer and bulk density data obtained on July 6, 25 days after planting, are shown for the deep tilled and conventionally tilled treatments in Figure 1. The data established the presence of a dense soil layer throughout the trial area, located between 10 and 35 cm from the soil surface with peak resistance values around 20 cm. Water contents obtained at the same time were higher with the CON than DT treatments. Those in the pan area were 0.124 and 0.103 respectively. Deep tillage to 35 cm removed all traces of the pan.

The higher soil strengths and densities within the pan layer had a significantly greater effect on early rates or root penetration of wheat than lupins (Figure 2). Average rates of root penetration through the pan after conventional tillage were of the order of 0.70 cm/day with wheat and 1.22 cm/day with lupins. Rates of root penetration over the same time period were significantly faster after disruption of the pan by deep tillage; 1.81 cm/day with wheat and 1.55 cm.day with lupins. Consequently by the time roots of CON wheat had penetrated the pan, the DT wheat roots were 30 to 60 cm deeper in the profile; with lupins this difference was of the order of 10 to 30 cm. Subsequent to penetration of the pan area, rates of root penetration tended to be slightly higher with both the CON and DT treatments of wheat (2.77 cm/day) than lupins (2.57 cm/day). The data also suggest that lupin root penetration may have continued for a longer period after planting than that of wheat. Sampling over this latter period was not carried through to harvest.

Some effect on sample "integrity" can be argued for the lupin roots as a consequence of a high incidence of root disease. This would be particularly relevant to data obtained mid-season, when data obtained from infected plants would have negatively biased the root depths reported for lupins, arguably perhaps to a greater extent with CON than DT. Because of this confounding effect, and because a harvest sampling was not carried out, comments on eventual maximum depths of rooting are held back until water extraction data are presented.

Figure 3 shows details of root distribution down the profile under CON and DT wheat and lupins at 4 times of sampling. Root densities (Rv,. cm^{-2}) of wheat tended to be higher with CON at the surface (0-10 cm depths) and invariably higher with DT than CON at all sampling intervals below 50 cm. The data for wheat suggest an inflection in the root density data for CON within the 10 to 30 cm depth region and for DT within the 30 to 50 cm depth region. The inflection for CON coincides with the higher pan soil strengths and densities while that for DT occurs immediately below the depth of soil disruption by deep tillage. Lupin root densities were only marginally higher at depth with the DT than CON tractments and generally gave no indication of responses to higher soil strengths and densities either within the pan (CON) or below the depth of soil disruption by deep tillage. Overall, lupin root densities were significantly lower than those of wheat at all depths in the profile.

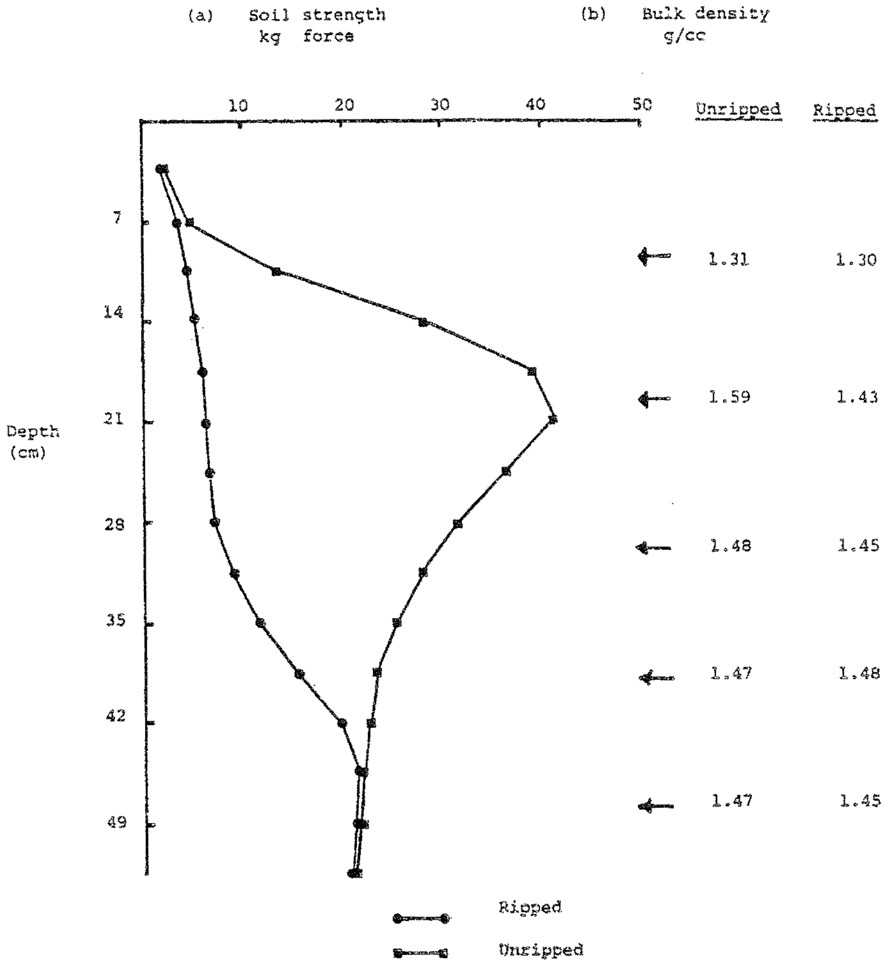

Fig. 1. Deep tillage effects on soil strength and bulk density.

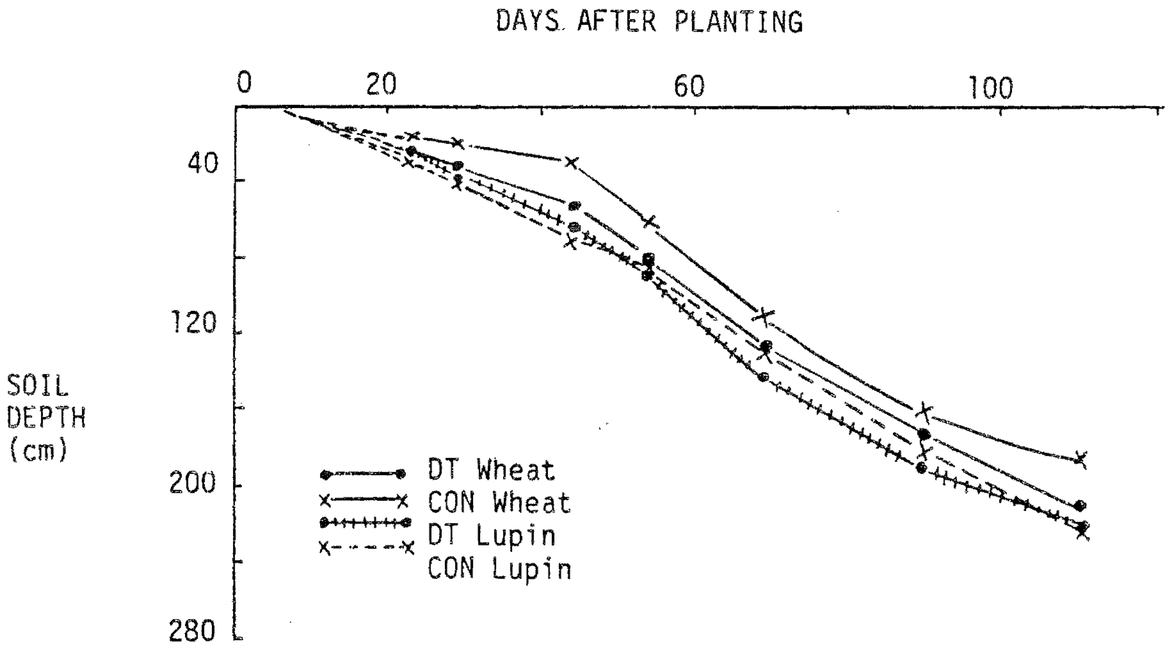

Fig. 2. Deep tillage effects on root penetration of wheat and lupins.

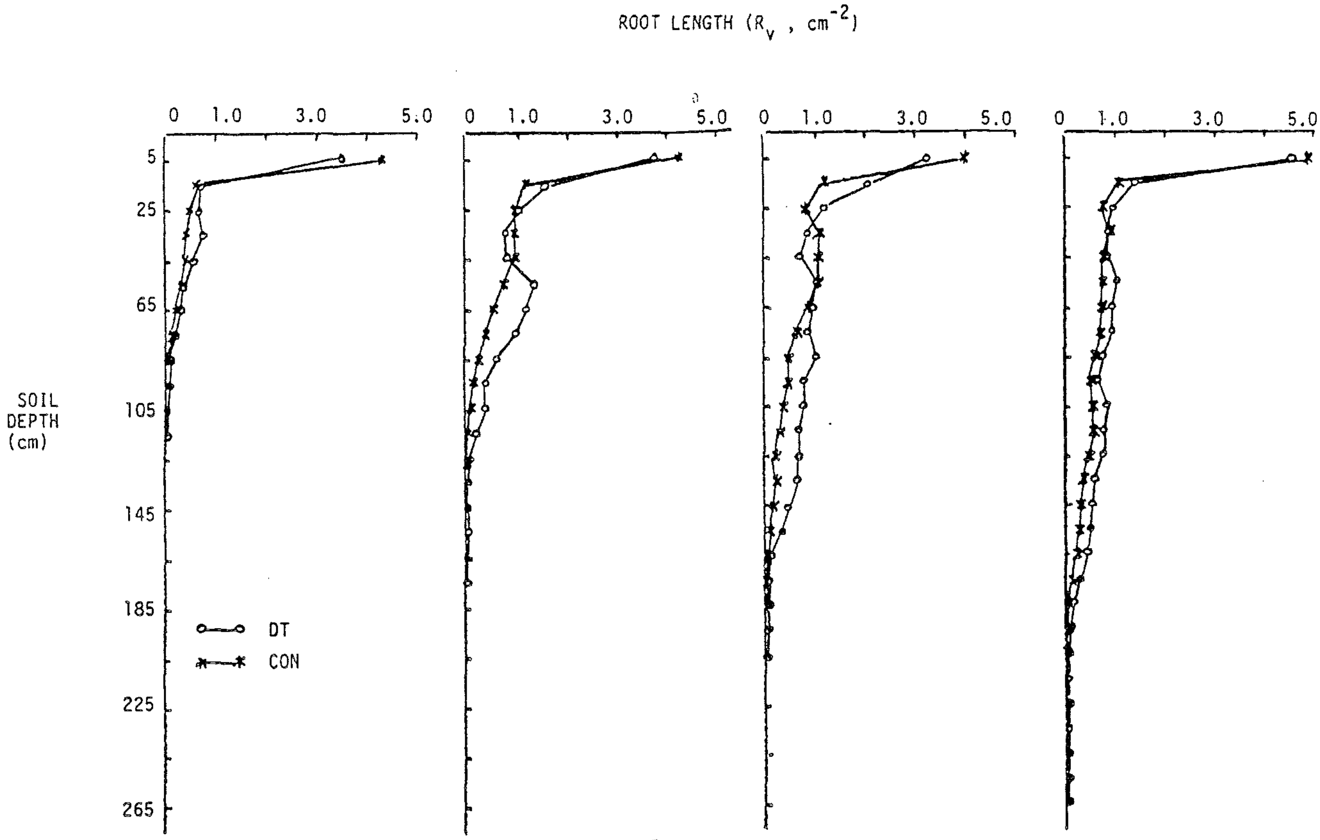

Fig. 3a. Root distribution (Rv^{-2}) of wheat at 4 times of measurement.

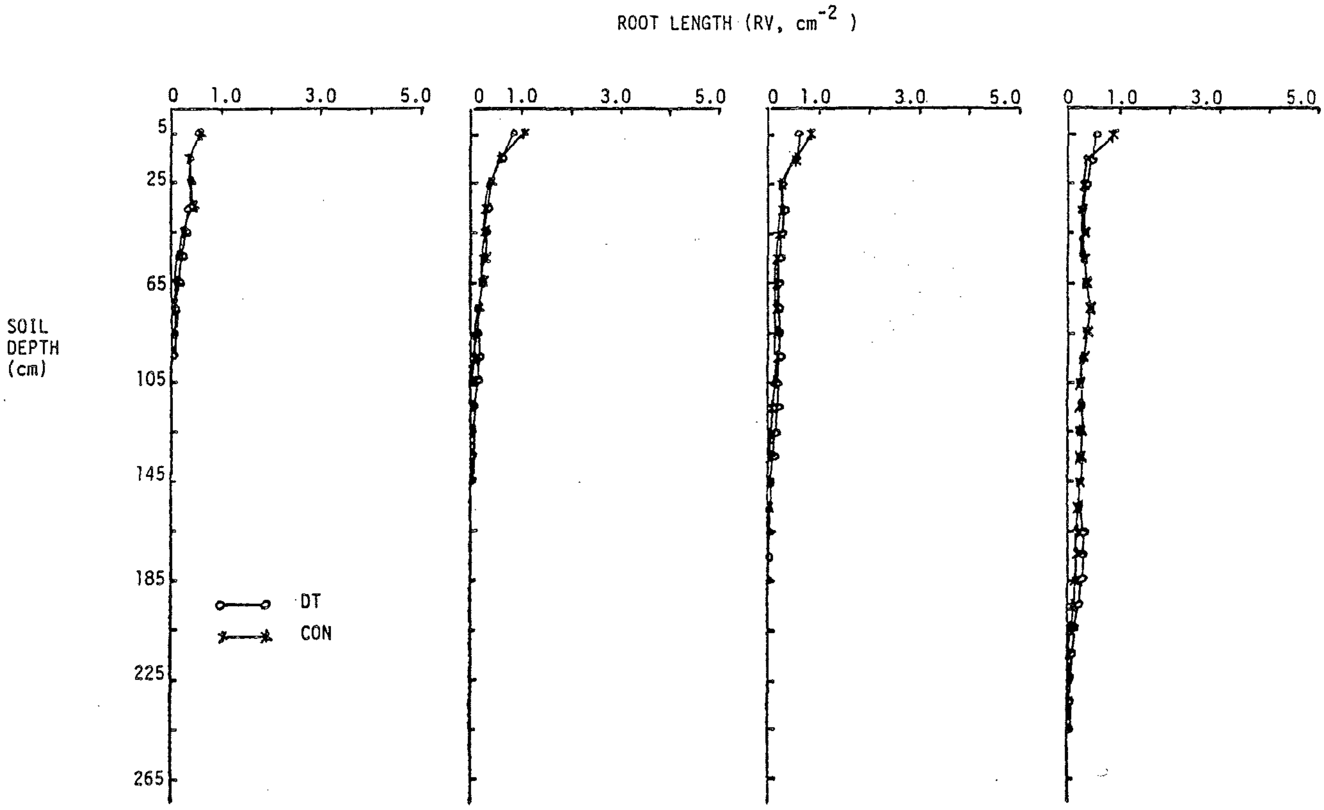

Fig. 3b. Root distribution (Rv^{-2}) of lupins at 4 times of measurement.

The root distribution data can be summed over all depth intervals to give information on total length of root in the profile under unit soil surface areas (Ra, cm^{-1}). These are listed for all treatments and times of sampling in Table 1. Total root lengths in the profile were higher with the DT than CON treatments of wheat at all times of sampling. Although a similar treatment order was consistently evident with lupins, this difference between DT and CON lupins was marginal at best. At the October 5, 113 days after planting the Ra value for DT wheat was 40 cm higher than that for CON wheat, compared to only a 9 cm difference between DT and CON lupins. As with the root density (Rv) data, total root lengths (Ra) were significantly higher with wheat than lupins, at all samplings done later than 44 days after planting.

Table 1. Effect of deep tillage on total length of roots per unit area of soil surface (Ra, cm^{-1}) of wheat and lupins.

Days after planting	Wheat - Gamenya CON	Wheat - Gamenya DT	Lupin - Yandee CON	Lupin - Yandee DT
44	24	36	18	20
58	66	72	24	32
72	103	131	33	38
93	127	161	38	42
113	142	183	57	67

Cumulative water loss (Transpiration + evaporation + drainage) data from 4 m soil profiles under the CON and DT wheat and lupin treatments are summarised in Table 2 in terms of total and average daily rates of water loss over each of 4 growth periods. To 8 weeks from planting, data showed no species differences in water loss, but suggested less water loss with the DT than CON treatments. This is consistent with expectation of greater water loss through evaporation from the denser and therefore wetter surface soil after rainfall of the CON than DT treatments. Between weeks 8 and 12, water use was greater with CON wheat than CON lupins. With both wheat and lupins, water loss was greater with deep tillage than conventional tillage. This advantage to DT than CON wheat was significant with wheat over the 12 to 16 week growth period, and much reduced over the 16 to 20 week growth period. With lupins, data suggested greater water use with DT than CON, but the data were not consistent over successive growth intervals and the differences were small. Overall, DT wheat used 24 mm more water than CON wheat. This relative difference with lupins was only 5 mm.

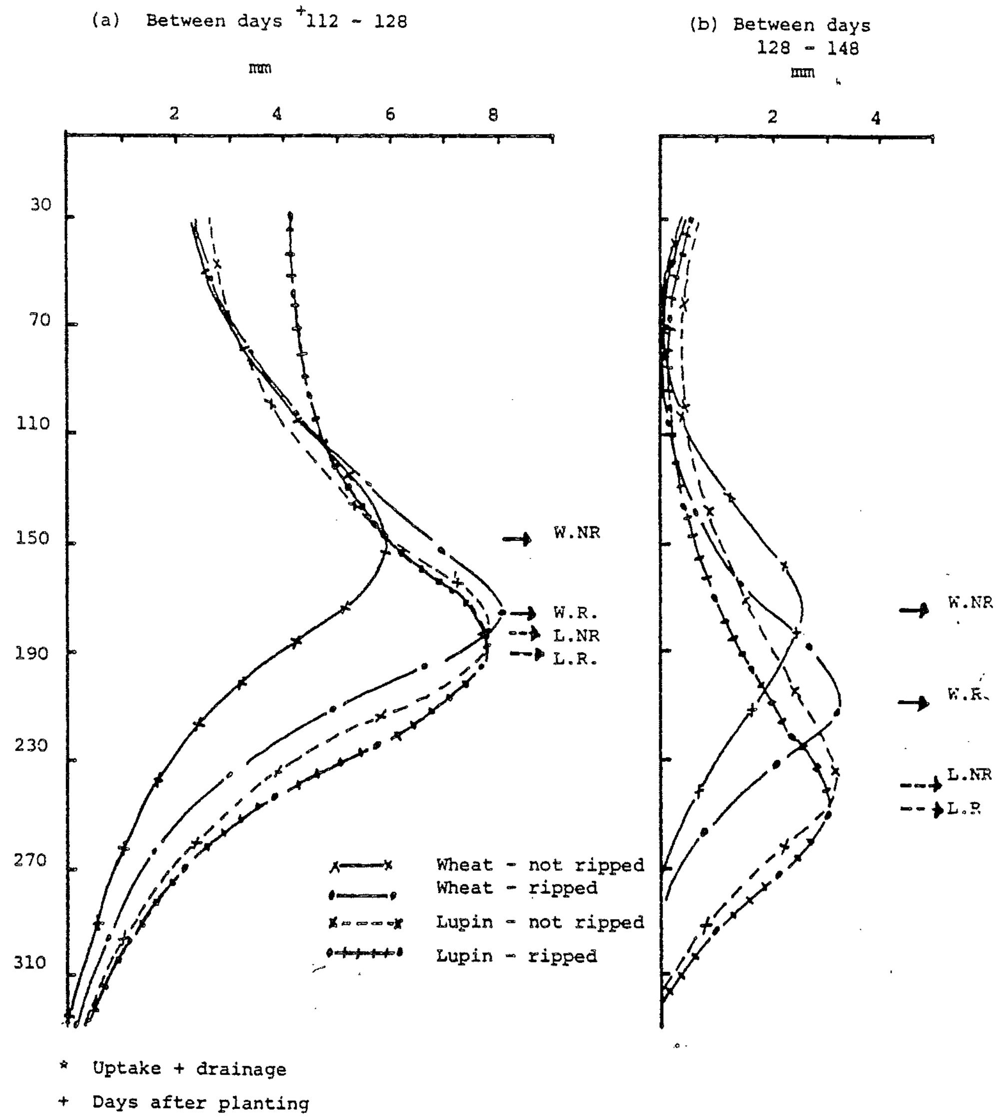

Fig. 4. Water depletion at each depth of measurement over two growth intervals.

Table 2. Effect of deep tillage on total (mm) and daily (mm/day) water loss from soil profiles to 4 m depths under wheat and lupins. (Daily rates in parentheses).

Growth period	Wheat - Gamenya		Lupin - Yandee	
	CON	DT	CON	DT
15-57 days	57.0 (1.4)	47.5 (1.1)	57.2 (1.4)	49.8 (1.2)
57-85 days	79.3 (2.8)	90.8 (3.2)	64.9 (2.3)	73.4 (2.6)
85-112 days	56.7 (2.1)	74.1 (2.7)	75.0 (2.8)	73.0 (2.7)
112-140 days	61.6 (2.2)	66.6 (2.4)	85.3 (3.1)	91.2 (3.3)
Total 15-140 days	254.7	282.9	282.3	287.4

Using the water profile data at each date of measurement, water depletion between selected dates of measurement can be calculated for each depth of measurement. This data for two growth periods (112-128 and 128-148 days from planting) are shown in Figure 4. The data identify depths of maximum water extraction over each growth period (Arrows - Figure 4). Over both growth periods, depths of maximum water extraction were 30 to 50 cm deeper in the profile with DT than CON wheat. This difference was only of the order of 10 cm with lupins. Between 128 and 148 days from planting, depths of maximum water extraction were at 170 and 240 cm with CON wheat and CON lupins respectively, 70 cm deeper with lupins.

The depths of maximum water extraction over the 128 - 148 day period from planting give a better indication of relative maximum depths of root penetration than the root pentration data of shown in Figure 2. In earlier work (Tennant 1983), maximum depths of rooting for wheat where shown to be of the order of 40 cm deeper in the profile than depths of maximum water extraction. A similar relationship is evident in data obtained for wheat and lupins at adjacent sites (Perry and Hamblin 1984, Tennant and Hamblin 1984). On this basis, maximum depths of rooting are estimated at being of the order of 210 and 280 cm with wheat and lupins respectively. Deep tillage increased depth of rooting of wheat by 30 to 50 cm and of lupins by 10 to 20 cm.

The water depletion data of Figure 3 differs slightly from the root penetration data of Figure 2, in that maximum water extraction occurs deeper in the profile with CON lupins than DT wheat, suggesting deeper root penetration with the former. Figure 2 data suggests the reverse to day 111, but as reported, this data may have been confounded with incidence of root disease with the lupins.

Dry matter production data for each day of sampling are shown in Figure 5. Separation of CON and DT wheat dry matter was evident as early as day 29 from planting but did not achieve significance until day 79 from planting. At all later times of sampling the wheat dry matter production was of the order of 20 to 40% higher than that of CON wheat. Though the trend to 120 days at least was for higher dry matter production with DT than CON lupins, these were never significantly different. Despite evidence in the dry matter data of a significant response to deep tillage with wheat, yields (Table 3) were not significantly different. Head numbers grain numbers/m were higher with DT than CON wheat. This order was reversed in the 1000 grain weight data. The yield data for lupins are conflicting in that treatment order is dissimilar with the hand and machine harvested data. These and other differences in the lupin harvest data were not significantly different.

Table 3. Deep tillage effects on yields, yield components and water use efficiencies of wheat and lupins.

	Wheat - Gamenya		Lupin - Yandee	
	CON	DT	CON	DT
Heads/m^2	280	311		
Grain/m^2	8623	9299	1315	1248
Grain/head	31	30		
Grain yield (kg/.ha)	2928	2980	2035	1911
Dry matter (kg/ha)	6108	7018	5723	5463
Harvest Index	47.9	42.5	35.3	35.0
1,000 grain weight (g)	33.9	32.0	155.4	152.8
Machine harvest yield (kg/ha)	2613	2697	1633	1747
Water use efficiency (kg/mm)	10.3	9.5	5.8	6.1

DISCUSSION

The results describing root growth and root distribution of wheat after conventional tillage are consistent with earlier findings (Tennant 1976, Hamblin and Tennant 1979, Hamblin et al. 1981). Two features reflect response to the presence of a traffic pan.

* Slow rates of root penetration within the 15 to 30 cm depth region.

* An inflection within this 15 to 30 cm depth region in the usual curve of decreasing root length densities with depth.

Because of the consistency of observation of these and other related features of wheat root growth, Hamblin and Tennant suggested in 1979, that traffic pan conditions were likely to be a more common phenomenon of southern Australian wheatbelt soils than previously supposed. This prediction is now supported by widespread observation of higher yields for wheat after deep tillage on coarse textured soils (Jarvis 1982, 1983) and repeated observation of high soil strengths in these soils at around 20 cm soil depths (Hamblin et al. 1981; Jarvis 1982, 1983).

Disruption of the traffic pan with deep tillage resulted in significant improvement in root growth of wheat. Early root growth was faster, maximum depths of root penetration were greater and total root length at depth was greater. These aspects of root growth generally contribute to better water relations and higher yields in low rainfall environments (Burnett and Hause 1967, Rowse and Stone 1981). In this trial, data suggest as much as 24 mm more water uptake by the wheat crop after deep tillage. On the basis of expecting a yield increase of wheat of at least 10 kg/ha for each mm of additional water used (Tennant 1981) and some benefit from greater nitrogen uptake (Rowse and Stone 1981), it would not have been unrealistic to have expected 400 kg/ha higher yields with DT than CON wheat. In other trials at Wongan Hills, Jarvis (1984) and Bowden (1984) obtained 800 and 500 kg/ha yield increases after deep tillage in 1983. Yet no yield benefit was realised for deep tillage with the trial described here.

Failure to realise higher yields with DT than CON wheat despite significant responses in terms of root growth, water use and dry matter production is perplexing. Over the three years of investigation of deep tillage at Wongan Hills, in every year, one trial in 3 or 4 has given nil or less than expected wheat yield responses to deep tillage. Areas of commonality have not been isolated. In 1983 data, in trials in which DT yields were 500 - 800 kg/ha higher than those of CON yields, machine harvested yields after application of 50 kg/ha N were 1.9 and 1.6 t/ha respectively, compared to the 2.6 t/ha of this trial. A site fertility or soil type contribution is implied - perhaps. Prior to trial work beginning in 1982, the site was cropped to wheat and lupins in alternate years. Clay content in the profile was as high as 20% at depths below 150 cm from the soil surface, compared to usual expectation of 12 -14% of Wongan loamy sand. Some interaction with rainfall may have contributed. Rainfall in 1983 was high and maintained soil profile wetness to near maximum water holding capacity to almost 100 days from planting. One consequence of wetter soil conditions was relatively rapid root penetration through the pan (0.70 cm/day compared to 0.25 cm/day at another site in 1982 - 152 vs 15 mm rainfall over the first 4 weeks from planting), presumably due to high soil water contents interacting favourably with soil strength (Hamblin and Tennant 1979) to result in a less restrictive environment for root growth. Another feature of the 1983 data (Table 2) was continuing high water use of DT wheat after anthesis (105 days after planting). In the 1982 study (Tennant 1983), significantly less water was used by DT than CON wheat after anthesis. Notwithstanding this, yields were 12% higher after deep tillage at the 1982 trial site.

Though not readily recognisable as being relevant to this set of data, it is interesting to note that yield responses, after disruption of a pan or hard layer in fine textured soils are not evident in high rainfall and irrigated environments (Burnett and Hauser 1967, Mech *et al*. 1967, Ech and Taylor 1969, Rowse and Barnes 1979).

With the lupin root growth data, not only were lupin roots shown to be only marginally responsive to the higher soil strengths and densities recorded for the traffic pan area of this site, but root lengths of lupins were found to be significantly lower than root lengths of wheat. In discussions concerning the capacity of lupin roots to rapidly penetrate traffic pans, Bohm (personal communication) stated that lupins were known to have a capacity for breaking up hard soils. I am not aware of information in the literature to support this view. Overall consequence of this capacity is a reduced potential for obtaining root growth responses to deep tillage with lupins. Despite low root densities, lupins were able to extract as much or more soil water than wheat (Table 2), yet were relatively inefficient in

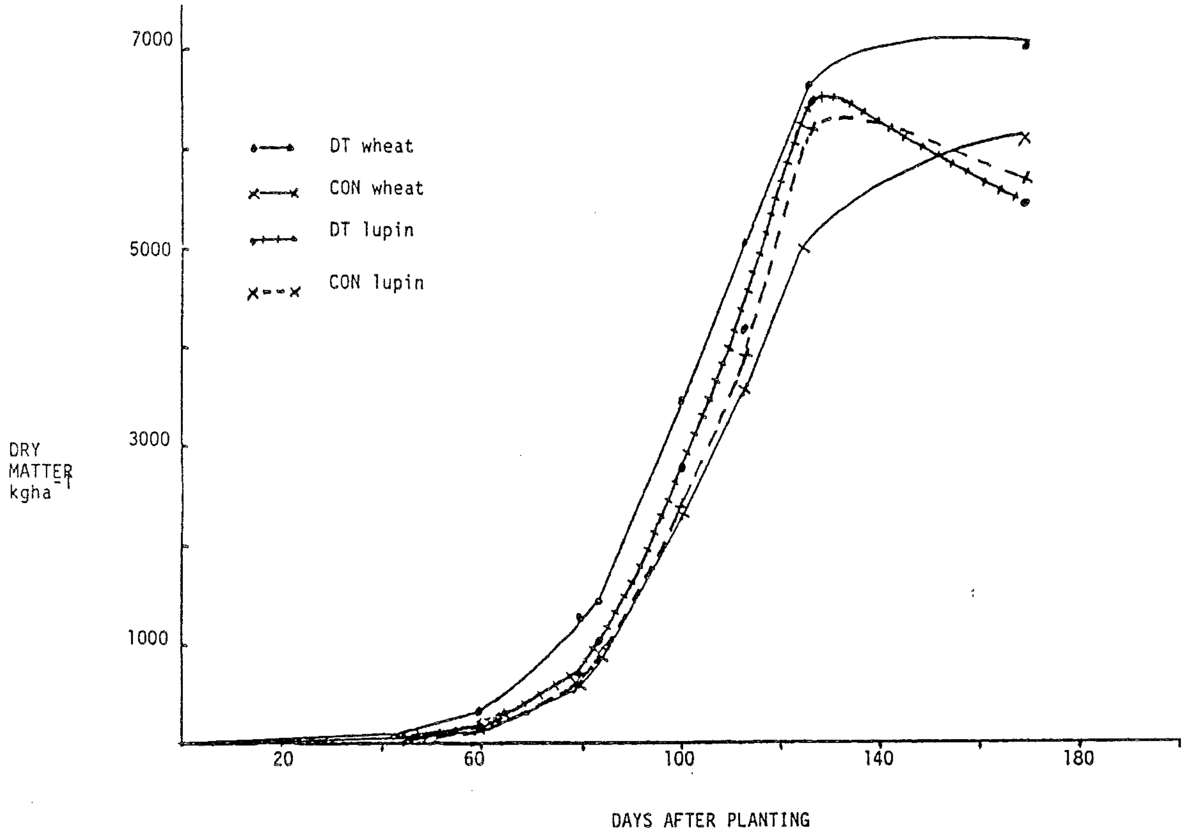

Fig. 5. Effects of deep tillage on dry matter production of wheat and lupins.

