A review of machinery for cropping with reduced water erosion

K.J. Bligh
IMPORTANT DISCLAIMER

This document has been obtained from DAFWA's research library website (researchlibrary.agric.wa.gov.au) which hosts DAFWA's archival research publications. Although reasonable care was taken to make the information in the document accurate at the time it was first published, DAFWA does not make any representations or warranties about its accuracy, reliability, currency, completeness or suitability for any particular purpose. It may be out of date, inaccurate or misleading or conflict with current laws, polices or practices. DAFWA has not reviewed or revised the information before making the document available from its research library website. Before using the information, you should carefully evaluate its accuracy, currency, completeness and relevance for your purposes. We recommend you also search for more recent information on DAFWA's research library website, DAFWA's main website (https://www.agric.wa.gov.au) and other appropriate websites and sources.

Information in, or referred to in, documents on DAFWA's research library website is not tailored to the circumstances of individual farms, people or businesses, and does not constitute legal, business, scientific, agricultural or farm management advice. We recommend before making any significant decisions, you obtain advice from appropriate professionals who have taken into account your individual circumstances and objectives.

The Chief Executive Officer of the Department of Agriculture and Food and the State of Western Australia and their employees and agents (collectively and individually referred to below as DAFWA) accept no liability whatsoever, by reason of negligence or otherwise, arising from any use or release of information in, or referred to in, this document, or any error, inaccuracy or omission in the information.
A Review of Machinery for Cropping With Reduced Water Erosion

K.J.Bligh

Resource Management Technical Report No.66
Disclaimer

The contents of this report were based on the best available information at the time of publication. It is based in part on various assumptions and predictions. Conditions may change over time and conclusions should be interpreted in the light of the latest information available.

© Chief Executive Officer, Department of Agriculture Western Australia 2001
1. Summary

Water erosion of cropland during episodic, extreme rainfall events in Western Australia is considerably in excess of probable soil formation rates. Both reduced tillage and stubble—retention cropping reduce water erosion. Their acceptance depends on the availability of suitable machinery.

The development of reduced and minimal soil disturbance, and stubble-retention machinery, is discussed in a whole—system context. Inexpensive modifications to existing sowing machinery, such as removing cultivating tines (if any) and fitting narrow winged, chisel or lucerne points, are available or can be developed for ready adoption by landholders, provided that weeds can be economically controlled using herbicides. More exotic tined, disced or disc-and-tine combinations should be developed, as sowing implements currently available on farms require replacement in the longer term.
# Table of Contents

1. **Summary** ........................................................................................................................................................................... iii

1. **Introduction** ........................................................................................................................................................................ 1

2. **Effects of Reduced Tillage and Stubble Retention on Water Erosion** ................................................................. 3

3. **Machinery for Sowing with Reduced Tillage** .................................................................................................................. 6

   3.1 Machinery for sowing into a pre—tilled seed bed ............................................................ 6

   3.2 Machinery for sowing without prior tillage with surface soil disturbance over the complete width of sowing ...................................................... 9

   3.3 Machinery for sowing into untilled soil with disturbance of only part of the soil surface ........................................................................................................ 10

      3.3.1 Narrow-tined implements ......................................................................................... 10

      3.3.1.1 Narrow tines with sowing boots attached .......................................................... 10

      3.3.2 Disc implements ..................................................................................................... 15

      3.3.2 Double-disc openers ............................................................................................ 16

      3.3.3 Triple—disc drills ................................................................................................. 17

4. **Machinery for Cropping into Stubble** ............................................................................................................................ 20

   4.1 Post—harvest treatments ................................................................................................................................. 20

      4.1.1 Straw choppers and spreaders .............................................................................. 20

      4.1.2 Grazing of stubbles .............................................................................................. 21

      4.1.3 Stubble slashing and flattening ............................................................................. 22

   4.2 Machinery for tilling through stubble ................................................................................................. 22

      4.2.1 Disc implements ..................................................................................................... 22

      4.2.2 Tined implements ................................................................................................. 23

   4.3 Surface stubble remaining after tillage .................................................................................... 23

   4.4 Machinery for sowing into stubble ................................................................................................. 27
4.4.1 Disc seeders .................................................................27
4.4.2 Tined seeders .............................................................27
4.4.3 Tine—and—disc combination seeders .........................28
4.4.4 Press wheels on seeders .............................................30

4.5 Harrows .................................................................................32
4.5.1 Tined harrows .............................................................32
4.5.2 Finger harrows .............................................................32
4.5.3 “Connor Shea”® Horizontal revolving harrows ...........32
4.5.4 “Flexicoil”® harrows .....................................................32
4.5.5 Chain harrows .............................................................32
4.5.6 “Phoenix”® rotary spike harrows ...............................33
4.5.7 Bar harrows .................................................................33

5 Relevance of Reduced Tillage and Stubble—retention Machinery in Western Australia .................................................34

6 References ..............................................................................37

7 Acknowledgements ................................................................42
1. Introduction

The aim of this review is to investigate machinery which can be used for reducing water erosion in small-grain cropping in Western Australia. Reduced tillage and increased vegetative cover reduce soil erosion by raindrop impact and overland flow (Freebairn and Wockner, 1986; Marschke, 1986; Bligh, 1984). The two are interrelated, because a lesser number and/or intensity of tillage operations can leave more stubble on the soil surface.