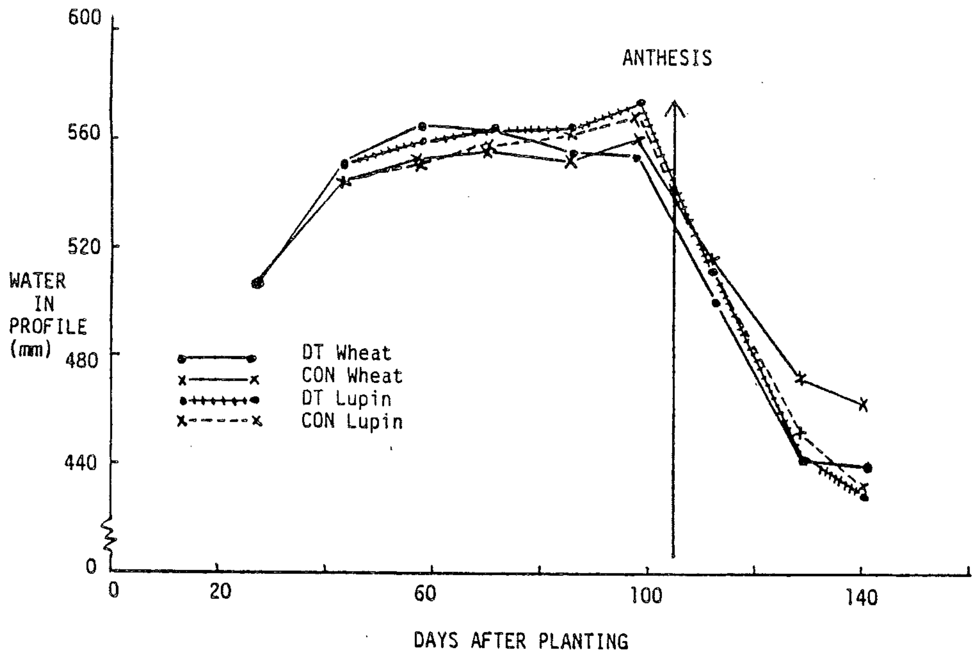

Fig. 6. Effect of deep tillage on availability of soil water at each time of measurement.

converting water used to dry matter and yield. Water use efficiencies in data obtained over 1983 (Hamblin and Perry 1984) and 1984 (Perry et al. 1985) were always significantly lower with lupins than wheat. Hence a second reason seems apparent for the lack of response to deep tillage with lupins - inefficiency of conversion of additional water uptake, if any, into higher dry matter production and grain yield.

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NUTRITION OR WATER - WHY THE RESPONSE TO RIPPING?

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BACKGROUND HISTORY AND DEFINING THE PROBLEM

My interest in ripping was aroused in 1981 when I was first inspired about season by treatment interactions. The ripping responses Ron Jarvis had observed varied markedly from 1980 to 1981. He also noted that the ripping response was reduced when nitrogen was applied at some sites. I saw my first ripping response on 77WH17 in 1981 when the ripped N plots looked more nitrogen sufficient than the non ripped 2N plots. We also sampled yellow crop from the wheel tracks on 76WH9 and found very low N levels compared with control plants 20 cm to one side of the compaction strips. Nitrogen was obviously involved in the ripping response. How did it work was the question?

Several hypotheses were floated to explain the effect.

The germ of one can be sheeted back to Norm Halse who had a theory that "factor X" in the lupin fertility story was due to the development of soil structure which in turn prevented infiltrating water completely equilibrating with nitrogen in the structural units. That nitrogen would be less leachable and more slowly available to plants than nitrogen in the mainstream of infiltrating water. I postulated that ripping might have the same effect due to more rapid infiltration in the ripping channels. Thus more nitrogen on a ripped soil would remain near the surface and in the active root zone than on a non ripped soil.

The second hypothesis found its origins in some comments by Jack Toms many years ago to explain the normally better nitrogen status of early sown crops compared with crops sown sometimes only a few days later. He suggested that the early crop roots could move down through the soil with the nitrogen while the later sown crop roots would follow behind the nitrogen front as it moved through the soil. By increasing the rate of root penetration, ripping would have an analogous effect to early seeding.

Dave Tennant, Ron Jarvis and I designed a time of nitrogen and time of seeding trials and made appropriate soil and plant measurement to test the hypothesis at WHRS in 1982. The time of seeding treatments were aborted but the trial itself produced some interesting results.

There was very little effect of ripping on nitrogen movement in the soil (Fig. 1). There was a marked effect of ripping on root penetration (Fig. 2). Our second hypothesis looked most appropriate. However there were several problems with the interpretation. Although we got a marked response in grain yield, biological yield and nitrogen uptake to both nitrogen and ripping treatments, there was very little interaction. Adding nitrogen did not reduce the response to ripping. (It was suggested that our N rates were probably not high enough to get the interaction.)

Further, although dry matter and uptake response to nitrogen were seen relatively early in the season (8 weeks) ripping responses were not obvious until later (10 to 12 weeks) as the crops were going into exponential growth

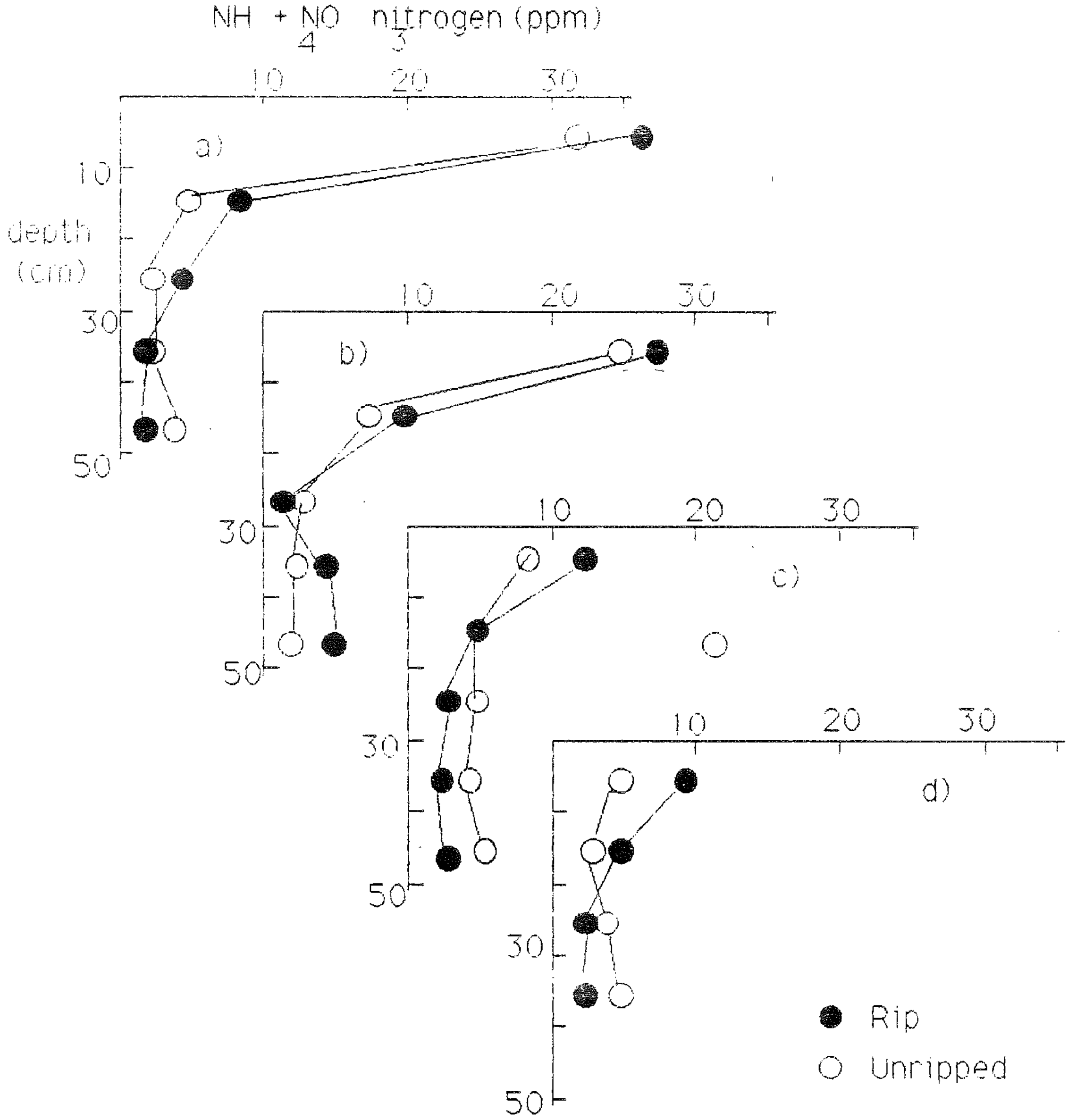

Fig. 1. Mineral nitrogen profiles from 82WH2.

	a)	b)	c)	d)
days post-sowing	32	41	54	69
cumulative rain (mm)	24	38	77	109

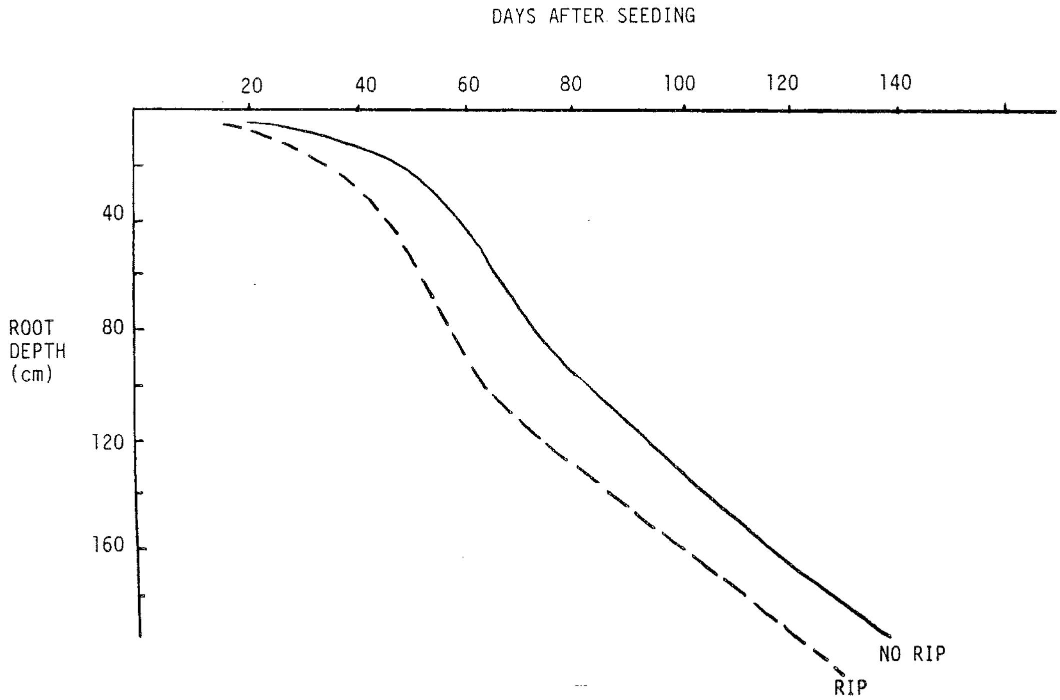

Fig. 2. Effect of ripping on root penetration (82WH2).

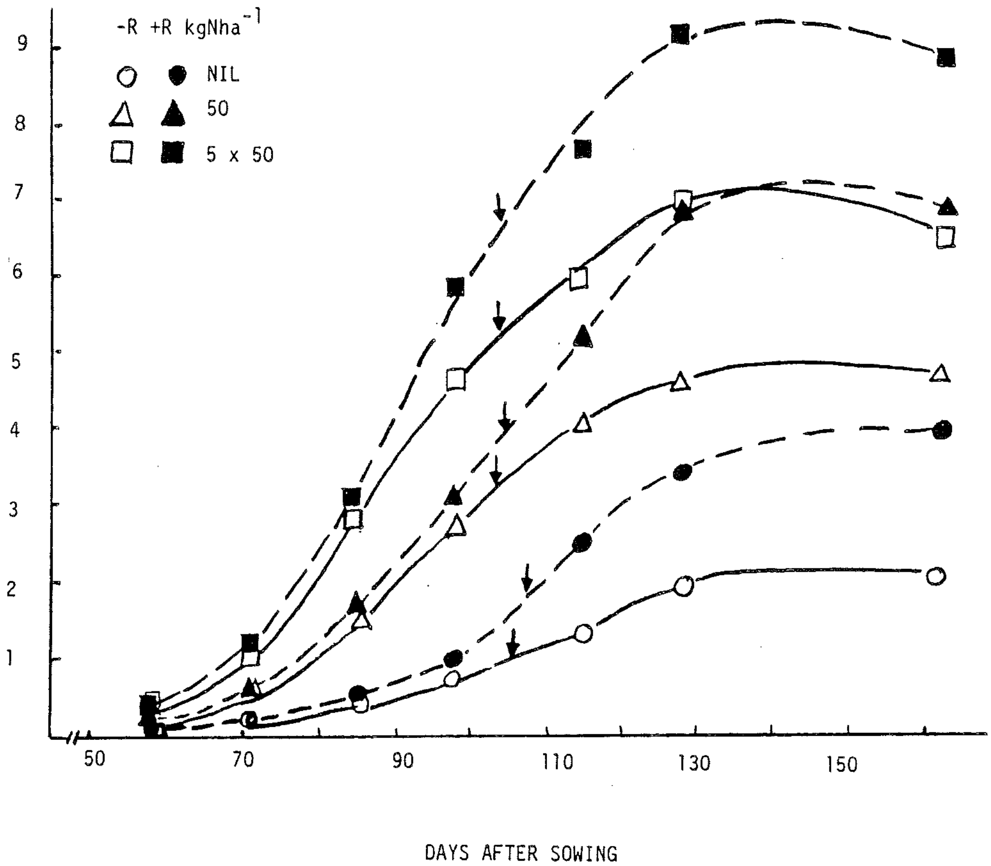

Fig. 3. Effect of nitrogen and ripping on top growth of wheat. Arrows show time of anthesis.

(Fig. 3). Because response to treatments normally imply a response to stress we began to think that maybe water was involved. This feeling was enhanced by calculations using the root distribution and rainfall figures which suggested that there could be upward of 50% better N relations for the ripped crop up to 8 weeks after seeding. After this the non ripped treatments should have caught up with soil nitrogen and suffered less stress. This calculated effect was demonstrated by chance to us. All through the season the ripped plots which received no nitrogen seemed greener and better grown than their non ripped counter parts. Crop regrowth on an area which was mown for the first field day (before anthesis) showed the reverse trend. Regrowth on the ripped plots was very N deficient while regrowth on the non ripped plots was green and healthy and even developed as far as producing small heads.

Our conclusion was that although nitrogen nutrition was involved it was not the whole story.

We got the key to the whole story in 1983 when we took steps to provide more than adequate nitrogen on some plots and we also looked at complete response curves. We had a further piece of luck in that one trial was obviously stressed during grain fill while another was under no stress because of the presence of a perched water table.

83WH31 was a ripping x time of seeding x levels and times of nitrogen trial on which we measured root growth, dry matter production and N uptake through time. We also took yield components and Zadok development scores.

There was a marked response in biological yield and grain yield to ripping and applied nitrogen (Fig. 4). There was again no evidence of nitrogen wiping out the ripping response even though some treatments had 5 dressings of 50 kg N ha^{-1} applied. (It could be argues that N from the later dressings may have been unavailable late in the season once the surface soil had dried out. In the following year we made sure nitrogen was present at depth as well as on the surface. We still observed a significant ripping response at these higher levels of N). Obviously the ripping effect did not significantly interact with the nitrogen effect?

On the second 1983 site (trial 82WH35) we obtained a large response in biological yield to ripping at all levels of N. In grain yield however there was a marked negative interaction (Fig. 5) (as had been observed by Jarvis earlier).

This interaction can be explained in terms of the simple GY vs BY relationship where there is a marked plateau in grain yield as BY goes above 6 tha^{-1}. On 82WH31 this effect was very small and no ripping x nitrogen interaction was observed in GY.

N uptake as a function of N applied for both trials showed a positive interation with ripping early to mid season (Fig. 6). This interaction tended to disappear as time proceeded (and one assumes that the roots on the non-ripped treatments caught up with the nitrogen and took up compensatory amounts compared with the ripped treatments).

From this and Tennant's work, it is obvious that ripping increases rates of root penetration to depth as well as increasing root density in the disturbed hard pan zone. The necessary consequences of this increased root growth is that uptake of nutrients (including water) will be higher on the ripped treatments when and if water or nutrient stress occurs. Even though

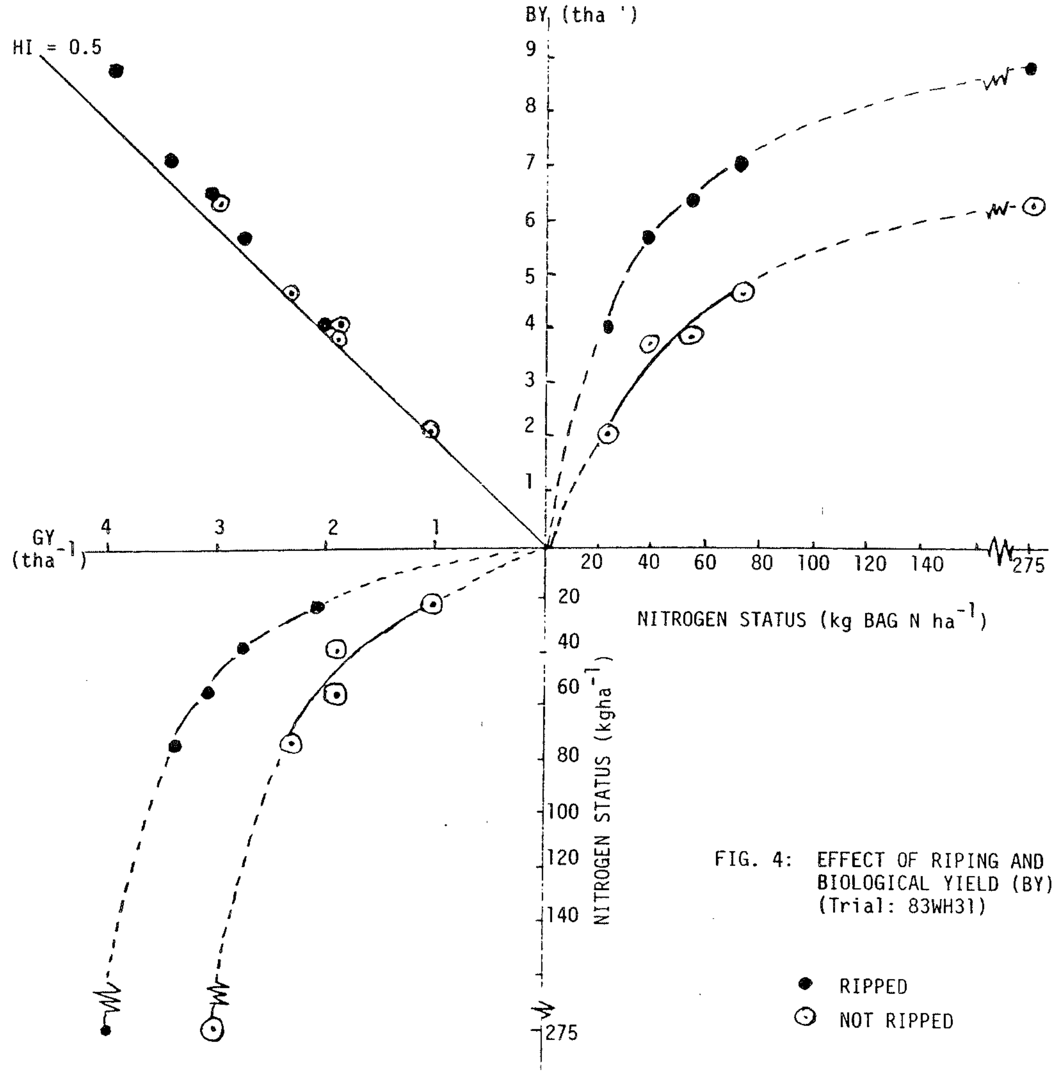

FIG. 4: EFFECT OF RIPING AND NITROGEN ON BIOLOGICAL YIELD (BY) AND GRAIN YIELD (GY) (Trial: 83WH31)

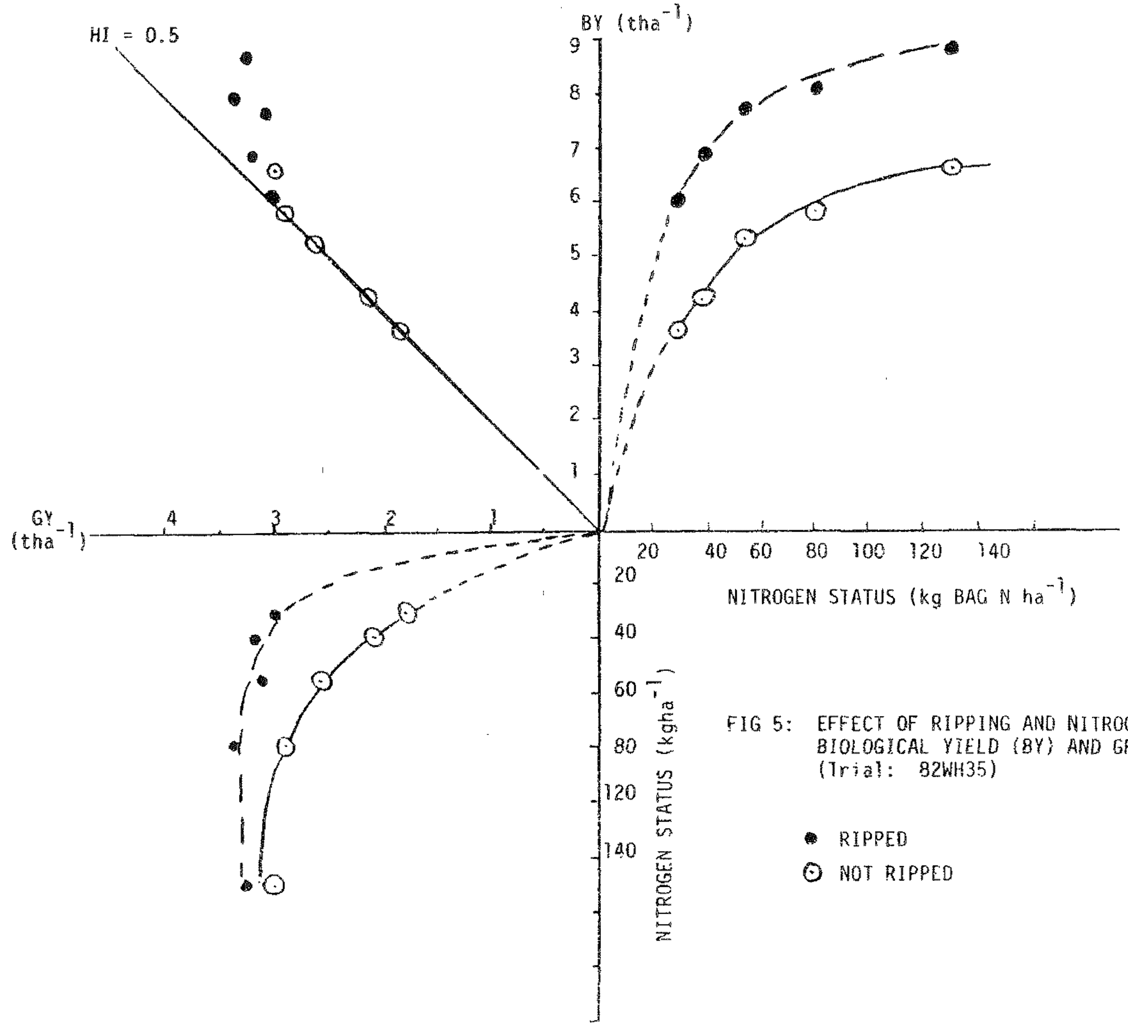

FIG 5: EFFECT OF RIPPING AND NITROGEN ON BIOLOGICAL YIELD (BY) AND GRAIN YIELD (GY) (Trial: 82WH35)

the differences in rooting behaviour can occur quite early, the effects on yield are often seen quite late (10 weeks at WHRS) because it is only when stresses (such as those associated with the high demand for resources during the exponential growth phase) are applied that dry matter responses will be seen.

These demands probably come earlier in the Geraldton region and stresses are likely to be greater earlier in the absence of nitrogen and in the presence of disease (Geraldton and Esperance results).

Improved root penetration will obviously improve the uptake of soil mobile nutrients such as nitrogen and water. We have seen and confirmed a sulphur response in wheat (and probably also in sub clover) following compaction in a trial when many passes of the drill were used to aply high rates of phosphorus ferilisers. On some trials the roots of the sub clover reached only 10 cm while adjacent uncompacted areas with healthy crop had roots down below 90 cm.

Analysis of Figures 4 and 5 shows that ripping has an impact above and beyond an effect on nitrogen uptake. In both trials, ripping increased biological yield by about 40%. It also seems that ripping increased the efficiency of N utilisation by about 50%.

Evidence that ripping and nitrogen can work in opposite directions on some processes was obtained on 83WH31 when Zadok ratings were made on September 4, 1983.

Table 1. Zadok Score of Wheat

			N level kg ha^{-1}		
Treatment	NIL	17	34	50	5 x 50
RIP	54/62	57/65	58/65	58/67	59/68
NO RIP	57/64	58/68	59/69	59/69	59/64

Ripping slows the rate of development as does nitrogen deficiency. This result can be interpreted in terms of early water use resulting in stress later at high levels of N. Ripping works in the opposite direction by allowing the plant access to more water at depth. Also the higher root densities allow better uptake at any soil water status. Small N deficient plants and large plants on ripped plots have access to more water and mature more slowly than their high N or non ripped counterparts.

Finally a note on nitrogen x ripping interactions. It is apparent from Figures 4 and 5 that there will be a strong positive interaction on soils of low nitrogen status (see Geraldton results). At high soil N status no interaction may be observed in the BY plots but strong negative interactions are possible in the GY plots if there is water stress at the end of the season.

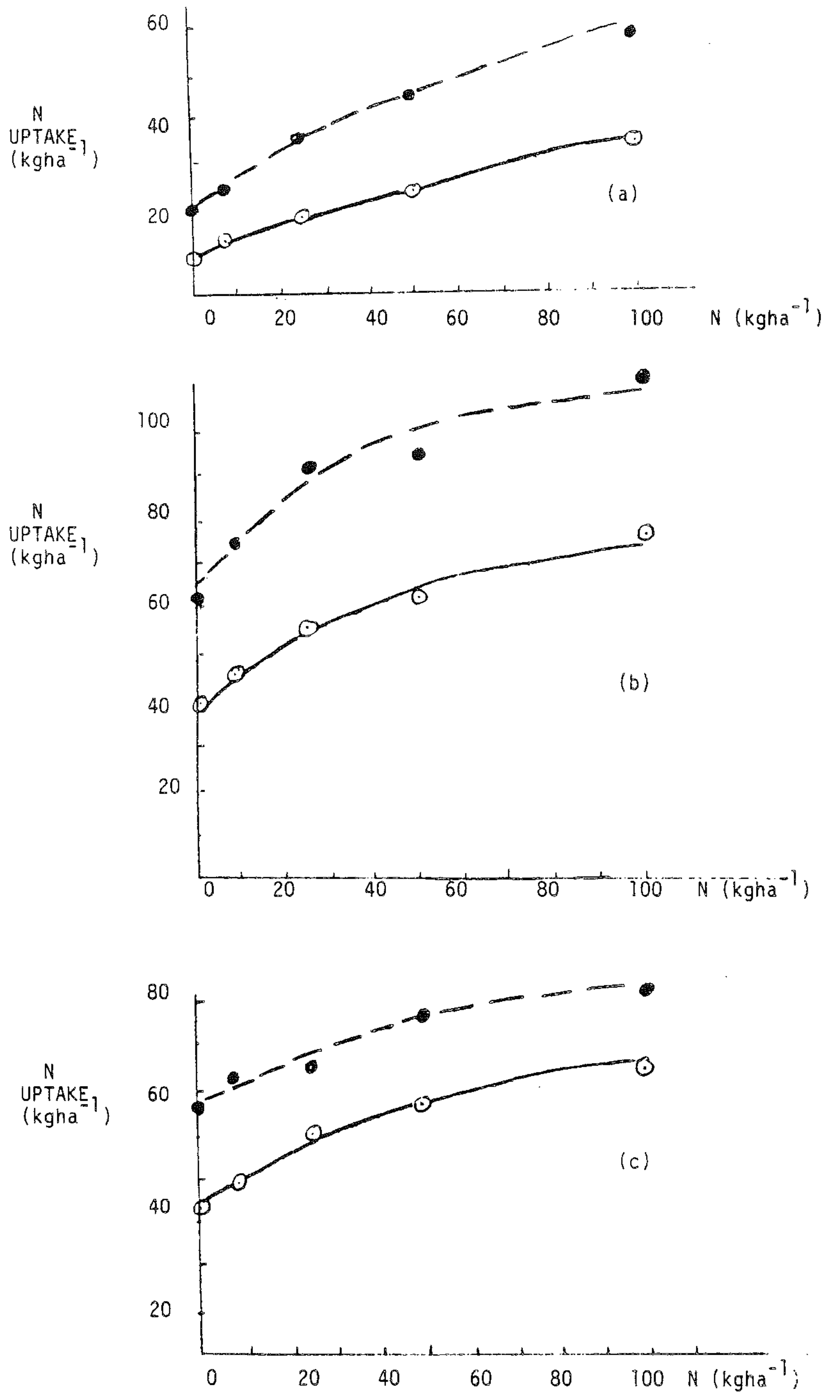

Fig. 6. Nitrogen uptake (82WH35) at -
a) 7 September (52 days)
b) 19 October (95 days)
c) Grain, 30 November (137 days)

CONCLUSION

In the Western Australian environment the major effect of ripping is to increase root penetration and density. This has obvious implications for nutrient uptake - especially the mobile nutrients such as water, nitrogen and sulphur. Responses in biological yield to ripping are observed when water and other nutrient stresses occur. These responses to biological yield are not necessarily reflected in proportionate responses in grain yield. Both positive and negative ripping x nitrogen responses are possible.