“Tillage” is defined as the mechanical preparation of the soil to facilitate the growth of crop or pasture, (Houghton and Charman, 1986) with the principal functions of seedbed preparation and weed control. “Reduced tillage” refers to any reduction in intensity of working the soil prior to planting. Therefore lesser disturbance of the soil occurs, usually with some of the traditional number of operations becoming redundant. “Minimum tillage” describes growing a crop with the fewest-possible tillage operations. “Minimal soil disturbance”, as used in this review refers to the least—possible disturbance of the soil on sowing without prior tillage, consistent with adequate crop establishment and yield. “No-tillage” and “direct drilling” refer to a single operation, in the course of which the seed is sown.

The discovery of the herbicidal properties of the bipyridyls in 1955 (Koronka, 1973) together with earlier demonstrations that working a seedbed was not necessarily required for adequate crop establishment and yield (Russell, 1945), opened up new possibilities for reducing water erosion. Tillage therefore became unnecessary for cropping on many soils. The development of a range of knock-down herbicides further widened the conditions under which minimal-soil-disturbance cropping could be practised. Sprague (1986) has recently reviewed the development of reduced-tillage agriculture.

Machinery developed for sowing into prepared seedbeds has generally been found to be poorly suited to sowing into undisturbed soil, chiefly because of penetration problems (Logan, 1979). Wheat yields were found to be maintained and soil structure improved under direct drilling on loamy soils (Jarvis, et al J., 1986; Jarvis, 1987). Direct drilling became an accepted practice for sowing cereals in Western Australia. It offered greater flexibility in expanded cropping programmes depending on seasonal conditions, and reduced capital outlay on machinery.

It is estimated that approximately 40% of cropland in Western Australia has been direct drilled in some seasons (G.A. Pearce, then Principal Research Officer, Weed Agronomy, W.A. Dept. of Agric. pers. comm. 1984; D.J. Gilbey, W.A. Dept. of Agric. pers. comm. 1987). Standard combine points range from approximately 100-150 mm wide when new, in rows spaced 75-90 mm apart. Therefore the soil is disturbed over the complete width of sowing. Seed is sown through boots behind every second tine, in row spacings typically of 150 or 180 mm. A “second knock” cultivation of young weeds which have emerged since spraying therefore automatically occurs in the course of direct—drilling
using a combine or air seeder equipped with standard points. Practitioners of minimal-soil-disturbance cropping using a triple-disc drill, with negligible soil disturbance at sowing, have sometimes found it necessary to apply a second, knock-down herbicide after sowing in order to kill all weeds prior to crop emergence (Richard Barber, pers. comm. 1984).

Sheet and nil erosion are less severe on well-vegetated than bare soil surfaces. Amounts of cover required to achieve pre-determined erosion limits have been identified for heavy-clay cropland (Freebairn and Wockner, 1986) and pastured land (Lang and McCaffrey, 1984). Stubble-retention cropping results in increased protection of the soil surface from effects of raindrop impact and overland flow by runoff, thereby reducing water erosion. Cropping with reduced tillage, and particularly with minimal soil disturbance, has the added benefit that it does not physically loosen the soil as much as with traditional tillage. Soil erodibility is therefore reduced. This is particularly important for reducing water erosion in Western Australian agricultural areas where 60-70 per cent of average annual rainfall is received in the May-October growing season.
2. Effects of Reduced Tillage and Stubble Retention on Water Erosion

Rainfall infiltration was found to increase following direct drilling with a combine in Western Australia, compared with traditional tillage operations which included two prior tillage operations using a scapanifien (Bligh, 1984). Infiltration was further substantially increased with minimal-soil-disturbance cropping using a triple disc drill in a wheat-pasture rotation, in which all vegetative material was burnt before cropping. Percentages of 253 mm of growing-season rainfall infiltrated increased from 79% for traditional tillage, to 86% for combine direct drilling and 96% for minimal soil disturbance cropping on non-calciic brown earth with a sandy loam surface texture (Db 2.12 Northcote, 1979). Runoff from the 4 m² infiltrometer microplots removed 51 g m⁻² of suspended sediment under traditional tillage, 31 g m⁻² under combine direct drilling and 6.6 g m⁻² under the minimal soil disturbance cropping.