In analysing ripping and nitrogen responses in cereals it is necessary to look at both BY and GY. Plots of yield components versus BY can also be very useful diagnostic tools.

CROP RESPONSE TO DEEP TILLAGE

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This paper contains research results from 1980-1984 on the following aspects of deep ripping:

* Soil Types
* Soil Compaction
* Species Response
* Operational Variables
    - Soil Moisture
    - Time of Ripping
    - Depth
    - Shank Spacing
    - Machines
    - Speed
* Nitrogen Interaction
* Effect on Rhizoctonia
* Residual Effect

SOIL TYPES

Penetrometer measurements from many soil types indicate that the depth of the vehicle compaction layer varies according to soil type. In sandy soils the maximum soil strength is deeper with lower clay content. "Wongan loamy sands" which hand texture as clayey sands have maximum strength at 20 cm. Some sites with greater than the 10-12% clay of WLS have shown the hard pan at 15 cm. This is the shallowest I have measured. Yellow earthy sands such as Eradu sandplain peak at 25 cm depth, and deeper white sands with a low clay fraction at 30 cm or more. Some measurements on white sands have indicated increasing strength with depth with no apparent pan. Crop responses on these have still occurred from ripping.

Wodgil, acid subsoil, yellow loamy sands commonly have compaction pans at 15-20 cm however crop reponses have been variable due to sub soil acidity preventing root growth, and to lack of finishing soil moisture.

Duplex soils of sand/clay and sand/gravel have measureable traffic hard pans if the B horizon is deep enough. Generally, on limited data, sand/clay will not respond to deep ripping unless the clay is deeper than 30 cm. Sand/gravel will respond if the gravel does not form an extremely restrictive barrier and the soil matrix allows root penetration.

Gravelly soils cannot be measured with the penetrometer. Responses can be predicted by examining the soil matrix texture, and applying these generalisations re response. If the conglomerate is close to the surface - no response.

Medium textured soils such as the Avon Valley loams, and fine textured clay loams (Salmon Gum/Gimlet) have not exhibited hard pans but show increasing soil strength with depth. Crop responses are uncommon.

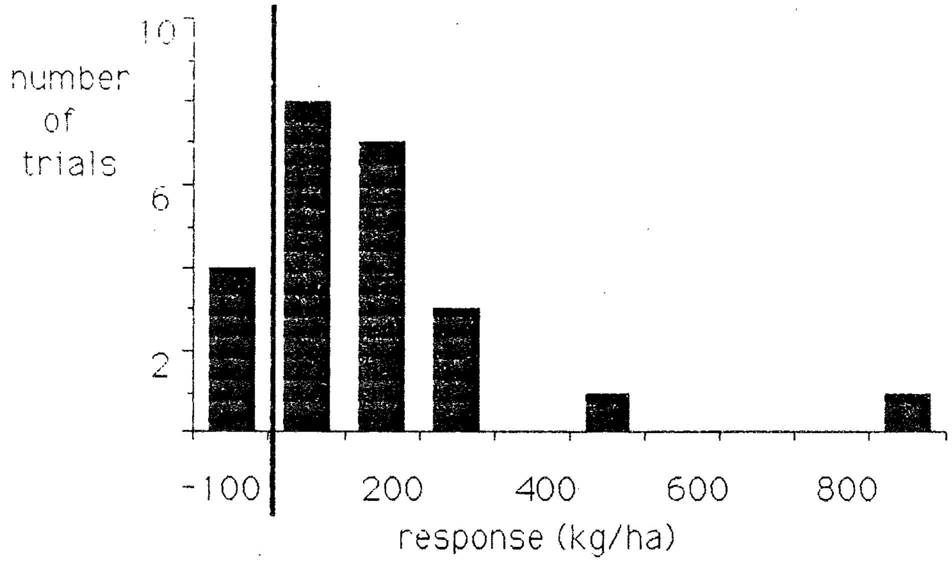

Fig. 1 Wheat yield response from cultivation versus direct drill on light land, uniform profile.
Mean response : 138 kg/ha = 10.7%.

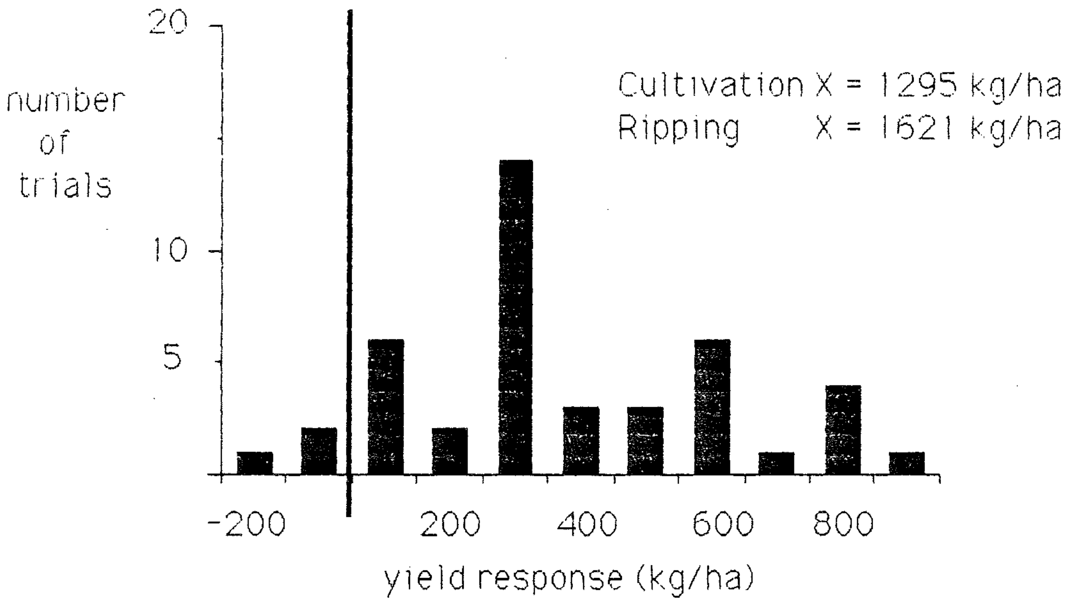

Fig 2. Wheat yield responses to deep ripping light land, uniform profile.
Mean response from 43 trials : 326 kg/ha (25.2%)

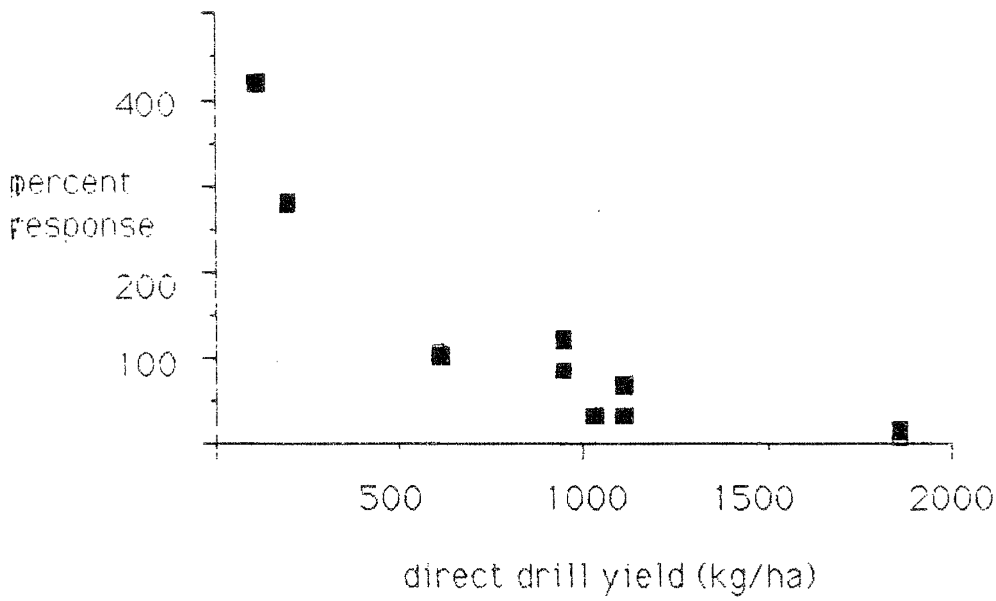

Fig. 3. Percentage response versus direct drill yield on a range of soil types. 82N34.

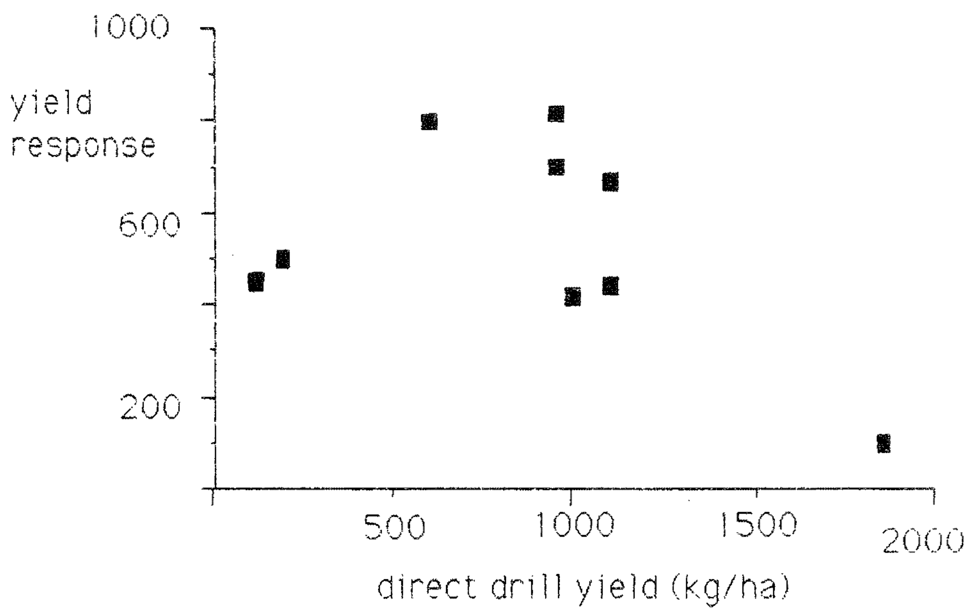

Fig. 4. Grain yield response versus direct drill yield on a range of soil types.
$Y = 422 + 0.69X - 0.0005X^2$ $r^2 = 0.67$ $n = 9$.

SOIL TYPE RESPONSES

Light soils - uniform texture to 50 cm

These soils respond to normal (10 cm deep) cultivation. Twenty-four of the deep ripping trials from 1980-1984 had comparisons of direct drill and "conventional" cultivation. The average response to cultivation was 10.7% (138 kg/ha), the average yields being 1,293 kg/ha and 1,431 kg/ha. Eighty-three per cent of the trials responded positively (average response 175 kg/ha) and 17% (4 trials) negatively, with average negative response being 46 kg/ha (Figure 1).

Deep ripping produced responses above that of conventional cultivation, and thus these responses are additive to the 10.7% mentioned (cultivation versus DD) when estimating deep rip response over direct drill. Most sites exhibited a hard pan although many of the earlier trials were established before penetrometer measurements were taken.

Over 43 trials deep ripping (30 cm depth) has outyielded 10 cm deep cultivation by 25.2% (326 kg/ha) with average yields of 1,295 kg/ha and 1,621 kg/ha. Ninety-three per cent (40 trials) responded positively, 7% negatively (by -2.9% or 54 kg/ha) (Figure 2).

There is a trend towards higher percent response in low yielding situations but this did not apply to kg/ha response. Figures 3 and 4 from a trial at Newdegate Research Station on a range of soil types demonstrate this.

DD = 100 CULT = 111 DR = 139

Light soils - acid subsoil

Responses on these soils have been variable. Possible advantages from deeper rooting are restricted by the sub-soil acidity. These soils have been researched in the drier wheatbelt and responses to ripping have also been limited by the crop putting on more vegetative growth early, running out of moisture and not finishing. This is similar to application of too much nitrogen in a particular season, and applies to the better class of soils in low rainfall areas. Ripping is a lower risk situation than nitrogen excess, as response to the one ripping in future years is probable (see later).

Figure 5 shows results from a trial at Merredin Research Station lease block in 1984. Overall the trial did not show a positive response to ripping. Soil pH measurements at depth showed replicates 1 and 2 to be on more acid subsoil (indicated by the lower yields). When reps 3 and 4 were analysed separately, there was significant response to ripping.

Duplex soils

Thirteen trial comparison are available for these soils which is insufficient considering the range of soils included. General comments are presented earlier in this paper. Response on sand/gravel has been as high as 640 kg/ha or 43% with a small response from sand/shallow clay in one trial out of six.

Medium textured loams

Only eight trials were analysed for responses. Generally the lighter soil end of this category has more chance of a response.

Fine texture clay-loams

Generally no response to ripping. Two trials have given a small response which I attribute to faster start of season rainfall penetration to depth before the ripping slots closed up, and hence stored moisture for grain filling. These two responses occurred in seasons with a wet start and dry finish.

Table 1 shows that overall there is no response to deep ripping heavy land. The deep rip 9 months before seeding appears at first to indicate a response however any heavy land comparison should include a conventional operation at the time when fallow may have an effect, and in these 6 cases shallow conventional working was as effective.

Table 1. Deep ripping heavy land - wheat yields (kg/ha) 1981-1984

No. of trials	DDC	CULT	DR near seeding	9 month fallow DR	9 month fallow CULT	DR residual (2nd crop)
8	995	949				
10		899	874			
6		1030		1190	1231	
7	843					834

SOIL COMPACTION OF LIGHT LAND

A trial on deep white sand over clay new land at Magenta in 1984 (Jarvis, Porritt) showed that levels of compaction traffic pans can be artificially induced by tractor wheelings.

Figures 6-8 show the peak strength at 30 cm (as predicted) and yield depression against a number of wheelings and penetrometer measurements.

Craig Henderson has data on this type of work for Eradu sandplain so I will not dwell here. Table 2 shows results from four trials sited near each other but on different rotations in which rough comparisons of % response to ripping and hard pan strength induced over the years by paddock traffic can be compared.

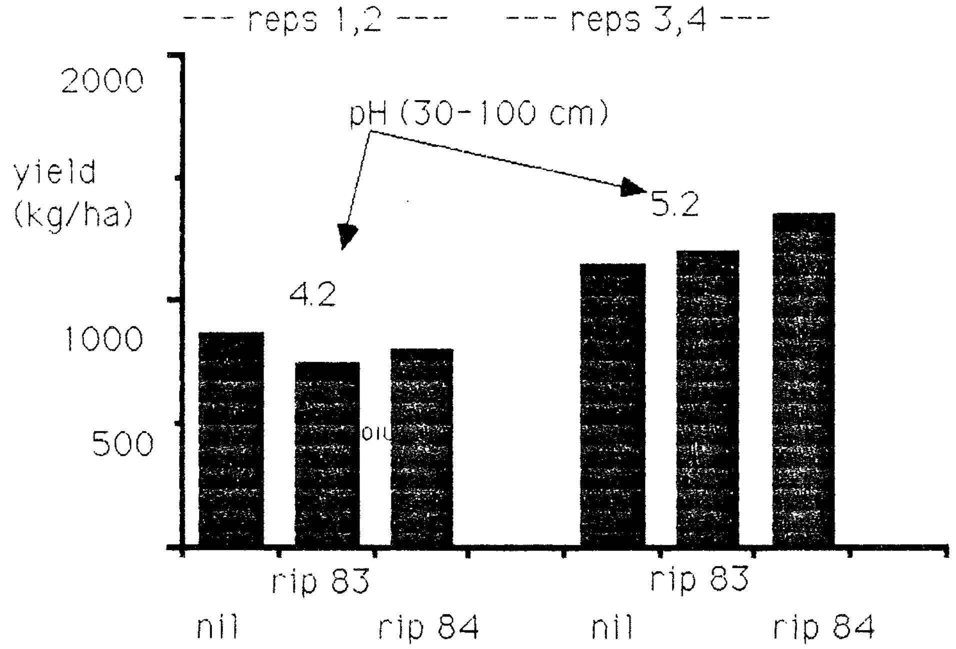

Fig. 5. Subsoil acidity prevents a response to deep ripping. 82M60, 1984.

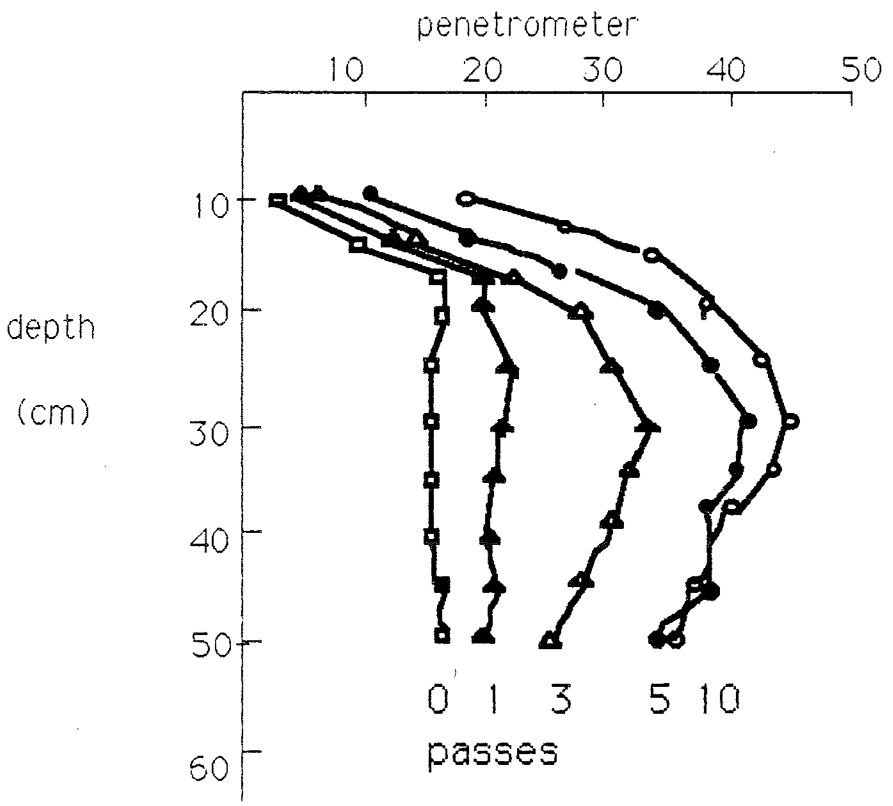

Fig. 6. Effect of number of passes with a tractor on compaction. 84LG37.

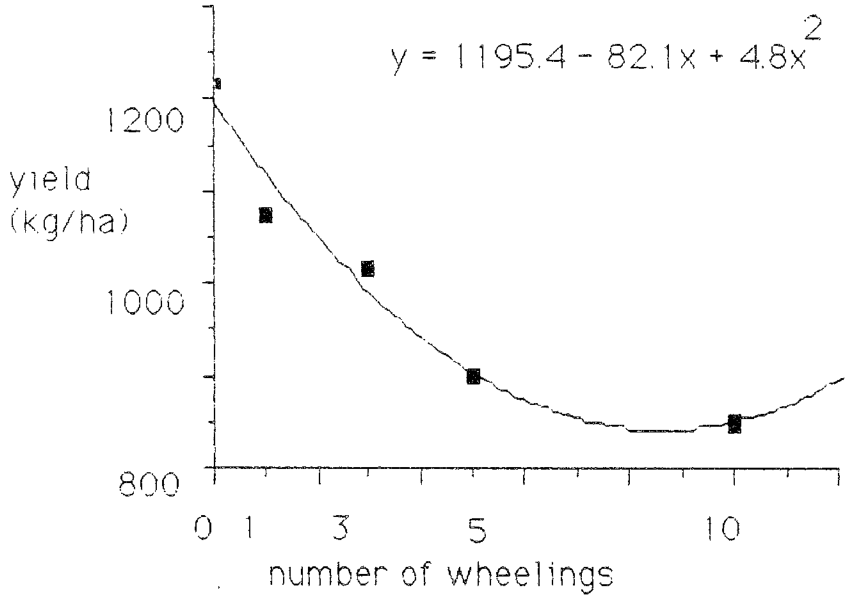

Fig. 7. Yield depression from soil compaction.
White sand. 84LG37.

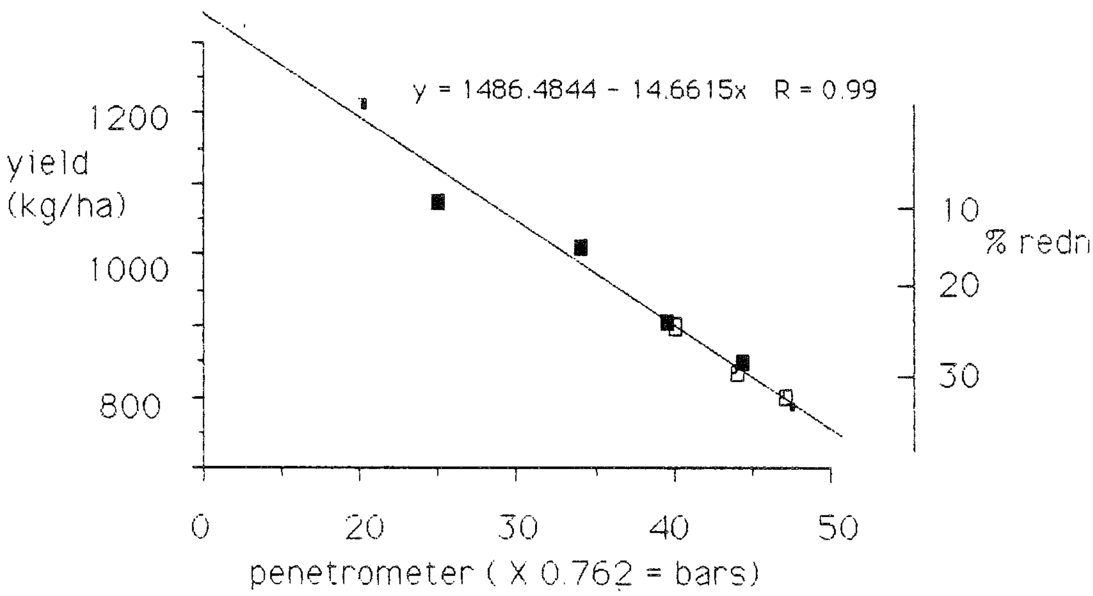

Fig. 8. Yield depression related to penetrometer
reading at 30 cm. 84LG37.

Table 2. Deep ripping responses from four rotations with different soil strengths - Eradu sandplain - Jarvis, Haagensen 1984

Trial	Rotation	Hard pan strength (bars)	Yields (kg/ha) - Rip	+ Rip	ΔY	%
C42	Continuous W	36	892	1,488	596	67
C43	W after L	30	2,187	2,721	534	24
C45	W after M	24	1,410	1,649	239	17
C44	L after W	29	1,132	1,266	143	12

Note the response by lupins (one of the few that have been significant) compared to that by wheat at the same hard pan strength.

SPECIES RESPONSE TO DEEP RIPPING

Craig Henderson is covering this more fully. My information to date shows that responses can be obtained by all cereals. Lupins generally do not respond. Ten trials 1982-1984 show the average result DDC = 1,339 kg/ha DR = 1,308 kg/ha. Three of the trials showed a positive response ($p < 0.05$).

Some trials showed a negative response due to deeper seeding in the ripped plots. Although emergence was not affected the effectiveness of simazine was reduced and nodulation appeared to be reduced.

Where wheat/lupin response comparisons could be made, wheat always responded by a far greater amount suggesting that farmers with a wheat/lupin response will be picked up the following lupin crop from the residual ripping softening. <u>Shallow seeding must be stressed</u>.

OPERATION VARIABLES

<u>Soil moisture at time of ripping</u>

Obviously moist conditions reduce fuel consumption and point wear (Riethmuller). Deep ripping when the soil is too dry results in large major cracks but large clods which are not shattered. Even root penetration down the profile is not possible and the response to ripping is probably reduced. There appears no good reason to research the effects of ripping in adverse conditions.

<u>Time of ripping</u>

John Hamblin is covering this topic. Some light land trials have shown a fallowing effect from pasture kill or deeper rain penetration when ripping pasture during the winter/spring period. Conventional fallow has done the same thing, however the possibility of soil conservation minded "semi fallow" above the ripping response will be investigated in 1985 by Tennant and Jarvis.

Apart from the fallow effect, ripping in spring, summer or just prior to seeding appears equally effective.

Depth, shank spacing and machines

The compaction pans are broad tapering bands and all of this induced root restrictive barrier must be removed for maximum yield reponse. Soil softening is not as deep between the tynes as near the points, and the wider the tyne spacing the less the softening will be in the spaces (Figure 9). A combination of spacings by depths will be tested in 1985.

Using currently available machinery (average 30-33 cm tyne or shank spacings) farmers should aim at a depth of 30 cm. Shallower may not achieve maximum response but may be a compromise in a farm programme of speed and hence hectares covered. Deeper would then be easier in subsequent years.

It is impossible to test all machines against each other. Chisel ploughs are unable to reach the depth required without the tynes springing or dragging back and therefore not effectively loosening the whole profile between the points. The Paraplow was tested against the Agrowplow in several trials on heavy soils (the former being developed for this) but the sites were unresponsive. A trial on Wongan loamy sand in 1984 showed a large response when both machines were worked at 30 cm depth with the Agrowplow softening the soil better, because of its closer shank spacings, and producing a better yield (Figure 10, Table 3).

Table 3. Effect of machine on wheat yield

Treatment	Wheat yield (kg/ha)
Scarified 10 cm	979
Agrowplow 30 cm	1,817
Paraplow 30 cm	1,687

Speed of working

Riethmuller's paper shows the effect on fuel consumption. Limited data shows no effect on the effectiveness of the operation except that one Paraplow trial showed less effectiveness with speed.

NITROGEN INTERACTION

There have been 18 trials where comparisons of ripping in plus and minus N situations can be compared. Means are shown in Table 4.

Table 4. Yield response (kg/ha) to ripping, by nitrogen (Means of 18 trials)

	DDC	DR	ΔY	%
-N	1,110	1,557	447	40.3
+N	1,533	1,907	374	24.4
ΔY	423	350	797	
%	38.1	22.5		71.8

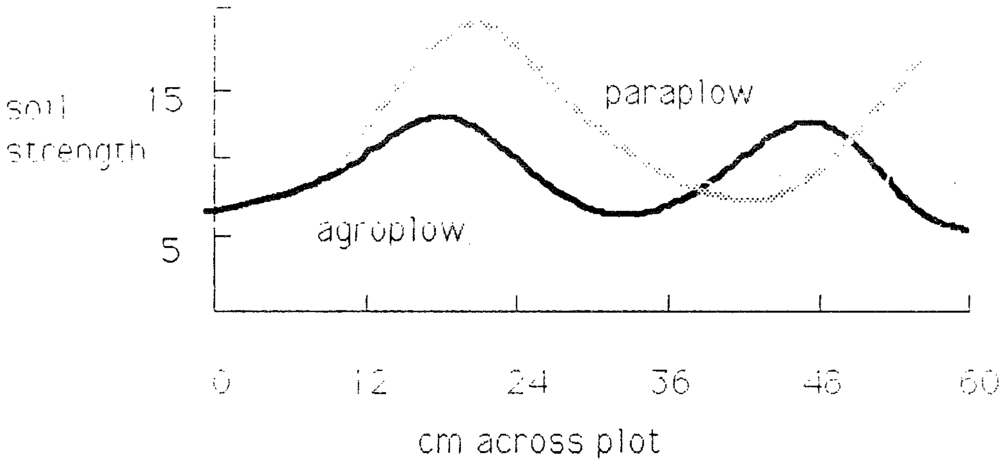

Figure 9. Plot transect : comparison of two deep tillage machines.

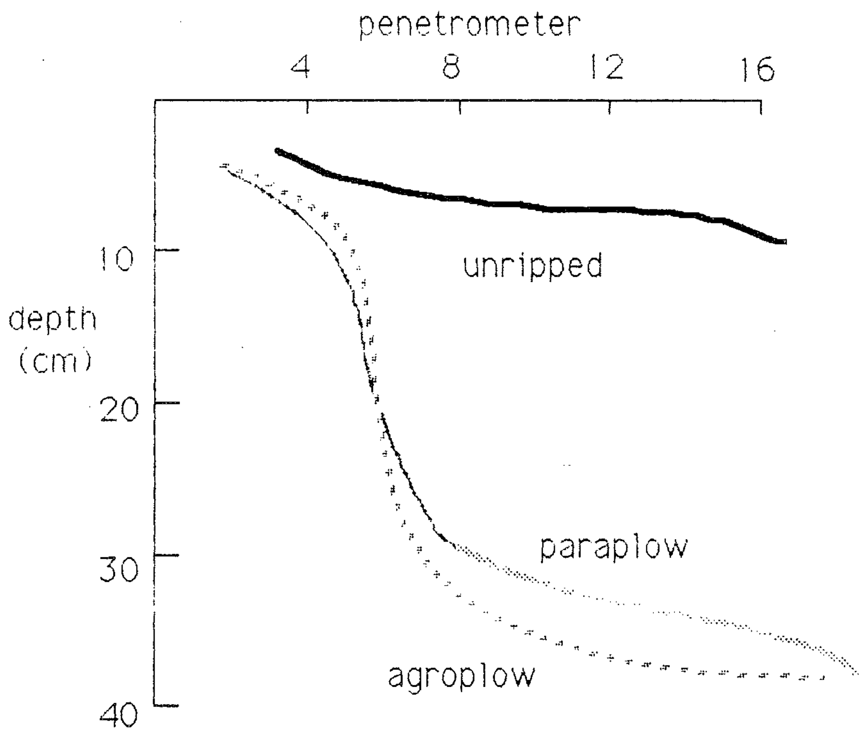

Figure 10. Comparison of soil loosening by an Agroplow and Paraplow. 84WH39.

RHIZOCTONIA REDUCED BY DEEP RIPPING

G. MacNish has shown that Rhizoctonia patch is greater in direct drilled crops and that cultivation will reduce the disease. Cultivation is undesirable on the wind erosion prone sands of the south coastal areas. We need cultivation methods which do not predispose the soil to erosion but are intensive enough to reduce Rhizoctonia.