Wheat yields were similar over ten years continuous cropping under all three tillage treatments on sandy loam soil in this 380 mm average annual rainfall zone, and increased under minimal soil disturbance cropping using a triple-disc drill at high rates of fertilizer nitrogen (Jarvis, R.J., W.A. Dept. of Agric. pens. comm. 1987). At a separate site with loamy sand—over-sandy-clay at 0.10 m (Db 1.41), relative percentages infiltrated after three years continuous cropping with stubble retained were less than 67% of 166 mm of growing-season rainfall for traditional tillage, less than 68% for combine direct drilling and 82% for minimal soil disturbance cropping (Bligh, 1984).

Research results indicate that considerable reductions in soil loss with reduced tillage occur on a field scale. Freebairn and Wockner (1983) report reductions in soil loss from 1 ha contour bays by two thirds under zero tillage compared with stubble mulch at two sites in southern Queensland. Incorporating stubble resulted in 2 and 4.5 times more soil loss than stubble mulching, while 10 and 16 times as much soil was lost from the grey clay (Ug 5.16) and black earth (Ug 5.15) sites, respectively. Sallaway (1983) report reduced runoff and soil loss from zero tilled than either disc or blade-ploughed contour bays in central Queensland. Edwards (1980) reports drastically reduced runoff under zero tillage compared with conventional tillage on small catchments in the United States. Smith (1979) report increased runoff but greatly reduced soil loss from untilled compared with various tilled treatments on large plots on clay—pan soils, which are not representative of many cropped soils in Western Australia.

The incidence of waterlogging may also be increased by increased infiltration under different tillage and stubble treatments. A stubble mulched treatment resulted in less surface runoff from contour bays than a stubble burnt treatment on a black earth (Ug 5.14), but greater interflow over less permeable subsoil at Gunnedah Research Centre in New South Wales (Marschke, 1986). Drainage structures such as seepage interceptor banks or slotted pipe may be required to reduce the incidence of waterlogging under reduced—tillage. A trade-off situation may therefore exist between reduced water erosion and an increased incidence of waterlogging, requiring interceptor bank construction in Western Australia.
Effects of tillage on interflow as well as surface runoff and soil loss are currently being investigated at West Dale, where a sandy loam overlies a less-permeable sandy clay at 0.4 m (Db 2.12), (K.J. Bligh and I.A.F. Laing, unpublished 1986). This project is funded under the National Soil Conservation Programme. Three tillage treatments, in the form of traditional tillage, combine direct drilling and minimal-soil-disturbance cropping, together with sub.clover-based pasture will be applied, each in two one-hectare bays, following calibration of the relative runoff behaviour of each bay.

The maximum stubble cover possible is considered desirable for reducing water erosion (e.g. Porritt, 1987), in addition to increasing crop yields by reduced evaporative losses in low—rainfall areas (Jarvis and Tennant, 1985). Freebairn and Wockner (1986a) report an 80% to 90% reduction in soil movement in runoff with 30% stubble cover. This corresponds to approximately 1.5—2.0 t ha⁻¹ of stubble remaining above the soil surface after sowing (Freebairn and Wockner 1986b). Sweeting (1985) suggests from research results overseas, that more than 2.24 t ha⁻¹ of stubble shows little additional benefit in mitigating water erosion. Only approximately 0.75 t ha⁻¹ stubble cover is required to reduce wind erosion to levels regarded as acceptable (Carter, W.A. Dept. of Agric. pens. comm. 1987).

A survey of 78 farms in Victoria carried out by the Australian Meat Research Committee (1984) showed that between 1 and 2 t. of stubble was produced per tonne of wheat, with a mean of 1.4 t. Therefore a wheat yield of approximately 2 t ha⁻¹ may be expected to produce an average stubble cover under Victorian conditions of 2.8 t ha⁻¹, with a range of 2 t ha⁻¹ to 4 t ha⁻¹.

Wheat yields in excess of 2 t ha⁻¹ are frequently achieved in medium rainfall, high-erosion-risk areas of the Western Australian wheatbelt, though yields in low rainfall areas may be less than 1 t ha⁻¹ in some seasons. Between approximately 10% and 30% of stubble may be grazed by sheep mainly leaf and husk the higher value applying in higher rainfall areas where stubble is typically heavier (H.E. Fels, W.A. Dept. of Agric. pers. comm.). It is therefore desirable that as much of the stubble as possible remain after sowing the subsequent crop, in order to effectively, reduce water erosion during early winter when vegetative cover provided by the crop is negligible.