For years I have been pushing the concept of a seeding machine that will cultivate to 10 cm while seeding shallow in a one pass operation. Figure 1 shows the response to the deeper cultivation in the absence of Rhizoctonia. In 1983 I showed the principle of the one pass machine was sound when our rough prototype modified combine (mod. c) significantly reduced Rhizoctonia below that of direct drill (and district practice) at Wongan Hills Research Station.

A trial at Esperance Downs Research Station in 1984 included numerous levels of intensity and depths of cultivation as treatments and some of the significant ones are presented in Table 5. Note Tr 3 had less Rhizoctonia than 1, 2 and even 4 ($p < 0.001$). We can direct drill, reduce Rhizoctonia and increase yield if we have the right machine. Maybe I am too late. Deep ripping is better still.

Table 5. The effect of direct drilling machines, cultivation and deep ripping on Rhizoctonia and wheat yield - EDRS - 1984 Jarvis, Brennan

Cultivation and Seeding Treatments	Rhizoctonia Patch m^2*	Wheat Yield kg/ha	ΔY	%
1 DDC	11.6	1,108		
2 DD Mod C (level)	10.1	1,287	179	16
3 DD Mod C (10 cm work)	5.7	1,557	449	41
4 Cultivation 10 cm	7.0	1,165	57	5
5 Agrowplow 20 cm	4.6	1,776	668	60
6 Agrowplow 30 cm	3.7	1,817	709	64
7 Agrowplow 30 cm plus cultivation 10 cm	1.4	1,857	749	68

* m^2 out of possible 64 m^2

RESIDUAL EFFECT OF DEEP RIPPING

We have conducted 8 trials in which we have directly compared the residual effect of ripping (light land) with a new ripping

DDC	1,104 kg/ha	
DR Residual	1,274	15%
DR	1,456	32%

The residual effect is from one crop year after ripping i.e. rips in pasture prior to first crop year are considered equal to those ripped immediately before the first crop and are not included in the "residual" until the following crop. Residual is 47% as effective. If we look at all the trials which have been cropped a second time after ripping (no direct new rip comparisons) the average response over 13 trials is 14.6%. This is also about half that achieved in all new rip trials.

Responses in the second residual year have been 18% (8 trials) and in the third 25% (only 5 trials).

Perhaps a "Bowden-Ball Park-Model" is, $R_T = \frac{R_O}{T + 1}$ where R_O response in first year (year 0) and T = subsequent years.

We have shown good responses in the fourth crop after deep ripping (Table 6).

Table 6: Wheat Grain yield response to 1981 ripping. 1981-1984 77WH17

Seeding System	1981 ΔY	1982 ΔY	1983 ΔY	1984 ΔY	%
Direct Drill TDD	655	208	704	310	20
DD Combine	664	156	282	269	15
District Practice	608	11	335	305	17

In 1982 large growth responses to the residual effect of the 1981 ripping were evident however this failed to be converted to grain responses.

The 1983 response was much greater under the TDD sowing which usually exhibits reduced root and top growth on this soil type in unripped situations. This was evident from its significantly lower yield in 1983 (as was the case in the previous two years).

The ripping in 1981 produced grain yield response in 1984 under the three tillage/planting systems. Yields of DDC and DP were equal to each other in the ripped and also in the unripped situations. The TDD yielded less than the others where no ripping had been carried out and the residual effect of the ripping raised its yield but only to the unripped level of the other two.

Over the four years an extra 1,370 kg of grain has been harvested from the one ripping treatment followed by direct drilling with a combine, compared with the four years direct drilling without a 1981 ripping.

RESPONSE OF CROPS AND PASTURES TO SOIL COMPACTION

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INTRODUCTION

Soil compaction research at Geraldton was initiated for a number of reasons, but particularly because of the impressive responses to deep tillage that had been recorded in our region, and elsewhere in the state. Our broad aim was to investigate the processes involved in development of compacted layers in sandy soils, and relate changes in the soil profile to crop and pasture responses. The work was and is part of a team approach to understand and overcome production limitations on the northern sandplain. The results and ideas reported here arise from the preliminary stages of these investigations.

Initial studies looked at two aspects of the soil compaction problem. The first objective was to assess if there was much variation in the way different crop and pasture species responded to the compacted soil layer that has formed on most of the cultivated sandplain. Response was assessed in terms of shoot growth and seed yield. Measurements of root growth were also planned, but difficulties with sample processing due to massive contamination with residual native vegetation roots meant this was not feasible.

The second objective was to investigate the response of a wheat crop to different levels of soil compaction, to see if a model could be developed to predict yield reduction due to soil compaction from a simple soil parameter. If this proved achievable, it would then be possible to determine when a paddock would economically benefit from a ripping/re-ripping operation. The experiments conducted also provided limited information on how quickly a soil compaction problem could develop in a virgin (vaguely analagous with deep tilled) soil.

METHOD

A newly cleared sandplain paddock was the site of two experiments in 1984. The soil type is a deep, yellow, earthy sand, Northcote classification Uc5.22, which has no identifiable compacted layer in the virgin state. A range of soil compaction situations were created by varying the number of passes of a tractor over each plot. The tractor specifications are given in the Appendix. The plots were compacted by driving up and down the plots the specified number of times, then doing similar adjacent wheelings, with minimal overlap. These compaction treatments were implemented when the soil was uniformly moist at field capacity about 6% gravimetric.

Several crop and pasture species were grown under the minimum and maximum soil compaction situations. In another experiment, wheat was grown over the range of traffic levels and at two nitrogen feriliser rates of 15 and 100 kg/ha. Shoot growth were measured monthly, while depth of water extraction as well as yield components were assessed at harvest. Soil penetration resistance was measured using the Bush Recording Penetrometer, when the soil was uniformly moist after rain.

RESULTS AND DISCUSSION

The effects of tractor traffic on the soil profile are demonstrated in Figure 1, which shows the change in profile penetration resistance after each pass of the tractor. The increase in maximum penetration resistance (which generally occurred between 25 and 30cm) was approximately linear up to four passes, after which there was no change. This was probably the maximum achievable density given the tractor specifications and soil moisture status. The resistance profile after six passes was similar to that commonly measured on compacted sandplain paddocks.

The growth over time of the wheat crop under different compaction conditions (Table 1) shows that soil compaction was affecting growth early in the season, with early growth limitations due to compaction accentuated by reduced relative growth rates at various intervals until maturity.

Table 1. The effects of tractor traffic on wheat dry matter production

		Dry Matter Production g m^{-2}			
Number of tractor passes	Nitrogen fertiliser kg/ha	Days after sowing			
		26	55	89	165
0	15	7.6	62.8	243	361
	100	6.9	66.9	353	597
1	15	6.4	52.6	222	389
	100	6.6	66.2	360	611
2	15	6.5	53.3	151	300
	100	6.9	57.8	247	510
4	15	5.3	49.9	141	255
	100	5.5	54.7	178	354
6	15	5.4	45.3	130	247
	100	5.9	53.9	205	352

Reduced early growth is due to soil compaction limiting root extension rates through and within the compacted zone. This reduced root length has several possible implications, including less surface area for water and nutrient uptake, fewer sites for plant hormone production and increased sensitivity to soil borne diseases. Roots also undergo physiological and morphological changes when subject to mechanical impedance, which in turn can affect uptake and transport mechanisms.

As the season progresses, the slower root extension rates mean that the plant is unable to keep up with draining water and leaching nutrients (such as nitrogen), and is also less efficient at exploiting deep subsoil nutrients and water. The net effects of all these limitations are dramatic reductions in growth and yield (Table 1, Table 2).

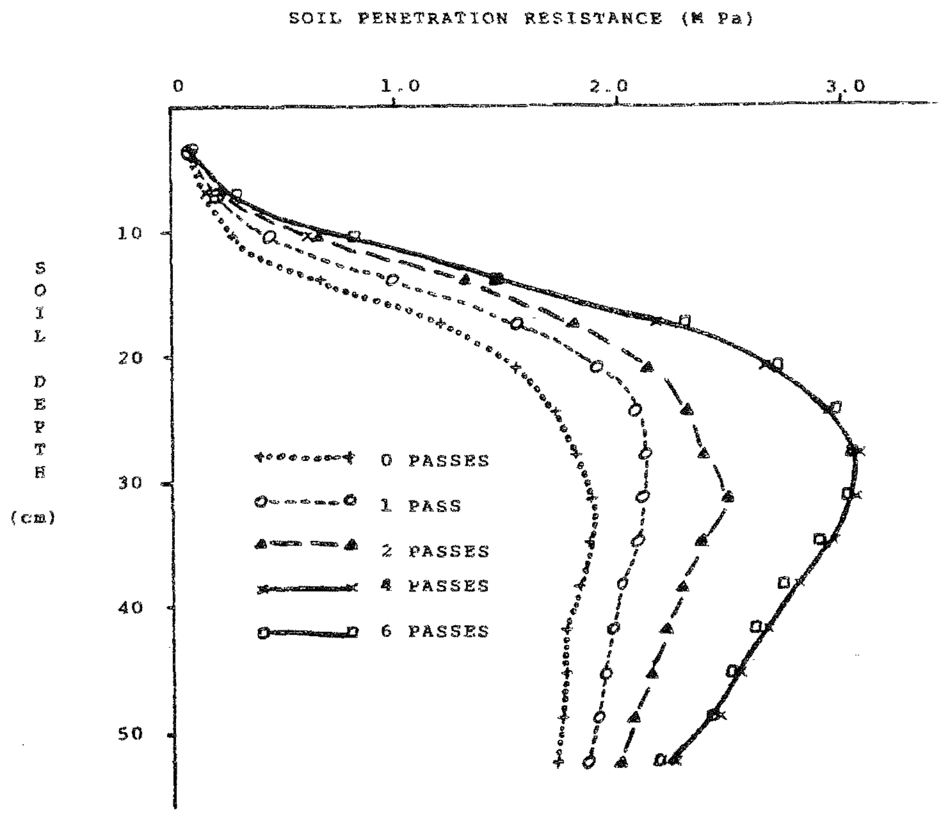

Fig. 1. The effects of tractor traffic on soil penetration resistance profiles with depth.

Table 2. The effect of soil compaction and nitrogen fertiliser rate on grain yield, grain number, grain weight, soil penetration resistance and bulk density

No. of passes	N level kg/ha	Grain yield gm^{-2}	Grain number m^{-2}	Grain weight mg	Soil penetration resistance kPa*	Bulk density kg m^{-3} * 10^3
0	15	173	4,383	40	1.9	1.60
	100	285	7,721	37		
1	15	188	4,983	38	2.2	1.64
	100	282	8,745	32		
2	15	155	4,354	37	2.5	1.57
	100	239	7,268	33		
4	15	122	3,398	36	3.1	1.62
	100	162	5,386	30		
6	15	109	3,410	32	3.2	1.69
	100	158	5,946	27		

* Soil pentration resistance and bulk density values are from the middle of the compacted layer, about 25 cm below the soil surface.

These results show that the first pass of the tractor had little effect on growth and yield, (and in fact may have increased it, due to better seed-soil contact). However, the second, third and fourth passes dramatically reduced growth and yield to about half of potential (Table 2, Figure 2).

However, this information is of limited use, because different size and type of tractor will obviously affect the soil to a greater or lesser degree with each pass. However, if penetration resistance is used as an index of the treatment effect, the results are very encouraging. In Figure 3, it can be seen that there is a good linear relationship between grain yield and penetration resistance at both nitrogen fertiliser levels. This linearity also held for biological yield measurements at anthesis and final harvest.

If the penetration resistance - growth relationships hold in different seasons, it should be possible to predict yield reduction due to soil compaction by a simple penetrometer measurement. This would be valuable in determining at what point a soil is sufficiently compacted/recompacted to warrant an ameliorative operation, such as deep ripping. Because penetration resistance is dependant on soil moisture content, it is important that these parameters are always measured in conjunction.

Bulk density data only varied between 1.57 and 1.68* 10^3 kg m^{-3}, across the range of compaction treatments, and was a much less precise index of soil compaction, (as interpreted by growing plants), than penetration resistance. This was probably because of the much greater number of penetrometer measurements that could be taken compared to bulk density samples.

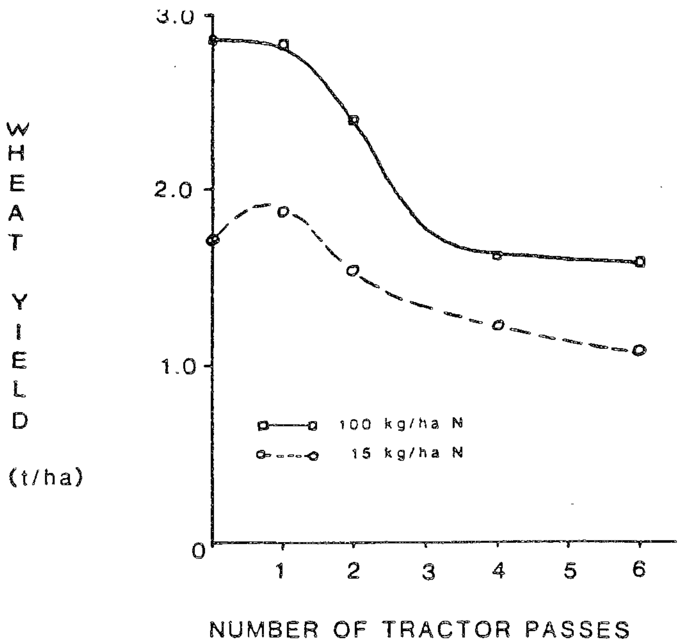

Fig. 2. The effect of tractor traffic on wheat yield.

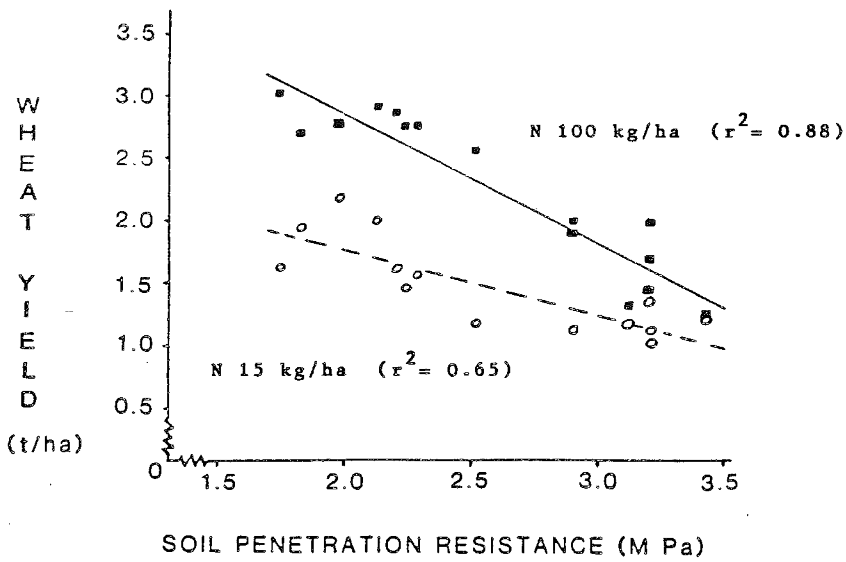

Fig. 3. The relationship between soil penetration resistance and wheat yield.

Plants in the compacted plots were much less efficient users of applied nitrogen, i.e. the extra 85 kg/ha N gave a grain yield increase of more than one tonne/ha in the zero pass plots, but less than half a tonne/ha in the four and six pass plots (Table 2).

The second experiment looked at sensitivity of several crop and pasture species to soil compaction. Results for lupins are not reported here because of severe problems with germination, brown leaf spot and herbicide drift.

Table 3 shows the growth over time of the seven species tested, and it is evident that soil compaction had a marked effect on early dry matter production, with dramatic growth and yield differences by the final harvest (Table 3). The number of replicates was insufficient for good statistical comparisons, but the consistent trends are very obvious.

Hypotheses on the reasons for the compaction response have been suggested earlier. In these experiments, the yield differences were mainly due to inhibition of seed set, rather than seed filling (Table 2, Table 4), which points to a pre-flowering growth limitation. If there was a photosynthetic, nutrient, and/or water limitation late in the season, seed weight may also be affected by soil compaction. There was some evidence of a reduction in grain weight on the compacted plots in the wheat only expeiment (Table 2). A visual observation was that the compacted plots suffered more from *Septoria nodorum* late in the season, as did the higher N plots. This may have reduced photosynthate production during grain filling by destroying active leaf area, with a consequence decrease in seed weight.

Table 3. The effects of soil compaction on dry matter production over time for several crop and pasture species

Days after sowing	33		55		102		172	
Compaction level	U	C	U	C	U	C	U	C
Crop or pasture species								
Wheat	16.6	10.3	55.6	39.5	291	209	342**	198
Barley	15.0**	10.6	60.4*	35.4	352	189	438**	228
Oats	12.8	11.3	52.4*	35.9	319	193	462*	283
Triticale	12.9	10.9	54.0*	33.9	336*	250	410*	273
Medic	4.7	4.2	16.1	10.6	234**	152	-	-
Subclover	3.2	2.9	17.0	12.8	236	156	-	-

U = Uncompacted plots C = Compacted plots

* Significantly different p = 0.05

** Significantly different p = 0.01

Table 4: The effect of soil compaction on seed yield and seed yield components.

	Yield g m^{-2}		Seeds m^{-2}		Seed weight mg	
Compaction level	U	C	U	C	U	C
Species						
Wheat	174**	102	4,458**	2,786	39	36
Barley	236*	124	5,161**	2,849	45	43
Oats	230*	157	4,801*	3,055	48	52
Triticale	209*	144	4,572*	3,220	46	45
Peas	278**	159	661**	378	420	420

U = Uncompacted plots C = Compacted plots

* Significantly different p = 0.05

** Significantly different p = 0.01

The poor use of rainfall by the plants growth in the compacted plots is indicated by the depths of effective water extraction (Table 5); an indicator of rooting density. It can be readily seen that the crops and pastures in the uncompacted soil were able to use more of the stored soil water than their compacted soil counterparts. This would have important implications for water use on saline groundwater recharge areas.

Table 5. The effect of soil compaction on final depths of effective water extraction (cm)

Species	Wheat	Barley	Oats	Triticale	Peas	Medic	Subclover
Uncompacted	210	150	190	190	130	170	170
Compacted	110	110	110	130	30	90	150

Farmer experience on the northern sandplain, and the results of the research indicates that soil compaction is the major degradation problem of the sandy soils in the Geraldton region. All of the species tested were affected by soil compaction. At this stage, no comment can be made on the relative sensitivities of the various crops and pastures, however this is the subject of further experimentation.

The work does indicate that there are large benefits in ameliorating a soil compaction condition on the northern sandplain, and that these gains are not confined to a single crop. Amerliorative practices, although relatively expensive, are justified by the large potential economic gains. The rapid rate of compaction of the near virgin country is a cause for concern, particularly with respect to the residual value of deep tillage. High priority must be given to developing farming systems that minimize the recurrence of soil compaction.

APPENDIX

Model:	Chamberlain 306
Weight:	4,700 kg
Rear wheel separation	168 cm
Front wheel separation	153 cm
Tyre size:	46.7 cm wide * 76.2 cm radius
Rolling radius:	70 cm
Rear wheel footprint:	38 cm wide * 53 cm long
Front wheel footprint:	20 cm wide * 31 cm long
Tyre inflation pressure:	90 kPa
Tractor speed:	10 kg/hr

SOIL COMPACTION, DEEP TILLAGE AND ROOT DISEASE

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INTRODUCTION

Deep tillage affects disease by reducing both soil compaction and pathogen inoculum

Increased soil compaction is commonly associated with increased incidence and severity of various root diseases. Root rots cause by pythiaceous fungi are thought to be particularly sensitive, but there are reports of several other fungi being implicated.

By increasing the soil bulk density, compaction changes the environment of the root-infecting fungus. An increase in the volumetric water content, and hence solute diffusion, is the major effect; this may enhance the activity of the fungus and increase infection. Changes in gaseous diffusion may also be significant. Perhaps more importantly, compaction slows down root growth, changes the cortical structure, and reduces physiological activity. These events may make roots more susceptible to infection. In addition, the relative effect of any root necrosis will increase as the root system is shortened.

Deep cultivation of various sorts has been shown to reduce infection by, for example, *Pythium ultimum* and *Fusarium solani* f.sp. *pisi* on peas, *Rhizoctonia solani* on beans and wheat, and *Drechslera sorokiniana* (*Cochliobolus sativus*) on wheat. In some of these cases, the effect was attributed to reduced compaction causing a reduction in either the absolute or relative levels of disease (e.g. Figure 1). However, in several instances the effect was thought to be due directly to a reduction in the level of inoculum of the pathogen (e.g. Figure 2). Deep cultivation is often superior to shallow cultivation in burying spores and infected plant debris. This may be particularly important if the pathogen is usually restricted to the top soil layer, and is sensitive to changes in the water, gaseous, nutritional or biological status of its environment. The effectiveness of any tillage system in burying debris will of course depend on the type of implement used, and the time for cultivation, and other factors.

In this paper I will present some of the results I have obtained on the effects of deep tillage on root diseases of wheat on the deep yellow sand at East Chapman Research Station (in collaboration with J. Hamblin, A.G.P. Brown, and others). The conclusions are preliminary, as they are for one season only (1984), and neither the measurements nor the analyses are yet complete. I will also speculate on the meaning of the results and the possible application of deep tillage as a control measure.

Deep tillage and wheat growth on the northern sandplain - 1984 (Trial GE84C15)

A multi-factorial experiment was conducted using the following factors as treatments

(a) Rotation - wheat after lupins vs continuous wheat (variety Eradu).

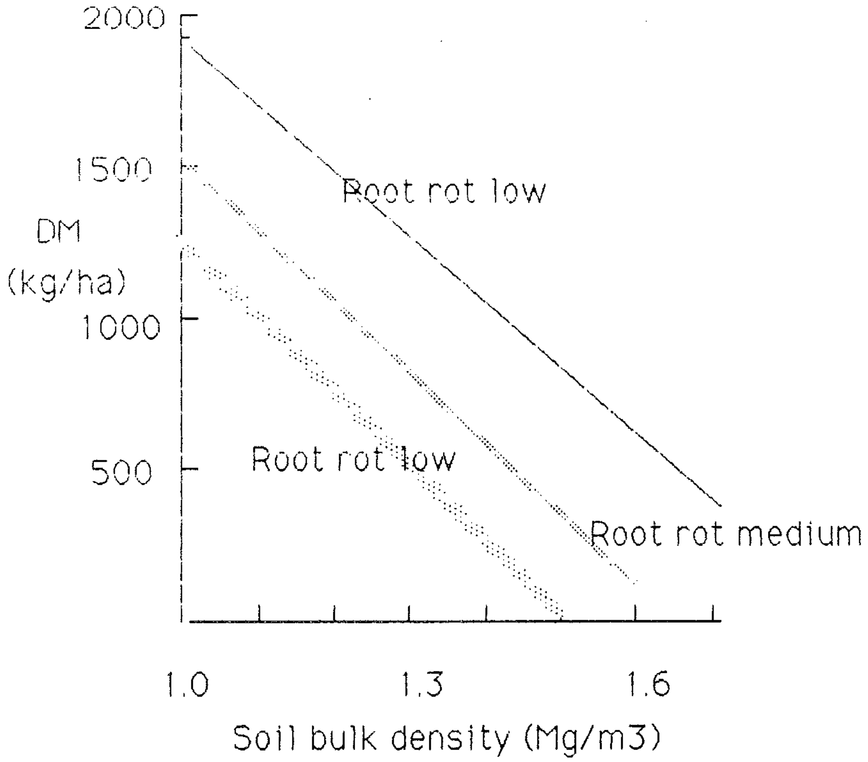

Fig. 1. Yield of peas versus soil bulk density for increasing levels of root rot index. (Raghaven et. al. 1982)

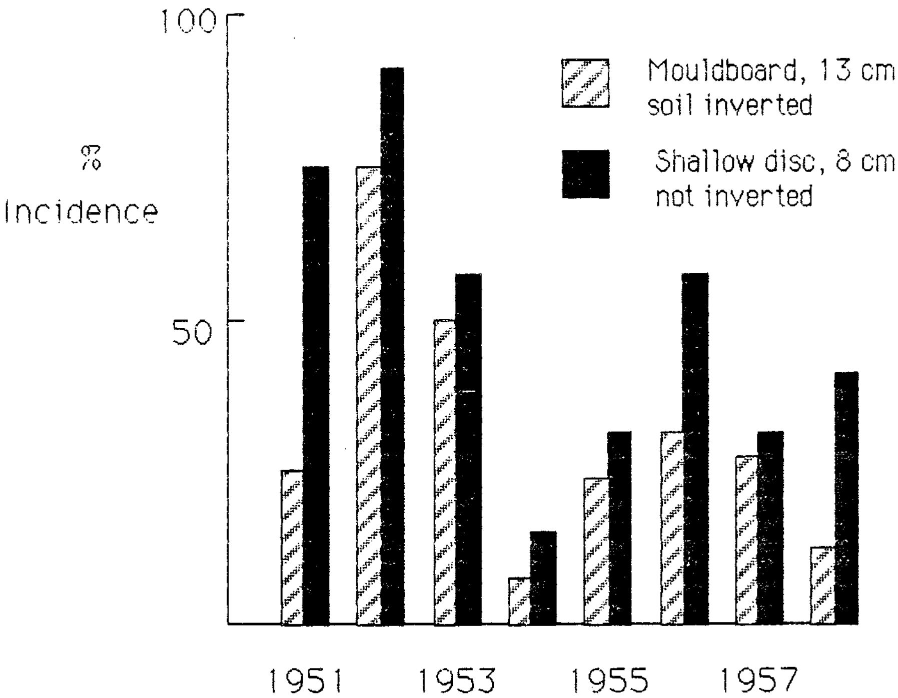

Fig. 2 Effect of two cultivation methods on the incidence of common root rot of wheat in a clay loam. Ledingham et. al. 1960.

(b) Leaf disease - three levels of leaf disease were artificially imposed using stubble burning, the addition of contaminated stubble, or the application of fungicide.

(c) Deep tillage (ripping) - ripped vs not ripped. (Agrowplow to 30 cm on 8.3.84, after heavy rain).

(d) Cultivation - conventional cultivation vs minimum tillage. (Cultivation by culti-trash to 10 cm on 31.5.84, 12 days before seeding).

(e) Nitrogen - 5 levels of nitrogen (0, 12.3, 25, 50 and 100 kg/ha), applied as Agran.

Measurements of root disease, root length and depth, grain yield, and yield components are presented in Figures 3 - 5 and Tables 1 - 5.

Yields

Most cereal crops in the northern wheatbelt of Western Australia yielded well in 1984, due to good rains throughout the season. Nevertheless the field trial showed that yields could be significantly increased by either ripping or rotation with lupins. Further increases were obtained by combining ripping and rotation (Figure 3). Nitrogen responses were of minor importance.

Variations in yield were mainly due to changes in the number of heads, and the number of seeds per head, rather than to changes in grain weight (Table 1). This suggested that the main limitation to yield in 1984 occurred prior to grain filling. The high harvest indices, and the minor differences in harvest index between the treatments, support this conclusion. Rapid growth early in the season is probably important if high yields are to be achieved on the northern sandplain.

Table 1. The effects of deep ripping and rotation with lupins on the yields and yield components of wheat. Data are for plots to which nitrogen was applied at 50 kg/ha

	Continuous wheat		Wheat on lupins	
	Ripped	Not ripped	Ripped	Not ripped
Grain yield, t/ha	2.63	1.40	3.23	2.17
Harvest index	0.49	0.51	0.48	0.51
Heads per m^2	191	135	273	188
Seeds per head	32.7	24.3	29.5	26.0
Grain weight, mg	4.23	4.06	4.09	4.20
Fertile spikelets per head	14.5	12.9	14.9	13.7
Seeds per spikelet	2.22	1.99	2.06	1.92

Incidence of root diseases

the most common disease symptom observed on the below ground parts was necrosis of the sub-crown internodes. As Drechslera sorokiniana was regularly isolated from these lesions, the disease is referred to as "common root rot". Other root pathogens observed or isolated were Gauemannomyces graminis ("take-all"), and species of Rhizoctonia, Fusarium and Pythium. Severe root damage was rarely seen. This supports the theory that root diseases in the Geraldton area are insidious, and usually cause reduced plant growth rather than death.

Both deep ripping, and rotation with lupins, decreased the incidence of root disease, particularly early in the season (Table 2). The severity of sub-crown internode damage was also decreased by these treatments (results not shown). The effect of deep tillage on disease incidence lessened as the season advanced, a fact which has also been observed elsewhere (see Figure 2).

Table 2. The effects of deep ripping, and rotation with lupins, on the incidence of root diseases of wheat. Data are for plots to which nitrogen was applied at 50 kg/ha.

Type of damage	Wheat on wheat		Wheat on lupins	
	Ripped	Not ripped	Ripped	Not ripped
Necrosis of sub-crown internode (D. sorokiniana, "common root rot")				
At 5 weeks	25	42	11	36
At 9 weeks	80	80	32	53
Necrosis of lateral and seminal roots (various pathogens)				
At 5 weeks	51	68	21	39
At 9 weeks	82	87	30	59

The effect of shallow cultivation on the incidence of root disease was not clear-cut, particularly for continuous wheat, but was generally less than that of deep tillage. The results for common root rot on wheat after lupins are shown in Figure 4. In this case, cultivation had no effect on initial infection, but appeared to reduce the rate of spread of the disease.

Root length and diseased root length

On the highly leached deep sands typical of the northern sandplain of Western Australia, rapid root developement is probably necessary if yields are to be maximised. In this trial, the final depth of rooting was similar for all treatments, but total root length, (and hence root density down the profile), increased with both ripping and rotation with lupins (Tables 3 and 4). However, the effects varied according to the time of sampling. Early in the season, there was a response to rotation, but the effect of ripping was negligible (Table 3). An anthesis, both ripping and rotation caused increased root length, but ripping was the more significant of the two factors (Table 4).

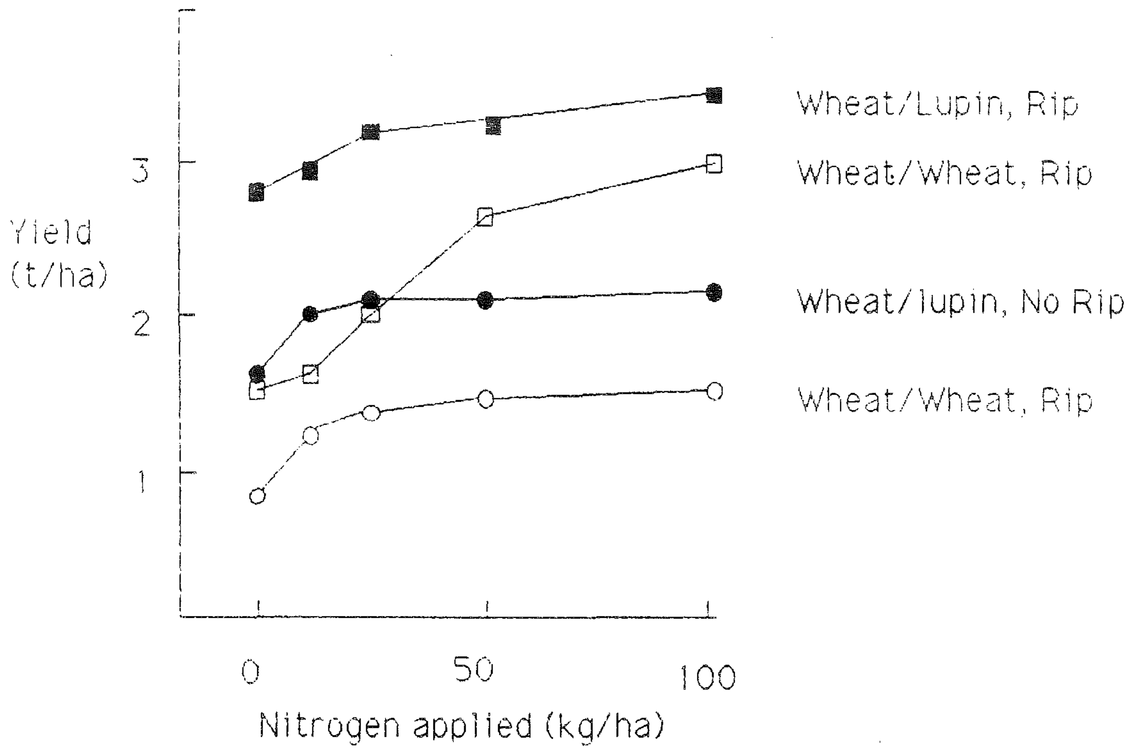

Fig 3. The effects of nitrogen applications, rotation with lupins and deep tillage on the yield of Eradu wheat. East Chapman Research Station, 1984.

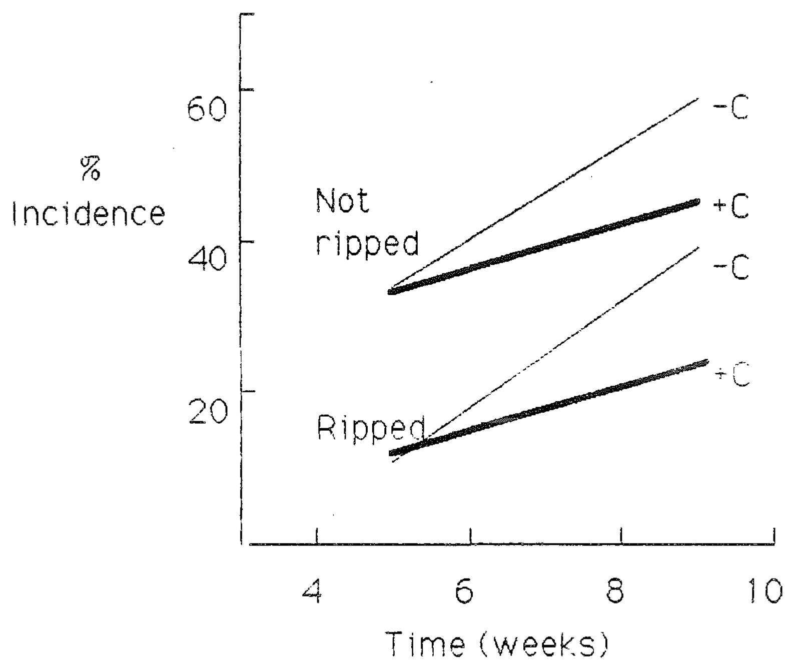

Fig. 4. The effect of deep tillage and shallow cultivation (+C) treatments on the incidence of common root rot on wheat following lupins.

Table 3. The effects of deep ripping, and rotation with lupins, on the length of healthy and diseased roots 5 weeks after planting.* Disease refers to any form of root necrosis

	Wheat on wheat		Wheat on lupins	
	Ripped	Not ripped	Ripped	Not ripped
Total root length (cm)	2,102	2,141	2,431	3,101
Root length diseased (cm)	307	346	170	494
Non-diseased root length (cm)	1,795	1,795	2,261	2,607
% root length diseased	15.0	15.0	7.4	16.4

* Average values for 5 plants. Total root depth was approx. 19 cm

Table 4. The effect of deep ripping, and rotation with lupins, on the length of healthy and diseased roots at anthesis (14 weeks after planting).* Disease refers to any form of root necrosis

	Wheat on wheat		Wheat on lupins	
	Ripped	Not ripped	Ripped	Not ripped
Total root length (cm)				
Total profile	6,475	3,703	6,850	3,647
Above 40 cm	4,220	3,198	4,555	2,851
Below 40 cm	2,255	511	2,278	801
Root length diseased				
Total profile	1,130	801	630	437
Above 40 cm	801	551	432	312
Below 40 cm	329	68	199	125
Non-diseased root length				
Total profile	5,373	2,925	6,225	3,226
Above 40 cm	3,419	2,471	4,124	2,539
Below 40 cm	1,954	454	2,096	687
% root length diseased				
Total profile	17.8	21.2	9.1	12.2
Above 40 cm	19.5	22.7	9.7	10.9
Below 40 cm	16.0	21.5	8.9	17.0

* In this trial, total root depth was approximately 2.4 metres of all treatments. In previous years difference have been observed with rotation and tillage treatments. Figures are for 5 cm diam. cores.

Penetrometer measurements of the plots showed that soil strength varied down the profile, with unripped plots having a compacted layer between depths of approximately 20 and 40 cm (data not shown). Deep ripping significantly reduced this compacted layer. It is well established that this reduction in soil strength causes a more rapid development of roots (e.g. data of D. Tennant and J.W. Bowden). However, an interesting finding from this trial was that the treatments affected the length and proportion of the diseased root was significantly reduced in the ripped wheat after lupin plots (Table 3). However, the unripped plots appeared to compensate by producing a greater length of root. Later in the season, diseased roots, characterised by vascular necrosis, occurred at all levels down the profile, even below 2 metres. The cause of this necrosis is not known. Both ripping and rotation caused reductions in the proportions of the roots which were diseased, but the effects were most marked below the compacted layer (i.e. below 40 cm), and were greatest for the ripped wheat after lupin plots (Table 4). Whether the disease impaired root function is not yet established.

Deep tillage vs root disease: Is it a significant relationship?

The effects of deep tillage on wheat root disease at East Chapman in 1984 are summarised in Table 5. The type of disease and the stage of crop development affected the responses. However, the main effects of deep tillage (with respect to disease) were on

(a) the incidence of disease, and

(b) the length and proportion of roots diseased.

The incidence of a disease is probably directly related to the amount of inoculum present. On the other hand, the length and proportion of roots affected will be greatly influenced by the rate of root growth, and hence by the direct effects of compaction on root growth. These are thus probably two distinct effects.

Table 5: Responses of root disease and root length to deep tillage in two rotations: Continuous wheat (WW) and wheat after lupins (LW).

	% response to deep tillage	
	WW	LW
Incidence of necrosis of sub-crown internode ("common root rot")		
At 5 weeks	-41%	-69%
At 9 weeks	none	-40%
Incidence of necrosis of seminal and lateral roots (various pathogens)		
At 5 weeks	-25%	-46%
At 9 weeks	- 6%	-49%
Root length at 5 weeks		
Total root length	- 2%	-22%
Non-diseased root length	none	-13%
Difference due to disease?*	2%	9%?
Root length at anthesis		
Total root length	+75%	+88%
Non-diseased root length	+84%	+93%
Difference due to disease?*	9%?	5%?

* The effect of disease will be different from values calculated in this way, for it will be related to the amount of root rendered inactive by disease. This may vary according to the transverse area affected and the position of the lesion on the root system (e.g.)

The effect of a root disease will depend not only on the extent of damage, but also on the type of damage caused. Pathogens can disrupt many plant processes, either by causing a physical obstruction (e.g. the blockage of xylem vessels), or the death or malfunction of cortical, phloem, or other cells. Drechslera sorokiniana ("common root rot") usually causes necrosis of the cortical cells of the sub-crown internode. However, it can also invade the xylem. Severe damage causes severance of the seminal roots. There have also been some reports that entry is aided by the production of a toxin. If so, this might disrupt the host physiology in other ways. Common root rot is widespread in the northern region but whether it is an important disease in terms of yield loss is not yet established. Figure 5 shows that there was a good relationship between the incidence of common root rot and biological yield for wheat after lupins at 9 weeks. Tillage appeared to mediate these effects,

Most of the disease observed on the root system proper was due to vascular necrosis (exact cause unknown). The effect of damage of this sort will vary according to the area of the root affected and the position of the lesion on the root system: a lesion at the top of a branching system might be expected to have more effect on root function than one nearer the tip. Thus

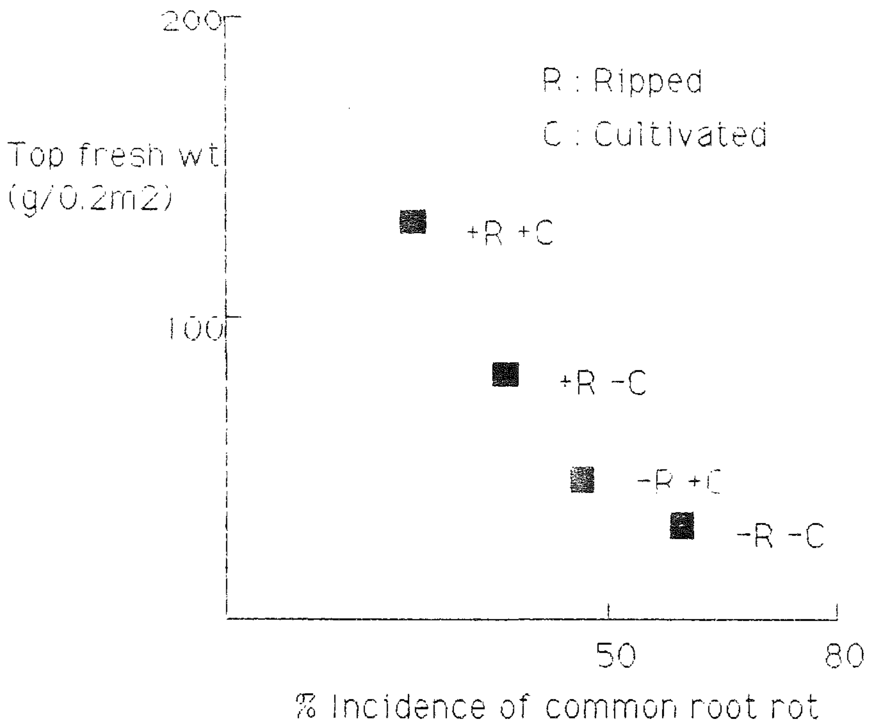

Fig. 5. Relationship between common root rot and top fresh weight at 9 weeks. Data for wheat on lupins, 50 kg/ha nitrogen.Each point is a mean of 3 replicates.

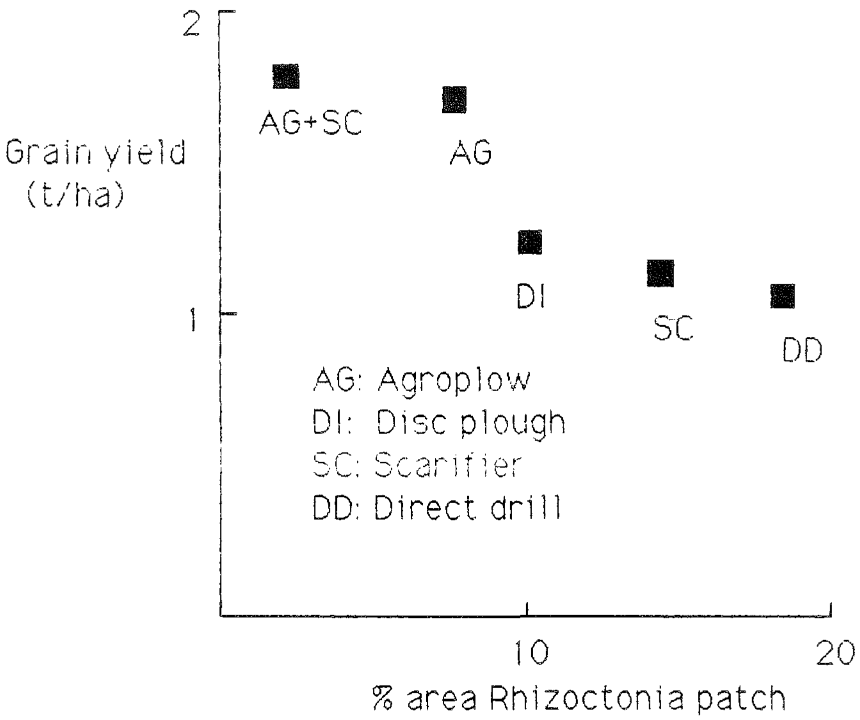

Fig. 6. The relationship between Rhizoctonia patch and grain yield of wheat , and the effects of various forms of cultivation. Data of Jarvis and Brennan . White sand Esperance Downs Research Station.

the percentages of the tillage responses actually due to disease are likely to be greater than those apportioned in Table 5. Nevertheless, the responses of root length to deep tillage were probably predominantly due to an increased rate of root growth, with reduced root disease being of lesser significance.

Is deep tillage superior to shallow cultivation?

Several disease of wheat (e.g. take-all and rhizoctonia patch) have been found to increase under minimum tillage. direct drilled systems. Shallow cultivation (to 10 cm) has in most instances been shown to reduce the incidence of these diseases (e.g. work of Rovira, S.A., Moore, N.S.W., McNish, W.A.). Little information is available on the mechanisms of the effect, but it is generally assumed that turning under infected debris reduces the level of viable inoculum. This may occur, either by burying the inoculum to a depth where the conditions (e.g. aeration?) are not suitable for survival, or by stimulating the activity of antagonistic micro organisms or soil animals.

The important question is whether deep tillage operates in the same way, or whether it has an additional or alternative effect. Data for wheat in Esperance in 1984 suggest that the deeper the tillage, the greater the reduction in rhizoctonia bare patch (Figure 6). The Geraldton data (Figure 4) showed differences between shallow and deep cultivation for common root rot, with deep tillage being superior to shallow in terms of disease reduction. However, interpretation of these results is complicated by the fact that deep and shallow treatments were conducted at different times (early March vs late May respectively). Differences in the environmental conditions, particularly the soil temperature, may thus have affected the result.

It is important to establish whether deep tillage is invariably better than shallow cultivation in reducing disease, or whether it is an artifact of the time of cultivation, the soil moisture or temperature conditions at the time, or the type of implement to attempt to assess some of these factors. We are comparing 4 cultivation implements, both deep and shallow, at 3 times of cultivation (March: dry,. hot; March: wet, hot; May: wet, cool). Measurements will be made of soil, disease, and agronomic factors.

Conclusion: What do we need to know about deep tillage and root disease?

Deep tillage can reduce both the incidence and severity of root disease. Whether there is a yield advantage attributable to the effect will depend on the particular disease, the type of damage caused, and the stage of crop development when the disease is most apparent.

Deep tillage may reduce disease by any of several mechanisms. Some of these are

(i) Reduction in soil inoculum either by burying infected debris and spores, and/or by increasing the competitive advantage of antagonistic micro-organisms.

(ii) Reduction in the "susceptibility" of the root to infection. The vigorous roots occurring with deep tillage may be infected less frequently, or may be colonised to a lesser extent than those restricted by compaction.

(iii) Reduction in the relative effect of any root disease. The proportional effects of any root necrosis will decrease as the root system lengthens.

Deep tillage appears to reduce disease to a greater extent than shallow cultivation, although this effect may vary according to the particular implement used and its mode of operation. It is possible that deep tillage operates similarly to shallow cultivation in terms of (i) above (i.e. reducing inoculum) but that it has an additional advantage in that it also interacts with root vigour (points (ii) and (iii) above.

Important questions to be answered are:

1. Under what soil and climatic conditions is deep tillage likely to reduce diseases?

2. Is it a widespread effect, or does it only hold for a few diseases?

3. Is deep tillage always superior to shallow cultivation in reducing disease. If so, why?

4. Does the time of tillage or the type of implement affect the result?

5. Can yield advantages be attributed to the effects of deep tillage on disease?

6. What soil microbiological changes occur with deep tillage, do these affect either root growth or disease?

DEEP TILLAGE IN FARMING SYSTEMS: TIMING OF DEEP TILLAGE AND INTERACTIONS WITH ROTATION AND CONVENTIONAL TILLAGE PRACTICE

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In this session I propose to examine a simplified system of rotations and ripping opportunities and try to determine guidelines for researchers and advisers in terms of farmers needs and future research objectives in deep ripping work. I have taken as my model the northern sandplain soil, but a similar approach could be used for any area where enough is known about the effects of ripping to be able to make an intelligent guess about its likely effects on crop yields.

The three rotations that I consider are:

Continuous pasture
Pasture/cereal
Continuous cropping

The continuous cropping system considered here is a wheat/lupin rotation, and ripping is primarily expected to benefit the wheat crop.

There are basically three ripping situations, these are:

Rip wet, but not on the break of the season
Rip wet on the break of the season
Rip dry over summer

Wet ripping, but not on the break of the season

Each ripping practice has disadvantages. When farmers rip wet (but not on the break of the season), then either there must be a non-crop phase in the rotation (pasture or fallow) to allow winter ripping; or they must rely on summer rain to wet up the soil sufficiently to allow deep ripping. In the continuous cropping system there is no break period, thus wet ripping can only happen if summer rain occurs. In the Geraldton region the frequency of getting more than 50 mm rain in a 3 day period in the months of January to April inclusive (arbitary definition of suitable conditions for summer ripping) is about twice in 7 years. At Wenmillia (M. Freeman) this was the observed frequency, however there was a run of 10 years in which the critical level was never reached. Summer rainfall therefore only supplies an occasional opportunity ripping situation for farmers who want to deep rip in a continuous cropping system.

Wet ripping on the break of the season

If we wait until the break of deep rip, then we are likely to delay planting. Delaying planting in the Geraldton region often reduced yield. Table 1 shows the effect of delaying seeding on the yield of the variety Gamenya in the northern part of the state. Both disease (Septoria) and weeds confound the relationship between planting date and yield. However for the purpose of this study it is assumed that weed control problems have been solved and that resistant varieties are available.

Therefore results are only considered where there is a reduction in yield with delayed seeding. This partially overcomes the confounding effects of weeds and disease. On average the effect of delayed planting was to reduce yields by 128kg/ha/week. I have used a figure of 100 kg/ha/week here. This figure approximates with that of Trevenan (1985), who suggested that in the Merredin region the effect of delayed seeding was about 70 kg/ha/week. The difference is probably due to the method of measurement, the trials used and the fact that the rate of evaporation is higher in the Geraldton region, putting a greater penalty on late planting.

Table 1. Effect of delaying planting on yield of Gamenya (kg/ha/week) in the northern agricultural region

Officer	Site	Year	Date (1)	Fungicide	Yield reduction (kg/ha/week)
Perry	BaRS	1981	26/5	+	122
Perry	BaRS	1981	17/6	-	199
Perry	WHRS	1981	17/6	+	271
Perry	WHRS	1981	17/6	-	241
Hamblin	Criddle	1982	25/5	-	33
Hamblin	ECRS	1982	27/5	-	29
Hamblin	Gill	1982	26/5	-	109
Hamblin	ECRS	1983	12/6	+	147
Hamblin	ECRS	1983	12/6	-	122
Fisher Zone	1 D	Many	1/5	-	92 (2)
Fisher Zone	1 D	Many	1/5	-	44 (2)
Average					128

(1) This was the date from which a reduction in yield was measured.

(2) The first case used all 5 date categories, the second only the first 4. The difference reflects the very rapid fall off in yield with July seeding in the dry northern region.

<u>Dry ripping over summer</u>

Ripping dry, although a reasonable option in the continuous cropping situation, also has problems. The wear and tear of ripping dry is greater than ripping wet, more fuel is required and the operation is slower. Also there may be a biological penalty from ripping dry as it is not so effective in breaking up the pan evenly, however we do not know if this occurs. This area needs research. However here I have assumed no biological penalty from ripping dry.

Table 2 shows the options for ripping for the three rotations.

Table 2: Rotation x ripping options

Continuous pasture	
1.	Rip wet, but not on break *
2.	Rip dry
Pasture/cereal	
1.	Rip wet, but not on the break *
2.	Rip wet on the break
3.	Rip dry
Continuous crop	
1.	Rip wet, but not on the break *
2.	Rip wet on the break
3.	Rip dry

I have marked (*) what I consider to be the best options. In the case of continuous pasture there is a suggestion from Craig Henderson's work on compaction, from Mike Ewing's work on species and varieties and John Howieson's work on acid tolerant rhizobium, that a large increase in productivity may be obtained by ripping pasture if a hard pan is present. This is being explored in 1985. If there is a big advantage, then ripping wet in the winter is the obvious solution. This also applies to the second rotation, pasture/cereal. In fact in a continuous pasture situation a single crop after ripping may be the best way of getting a quick return on the ripping operation. In both these two situations, if ripping is to occur it should occur in the pasture phase, after the pasture is well established and when the profile is wet. This option gives good ripping conditions, does not kill the pasture and fits well into the farming year.

The problem situation is the continuous crop rotation. Here the two options are to rip on the break and delay seeding or to rip dry and incur greater costs and possibly suffer reduced biological benefit. I have attempted to analyse these options. First I have taken all ripping trials in the northern area and farmer experience and come up with an average response to ripping of 60%. The trials involved are listed in Table 3. Then I have carried out a crude yield analysis to compare no ripping with ripping wet on the break and ripping dry over summer. I have not put $ costs on my calculations as the price of wheat varies considerably from year to year.

Table 3. Responses to deep ripping in the northen region (% increase over unripped control)

Officer	Site	Year	Rotation	Comments	Increase %
Jarvis	Naraling	1982	W/L	-	74
Jarvis	Naraling	1983	W/L	-	74
Jarvis	Naraling	1984	W.L	-	50
Wilson	ECRS	1984	W/W	-	92
Wilson	ECRS	1984	W/L	-	54
Henderson	Gills	1984	W/L	Compaction trial	69
Hamblin	ECRS	1983	W/W	Poor rip + fungicide	119
Hamblin	ECRS	1983	W/W	Poor rip = fungicide	79
Farmers	General	3 years	-	Poor control	52
Average					64

Note: Hamblin (1983) the control was the wheat on wheat conventional cultivation plot of the large rotation trial, whereas the ripped treatments was the stubble mulch plot. The farmer yields results also suffered from poor control yields.

The assumptions used in my analysis are shown in Table 4. I have worked on the basis that ripping has no effects on farm operations except in terms of the cost of the operation and the effects on the yield of wheat.

Table 4. Assumptions used in the yield analysis comparing ripping options in a continuous crop rotation

Factor	Not ripped	Rip on break	Rip dry
Farm size	2000 ha	2000 ha	2000 ha
Area wheat	60 ha	960 ha	960 ha
Area lupins	960 ha	960 ha	960 ha
Lupin seeding	Dry	Dry	Dry
Planting width (1)	10 m	5 m	10 m
Planting speed (2)	10 kph	7.5 kph	10 kph
Area planted/day (3)	100 ha	37.5 ha	100 ha
Wheat yield (4)	1 t/ha	1.6 t/ha	1.6 t/ha
Time to plant wheat	9.6 days	25.5 days	9.5 days
Wheat production (5)	1978 t	1549 t	1654 t
Yield differences			
rip dry v not ripped	= 576 t or .60 t/ha		
rip on break v not ripped	= 471 t or .49 t/ha		
rip dry v ripped on break	= 104 t or .11 t/ha		

(1) Assumed tractor can pull 2 x 28 run combines (10 m or can pull one deep ripper (5 m) + a 28 run combine (5 m).

(2) Planting speed 10 kph for combines, 7.5 kph for ripper and combine.

(3) 100 ha = 10 m x 10 kph x 10 hours: a 2 man operation
37.5 ha = 5 m x 7.5 kph x 10 hours

(4) Wheat yield average for district = 1 t/ha approx. This covers a wide range of planting dates. The ripped yields are 60% up on this and equal 1.6 t/ha.

(5) Total production takes account of effect of planting date.

All wheat planted in week 1 yields .15 t/ha above average;
All wheat planted in week 2 yields .05 t/ha below average;
All wheat planted in week 3 yields .05 t/ha below average;
All wheat planted in week 4 yields .15 t/ha below average;

The above analysis shows a marked advantage to ripping, under the yield assumptions outlined. Also Table 4 shows an advantage for ripping dry compared to ripping wet and taking a penalty for delayed seeding of .11 t/ha. This is the margin available to pay for the greater wear and tear to machinery and also any biological penalty that may occur when ripping dry as compared to ripping wet.

This analysis could be carried out for any set of yield and cost assumptions. Obviously it is highly sensitive to the yield response that occurs after ripping. However the message that comes out is clear.

1. It is important to determine if there is a biological penalty from dry ripping.

2. If there is what is its scale.

3. Independent of whether there is a biological penalty or not from dry ripping, it is important to minimise the costs of this operation. The effects of factors such as choice of implement, tyne spacing, speed and critical depth, etc., must be established. As dry ripping gives the farmer greater flexibility in terms of giving him more time at planting and so makes that crucial operation less risky.

CURRENT FARMER ATTITUDES TO, AND APPLICATION OF, DEEP CULTIVATION

GERALDTON REGION

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Farmers on medium or heavy land have always tended to look towards deep cultivation as a method of rectifying soil problems and increasing crop yields. On the sandplain soils the opposite viewpoint has been held - sandplain was not worth anything until it was compacted by sheep and machinery and a vehicle could be driven safely over it.

These divergent views, dependent on soil type, are still held strongly in the farming community - in other words most of the deep working of soil is still done on the more clayey type soils - with chisel ploughs or similar tyned equipment.

Of course the sandplain farmer has noted that an old track or road is visible even after several crops. Likewise he has often noted that the crop growth over a polypipe buried in the paddock is often superior to the rest of the crop growth.

Although Jarvis and ourselves have noted large wheat yield increases from deep ripping since 1982 on yellow sandplain we have adopted a passive extension role. That is, results have been published in Agmemos without comment, and field walks have been held without strongly urging farmers to buy expensive machinery. At the back of our minds we hoped that the biological deep ripping of a lupin/wheat rotation would replace the need for mechanical ripping. For 3 successive years (1982, 1983, 1984) we have had significant yield increases of wheat to deep ripping. The better the year in terms of rainfall the higher the response level to deep tillage.

I have been able to contact, after vigorous canvassing, only 9 farmers who are actively deep ripping sandplain soils. One of these farmers has been ripping since 1977 and it is now part of his farming practice. Two others are in the same category whilst the other 6 are ripping on an experimental basis. 1984 was an ideal year for experimental work on deep ripping in that there was adequate summer rainfall for the operation to be carried out, and adequate finishing rains for the potential yield to be achieved.

In 1985 more interest is being shown in deep cultivation of sandplain soils. Agrowplows, etc., are being purchased by individuals or groups, and deep tillage equipment is available for hire at $120/day - the lessee supplying the points. Many farmers will also use cultivator bars, chisel ploughs, and other equipment already on the farm. Unfortunately summer rain has not been plentiful this year and therefore experimentation may be limited. Two of the three farmers who have adopted deep ripping as part of their farm programme are ripping in a pasture phase, when the soil is wet.

Before we can actively promote deep ripping as a successful farm practice, we need to know all the interacting factors - when, where, how often, how deep, etc., etc., so that a package approach to deep ripping can be promoted.

MIDLANDS AND NORTH-EASTERN WHEATBELT

Eric Thomason
Moora District Office
Department of Agriculture

The attitude of farmers in the Midlands and North-eastern wheatbelt towards deep ripping is one of high interest and close observation of trial results and other farmers experiences.

Wheat yield responses of around 30 to 50 per cent have frequently been obtained on Wongan loamy sand following deep ripping.

Deep ripping is a very costly operation in terms of time, machinery cost, machinery wear and tear and other operating costs. The following information needs to be obtained before wider adoption of the practice is implemented.

1) Soil types

Yield responses have been obtained on loamy sand at Wongan Hills, pear/pine sands at West Pithara in trials. Farmers have ripped many categories of light land (most farmers rip whole paddocks if they contain predominantly light land regardless of light land soil type) and most have found the largest response on Wongan loamy sand. Further investigation is needed on lighter soils such as found at Watheroo and the West Midlands.

2) Time of ripping

Ideally ripping is undertaken when the soil is moist. Dry ripping has been reported as being less effective, brings subsoil clods up to the surface, higher power is required, more wear and tear on points and machinery and is slower. However one farmer at West Pithara claims he can rip pine/pear tree yellow sand in early Autumn with good results despite a dry summer.

Lupin:cereal rotations are the most likely option for much of the rippable good light land. Time of ripping is restricted to at the break, which is not viable because of delayed seeding, or opportunistic ripping following summer or autumn rainfall which may occur in some seasons only and time suitable for ripping may be restricted. Dry ripping might be an alternative on some soil types.

3) Depth of ripping

Virtually all farmers are ripping at 30 cm using Agroplows.

4) Period between deep rips

The residual value of deep ripping needs more research. At Wongan Hills, the residual value has lasted four years to date.

The re-ripping period is expected to vary with soil type. Farmers are tending to rip just prior to cereal of the rotation.

5) Species

Wheat has the largest response to deep ripping. Most farmers are ripping land carrying a wheat:lupin rotation. Lupins are showing small responses (about 10 per cent) to ripping. More research is needed with other crop and pasture species.

MERREDIN REGION

Geoff Fosbery
Dryland Research Institute
Department of Agriculture

West of Trayning and Koorda on the Wongan type loamy sands many farmers are either deep ripping as part of their programme or at least putting in trial areas. Many responses have been dramatic. Ripping is being carried out during a pasture phase, or opportunistically after a good summer rain.

Some farmers still deep rip their so called heavy land (red-brown clay loam), but many have recognised the response to a summer fallow effect if they have had a positive response. Most are now looking to gypsum to break open their 'tight' soil.