It is estimated that approximately 0.5 million hectares of the approximately 6 million hectares sown to wheat, lupins, oats and barley in Western Australia in 1986 was in a continuous cereal rotation (Porritt, 1987). An additional 1.32 million hectares of mainly sandy-surfaced soils were considered to be cropped to a wheat-lupin rotation. Current trends towards a wheat-pea continous cropping rotation on loamy soils may increase the estimated 40,000 ha sown to field peas in 1987. Therefore a total of approximately 1.9 million hectares of the 6 million hectares is currently estimated to be cropped into stubbles of lupins, cereals, or peas. Cropping of more than 4 million hectares, or approximately two—thirds, therefore follows annual pastures, which are generally closely-grazed, providing negligible vegetative cover after tillage and sowing.

Water erosion from episodic sustained rainfall events, may erode of the order of 1 mm of topsoil averaged over cropped areas in medium and higher rainfall areas of Western
Australia (e.g. Bligh 1987). Since soil formation is known to occur at rates of the order of only 1 mm per thousand years (McFarlane and Ryder 1987), such soils may be considered effectively non-renewable. Tillage reduced to the minimal soil disturbance required for adequate crop establishment and yield is therefore desirable in order to obtain the maximum possible reduction in water erosion.

Machinery for sowing with reduced tillage in North America has recently been reviewed by Throckmorton (1986). Frye and Lindwall (1986) conclude from an international workshop on zero—tillage research priorities, that the physical requirements of the seed zone should be the subject of further research. Less heavily ballasted tractors are then required for the less intensive tillage in the sowing operation, reducing soil compaction, though the number of passes by lighter spraying equipment may increase.

Sweeting (1985) observes that the dearth of satisfactory seeding equipment is hindering the widespread adoption of direct drilling in Australia. The development of satisfactory machinery is considered crucial for the widespread acceptance of conservation cropping techniques (e.g. Chamala and Coughenour, 1986).
3 Machinery for Sowing with Reduced Tillage

The main purpose of tillage in cereal-growing areas of Western Australia was, formerly, to kill weeds (Halpin and Bligh, 1974). Before “knockdown” herbicides become available, tillage was the sole method of weed control before sowing. Cropping to cereals usually required three tillage operations in most seasons on established farm land. If the “break-of—season” rains were late in this winter-rainfall area, crops could be sown as part of the second weed-killing tillage operation using a combine. The primary tillage operation was typically carried out after the opening rains of the season originally using a mouldboard plough, which was superceded by the stump-jump disc plough (Plates 1 and 2). A secondary tillage operation then killed the next germination of weeds using a scarifier or light cultivator bar. Sowing was then usually by means of a combine or air-seeder. Where weed-seed burdens were less severe because the land had either been newly—cleared of native vegetation, or had been continuously cropped, reduced cultivation in the form of disc ploughing followed by sowing using a disc drill or combine was commonly practiced.

The time required for weeds to germinate and each tillage operation meant that less of the growing season was available for crop growth. Reduced tillage and direct drilling using standard points on a combine or air—seeder became attractive when knock-down and in-crop herbicides become available, for reasons of both economy and yield. The yield penalty is commonly estimated at approximately 10 kg ha~ of wheat for each day’s delay in sowing on average in lower-rainfall wheat belt areas (M. Perry, W.A. Dept. of Agric. pers. comm. 1987).

3.1 Machinery for sowing into a pre—tilled seed bed

Available seeders for traditional tillage have performed adequately in terms of crop establishing when the soil was already loosened by prior tillage. One—way or offset discs, in the form of disc drills, plough or culti—trash seeders, have been used on recently-cleared or stubble land, where the traditional Australian combine drill or its more recent air—seeder variant, may suffer frequent blockages by roots or stubble. Inadequate weed control by the disc drill, and perceived too—deep sowing by plough and culti-trash seeders have limited their use in sowing small grains in Western Australia, with the exception of culti-trash sowing of the larger lupin seed, which simultaneously achieves the required incorporation of residual herbicides.
Historically, the traditional combine was developed for sowing into a tilled seed-bed free of surface obstructions. When first produced it was in a light, spring-tine version on a float system, in which each tine functioned as a spring for its necessary stump-jump capability. A spring-release version with a relatively rigid tine was subsequently developed for sowing into harder soils (Plate 3). Breakout forces defined as the force of the tip of the point which will just cause pivotting of the tine stump-jump mechanism (Houghton and Charman, 1985), were in the range of 0.17—0.25 kN (Norris and Ward, 1983). Four ranks (i.e. lateral rows at a right angle to the direction of travel) were spaced approximately 0.4 m or less apart. The front and rear ranks of tines were for tillage alone, spaced 180 mm apart in the direction of travel. A similar spacing of sowing tines with sowing boots and tubes under a seed-box were spaced midway between the cultivating tines at the same depth. The soil was disturbed at approximately 90 mm spacing using 100-150 mm wide points, with the aim of achieving weed control by tillage.

Recent variations to the traditional combine have included a rigid frame rather than a float system, with the breakout force adjustable to more than 0.7 kN (Robotham and Norris, 1986). Forward ranks of cultivating tines may have the ability to till at a greater depth than rear ranks of sowing tines. Increasing the spacing in the line of travel to five and six ranks also increased trash flow past the now wider-spaced tines. Combines such as the International “Vibrashank”® which sow on every tine at 150 mm or 175 mm row spacings, are also currently available. This allows greater distances between tines arranged in four ranks than on the traditional combine for improved trash flow. The enhanced flexibility offered by air—seeders allows even greater distances between ranks of tines than combines, which rely on gravity for delivery of seed and fertilizer to the sowing boot.

The configuration of each tine remains essentially vertical to frame height, providing superior trash flow characteristics than the more semi-circular shape of older spring-tine combines. Tined harrows which were commonly attached behind combines in order to level ridges, may now be replaced by a range of finger, rotary, chain or helical coil harrows.

Row spacing has typically remained at 150 or 180 mm, though some air-seeder bars have been used in Western Australia with spacings of up to 300 mm. Row spacings trials reported by Burch (1986) show generally improved wheat yields at 180 mm than wider spacings, with higher yields still at 90 mm spacing. Conversion of an 80—row Shearer Wideline® seeder to sow 160 rows at 90 mm spacing resulted in an average 10% wheat yield increase (G. Fosbery, R. Doyle, pers. comm. 1987). Therefore it is considered desirable that seeders should be capable of sowing at row spacings closer than 180 mm in Western Australia.
3.2 Machinery for sowing without prior tillage with surface soil disturbance over the complete width of sowing.

Culti-trash and modern combine seeders have proven capable of providing soil disturbance over the complete width of sowing into moist, untilled soil. The culti-trash can sow into sandy-surfaced soils, which do not set as hard on drying as the more erodible loamy soils. Control over depth of sowing is inferior to that of a combine with a float system, leading to more variable seed spacing and depth, and perceived poorer emergence of small cereal seeds using a culti-trash. Wide combines without floats, or rigid-framed air seeder bars may also sow too deep or shallow on an undulating soil surface.

Plate 3. A four—rank, spring—release combine with four tines per float, used for sowing into a pre-tilled seedbed. Sowing tines are on the middle two ranks. Toothed harrows were commonly trailed to smooth the ridged soil surface.

Deteriorating structure and hardness on drying following frequent tillage operations (e.g. Hamblin, 1984) required that the combine be constructed stronger for penetration of hard soils. In its more developed form, it also proved capable of sowing into undisturbed moist soils. Logan, (1979), for example, considers it exceptional in its ability to direct drill, though G.A. Pearce (pers. comm. 1977) considered it unlikely that the standard combine would prove optimal for direct drilling. Since there was a combine on practically
every farm, its ready availability resulted in its common use for direct drilling in Western Australia.

Penetration remains a problem in low—rainfall areas where there is frequently only a brief period during which combines can penetrate after rain, after which the soil dries and hardens excessively. Point wear is also increased in hard soils, requiring increased down-time and costs of changing points. An initial disc-ploughing under such circumstances may then provide an earlier sowing opportunity, without the yield penalty likely to be incurred by waiting for further rain. Direct drilling in drier areas tends to be an opportunistic practice to crop early.

3.3 Machinery for sowing into untilled soil with disturbance of only part of the soil surface

Disturbance of only part of untilled surface soil may be achieved on seeders using either tines or discs at the sowing boot. The degree of surface soil disturbance can range from near total to minimal surface disturbance, with or without tillage of a sub—surface seed zone. Reduced germination of weed seeds may occur between rows sown with minimal soil disturbance (Krell and Dubbs, 1979). Regeneration of subterranean clover-based pastures has also been increased in the year following cropping because of less deep burial of seeds (Jarvis, 1986).

Complete disturbance of the surface soil has traditionally been perceived necessary, in order to provide a “second knock” to kill weeds, which have emerged since cultivation or spraying, and to provide a seed-bed. However experimental evidence on loamy soil types in Western Australia suggests that cereal yields may be maintained or even increased, cropping with negligible soil disturbance (Jarvis ~ .1986) provided that weed control is adequate.

3.3.1 Narrow-tined implements

 Implements with narrow tines relative to the row spacing may prepare a satisfactory micro—seedbed, with little surface disturbance of the inter—row area resulting in less weed germination at sowing.

The mechanical properties of the surface soil, and its moisture content, affect its strength. Dry, hard-setting soils tend to fracture over the entire surface, for example, though in a relatively moist condition a seed-bed little wider than the width of the point is created. The time available for sowing before a soil dries and hardens after rain, may therefore be critical to the area that can be sown using a particular machine.