Saline hillside seepages are being deep ripped in an effort to enhance the water infiltration characteristics and leach some of the salt. This is usually carried out as a part of an integrated approach to hillside seepage control (amelioration).

Implements used in deep tillage could be:

1. Agrowplow
2. Chisel plough
3. Blade plough
4. Root ripper

Future

It is unlikely to become a widespread practice in this district as much of the eastern wheatbelt light land receives low annual rainfall and has relatively acid subsoil.

NORTHAM REGION

Tom Sweeney & Chris Broun
Northam District Office
Department of Agriculture

Only about 20 farmers are in the habit of deep ripping their land at this moment. Among their staunch beliefs are:

1. Deep ripping increases yield between 20% and 100%.
2. Sands with a hard pan are most responsive but heavy soils respond also.
3. Working wet beats working dry.
4. Ripping the winter before beats autumn working.
5. Ripping is no good on lupins.
6. A depth of 20 cm minimum seems the norm.
7. Agroplows, blade ploughs and home-made rippers are all used.
8. Extra fuel used is of little significance.
9. You need to re-do it every 3 years.

In the Quairading and Dowering shires approximately 500 ha has been ripped. The practise is still in the testing stage and has not reached the adopting stage.

NARROGIN REGION

Ted Rowley
Narrogin District Office
Department of Agriculture

Deep tillage for crop establishment in the Narrogin Region must be considered for cereal growing areas eastwards and more livestock orientated areas westwards.

East of Narrogin

Deep tillage is mostly confined to areas of deep yellow sandplain soil types which do have cereal crop growth responses to removal of traffic formed hard layers. Farmers who deep till this soil type are few and some have given it up, inspite of an apparent response, albeit inconsistent.

Some farmer experimenters continue to explore the possibilities of deep tillage on heavy (Salmon Gum) and medium (York and Jam) soil types.

West of Narrogin

The presence of widespread gravel soils has made assessment of likely deep tillage responses difficult and it is on these soils that some farmers are claiming positive responses to deep tillage. The preponderance of heavy and medium (Salmon Gum, Jam, York Gum, and Whitegum sands/gravels) soils with a poor response to deeper tillage has given farmers little incentive to continue deep tillage experimentation.

LAKE GRACE AREA

Bill Smart
Lake Grace District Office
Department of Agriculture

Very little deep ripping has been done in the district so far and some that has been done has been on heavy soils. Other farmers comment that they have new farms and either don't believe they have compaction problems, or have other financial priorities.

Where deep cultivation has been tried, reasons given for adoption were:

- To re-vegetate heavy land scalds
- To increase root depth on sand/clay soils by breaking the top of the clay layer
- To break heavy land pans and work through stubble.

Hyden

Heavy land ripped, claimed two pans at 10 cm and 25 cm, used Agroplow in moist soil but needed to re-work because of lumps. Observed better moisture infiltration and a large response to ripping.

Lake Grace

One farmer has ripped heavy land to break up bare patches that blow out - now using gypsum. Observed that lake bank country stayed greener 3 weeks longer in the first year after ripping.

Pingrup

1700 acres treated over 4 years using an Agroplow grasslands conversion - rip up, turn back, Agroplow, combine. Blackbutt soil - Pan formed after 60-70 years, ripping to 25 cm gave a big response in 1980, little in 1984. Mallee sand/clay - Ripped to 30 cm in two stages, thinks pan not so well developed. Hopes to deepen root zone by ripping into the clay.

JERRAMUNGUP

David Rees
Jerramungup District Office
Department of Agriculture

Interest in deep tillage in this area began around 1980. Larger capacity tractors had come into the district in previous years, and with the extra power, several farmers began to experiment with Agroplows and chisel ploughs.

Most of the initial interest was in cultivation equipment to penetrate the hard setting soils of the district.

Yield responses in commercial crops with this machinery have not been clear cut or convincing. However several trials by the Jerramungup Department of Agriculture have demonstrated significant responses on deeper sandy soils (30 cm of sand).

These soils are types which farmers would prefer to direct drill because of wind erosion problems.

Application of deep cultivation at this stage appears limited within the district although significant. Sandy soils as deep as 30 cm are the exception, and the district has been mostly cleared only in the last 10 years. However, because of wind erosion risks and yield penalties on sandy soil with direct drilling, a strategic deep cultivation could be the way to make "direct" drilling equally effective.

ESPERANCE

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Department of Agriculture

Over the last three seasons enthusiastic extension - salesmanship by the local Agroplow agent has seen the adoption of deep ripping over a wide area. This has extended from the sandplain soils (sand/gravel) to the mallee soils (sand/clay) and from 550 mm rainfall to 300 mm of rainfall.

Demonstration strips have been done over by the Agroplow agent and very good visual responses achieved, in most cases. Farmers talk about the responses to deep cultivation in very subjective terms but no yield responses are quoted to support these observed responses. Previous trials (1979-1980) on the sandplain soils had shown a 12-18% response under direct drilling and 8-10% response (but not significant) under conventional cultivation.

For each farmer who is enthusiastic about the deep ripping there must be five who have tried strips in their paddocks (both crop and pasture phase) and not been convinced of any benefit. We do have one claim of pasture response, but once again very subjective, or inconclusive because of different histories.

It is of concern that farmers are deep ripping mallee soils of shallow sand over clay at 10-15 cms. The clay horizon is saline and dispersive. With the mixing of this subsoil with the sand they will promote crusting and be faced with the need for gypsum at a later date.

It is of interest to note the response in the trials at EDRS this year, especially the effect on Rhizoctonia as this disease could be a serious problem in the near future.

In summary, it would be fair to say that a lot of the deep cultivation that is being carried out in our area would fall into the "recreational tractor driving" class.

NORTH MIDLANDS

Eddy Pol
Three Springs District Office
Department of Agriculture

The present situation with deep tillage in this area is that few farmers have considered it an integral part of their farming system.

The attitude of most sandplain farmers would be that they do not have a hardpan problem on their soils. This has been shown to be incorrect in the last few months by penetrometer readings carried out by this office. A graph of the results from one property is included. The results are from two paddocks which have been in a lupin/wheat rotation for 15 years, and a piece of virgin scrub nearby.

Another theory about hardpans maintained by farmers is that they will aid in reducing the rate of leaching of nutrients from the soil profile. This is also known to be incorrect.

The people who have experimented with deep tillage are very few. Two years ago the Carnamah Improvement Group set up a number of trials to look at deep tillage. Unfortunately the soil types chosen were mainly red loams. One trial on a sandy loam soil gave a response to deep tillage. The crop grown was Illyarrie Lupins. The results of these trials did not make farmers believe that deep tillage was important and therefore the idea was shelved.

The only other use of deep tillage in this area would be a few farmers who have borrowed or leased equipment from machinery dealers, and once again no-one has become enthusiastic about the operation. One or two farmers are again trying the system in 1985 and we hope to monitor these paddocks.

As you can see from this report, deep tillage is virtually non-existant in this region.

EFFECTS OF SPEED AND TILLAGE DEPTH ON FUEL USAGE

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Deep tillage of sandy loam soils has been shown to give dramatic yield responses under some circumstances. Since little was known about the machinery requirements of such operations, work was begun to investigate them. An Agrowplow was chosen as the deep tillage implement. Table 1 shows the speed/depth/draft relationships for this implement on two soil types.

Table 1

Speed km/hr	Depth cm	Average unit draft kN/m	Unit Power kW/m	Fuel Consumption L/ha	Fuel Cost $/ha	% Increase on 3 km/hr
SANDY LOAM						
3	30	11.7	13.2	16.4	5.90	0
5	30	13.0	24.4	18.2	6.55	11
7	30	14.3	37.6	20.0	7.21	22
9	30	15.6	52.7	21.8	7.86	33
11	30	16.9	69.8	23.7	8.52	44
CLAY LOAM						
3	30	17.3	19.5	24.2	8.72	0
5	30	19.2	36.0	26.9	9.68	11
7	30	21.2	55.7	29.7	10.68	22
9	30	23.2	78.4	32.5	11.69	34

(Note: Fuel consumption uses 2.419 kWh/L drawbar efficiency and 90% working width efficiency. Unit draft is force per metre width of implement in kilonewtons per metre and unit power is the tractor drawbar power (Nebraska test) required in kilowatts per metre width of implement).

Table 1 shows that on both soil types the fuel consumption per hectare increased with speed of operation.

The problem faced by most farmers when considering deep tillage is to know what size "ripper" to purchase to match their existing tractor. Information from Table 1 can be used to assist in this decision.

<u>Example:</u> A farmer has a STEIGER CM-325 tractor and wishes to deep rip a sandy loam. Nebraska test No. 1236 shows:

Two hour maximum drawbar power = 201 kW.

The farmer can now calculate the width of Agrowplow for each speed of travel.

At 5 km/hr

Unit power	=	24.4 kW/m
Therefore width	=	201/24.4
	=	8.24 m
Maximum work rate	=	$\frac{\text{width x speed}}{10}$
Maximum work rate	=	4.12 ha/hour
Fuel cost	=	$6.55/ha

Similarly at 9 km/hr

Width	=	3.81 m
Maximum work rate	=	3.43 ha/hour
Fuel cost	=	$7.86/ha

N.B. The practical work rate is usually about 80% of the maximum.

The slower working speed has a better fuel consumption and work rate but a higher implement capital purchase price. Given these figures farmers have objective information with which to make rational decisions about the trade off between capital and operating costs.

DEEP RIPPING: AN APPLICATION OF THE EASTERN WHEATBELT FARM MODEL

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1. Introduction

This paper examines deep ripping options in Eastern Wheatbelt areas through application of the Eastern Wheatbelt farm model (EWM). The detail of the model is not presented in this paper and the interested reader is referred to Kingwell, Pannell and Morrison (1985) for such detail. Rather this paper presents in the following order: an overview of the model; data and assumptions concerning deep ripping options; and results from various modelling exercises involving deep ripping.

2. The EWM: An Overview

The EWM is a mathematical programming model designed to describe an average farm in the Merredin area of the Eastern Wheatbelt. The model considers simultaneously available farm resources (e.g. land, credit); farm activities reliant on these resources; and interdependencies, both beneficial and adverse, between the activities. By considering simultaneously farm resources, activities and their interdependencies, the EWM can describe whole-farm effects of various changes (e.g. the introduction of deep ripping options).

The main features of the EWM are as follows:

Farm resources

- The EWM is based on an average Merredin farm of 2600 ha, of which 2300 ha are arable. the farm comprises four soil types classed as poor light (460 ha), good light (575 ha), medium (575 ha) and heavy (690 ha).

- Two labour units are available during the critical periods of seeding and harvesting, and additional labour can be hired.

- The farm business is structured as a partnership with access to overdraft credit of $55 000. Commercial bills are also available.

Farm activities

Farm activities can best be described as sub-groups, the first being:

A. Rotations

On each soil type, there are eight basic rotation options, ranging from permanent pasture through to continuous cereal cropping. Additionally, on all soil types except heavy soils, six lupin-cereal rotations are possible.

B. Crop options

On every soil type, wheat and barley are options. Lupins are an option on all soils except heavy soils. Oats and triticale are only options on poor light land. The yield response curves to nitrogen of each of these crops (except lupins) on each soil type are described. The grain produced from these crops can in general be sold or stored for later grain feeding of sheep. The amount and nutritional value of the stubbles of these crops is recorded and traced through the farm year.

C. Farm machinery

Though particular machinery configurations can be included in the model, usually machinery requirements are treated as variable. Machinery options at seeding are linked to labour options. There are options to maintain a tractor complement; options to use combine-seeders, or air-seeders with or without hiring additional labour; options to maintain other seeding gear; options to use PTO or SP headers, plus requirements to maintain an inventory of other general farm machinery and equipment. There are also options to seed over various lengths of time with consequential imposition of yield penalties.

D. Livestock options

Basically, the EWM considers a steady-state merino flock, whose size and composition are determined within the model's optimisation procedures. Mated and maiden ewes can be bought in, replacement rams are bought, wethers can be bought in and run over summer stubbles. Lambs and hoggets can be retained and/or sold off. Shipping wethers can be kept for various ages and sold off at four different selling periods within a year. Wethers can be retained for up to six years. Deaths, births and standard culling rates are recorded, as are wool cuts for each animal class.

E. Livestock feeding

The farm year is divided into four feeding periods: a period of feed scarcity (May to July); a period of green feed (August to November); a period of dry pasture and early stubbles (December to February) and a period of deteriorated late stubbles (March to April). The energy requirements of the various livestock classes are recorded for each of these periods and these requirements can be met from pasture, stubble and grain-feeding. Allowances are made for changes in the amount and energy concentration of feeds available to sheep and their voluntary feed intake capacities.

F. Farm finances

Financing farm activities is through dependence on funds generated internally (e.g. wool or grain sales) and on external funds such as overdraft and commercial bill facilities. The flow of farm funds is represented by a bi-monthly cash flow.

Farm household overheads are represented in the model, as are the taxation concessions and conditions associated with all farm activities.

Interdependencies

Indicative of the sorts of interdependencies represented in the model are:

- crop stubbles available as a sheep feed;
- nitrogen supply by leguminous crops and pastures being available to subsequent cereal crops;
- the negative effect on pasture production of increasing stocking rate;
- the depressing effect of cropping on subsequent pasture production;
- weed control problems in some crops, exacerbated by pasture phases of rotations;
- ability of livestock activities to ease cash-flow problems associated with cropping activities.

3. Data and Assumptions for Inclusion of Deep Ripping in the EWM

The inclusion of deep ripping in the EWM necessarily required changes to the EWM and the invoking of several assumptions - some easily defensible, others open to criticism. The main changes to the EWM were the inclusion of a set of rotation options that conveyed ripping opportunities; representing the yield increases associated with ripping; representing machinery requirements for ripping and including the option to hire a contractor to undertake the ripping. The assumptions invoked were:

(i) Ripping is likely to be considered initially only on good light land.

(ii) Ripping can be undertaken by a contractor either in winter or early spring, or after the break of season prior to seeding, at a cost of $40 per hectare. As opportunities to rip in summer are uncertain and often limited in time, summer ripping by a contractor is considered infeasible.

(iii) Opportunities to rip in summer are limited and are only available to the farmer who has the necessary gear. Opportunities eventuate every second year on average and are restricted to a five-day period. In four separate years over the period January to April in 1978 to 1985, there has been recorded in the Merredin area rainfall greater than 25 millimetres in a two-day period. Such rainfall is probably sufficient to allow deep ripping.

(iv) Ripping in winter after seeding, or in early spring, is restricted to pasture phases of rotations. Such ripping causes a ten per cent loss in usual pasture production in the spring period.

(v) Ripping after the break of season prior to seeding is undertaken by a contractor only. Such ripping, and the later ripping of a pasture subsequently cropped, constitute a working-up operation and save the farmer the need to work-up the ripped land.

(vi) If ripping is undertaken by the farmer, then his tractor complement needs to be at least 125 kW. Note that this does not mean a 125 kW tractor is required for ripping, but rather the farm's tractor complement (e.g. an 80 kW tractor plus a 45 kW tractor) needs to be at least 125 kW. Tractor and ripping operating costs are:

	$/ha
Tips, blades, adaptor replacement	2.15
Fuel (21.8 L/ha @ 41.01¢/L)	8.94
Tractor repairs & maintenance	1.24
	$12.33

Capital costs associated with ownership of ripping gear depend on the size of gear selected. If deep ripping is undertaken by the farmer, then capital costs are at least those associated with a 7=tyne Agrowplow and the necessary 125 kW tractor complement. Predictably as the size of Agrowplow increases, so do capital costs. The work rates are 9.338 ha per metre of ripping width per day in summer (working 15 hrs/day) and 6.225 ha/m/day in winter (working 10 hrs/day).

(vii) Frequency of ripping depends on the rotation and is given in Table 1

Rotation	Ripping frequency	Summer	Prior to seeding	After crop establishment
PPPC	1 in 4 years	x	x	x
PPC	1 in 3 years	x	x	x
PCPC	1 in 2 years	x	x	x
PPCC	1 in 4 years	x	x	x
PCC	1 in 3 years	x	x	x
PCCC	1 in 4 years	x	x	x
CLCL	1 in 2 years	x	x	
CCL	1 in 3 years	x	x	
PLCC	1 in 4 years	x	x	x

(viii) The yield increases due to ripping are restricted to cereal crops. Various ways of describing the yield increases were considered, yet given the variability of yield response and limited Merredin trial data, a reasonable yield assumption appeared to be simply that ripping raised cereal yields by 200 kg/ha in the first year and 100 kg/ha in the second year. In subsequent years, no yield increases were assumed.

4. Results

In the EWM, there are several basic ripping options which can be summarised as:

(i) no ripping;

(ii) contract ripping (this can be further divided into an option to rip after the break of season prior to seeding [option A] and an option to rip later in the pasture phases of rotations during winter [option B]);

(iii) ripping by the farmer (similarly, this can be divided into an option to opportunistically rip in summer [option C] and an option to rip in the pasture phases of rotations during winter [option D]);

(iv) ripping by contractor and/or the farmer.

The above options canvassed in this paper are (i), (ii), option B, (iii), option D and (iv)*. These options are compared in Table 2. Though a great deal more data could be presented to expand on the comparison of these options, the summary of Table 2 should give sufficient indication of the differences and similarities of the options.

Results in Table 2 indicate that deep ripping is marginally profitable whether undertaken by contractor or the farmer. Its profitability is almost entirely due to increased wheat production† and yet is dependent on maintenance of a wheat-wheat-lupin rotation on good light land, subject to ripping.

In many modelling exercises involving the EWM, often the wheat-wheat-lupin (WW:L) rotation on good light land is selected as part of the set of profit-maximising farm activities. In other words, there are few rotation options on good light land that appear as profitable as the WW:L, or W:L rotations. Hence if this rotation can be retained in conjunction with ripping, then ripping is profitable.

If the WW:L or W:L rotations are removed as rotation options, as in the case of constrained acceptance of pasture ripping by the farmer or contractor, then farm profits fall, in spite of whole-farm rotation reorganisation. For example, the imposition of contract ripping in pasture reduces profit from $45 158 to $39 722 and suggests rotations on poor light land should move to PPP:W and on heavy land to P:W:P:W.

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* As the results of (iv) are identical to those of (ii), only the results of (ii) are presented.

† Carrying capacity is only slightly higher on stubbles from crops with yield improvements attributable to ripping.

Table 2: A comparison of deep ripping options

	No ripping	Contract ripping	Farmer ripping	Contract pasture ripping	Farmer pasture ripping
After-tax profit ($)	45,158	46,319	45,648	39,722	41,013
Area annually ripped (ha)	-	192	92	144	287
Poor light land use	PPPP (233 ha)	PPPP (233 ha)	PPPP (233 ha)	PPP:W	PPPP (39 ha)
	PPP:W (227 ha)	PPP:W (227 ha)	PPP:W (227 ha)		PPP:W (421 ha)
Good light land use	WW:L	WW:L	WW:L	PP:WW	P:W:P:W
Medium land use	WW:L	WW:L	WW:L	WW:L	WW:L
Heavy land use	PP:W	PP:W	PP:W	P:W:P:W	P:W:P:W
Wheat production (t)	1,319	1,375	1,347	1,333	1,327
Agrowplow size	-	-	7 tyne	-	7 tyne
Sheep number (DSE's)	4,159	4,164	4,164	4,396	4,340

If a contractor can be employed after the break of season prior to seeding to rip land subsequently cropped to cereals, or when the farmer can opportunistically rip stubbles in summer in the WW:L rotation, then ripping is profitable. However, the profitability of summer ripping is limited by the expense of deep ripping gear. For example, in the farmer-ripping option, a small Agrowplow (7 tyne) is selected and worked for the maximum allowable five days. The limited ripping capacity of the gear results in only 92 our of a possible 192 ha being ripped. Larger ripping gear can be selected but the expense of the gear, which can include further investment in tractor power, restricts further ripping.

If the EWM is constrained to select a rotation that includes a ripped pasture phase, then profit falls, rotation choice across most soil types changes, and the preferred rotations on the good light land become PP:WW and P:W:P:W, depending on who does the ripping. If ripping is undertaken by a contractor, then PP:WW is selected. If ripping is by the farmer, then P:W:P:W is selected. The different selections are mainly due to the costliness of contract ripping (in the PP:WW rotation only 144 ha are ripped, versus 288 ha in the P:W:P:W rotation).

Conclusions

From modelling exercises involving the EWM and deep ripping options, several conclusions arise:

- Because of the particular profitability of lupin:cereal rotations on good light land, the desirability of ripping is restricted to its compatability with these rotations. If contract ripping before seeding is possible or opportunistic summer ripping by the farmer, then, in general, these activities are profitable in combination with the lupin:cereal rotations.

- The cost of deep ripping gear which may include increased tractor power, limits the extent to which opportunistic summer ripping is profitable.

- In general, a cereal:lupin rotation which includes no ripping, is more profitable than other rotations that include a ripped pasture phase.

- When the EWM is constrained to select a rotation that includes a ripped pasture phase, the more profitable rotations are PP:WW and P:W:P:W, and it is usually more profitable for the farmer to undertake the ripping than hiring a contractor. The selection of such rotations also requires major adjustments of rotation choice on other soil types - otherwise profit falls even further.

- Given the data and assumptions used to examine deep ripping options in the EWM, the main finding is that after-tax profit may increase by only around 2 per cent on average if the more profitable ripping options are adopted.

References

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AN ECONOMIC ANALYSIS OF DEEP TILLAGE

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In these days of low crop margins and difficult to balance budgets, a treatment which can offer quite spectacular wheat yield increases is certain to create a lot of farmer interest, and deep ripping has most definitely attracted much attention in the rural community, combining as it does the prospect of higher income and the chance to really dig up the soil, both of which have a certain special appeal to the man on the land.

Like most technical innovations there is a cost involved, and if the returns look spectacular then so too is the process itself, demanding as it does:

* specialist digging equipment
* high traction requirements which in tight but responsive country make 4WD mandatory
* high power requirements
* high wear rates on the digging tools and the power unit.

The objective of the process is obviously to shatter the traffic pan at 20-30 cm depth with non inversion and minimum soil surface disturbance. A range of machines is available but the following calculations have been based on the Agrowplow (R) range. These machines have a 33 cm tyne spacing and cost approx. $1,600 to $1,750 per tyne depending on equipment levels.

Power requirements

Agrowplow (R) state 7.5 draw bar KW per tyne - (approx. 10 PTO KW).

Traction

Traction as opposed to engine power is likely to be the major limiting factor hence on the most responsive tight loamy sands, 4WD becomes mandatory.

Operating costs

Ripping through tight soil brings massive forces into play with high power and traction and low speed causing high fuel consumption, heavy wear on digging tools, tyres and transmissions, and high labour input. Wearing points require routine hard-facing and regular inspections to check for wear, breakage or loss. The process is anything but cheap.

Ownership costs

In common with all high capital operations the most significant single cost is the fixed or ownership cost. Ownership costs remain similar whether a machine does 100 or 300 hours per year, so the penalty for under-utilisation can be very high indeed.

(1) Estimate of deep ripping costs in $/hour

	1 New 135 KW 4WD	2 2nd Hand 170 KW 4WD	3 2nd Hand 110 KW 2WD	4 Contract 300 KW
Tractor Ownership (600 hrs/yr)	* 42.00	* 30.5	* 9.0	
Operating	30.00	34.5	28.0	
	72.00	65.00	37.0	
Agrowplow (250 hrs/yr) Ownership	* 16.80	* 16.8	* 14.0	
Operating	16.50	18.2	6.0	
	33.30	35.0	20.0	
Total	105.30	100.0	57.0	125-150
	* = 56%	* = 47%	* = 47%	
Output Agrowplow tynes	13	13	11	23
Speed	6.4 Kph	7.2 Kph	3.5 Kph	5.4 Kph
Ha/Hr	2.7	3.1	1.27	4.8
Cost/ha	$39	$32	$45	$25-30
	Ave. $35			

N.B.: If hours worked/year are reduced by 25% for both tractor (to 450 hours pa) and Agrowplow (to 190 hours).

		1	2
Total Ownership costs	=	78.0 = 63%	63 = 54%
Total Operating costs		46.50	53
New Total		124.5	116
Cost/ha	=	$46	$37

(2) Estimated Returns from Deep Ripping

Assumptions:

25% initial yield response
Response decays @ approx. 50%/year over 4 years

	Control	Year 1	Year 2	Year 3	Year 4
Response -		25%	12.5	7	4
Yield	1.65 t/ha	2.05	1.85	1.76	1.71
Gross Inc. $/ha	206	256	231	220	214
Extra Income		50	25	14	8
Current Value if extra Income discounted @ 15%		50	21.74	10.58	5.26

= Total 87.58

Cost/ha	$35
Return/ha	87.58
Surplus	$52.58

= 150% return on outlay

(3) Effect on Gross Margin

	Control	Year 1	Year 2	Year 3	Year 4
Response %		25	12.5	7	4
Yield t/ha	1.65	2.05	1.85	1.76	1.71
Gross Inc $/ha	206	256	231	220	214
Variable costs $/ha	125	128	127	126	125
Ripping cost $/ha		35			
Gross Margin	$81/ha	93	104	94	89
Income in G.M.		+15%	+28%	16%	10%

Ave G.M. for 4 years after ripping $95 = 17% increase.

(4) Economic Effects of varying yields and yield responses to deep ripping

	(1) Ave Resp. Ave Yld	(2) Ave Resp. Lower Yld	(3) Ave Resp. Low Yld	(4) Lower Resp. Ave Yld	(5) Lower Resp. Lower Yld	(6) High Resp. Ave Yield
Initial Resp.	25%	25%	25%	15%	15%	40%
Yield t/ha	1.65	1.3	1.1	1.65	1.3	1.65
Cost of ripping/ha	35	35	35	35	35	35
Current value of extra Inc @ 15% discount	87.58	71	57	50	39	141
Surplus	52.58	36	22	15	4	106
% Return on outlay	150%	103%	63%	43%	11%	303%
Assume R/cost up by 25% to $44/ha						
Surplus then	44	27	13	6	-5	97
% Return on outlay	100%	61%	30%	14%	Tax Loss?	220%

Summary

* Initial deep ripping is an inherently high cost operation.

* Actual costs will vary substantially between individuals, and between different paddocks for the same operator.

* A range of $25 to $45/ha is likely to cover most situations, with $35 per hectare an average which assumes efficient utilization of both the power unit and digging equipment.

* Contract ripping is almost certain to be the cheapest option, but few contractors mean that availability is the limiting factor. In addition the need for moist soil at the time of ripping limits contract work to the late winter and spring period. The unpredictability of sufficient rain to facilitate Autumn ripping makes significant use of contractors impossible at this time.

* The economics of the exercise are determined by the following factors:

  - Cost of Ripping
  - Grain price
  - Base grain yield
  - Percentage response to deep ripping
  - Rate of decay of ripping response
  - Undesirable side effects of ripping such as:
    - ° loss of paddock feed after ripping
    - ° increased potential for bogging vehicles
    - ° possible soil erosion risk - wind and water - (stay on the contour)

* A more detailed examination of the relationship of these factors is obviously necessary, but the initial impression is that rate and duration of response are the most critical factors in the equation. Ripping low or unresponsive soils is simply burning up dollars.

* While there have been some very spectacular yield responses from trials on specific soil types (e.g. +62% on Wongan Hills in 1983) individual paddocks and farms inevitably present some areas which are:

  (a) impossible to rip e.g. stony areas, gravel ridges over shallow conglomerate rock, low lying wet areas, or

  (b) unresponsive or marginally responsive

  e.g. heavy clay soils
  low fertility deep sands
  highly acid wodjil sands

  Accordingly farmers contemplating a deep ripping programme must use a conservative estimate of average anticipated yield response, rather than base their calculations on the best local result in a particular season.

* While these comments have all related to costs and responses to initial ripping, both trial results and farmer experience indicate exciting potential for profitable responses to second rippings.

  e.g. Wongan Hills in 1984, where another deep working in that year following the initial 1983 ripping, produced a 24% yield increase (.5 t/ha).

  The exciting aspect of this result is that the cost of second workings is drastically reduced, and would on average be in the range of $18-$20 per hectare, indicating a possible net return of $42/ha or 212% on the second working.

Deep Tillage Research Workshop

Department of Agriculture

Perth, Western Australia

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Deep Tillage Research in Eastern Australia

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Interest in loosening dense subsoils to improve plant growth has received sporadic attention around the world over many years. Like many farm practices it is not new; a subsoil loosening plough to operate at 40-45 cm depth was described 150 years ago (Anon. 1835). Sixty years ago experiments were done at Rutherglen to investigate deep ripping to 55 cm depth for grapevines, and "trenching" as it was called became common practice. In the 1950's and 1960's a series of experiments on deep tillage for dryland crops were done in Victoria; tillage depth was about 20-25 cm depth. As little benefit was observed, and farmers did not have high-powered tractors available, the experiments had little influence on farmers' practices.

In irrigated areas of Eastern Australia, problems of penetration of water, air and roots into dense subsoils have been subjects of research for many years, and the problems now are well defined. Some of the recent research is listed later in this paper. On dryland farms, interest in subsoil density has been reawakened over the last 7 or 8 years, but there has not been detailed research done as for the irrigated soils. Some areas undoubtedly had naturally dense subsoils, but speculation arises as to whether farming methods have added to the problems. A further factor adding to the interest in subsoil loosening is that many farmers now have adequate tractor-power and machines suitable for tackling the job.

The research on subsoil density, or compaction and loss of subsoil structure in Eastern Australia appears to have been done mostly by agriculturalists. Management-induced subsoil compaction may be associated with grazing animals, but other aspects associated with tree-clearing and cultivation clearly have an engineering input. Yet, engineering research on agricultural soils seems to be more concerned with the efficiency with which steel tools can be pulled through soil, a process which has little intrinsic merit in itself. Higher-powered tractors are enabled to put more shearing forces into soil by the expedients of increasing vehicle mass and adding wider, ballasted wheels, which has the effect of transmitting forces deeper into subsoils. There would appear to be scope for agricultural engineers to do more research on destructive effects of tillage, traction and traffic, taking further the work of Arndt and Rose (1966). Conversely, agriculturalists may need to expand their reading into the engineering journals; a good starting point may be Chancellor (1977).