3.3.1.1 Narrow tines with sowing boots attached

Available combine and air-seeders may be equipped with a limited range of narrow chisel or lucerne points from approximately 60 mm down to 12 mm wide, A narrow channel is created in moist soil into which the seed is placed. The elevation of the
sowing boot behind the point affects both the sowing depth as the soil fills in once the tine has passed, and the likelihood of its becoming blocked by sticky soil.

The ground speed of the seeder also affects its sowing depth, because of changes in the rate at which the soil fills into the furrow created by the passage of the tine. Therefore the sowing boot height must also be adjusted to give the required sowing depth at the particular speed of operation. Chisel points 50 mm, wide fitted to a combine with sowing tines only and with sowing boots raised (Plates 4 & 5), resulted in dry matter production of 7.9 to 10.6 t ha$^{-1}$ and wheat yields of 1.6 to 2.4 t ha$^{-1}$ on gauged contour bays at Chapman Research Station, near Geraldton (K.J. Hugh and I.A.F. Laing, unpublished, 1987).

3.3.1.2 Separate sowing points behind tillage tines

An alternative to sowing through a boot attached to the tine which forms the micro-seedbed, is to place a separate sowing tine directly behind. Such a double-tine concept offers the possibility of deeper tillage by the forward tine than sowing by the rear tine. Machines developed for sowing into sandy soils by R. Jarvis and W. Crabtree (W.A. Dept. of Agric. pers. comm. 1987) successfully use this principle. Belford and Harvey (1986) report that accurate depth control of the sowing tines is required in order to maintain optimum sowing depth at increased depths of tillage. Wheat yields on loamy sand sown using this machine increased from 2.5 t ha$^{-1}$ to 2.9 t ha$^{-1}$ as the depth of the leading 50 mm-wide tine was increased from 30 mm to 130 mm below the soil surface, confirming earlier trends towards yield increases with micro—seedbed disturbance in sandy soils (Jarvis et al., 1986). Seed and fertilizer may equally be delivered through a boot attached to a disc which follows directly behind a narrow tine forming a micro-seedbed. Such a machine, using wide points for complete surface disturbance has been used successfully by Mr Derek Morrell of Moonyoonooka near Geraldton, Western Australia for several seasons (see Plate 11, Section 4.4,3).
Plate 4. Chisel points 50 mm wide fitted to a combine equipped with sowing tines only. Sowing boots are set higher than the point in order to achieve shallower sowing, with tilled soil below the seed zone to facilitate seedling root establishment.

One of the earliest Australian reduced—tillage seeders, the “Siroseeder” (Anon, 1976) utilizes a similar concept. Fertilizer is delivered through a leading tine and seed through an attached trailing tine. A trailing slug or ribbed press-wheel (Anon, 1979) then compacted the seed-zone and pushed pasture sod away for sowing into pasture (Stegall, 1979).
Research carried out in tillage bins at Massey University, New Zealand showed superior emergence of wheat after sowing using a winged opener than with either a traditional hoe point or a triple-disc drill (Baker, 1976). Choudhary and Baker (1982) subsequently observed significantly improved field performance over the traditional hoe point in one of 13 field plantings, and over the triple disc in two, where no emergence had occurred after three weeks under any of the treatments. The conditions which produced differences between openers were very dry, though seedlings had survived below ground at two sites using the winged opener. In reviewing field and tillage-bin trials, Baker (1983) observed that the winged opener always achieved seedling emergence superior to or comparable with the hoe point or triple-disc drill.

An early version of this opener concept, now widely available in Australia, is the so-called "Baker boot" winged opener. It effectively achieves a sub-surface seedbed with little surface disturbance. Surface disturbance increased with moisture content in a silt loam soil (Baker, 1976). The "Baker boot" winged opener has been produced commercially on 3-point-linkage seeders by Connor-Shea Pty Ltd. Coulter drills such as that produced by John Shearer Pty. Ltd. also have winged points. A winged point is also available for combines in a "Nok-on" version from Ralph McKay Pty Ltd. (see Plate 10, Section 4.4.2).

A subsequent development of the winged opener concept separated the now-replaceable wing on either side of a 460 mm diameter scalloped disc, with following press-wheels which also control sowing depth (Baker ~t~ 1979b). This latter development, termed the "Bio-Blade®, has not yet been manufactured commercially though discussions with possible manufacturers are proceeding (W.R. Ritchie, Massey Univ, pers. comm. 1987).

Seed and fertilizer are separately placed on either side of the disc, at different depths, if required (Baker, et al., 197gb). The downward force required for penetration by the "Bio-Blade® in a dry soil is increased to approximately that required for a triple-disc drill (125 kg per row). The pull required at a ground speed of 4 km hr~ with 25 mm wings on either side was approximately double that of the winged opener alone. Wear of the "Bio-Blade® is reduced compared to the winged opener.