South Australia

From discussion with Departmental staff in S.E. South Australia it seemed that there were few problems of soil compaction resulting from farming activities. However some major soil types had naturally occurring hardpans. Podzols and soils with calcium carbonate horizons are examples. No research on subsoil tillage was in progress in 1982. Further north, much detailed research on problem subsoils (principally red-brown earths) has been done by staff of the University of Adelaide and by C.S.I.R.O. A brief but useful review of subsoil structure was given by Oades (1981). Graecen (1984) studied growth of bean roots in ballotini pressure cells, and confirmed that relatively low pressures restrict root growth, but suggested that conclusions drawn at Letcombe may be wrong and indicated the need for further research. Oades (1984) considered the use of calcium compounds to improve soil structural stability, and concluded that Ca compounds with or without organic matter are the only materials likely for economic improvement of soil structural stability. Muneer (1984) discussed other aspects of this work. Both coagulation and cementation of clay were shown to be important (Shanmuganathan and Oades 1983). The amount of dispersible clay in subsoil was suggested as a useful characteristic of soils, as it appeared to govern swelling, porosity, water retention capacity, hydraulic conductivity, friability and modulus of rupture(Shanmuganathan and Oades 1982). This work has important implications for deep tillage research. Other detailed information was given in Oades, Lewis and Norrish (1981).

Queensland

Rose (1984) in discussing recent advances in research on soil erosion processes did not mention any possibility that subsoil density and hydraulic conductivity could be involved. While acknowledging the importance of surface conditions, as there does not seem to have been a dramatic reduction in soil erosion as a result of these advances, one is driven to think about the relative merits of studying symptoms instead of all the causes. Sallaway et al. (1984) indicated that depth of wetting is important, for example.

Deep tillage research would appear necessary in Queensland. Wood (1984) reported that one aspect of crop loss due to soil degradation under sugar cane is loss of organic matter and vehicular compaction, but did not mention subsoil loosening as part of the treatment. Bridge and Ross (1984) showed that water infiltration into subsoil of a black earth was very slow, and that cracks were important in this regard. The implications of this in irrigated agriculture where cracks may not be allowed to develop are important. These soils can be extremely hard, however, and a contractor ripping such soils in Northern Queensland reported constant machine breakages (G. Ferguson, pers. comm. 1984).

Physical and chemical aspects of soil suitability for irrigated cropping in the lower Burdekin Valley were reported in detail by Smith and McShane (1981). Soils are grey clays, solodics and solodized solonetz, with problems associated with high levels of exchangeable sodium and magnesium leading to low plant available water capacity. They concluded that many of the soils could be modified by deep ripping and subsoil mixing, with gypsum to prolong the beneficial effects. Soils likely to respond are those with slow water recharge of subsoil and those with restricted root ramification, indicated by slow water extraction below 40 cm depth. They stated that deep ripping is difficult to quantify, and suggested that best results would be obtained on duplex soils with impermeable subsoils. Other information for the

Burdekin-Elliot River area was given by Gardner and Coughlan (1982) with measurements of water, salts, roots, and penetrometer resistances.

Among their conclusions was one that massive profile disruption of duplex soils would double the available soil water store to the depth of ripping.

New South Wales

In a review of tillage practices, Osborne (1984) concluded that results of tillage experiments are site specific. The implication is that extrapolation of results to other sites may be misleading, at least as far as productivity is concerned; an example of such site specificity for surface tillage was given by Burch, Ellington and Fischer (1984). Osborne suggested a modelling approach to tillage may be appropriate. He also mentioned the concern shown by Loveday (1980) that deep tillage of sodic subsoils may speed up the effect of clay dispersion.

Yield increase from sunflowers grown on unstable grey clay occurred both with gypsum and deep tillage, because of reduced crust strength and increased water in the profile (Mazloumi, McGarity and Hoult 1984), and residual effects were still seen after 4 years.

Extensive research on a brown clay used for cotton-growing was reported by Loveday et al. (1970) and Muirhead et al. (1970). Treatments included deep ploughing and deep ripping, gypsum and organic matter. Deep ripping improved porosity of subsoil but the effects were lost by the end of the second season. Significant interactions of tillage x depth occurred on soil water and water entry. Cotton yields were increased about 15% in year 1, but in year 2 only a combination of deep ploughing and deep ripping increased yield. Gypsum increased yield in both years, despite an increase in terminal damage of plants in year 1, but did not ameliorate the rate of structure decline with deep tillage.

Loveday (1984) discussed management of vertisols in irrigated agriculture, noting the consequences of tillage at inappropriate moisture contents. Deleterious effects on soil and plants occurred after just one season of cultivating soil when wet (McGarry 1984). Compaction effects on these soils may be deeper (20-40 cm) than on lighter textured soils). Persistence of deep tillage effects was likely to be greater, the greater the degree of soil disturbance, and when the layer disrupted was genetic rather than induced by management. Loosening of subsoil should be only deep enough to fracture the problem layer, as deeper loosening may lead to deeper compaction later. Traffice compaction (Pidgeon and Soane 1978) can be reduced by "tram-lining" where traffic is restricted to lanes. The use of floatation tyres and dual wheels seems to have little to offer in reducing compaction.

Other work on structurally degraded verstisols was reported by McKenzie et al. (1984). Again, cotton yields were increased by deep ripping or gypsum, and subsequent wheat yields were also increased, with benefit/cost ratios of 3:1 (ripping) and 1.1:1 (gypsum). Enhanced water intake was thought to be the most important mechanism, but again the effect was shortlived. Effects on bulk density lasted longer. McKenzie et al. (1984b) concluded that chisel ploughing to 25 cm may be the most economical treatment for these soils, together with crop rotation (drying the subsoil) instead of continuous cotton, and minimum traffic and tillage.

On lighter-textured soils (red-brown earths) surface structure problems under irrigation were partly overcome by deep mouldboard ploughing (45 cm) to increase clay in the topsoil, and applying gypsum (McKenzie et al. 1984b). Cotton yields increased from 39 to 220 bolls m^{-2}. Repeated gypsum applications are necessary as part of the improvement is associated with the electroylte effect. Again, treatment should be followed by changed management practices as above.

In the dryland wheat situation on red-brown earths, Harte and Armstrong (1983, 1984) stated that farming has led to reductions in soil organic matter and aggregate stability, with increased subsoil density. Deep ripping with a Paraplow (35 cm depth) reduced subsoil bulk density, doubled infiltration for more than one year, but had little effect on wheat yield in the very wet 1983 season. Gypsum (2.5 t ha^{-1}) only improved water stable aggregation, and reduced wheat yields. (It appeared that water-logging may have occurred, and nitrogen fertility was probably low due to 15 years of cropping). Rainfall runoff and soil loss were halved by deep ripping. Calcareous red earths also deteriorated in subsoil structure under cultivation and deep ripping was considered necessary, followed by minimum traffice and tillage. Further work was reported by Harte (1984), and a euchrozem was found less susceptible to plough-pan formation than a red-brown earth or a red earth.

Deep tillage experiments on a range of soils of the Southern Tablelands have been conducted by Dann (1985). Over 5 years, deep tillage gave no response from pasture or crop on 20 occasions, yield increases on 13 occasions, and there were 6 yield decreases. Deep tillage generally increased soil moisture, reduced soil compaction, and had little effect on pH. Criteria for site selection were not given; seasonal conditions and the timing of deep tillage were said to be important, and soils with a hard layer were likely to be more responsive than friable soil. Soil fertility was also important in governing a response to tillage.

In general, much more is known about subsoil compaction on irrigated land than on dryland in New South Wales. To overcome this deficiency a Departmental Working Group was set up in 1982 to institute guidelines on requirements for experimentation. It was stressed that soil compaction can occur not only with cropping but also with intensive grazing.

Victoria

The 3rd Australian Agronomy Conference at Hobart (1985) devoted a section to deep ripping, with papers from New South Wales and Victoria.

Deep ripping research in Victoria is done almost exclusively by the Department of Agriculture, although Soil Conservation officers are now taking an interest. The most detailed work has been done on irrigated land, with dryland work centring on Rutherglen and to a lesser extent Horsham and Hamilton.

In the dry calcareous brown soils and sandy earths of the Victorian Mallee there is no research interest in deep ripping, although calcareous hardpans do occur. In the higher rainfall areas where waterlogging is a problem, some research on duplex soils has been initiated by Gardener at Horsham and Hamilton. Few results are available as yet, but it seems that other problems occur as well as dense subsoils. Other work by Bakker and R. Van der Graaff (pers. comm. 1985) aims at alleviating the waterlogging; for lucerne, there was good evidence that deep ripping made more water available.

Also in the Western District, Conley (1984) reported that deep ripping in a pasture resulted in poor growth of clover in rip lines, but excellent growth between them where the organic mat remained undisturbed but the subsoil had been loosened. In the Ballarat area a survey by R. Smith (pers. comm. 1984) suggested that two of the four main soil types (derived from granitic or ordovician parent material) had dense layers which may be barriers to root growth. However, an experiment in the area (A. Flynn pers. comm. 1984) produced no positive result; again there may have been other factors involved, but there were few soil measurements.

In the dryland cropping area of Central Victoria, there has been little interest in deep ripping, perhaps because it is known that subsoils are dispersive. Ford has shown large increases in wheat yield following the use of gypsum on the surface. The increases followed improved water penetration into soil. The effects of gypsum on soil cation exchange capacity were reported by Greene and Ford (1985); exchangeable Ca was increased to 25 cm depth, and exchangeable Mg and Na were reduced to 15 cm depth 5 years after 15 t ha^{-1} gypsum was applied. However, it was assumed that half of the gypsum may have been leached below 25 cm, or even 1 m depth. Current methods of calculating gypsum requirements were shown to produce underestimates of the amount actually required to lower E.S.P. to <6 and exch. Mg to <25.

Much work has been done on irrigated red-brown earths in Central Victoria by staff at Tatura and more recently at Kyabram. Early studies by Cockroft (1964) have led to much more detailed studies in these soils. Bakker (1977) reported that deep ripping and gypsum for peach trees increased butt area from 4.9 cm^2 to 8.3 cm^2, while mixing A and B horizons and adding organic matter gave a further increase to 11.1 cm^2. He concluded the improvement was due to improved drainage. Mehani (1974) suggested the effects of deep ripping and chemical methods on soils and plants were independent, with the greatest effect from gypsum.

Cockroft and Tisdall (1978) summarised much of the earlier work. For peach trees they showed that shattering the subsoils by ripping, stabilising it with gypsum, and stabilising the surface using organic matter mulches, and slow wetting, while eliminating traffice in the tree-line resulted in quadrupled yields to 75 t ha^{-1} and reduced tree mortality. Cockroft (1984) showed the problems have been clearly defined, and this is essential for the progress of future research and development. He suggested that the best approach for improved yields is to consider the soil as an environment for roots, which can be considered in theory, in practice and in experiment. He indicated that the ideal subsoil is soft, porous and permeable, well aerated, non-dispersive and well drained, but topsoil and chemical properties must also be ideal. The key to improving our soils lay in increased biological activity, but he knew of only one research worker in this field (Judy Tisdall).

The Tatura system of soil management includes soil modification to 60 cm (ripping), hilling the surface soil, zero cultivation, straw mulch and frequent watering. This trebled yields of peaches (Tisdall, Olson and Willoughby 1984). The soils remained well drained and aerated, and penetration resistance remained below 1 MPa at -10 kPa matric potential.

Lucerne also responded to subsoil modification on these difficult soils, with yield increases up to 57%, as a result of improved water penetration and subsequent use by the crop (Taylor and Olsson 1984). Untreated soil had a low saturated hydraulic conductivity (25 mm d^{-1}) and high penetrometer resistance (>1.4 MPa at -10 kPa matric suction). Treatment reduced penetration resistance to 0.4-0.8 MPa and markedly increased root quantity in the modified zone, but did not improve roots to the quantity or depth found in well-drained light-textured soils. Much of the benefit seemed to come from the use of gypsum, while deep ripping gave a further yield increase only with spray and not with flood irrigation (Taylor and Olsson 1985).

Further knowledge of physico-chemical properties and management of red-brown earths was given by Green and Wilson (1984), Rengasamy et al. (1984a) and Rengasamy et al. (1984b). Leaching to 80 cm depth was shown to occur, gypsum lowered soluble salts in the profile, but Ca-Na exchange was mostly limited to the 0-10 cm horizon.

A scheme was proposed for predicting dispersive behaviour of the surface of these soils, based on 6 soil classes. The scheme did not fit red clay and black earth profiles, nor those containing free lime. A further problem group is soils containing much exch. Al (R. Greene, pers. comm.). The scheme was discussed with regard to gypsum requirements of low-sodic soils and seems to hold considerable promise.

Other work on irrigated red-brown earths (Lemnos Loam) in Northern Victoria was reported by Mason, Small and Pritchard (1984). The aim was to determine whether management systems for continuous double-cropping or crop/lucerne rotations could be developed. A range of tillage levels including deep ripping, organic matter additions, and irrigation treatments were examined. Soil strength was reduced by ripping, but it was concluded that further improvements in oxygen supply and drainage, and reductions in soil strength will be required before these subsoils become suitable for active root development. A later report suggested that soil conditions and crop yields continued to improve as time progressed (Mason 1984). On pasture, however, total profile modification had no effect on production, and subsequent treading by cattle reduced pasture production by 12% in the third year. The effect of treading was confined to the top 15 cm of soil, but grazing was only allowed when the soil was dry (Kelly 1984), unlike the situation in farm practice.

Deep Ripping in North-East Victoria

For dryland cropping intensive research on liming and deep ripping in North East Victoria began in 1980 at Rutherglen.

Soils in North-East Victoria vary from the alkaline red-brown earths in the drier West, through a range of transitional soils to the acid podzolic soils in the higher rainfall areas to the East and South. Most of the soils are described as duplex, that is, they have subsoil layers of heavier texture than the surface, and this influences soil development and plant growth. The higher rainfall also favours development of greater soil acidity. Many of the soil types in the Southern Riverina also are duplex, which means that both areas have some characteristics in common. The major common factor is that many of the soils suffer from periodic sub-surface waterlogging (Map of Australia Soil Resources, 1976-77, K.H. Northcote, NATMAP), with all the problems of soil, plants and animals that go with waterlogging.

The red duplex soils (red-brown earths) of Northern and North-East Victoria are generally not acid, although strongly acid soils do occur within the group (1971 results). More research on these soils is needed, but it appears that their treatment will require deep ripping and additions of gypsum or gypsum-lime mixtures. The area covered by this group in Victoria is about 1.2 million ha, and about half seems to need treatment now.

The transitional soils in cropping and mixed farming areas of Victoria, generally receiving 500-650 mm rainfall annually, constitute a wide range cf soil types. As a generalisation, 66% need deep ripping, and 40% are strongly acid and need lime if profitable cropping is to continue. The area involved is about 2 million ha, of which half is in need of treatment now. Deep ripping will help to alleviate the subsurface waterlogging problems, but drainage will also be needed in some areas.

In the higher-rainfall areas of Victoria, for many years crops have shown patches of stunted, yellow growth. Research in the North-East showed that this could not be alleviated by nitrogen fertiliser, but observations suggested that it was alleviated for one or sometimes two years after a period of pasture. Further observations in 1978 and 1979 indicated that the problem was associated with stunted root growth and shallow hardpans or layers of compacted soil. In 1979, 70% of crops in North-East Victoria were affected, and 70-90% of crops in the area between Horsham, Stawell and Ballarat. In 1980 a crop survey was done in North and North-East Victoria to determine the extent, severity and possible causes of the stunted growth, and the estimates are shown in Table 1.

Table 1 Extent and severity of stunted and yellow growth of crops in North and North-East Victoria, 1980

	%
Crops affected (% of total no. of crops)	80
Mean area affected in each crop	48
Mean dry matter yield reduction in affected area (% of growth in green area)	69
Mean grain yield reduction in affected area (% of yield in green area)	64

In a set of test strips, mean yields of grain in green areas was 1.9 t ha^{-1}, and in yellow areas it was 0.6 t ha^{-1}; adding nitrate fertilisers raised yield of the latter only to 0.9 t ha^{-1}.

The lost yield potential amounted to 25% of the total for the area, with a value of $9.5 million, and it occurs to a greater or lesser extent every year.

Factors associated with the stunted growth are shown in Table 2. Rotations were described as ineffective unless they contained a legume (pasture or crop) every third year. The hardpans were detected only to spade depth, and nearly all of the soils with bad drainage had hardpans. The occurrence of root defects were closely related with hardpans and bad drainage. Weeds, herbicides and nematodes were not related with the stunted growth.

Table 2 Factors associated with stunted and yellow growth of crops in North and North-East Victoria, 1980

	% of crops
Inadequate pasture/crop rotation	55
Hardpan in yellow patches	64
Inadequate drainage	26
Acid soil	41
Defects in root systems	78

Chemical analyses showed that soils in affected areas tended to be acid in higher-rainfall areas, and were low in nitrogen, calcium, magnesium, and were high in aluminium and manganese. Plant analysis reflected these findings, and plants were very low in magnesium, molybdenum, and boron.

A survey of pastures also was done in 1980 by Tim Reeves and Jeff Hirth. About 40% of the pastures were unsatisfactory with regard to clover establishment and growth. In many cases, this could be attributed to poor sowing techniques, but particularly on the lighter-textured soils there were also other problems. Many of the paddocks were found to have acid soil, and it appeared that soil compaction was also implicated. In non-cropping areas, Jim Shovelton also concluded that soil compaction associated with grazing animals is of major concern.

These surveys have led to increased extension campaigns on direct drilling and minimum tillage, crop rotation, and sowing techniques for pastures, and to a range of experiments on soil compaction, acidity, plant nutrition and diseases. Significant results have been obtained on both crops and pastures, both from correction of acidity and from loosening dense subsoil. It is important to note that responses to deep ripping can be greatly reduced by other soil problems such as acidity, waterlogging, and dispersive subsoils, and corrective measures must be taken where they occur.

Where deep ripping is now recommended, the adoption of minimum traffic systems is regarded as an integral part of the soil management, to prevent or delay reoccurrence of soil compaction.

Results

Crop Experiments on Rutherglen Research Institute

The first experiment in the crop yellowing research programme at Rutherglen was started in 1980 to examine effects of deep ripping on wheat. The soil, a soloth, was not acid, and was thought to be uncompacted, having been under pasture for many years. The field layout permitted normal patterns for cultivation, sowing and harvesting with farm equipment, not experimental equipment. Deep ripping was followed by either conventional cultivation or direct drilling for several years.

First-year results showed that a naturally compacted layer of soil occurred at 40 to 60 cm depth, and this markedly reduced root penetration. Ripping above this layer had little effect on yields, while ripping through it increased root growth in the deep subsoil and increased crop yields (Table 3). Cultivation began to form a hardpan even in the first year, while direct drilling maintained the porous nature of the subsoil and has given higher yields, particularly in 1983.

Table 3 Yields of wheat and lupin grain (t ha^{-1}) after deep ripping followed by conventional cultivation (C.C.) or direct drilling (D.D.)

Treatment in 1980	Wheat 1980 CC	Wheat 1980 DD	Lupins 1981 CC	Lupins 1981 DD	Wheat 1982 CC	Wheat 1982 DD	Wheat 1983 CC	Wheat 1983 DD
Not ripped	5.1	6.0	1.3	1.5	0.5	0.5	0.8	0.9
Rip 20 cm	5.1	5.8	1.2	1.7	0.5	0.6	0.8	1.5
Rip 40 cm	5.3	6.0	1.2	1.6	0.6	0.6	1.0	1.6
Rip 70 cm	6.1	6.3	1.8	2.0	0.9	1.0	1.9	2.6
Differences:								
CC vs DD	*		**		n.s.		**	
Rip	**		**		**		**	
C x R	n.s.		n.s.		n.s.		n.s.	

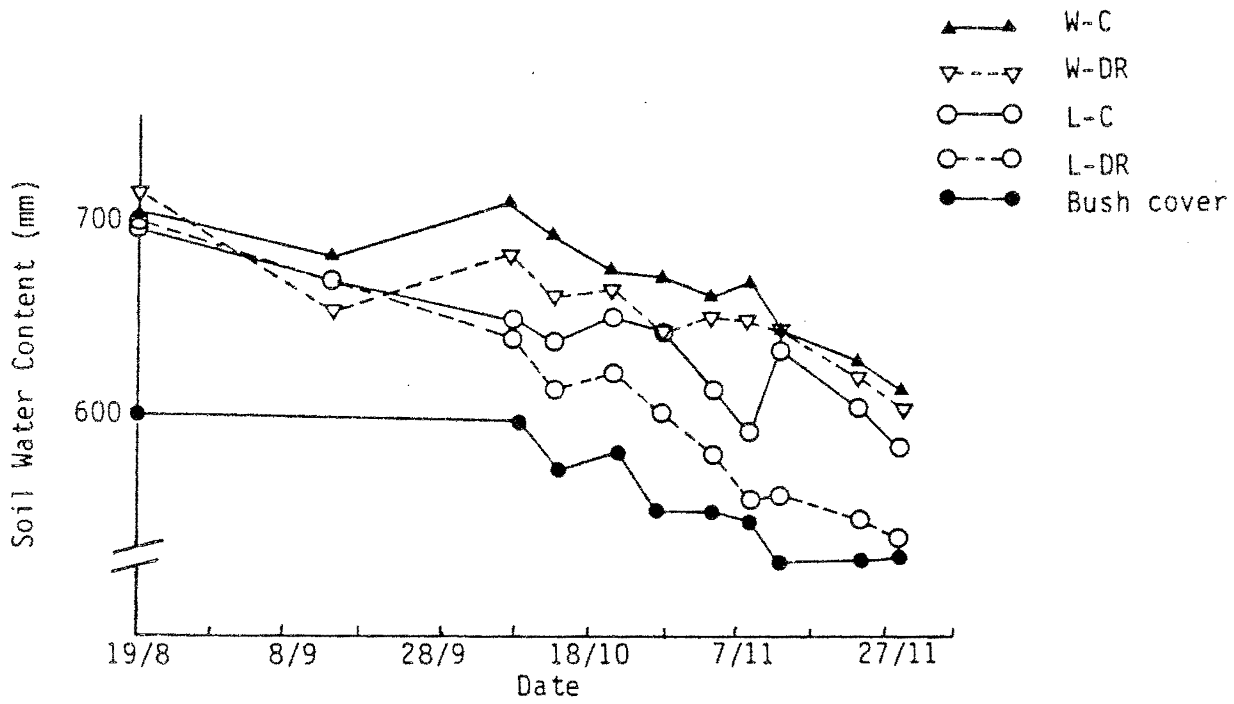
† One cultivation to level the soil after ripping in 1980 only.
†† Drought in 1982 affected all experiments.

Some measurements of saturated hydraulic conductivity of the soil were done in 1983. With direct drilling, values of 1.9, 0.8 and 1.4 m day^{-1} were obtained with soil not ripped, or ripped at 40 and 70 cm in 1980 respectively. For cultivated soil either unripped or ripped, the values could not be calculated; it appeared that there was very little flow of water in the subsoil, and all of the water flow came from the cultivated layer (0-10 cm), which was saturated.

The rip 70 cm treatment followed by direct drilling on this site would have been highly economic. Over four years it produced 1.2 t ha^{-1} more grain than rip 70 cm cultivated, and 4.2 t ha^{-1} more grain than the conventional cultivation treatment.

In 1981 and 1982 two more 3-year experiments were started on the same soil type. These experiments had the same treatments as the first one, but were split for gypsum applications. The Howard Paraplow was included in the 1982 experiment. On both sites it was necessary to use a spike roller and to cultivate to reduce surface clods after deep ripping. Neither site had a ploughpan to start with, and the soils were not acid (pH 6.0).

Figure 1 Changes in soil water content (0-1.8 m) under wheat (W) or lupins (L) grown after conventional cultivation (C) or deep ripping (DR), compared with those under native timber



(Ellington, Angus, Carlsson and Henriksson, to be published)

In the experiment commenced in 1981, wheat yields were increased significantly by deep ripping by about 0.5 t ha^{-1}. Soil water use was increased by deep ripping, and lupins on ripped soil used almost as much water as did the cover of grey box trees (Fig. 1). Lupin yields in the drought of 1982 were increased by 0.2 t ha^{-1} but the effect was not significant, probably because lupins were infected with root-rotting organisms. Wheat yields in 1983 again were increased by ripping, from 4.4 to 4.9 t ha^{-1}. There were no significant effects of direct drilling or gypsum. The site was variably affected by waterlogging which increased variability.

In the experiment commenced in 1982 (on a site ripped in 1925), the ripping treatments were done at different times between March and April, and the soil dried out to different amounts prior to sowing. Normally this would have mattered little, but it became significant as the drought progressed. The only significant effect was that the rip 20 cm treatment and gypsum both depressed yields by 0.1 t ha^{-1}; the other rip treatment yields were all higher than control but not significantly, with the Paraplow giving highest yields. The site was in lupins in 1983, and was variably affected by waterlogging. The only significant effect was that gypsum depressed yields by 0.5 t ha^{-1} (P0.01). In 1984 wheat was sown after the lupins; yields ranged from 5 to 6 t ha^{-1}, and there was little effect of ripping.

An adjacent site had been deep ripped with a Paraplow and sown with lupins and rape in 1982, and both crops failed to grow. The site was direct drilled to wheat in 1983, and waterlogging damage commenced within a few days of sowing and continued through the winter. The deep ripping alleviated the initial damage and increased yields by 1.0 t ha^{-1}, from 2.9 to 3.9 t ha^{-1} (P0.01). There was no effect of the previous (failed) crop, nor of gypsum.

A fourth site was used in 1983 for two experiments and for a demonstration. The soil was strongly acid (pH about 5.0, 0-10 cm), it had a severe but variable hardpan at 10 cm depth, and is often waterlogged. At the end of winter lime had raised pH of the 0-10 cm soil to 6.1 without ripping and to 6.3 with deep ripping (Paraplow).

Wheat yields (t ha^{-1}) in the main experiment were:

	Not ripped	Ripped
No lime	2.77	2.94
Lime 2.5 t ha^{-1}	3.17	3.45

Waterlogging had reduced the effects both of lime and of ripping. In the second experiment, plant populations were reduced by deep sowing on ripped areas, which yielded only 0.25 t ha^{-1} more than direct drilling (n.s.), and waterlogging reduced yields also.

The adjacent demonstration was intended to illustrate the effects of drainage, liming and ripping acid and compacted soil where waterlogging was a problem, on a range of crops and pasture species.

This paddock gives consistent crop failures in wet years. Yields of wheat, barley, Hamburg lupins, and oilseed rape were all increased by drainage, and ripping with a Paraplow (Table 4), while lime increased yields of all species except lupins.

Table 4 Grain yields t ha^{-1} of wheat and barley, oilseed rape and Hamburg lupins after subsurface drainage, liming and ripping

	Wheat	Barley	Rape†	Hamburg Lupin
No drain No Rip No Lime	1.8	0.8	0.18	0.13
Lime 3 t ha^{-1}	2.6	0.8	0.21	0.14
Drained No Rip No Lime	2.3	1.0	0.35	0.59
Lime 3 t ha^{-1}	3.5	1.7	0.55	0.33
Drained Rip 35 cm No Lime	3.9	2.1	0.50	2.38
Lime 3 t ha^{-1}	4.2	2.5	0.98	1.07

† Hail caused 50% loss of rapeseed

Hydraulic conductivity increased from 0.1 m day^{-1} (unripped) to between 0.6 and 1.5 m day^{-1} (Paraplowed). The watertable was lowered from 2-10 cm depth (unripped) to 35-40 cm depth (ripped) over a period of nearly two months (Fig. 2). Commensurate increases in growth of crops occurred.

Wheat Experiments in Farmers' Paddocks in North-East Victoria

In 1981, three sites off-station were selected as being representative of farmers' paddocks which produced stunted growth of wheat. Two sites were strongly acid (pH about 5.0), while the third, near Dookie, had very weak structure but a pH about 5.6. All sites had severe hardpans at 10 cm depth, and wheat plants appeared to have nutritional problems.

On the Lilliput site (near Rutherglen), lime was applied at several rates as main treatments, ripping to 40 cm depth as a sub-treatment, and combinations of fertilisers and trace elements as sub-sub-treatments. Some effects on yields are shown in Table 5.

Figure 2 Rainfall, depth to water-table and drain flow (1983)

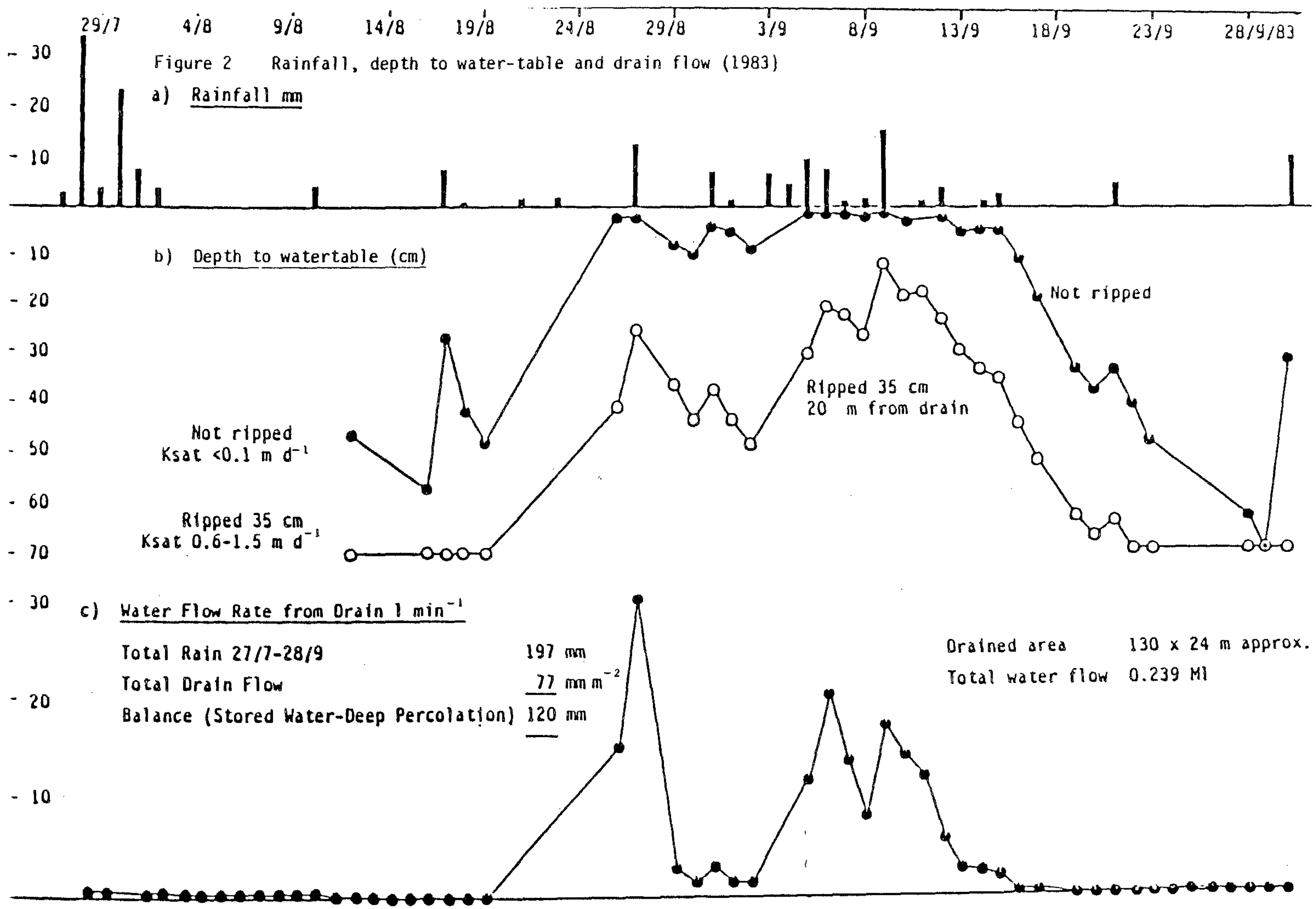


Table 5 Effects of lime and deep ripping on wheat yields (t ha^{-1}) at Lilliput

	1981		1982		1983	
	No Rip	Rip 40 cm	No Rip	Rip 40 cm	No Rip	Rip 40 cm
No Lime	1.3	1.3	0.3	0.5	1.6	1.8
Lime 0.5 t ha^{-1}	1.2	1.6	0.4	0.6	1.8	2.3
1.0 t ha^{-1}	1.8	2.5	0.6	0.9	2.1	2.4
2.5 t ha^{-1}	2.2	2.7	0.6	0.8	2.1	2.4
5.0 t ha^{-1}	2.2	2.4	0.7	0.9	2.1	2.1

Differences (P0.05)

	1981	1982	1983
Lime	*	*	*
Rip	*	*	*
L x R	n.s.	n.s.	n.s.

(Coventry, Brooke, Burnett and Reeves 1985)

Because some plots were waterlogged in 1981, a Paraplow was used on the rip treatments in autumn 1982 prior to sowing. Soil resistance to loosening was not great however, and plots ripped in 1981 and not re-ripped still yielded over 0.7 t ha^{-1}.

Wheat growth in 1983 was increased over 50% by the combined treatments, but yields were subsequently reduced by lodging caused by Pseudocercosporella. Generally, the effect on yields of subsoil loosening was not great unless soil acidity was corrected, in which case soil loosening had a considerable effect.

The other two sites at Rutherglen and Boxwood, (near Dookie) each had two experiments commenced in 1981. The following results were reported by Ellington and Fung (1984).

Treatments were aimed at alleviating the soil physical and chemical problems. Treatments in 1981 involved gypsum applications (0 and 5 t ha^{-1}) then deep ripping (0, 20 cm and 40 cm depths), to be followed by either cultivation or direct drilling of wheat for 3 years. The experiments were split in 1982 and lime (0 and 2.5 t ha^{-1}) was applied as a main treatment.

Annual rainfall varied markedly between seasons, with 838 mm, 295 mm, and 694 mm falling in 1981, 1982 and 1983 at Rutherglen. Rainfall was not measured at Boxwood but average rainfall is about 60 mm less than the Rutherglen average of 589 mm. Rain, or lack of it, had a major effect on yields.

1981 Results

At Rutherglen, wheat growth was normal until July. Deep ripping increased wheat top growth to that stage. As wet soil conditions developed, gypsum-treated wheat became chlorotic, with necrotic spots appearing on the leaves. Waterlogging which was severe from June to September prevented adequate sampling, and prevented herbicide spraying. Limited sampling for dry matter and root growth showed that deep ripping eliminated thickening of roots in the region of the hardpan and permitted roots to penetrate deep into the profile. Plant yields and soil pH showed no conclusive treatment effects (Table 6), but the trends were the same as at Boxwood. Ripping raised wheat

Mo content (P0.05), while wheat contents of Ca, S, Cl, Mn, and Al were raised, and contents of Mg were lowered by gypsum.

Table 6 Wheat dry matter (kg ha^{-1}) and soil pH (0-20 cm) at Rutherglen as influenced by deep ripping and gypsum (11/9/81)

	DM kg ha^{-1} Gypsum t ha^{-1}		pH Gypsum t ha^{-1}	
	0	5	0	5
Cult. Not ripped	420	389	6.36	6.02
Rip 40 cm	501	453	6.05	5.95
	n.s.		n.s.	

In 1981 at Boxwood, the soil was dry and deep ripping left the soil in a cloddy condition; this reduced wheat emergence and establishment. Waterlogging later was of minor and sporadic occurrence. Treatment effects showed the same trends as at Rutherglen, but the effect of gypsum on plants was not so severe. Effects on top and root dry matter yields and soil pH are shown in Table 7. There were no significant effects on primary roots, and ripping eliminated root thickening at the depth of the hardpan (P0.01).

Table 7 Wheat tops and secondary roots (DM kg ha^{-1}) and soil pH (0-20 cm) at Boxwood, as influenced by deep ripping and gypsum (10/9/81)

		Tops	Secondary roots	pH (1:5 water)
Cult.	Not ripped, Gyp 0	1020	106	5.97
Direct Drill,	Not ripped	1485	258	5.90
Cult.	Rip 40 cm	2305	592	5.91
Cult.	Not ripped, Gyp 5 t ha^{-1}	687	85	5.35
Direct Drill,	Not ripped	881	170	5.32
Cult.	Rip 40 cm	1252	191	5.26
Differences:				
Rip		*	*	n.s.
Gypsum		**	*	**
R x G		n.s.	n.s.	n.s.

* $P<0.05$ ** $P<0.01$

Wheat contents of Ca, S and Mn were raised by gypsum (P0.01). Ripping and gypsum interacted (P0.05) on wheat Al content; ripping and direct drilling lowered wheat Al in the absence of gypsum, ripping lowered it where gypsum had been applied, and gypsum raised wheat Al with cultivation and direct drilling.

At Rutherglen, wheat growth differences disappeared because of prolonged waterlogging and severe competition from Juncus bufonius (toadrush). The few plots which were harvested for grain yield averaged about 0.2 t ha^{-1}. At Boxwood waterlogging was less severe, weeds were controlled, and grain was harvested; yield results are in Table 8.

Table 8 Wheat grain yields (t ha^{-1}) at Boxwood as influenced by direct drilling, deep ripping and gypsum (1981)

	Cultivated Gypsum t ha^{-1} 0	Cultivated Gypsum t ha^{-1} 5	Direct Drilled Gypsum t ha^{-1} 0	Direct Drilled Gypsum t ha^{-1} 5
Not ripped	0.9	0.7	1.1	0.6
Rip 20 cm	1.3	0.9	1.0	0.9
Rip 40 cm	1.4	0.9	1.2	1.0

Differences:

Direct drill	n.s.
Rip	*
Gypsum	**
Interactions	n.s.

* P 0.05 ** P 0.01

1982 Results

Lime was applied as a main treatment to two replicates in 1982, to try to alleviate the effects of gypsum. Drought delayed sowing and restricted growth throughout the season of 1982. In addition, frosts of -7°C and -8°C occurred on 8-9/10/82 at Rutherglen, and further reduced grain yields.

Wheat and soils were sampled during September. Wheat yields of dry matter averaged 205 kg ha^{-1} at Rutherglen and 80 kg ha^{-1} at Boxwood. The only significant treatment effect on growth was that ripping (in 1981) had reduced dry matter yield at Boxwood to 68 kg ha^{-1} (P0.05); Troughton's (1974) explanation seemed to apply. Treatment effects on wheat chemical composition were minor at Rutherglen except for an interaction of lime, direct drilling and gypsum on Mo (P0.05). Direct drilling alone raised Mo content to 0.9 ppm, lime lowered Mo with direct drilling to 0.2 ppm, and gypsum plus lime lowered Mo to 0.2 ppm with cultivation. In a companion experiment, molybdenum fertiliser significantly increased wheat grain yields to 0.55 t ha^{-1} (P0.01). At Boxwood, the lime x direct drill x gypsum interaction resulted in direct drilling giving highest Mo contents and in lime raising Mo in wheat with cultivation and depressing it with direct drilling, the depression being more severe with gypsum (P0.05). This interaction was also significant on wheat K, Ca and Mg contents, and gypsum increased wheat Mn from 260 to 308 ppm (P0.01).

In the soil, pH values were much lower than in 1981. Lime raised mean pH values and gypsum depressed them, with first- and second-order interactions occurring at both sites (Table 9).

Table 9 Effects of lime, direct drilling, deep ripping and gypsum application on soil pH at Rutherglen (13/8/82) and Boxwood (19/8/82)

Rutherglen

	Not ripped	Rip 40 cm		0-10 cm	10-20 cm
Cult.	5.15	5.06	Lime 0	5.06	4.79
D.Drill	5.10	5.18	Lime 2.5 t ha^{-1}	5.69	4.94
Interaction:	* (P0.04)			** (P0.001)	

		0-10 cm	10-20 cm
Not ripped, Gypsum	0	5.53	4.88
	5 t ha^{-1}	5.29	4.81
Rip 40 cm	0	5.48	5.06
	5 t ha^{-1}	5.23	4.73
Interaction:		* (P0.04)	

Boxwood

Gypsum	0	5.73
	5 t ha^{-1}	5.42
Main effect:		** (P0.002)

		Cultivate		D. Drill	
		0-10 cm	10-20 cm	0-10 cm	10-20 cm
Lime 0,	Not ripped	5.40	5.08	5.40	5.23
	Rip 40 cm	5.48	5.18	5.40	5.13
Lime 2.5 t ha^{-1},	Not ripped	5.88	5.40	6.20	5.55
	Rip 40 cm	6.15	5.70	6.20	5.83

Interactions: Lime x Depth ** (P0.000)
Lime x Rip x Depth (P0.06)
Lime x D.Drill x Rip x Depth (P0.06)

* $P<0.05$ ** $P<0.01$

Lime tended to give higher pH in surface soil with direct drilling, and deep ripping increased the effects of gypsum and lime in the deeper soil.

The treatments influenced soil available K and exchangeable cations, Ca in particular, the major effects being of lime in surface soil and gypsum in surface and subsurface soils.

There were few significant effects on soil exchangeable Mn values, which were higher at Rutherglen than at Boxwood and which increased with depth in the soil. Some values are shown in Table 10.

Table 10 Soil exchangeable manganese (ppm) at Rutherglen (13/8/82) and Boxwood (19/8/82)

	Rutherglen	
	Gypsum 0	Gypsum 5 t ha^{-1}
Not ripped	46	44
Rip 40 cm	43	48
Interaction:	*	
Depth 0-10 cm	40	31
10-20 cm	49	60
Interaction:	**	

	Boxwood	
	Lime 0	Lime 2.5 t ha^{-1}
Depth 0-10 cm	21	14
10-20 cm	31	29
Interaction:	(data not analysed)	

* $P<0.05$ ** $P<0.01$

Gypsum decreased exchangeable Mn in surface soil and increased it below the surface, the effect apparently being greater with deep ripping, at Rutherglen. At Boxwood, the only noticeable effect was of lime in the surface soil.

Soil exchangeable Al values were higher at Rutherglen than at Boxwood, and increased with soil depth. At Rutherglen, lime and gypsum reduced exchangeable Al, the reduction being greatest in surface soil and influenced by cultivation or deep ripping.

Table 11 Soil exchangeable aluminium (ppm) at Rutherglen (13/8/82) and Boxwood (19/8/82) as influenced by lime, direct drilling, deep ripping and gypsum

Rutherglen

		Gypsum 0	Gypsum 5 t ha^{-1}
Lime 0,	Cultivate	60	37
	D.Drill	45	31
Lime 2.5 t ha^{-1},	Cult.	30	27
	D.Drill	39	24
Interaction:		*	

		Depth 0-10 cm	Depth 10-20 cm
Not ripped,	Gypsum 0	24	69
	Gypsum 5 t ha^{-1}	15	36
Rip 40 cm,	Gypsum C	29	52
	Gypsum 5 t ha^{-1}	19	50
Interaction:		**	

		Depth 0-10 cm	Depth 10-20 cm
Lime 0,	Cult.	40	57
	D.Drill	21	55
Lime 2.5 t ha^{-1},	Cult.	9	49
	D.Drill	17	46
Interaction:		*	

Boxwood

		Depth 0-10 cm	Depth 10-20 cm
Gypsum 0		5	14
5 t ha^{-1}		5	11
Interaction:		*	

		Depth 0-10 cm	Depth 10-20 cm
Lime 0,	Cult.	8	20
	D.Drill	8	14
Lime 2.5 t ha^{-1},	Cult.	1	6
	D.Drill	3	11
Interaction:		*	

* $P<0.05$ ** $P<0.01$

Wheat yields were low because of drought, and frost at Rutherglen. Yields ranged from about 0.6 to 0.9 t ha^{-1} at Rutherglen and 0.2 to 0.3 t ha^{-1} at Boxwood. The only indication of a treatment effect was a rip x gypsum interaction at Rutherglen, where the rip 40 cm plus gypsum treatment yielded almost 0.9 t ha^{-1} of grain. There were no other treatment effects, so the results are not reported here.

1983 Results

In 1982, penetrometer measurements indicated that the Rutherglen subsoil was still loose after deep ripping in 1981, but the Boxwood subsoil seemed to be cloddy and had partially recompacted. Accordingly, a Paraplow was used on the Rip 20 cm and Rip 40 cm treatments at Boxwood. Digging showed that a tilth had been produced in the loosened subsoil; no cultivations were required to level the surface for direct drilling.

Measurements of penetrometer resistance were done before and after the deep ripping at Boxwood in 1983. The soils ripped in 1981 did not exhibit the wide variability in resistance which was obvious in the 1982 drought, and there was still an obvious effect of deep ripping in 1981 on soil resistance prior to re-ripping in 1983 (Figure 3). The soil which had been cultivated for 2 years after ripping had obviously higher resistance to penetration than did the soil direct drilled after ripping. Soil in wheelmarks was recompacted to the same resistance as unripped soil.

Although 1983 was wet, wheat germination and early growth were good, and waterlogging did not prevent weed control at either site; wheelmarks from spraying were not noticeable on direct drilled plots, but markedly reduced plant growth in cultivated plots. During June the wheat again turned yellow on gypsum-treated plots. Sampling was done of crop and soil at Rutherglen, and soil only at Boxwood. At Rutherglen on 22/6/83, wheat plants were small and averaged about 200 kg ha^{-1} dry matter. Lime increased growth by about 10%, and direct drilling and gypsum both decreased growth by about 10%.

Chemical analysis of the plants was influenced by treatments. Lime increased contents of Ca, Mg and Mo, and decreased Mn from 354 ppm to 276 ppm, while ripping increased Mn from 292 ppm to 339 ppm. Gypsum increased wheat K, Na, Ca, S, Cl, and Mn (the latter from 281 ppm to 350 ppm), and decreased Mg from 0.073% to 0.067%, and Mo from 0.29 ppm to 0.20 ppm.

Penetrometer resistance of the soils were measured again on 24-25/10/83. The hardpans at about 10-12 cm depth were very noticeable in unripped soil, and deep ripping greatly reduced resistance in the subsoils. There was an indication that the 1983 cultivation at Boxwood had caused some compaction at 10-15 cm depth, as compared with direct drilled soil (Figure 4). Gypsum with ripping and direct drilling gave appreciably lower resistance than the other treatments. At Rutherglen (Figure 5), the ripped soils had much lower resistance than unripped, and there was little difference between soils which were cultivated or direct drilled after ripping. Gypsum had little effect on resistance at this site.

In September at both sites, the chlorotic gypsum-treated wheat had reverted to a normal colour. Lime and deep ripping improved wheat growth, and direct drilling reduced wheat variability. Waterlogging contributed greatly to increased variability in wheat growth, in conjunction with the natural soil variability.

Wheat grain yields were appreciably higher in 1983 than in the previous years (Table 12). There was no evidence of an interaction between direct drilling and deep ripping at Rutherglen; at Boxwood, however, with the rip 40 cm treatment, wheat direct drilled outyielded wheat cultivated by 0.3 t ha^{-1}.

Figure 3 Change in penetrometer resistance of a red duplex soil at Boxwood as influenced by deep ripping in 1981, cultivation or direct drilling, and traffic (14/4/83)

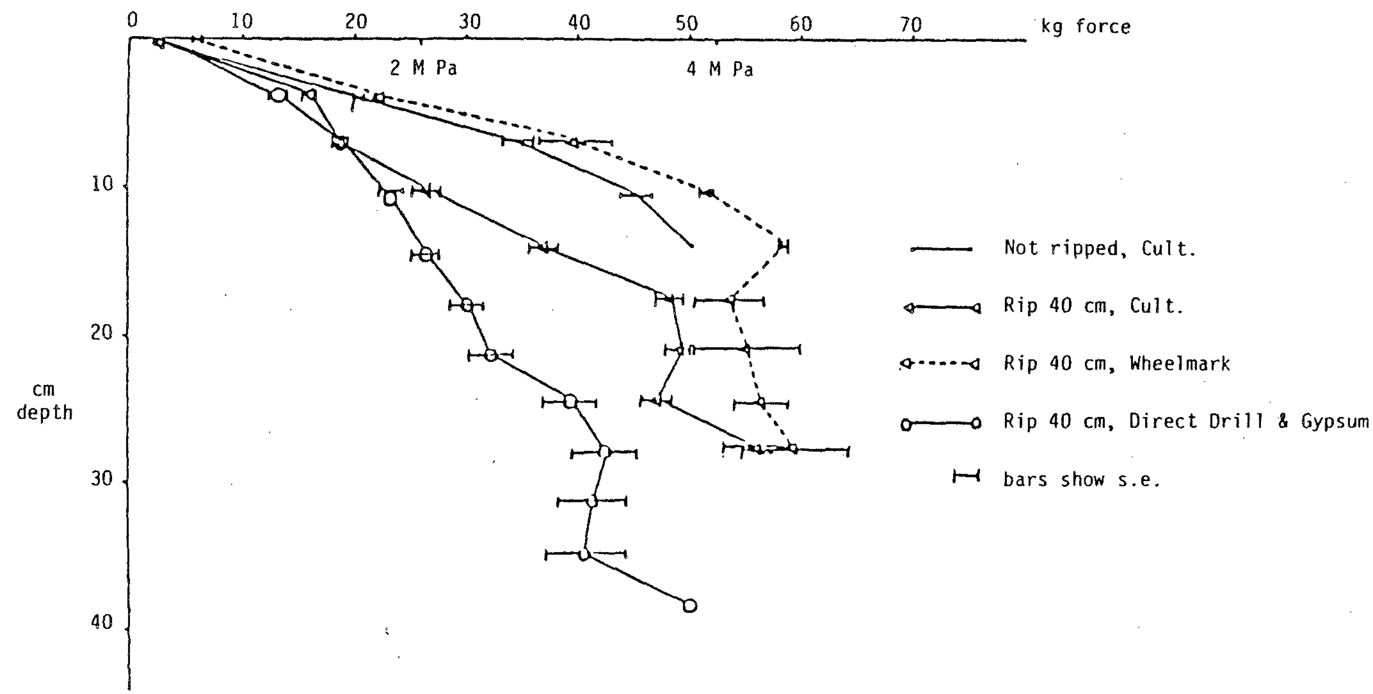


Figure 4 Change in penetrometer resistance of a red duplex soil at Boxwood as influenced by deep ripping in 1981 and 1983, followed by cultivation or direct drilling and gypsum (24/10/83)

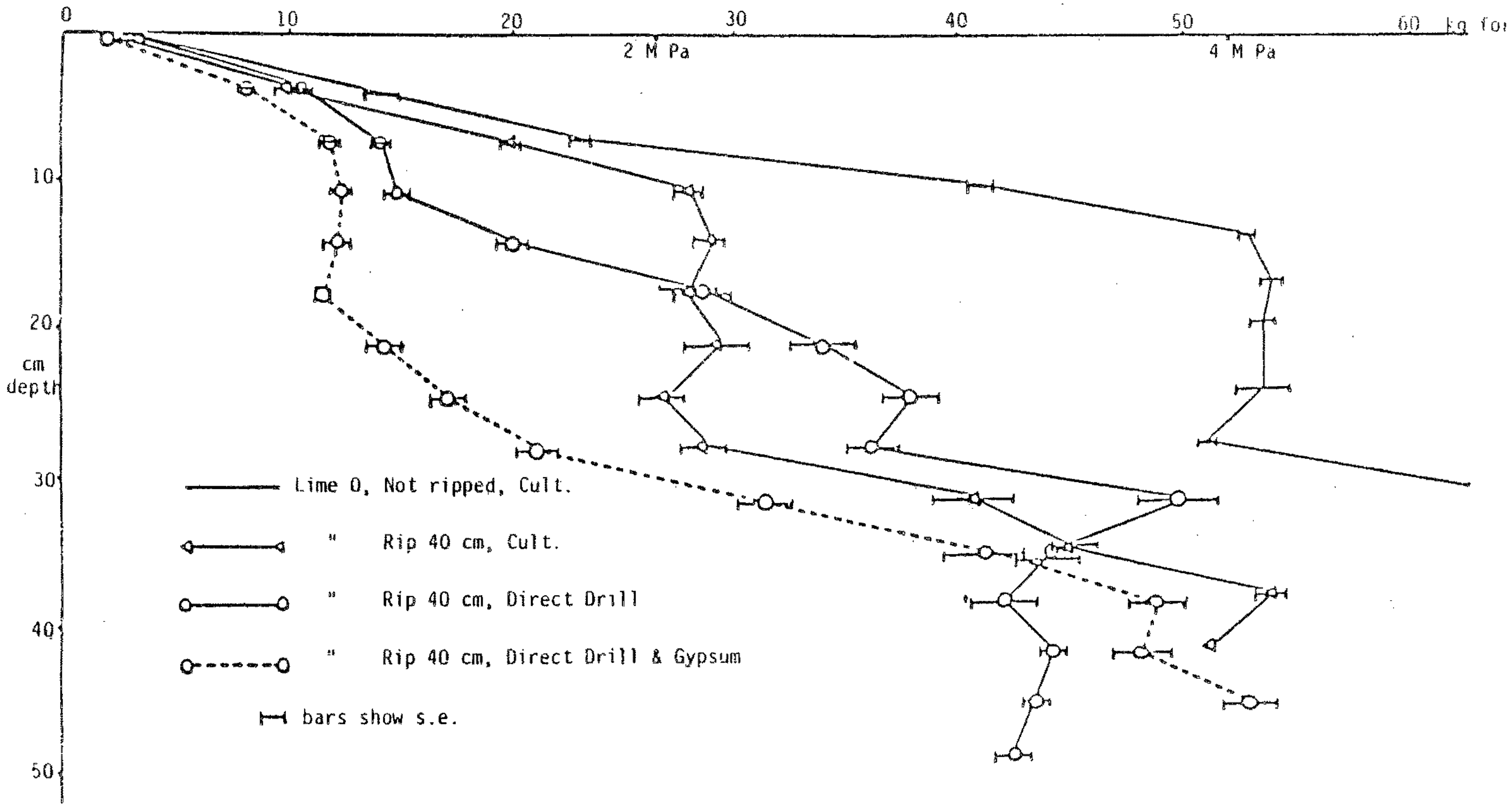


Figure 5   Change in penetrometer resistance of a yellow duplex soil at Rutherglen after deep ripping in 1981 and cultivation or direct drilling (25/10/83)

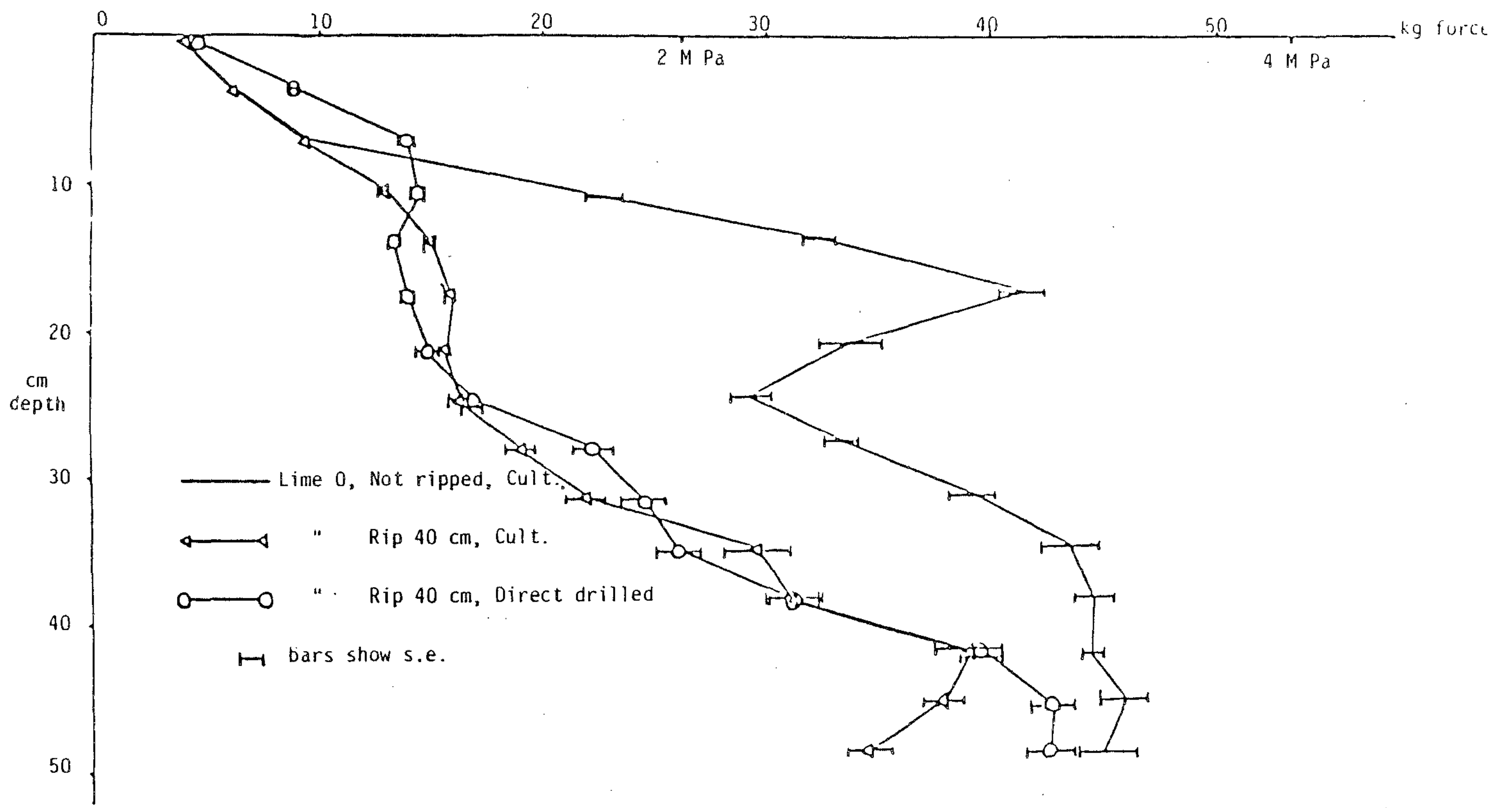


Table 12 Wheat grain yields (t ha^{-1}) in 1983 at Rutherglen and Boxwood, as influenced by lime, direct drilling, deep ripping and gypsum

Rutherglen

		Gypsum 0	Gypsum 5 t ha^{-1}
Lime 0,	Not ripped	2.5	3.1
	Rip 20 cm	3.0	2.9
	Rip 40 cm	2.8	3.6
Lime 2.5 t ha^{-1},	Not ripped	3.4	3.6
	Rip 20 cm	3.6	3.7
	Rip 40 cm	3.8	4.2

Differences: Lime n.s., Rip *, Gypsum **, R x G *

Boxwood

		Gypsum 0	Gypsum 5 t ha^{-1}
Lime 0,	Not ripped	2.2	2.4
	Rip 20 cm	2.7	2.7
	Rip 40 cm	3.0	2.9
Lime 2.5 t ha^{-1},	Not ripped	2.5	2.3
	Rip 20 cm	2.5	2.8
	Rip 40 cm	2.8	3.4

Differences: Lime n.s., Rip **, Gypsum n.s., L x R x G *

* $P<0.05$, ** $P<0.01$

The lime effect at Rutherglen was not statistically significant because of the lack of replication, but in the companion fertiliser experiment the lime effect was significant at the 1% level. At Boxwood however, there was little effect of lime on grain yields in either experiment, apart from the interaction noted in Table 12. Ripping increased yields, but the effects were not large unless lime or gypsum had been applied.

The large effect of lime at Rutherglen was explicable in the reduction of the high levels of exchangeable Al. At Boxwood, the lime effect occurred only where gypsum was applied, with the rip 40 cm treatment. More exchangeable Al was present in the subsoil than in the surface, and it is possible that the hardpan prevented movement of lime into the subsoil unless the soil was ripped.

Conclusion

In general, soil loosening has raised crop yields by about 30% where a hardpan exists. At Rutherglen gypsum was applied to several experiments to try to improve subsoil structure; two of the four experiments, on sandy acid soils, showed 30% yield depressions associated with increased acidity from the gypsum. Soil acidity can affect the response to subsoil loosening. Other experiments indicate that flooding or waterlogging will negate the beneficial effect of soil loosening, so flooding must not be permitted. The effect of ripping only lasted one year on one site, but on five other sites the effect has lasted up to four years, and is still continuing, being best with direct drilling. Lupins and rape benefit markedly from loosening dense soils. Magnesium and boron have had no beneficial effect on wheat growth, but molybdenum increased wheat yield in 1982 on one site.

In summary, a better understanding of soil processes and soil/plant ecology can lead to increased productivity of crops and pastures, with improvement of soils, rather than degradation, in the long term. A piecemeal approach to soil management is unlikely to pay dividends; the adoption of a whole system of management, with attention to all of its components, will be required to gain maximum advantage in the long term.

Such a farming system, either with permanent pasture, ley farming, or continuous cropping, aims at promoting development of a deep, porous soil with a high degree of biological activity. Having produced a porous soil, the system will keep it in that condition by using reduced tillage and reduced traffic, by keeping organic matter on the soil surface, and reducing grazing pressure in very wet or drought conditions. All aspects of good husbandry with regard to pasture and crop establishment must be given attention. Adequate inputs of legumes are required, and a range of species, including those with deep roots, grown often in the rotation, to improve soil physical conditions and reduce diseases. The replacement of nutrients lost in produce removal and leaching is required, and amelioration of mineral deficiencies or toxicities. Any major physical or chemical barriers to plant growth, for example waterlogging or great acidity, must also be corrected.

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