A narrow winged point with a 50 mm-deep vane below the seed zone has been used in experiments carried out by CSIRO Soils Division, Adelaide (J. Riches, W.A. Dept. of Agric., pers. comm.). Reductions in root damage due to rhizoctonia infection when fertilised with nitrogen have been reported (M. Sweetingham, W.A. Dept. of Agric., pers. comm., 1987).

A similar point has been used in Department of Agriculture experiments in southern New South Wales, and by a farmer near Moree (W. Johnson, Ralph McKay Limited, pers. comm. 1987). Since the vane may operate in compacted and previously unttiled soil, higher break-out forces may be required than with the winged point alone. Such
modifications may prove beneficial, particularly on sandy-surfaced soils which tend to maintain more of their dry strength when wet, with more resistance to root establishment, than loamy soils.

3.3.1.4 Point wear

As soils dry and harden after rain, increased point wear results in the more frequent need to replace worn points. There is therefore a timeliness—of sowing cost resulting from the down-time, in addition to the cost of the new points. Time lost in changing or adjusting points becomes particularly important in conditions in which there is frequently only an interval of a few days during which soils remain an appropriate moisture content for satisfactory micro-seedbed formation.

Chisel points of the clamp-on, slip—down type are progressively adjustable downwards as they wear, as used on some chisel ploughs. They use more of the higher-grade steel point material than simple bolt-on or reversible points and may therefore be more economical. Less down—time normally is required in adjusting clamp-on, slip-down points than in changing points.

Penetration of hard soils may deteriorate as points wear and become more rounded at the leading edge. Cast spear points with a triangular lateral cross section have been observed to remain sharp when fitted in a downward angled position.

Cast steel points are available, with greater thicknesses of wearing material, though at the cost of increased brittleness of the cast points leading to possible breakages in stoney soils. The metallurgy of the steel used in tillage points also affects their operating life. Metallurgical developments are reported to have achieved up to 50 per cent reduction in wear of excavator bucket teeth. If such improvements can be successfully incorporated into tillage points (e.g. Lundy, 1987), benefits of reduced down-time may also be realized.

3.3.2 Disc implements

Self-sharpening discs generally have superior penetrating ability to tines, because they slice rather than burst through the soil. In addition, down-time is greatly reduced, as discs need to be replaced much less frequently than tines. For example, new discs may be placed on a machine before the busy period of sowing and, depending on use, may not need to be replaced for several seasons. Points on tined implements, on the other hand, may need to be replaced daily, or more frequently in hard-soil conditions. Disc implements also have an implicit advantage over tines in their ability to slice through and displace stubble, with less blockages.
3.3.2.1 Single—disc seeders

The traditional disc drill generally results in inadequate soil coverage of seed in untilled soil. In order to provide improved soil coverage, Mr Harry Williams of Nungarin, near Merredin, utilized a novel concept by adding a light steel plate at an empirically-determined angle (Plate 6). The plate floats in the soil stream thrown up by spring-loaded, plain spherical discs approximately 35 cm in diameter. While some soil is also splattered between the rows, sufficient seed coverage has been achieved over several seasons for adequate plant establishment and yield of both small grains and lupins.

The International “Colta-.disc®” combines a disc opener with a following press-wheel. The large plane disc is set at a slight angle to the line of travel, slicing out a soil groove, into which seed and fertilizer are placed through a sowing boot. A metal press-wheel then pushes the sides of the groove around the seed and fertilizer. When formerly marketed as the “Ryan Seeder®”, reasonable establishment was observed though penetration was more difficult than with tines on hard, sandy clay-loam soil and through stubble trials (G. Riethmuller, W.A. Dept. of Agric. pers. comm. 1986).

3.3.2 Double-disc openers

Double disc openers were used on seeders in tilled soils in Australia at the turn of the century (Norris and Ward, 1983) and are currently used in Europe and North America (Allen, (1981), Allen and Fenster (1986); Koronka, (1973)). Their inability to penetrate untilled soils to the depth required for cereals has generally limited their use in Australia to sowing small seeds, including horticultural crops (Logan, 1979).
Plate 6. A twin-disc stump-jump seeder developed by Mr Harry Williams of Nungarin, Western Australia. The trailing small angled plates float in the soil stream at ground speeds of up to 15 kilometres per hour, deflecting soil cut by the discs to provide seed coverage in the furrows.

3.3.3 Triple—disc drills

The addition of a disc coulter in front of the double—disc opener resulted in a lesser pull and load requirement in untiiled soil than a disc-and-knife opener (Koronka, 1973). Triple—disc drills are currently available from several manufacturers, and are used in parts of Europe, North America, Australia and New Zealand for sowing a range of crops (Plate 7).
Plate 7. Rear view of double-disc openers on a Western Australian-made triple-disc drill assembly.

Physical problems commonly experienced using the triple-disc drills include smearing of the sides of the slot in most soils, and inadequate slot closure for seed coverage. Choudhary and Baker (1981) observed similar seedling performance with and without soil smearing when deliberate attempts were made to achieve smearing. The use of a fluted rather than plain disc coulter in front of the double-disc opener loosened drying soil and increased seed coverage at Merredin (W. Booth, Research Station Manager, pers. comm. 1984). Steel reinforcing mesh or upturned toothed harrows were trailed behind to spread further loose soil into the drill slot. Rubber-tyred rollers have been used behind triple-disc drills in some areas in an effort to increase seed coverage, with uncertain results. Phillips 1984 suggests a slightly off-set alignment of the double-disc opener behind the coulter as a means of increasing soil shelter and coverage of seed.
Front discs of triple—disc drills are reported to typically require replacing after sowing 800 ha with a 3.5 m wide drill at 150 mm row spacing (P.J. Clarke, P. & D. Duncan Ltd, pers. comm. 1984). On stoney soils front discs have been severely worn down after sowing approximately 205 ha (K. Burchell, W.A. Dept. of Agric., pers. comm. 1987) (Plate 8). Bearing wear may also be considerable, in view of the relatively large load requirement of 125 kg per row (Baker ~t Œ.. 1979) in order to achieve penetration of dry soils.

Plate 8. Worn front coulters of a triple-disc drill after sowing approximately 205 ha of stoney soil.

Perceived inferior establishment of cereals using triple disc drills has largely confined their use in Western Australia to re—sowing sub.clover seed into cereal stubble and pasture, and lucerne establishment in south coastal areas.
4 Machinery for Cropping into Stubble

Effects of stubble on reducing wind and water erosion have long been observed in Western Australia. Porritt (1987) considers that erosion reduction is likely to remain the primary function of stubble retention.

4.1 Post—harvest treatments

Treatment of stubbles from harvest, onwards, affects the ease which a following crop can be sown. The direction of working may determine whether a seeder can operate through stubble, as harvesting at right angles to the direction of sowing reduces the constant bulk of stubble from a header trail which can block tillage implements. An intermittent load may be dispersed through the seeder before the next header trail is crossed. Alternatively, the header trail may be spread at harvest using straw choppers and spreaders.

4.1.1 Straw choppers and spreaders

The range of choppers and spreaders available for fitting to combine harvesters to spread straw and chaff (e.g. Plate 9) has recently been reviewed by Porritt (1987). Open—front headers can cut lower in the crop than comb—front headers, and therefore pass more material through the machine with more need for spreaders. Comb—front headers therefore leave longer standing stubble. Porritt (1987) noted that lowering the harvesting height from 0.40 m to 0.25 m above the soil surface, increased the amount of loose stubble after a 1 t ha$^{-1}$ grain yield from 500 kg ha$^{-1}$ to 900 kg ha$^{-1}$. 
Plate 9. A “Straw-Storm”® straw chopper and spreader also spreads material from the sieves, reducing weed-control problems in the header trail in the following year.

4.1.2 Grazing of stubbles

Grazing of stubble by sheep is an economically important component of cereal farming systems in Western Australia. The nutritional value of stubble is chiefly in the fallen grain, leaf and chaff (Purser, 1983). Since the straw has low nutritional value and is generally not grazed by sheep, systems of stubble retention with grazing are therefore possible. Proportions of cereal stubbles typically removed by grazing sheep are estimated at approximately 10% of the total mass of stubble in low rainfall areas of Western Australia (less 350 mm per annum average), up to approximately 30% in higher rainfall areas, where amounts of stubble are typically greater (H. Fels, W.A. Dept. of Agric. pers. comm. 1987).

A proportion of standing stubble is also flattened by grazing sheep. Porritt (unpublished data 1987) observed higher proportions of stubble cut 0.3 m above the ground surface flattened, than stubble cut 0.2 m and 0.1 m high. Flattening stubble increases the amount of straw which is in contact with the soil surface. Such contact cover reduces sheet erosion by overland flow, in addition to absorbing raindrop energy (Freebairn and Wockner, 1986) and is therefore beneficial for reducing water erosion.
4.1.3 Stubble slashing and flattening

The height of standing stubble may be reduced either by cutting low with an open-front header, or by slashing after harvest and prior to grazing. The objective is to reduce maximum straw length relative to the distance between the tines of cultivating and sowing machinery, and facilitate the smoother flow of stubble through the machine.

Flattening or partial flattening of the stubble may be achieved by dragging conveyor-belt matting, or chains over the stubble. Working in the same direction as future tillage or sowing operations under these circumstances may facilitate trash flow through machines. A second working by conveyor-belt matting or chains, towed at speed in the opposite direction on hot days, when the air temperature approaches 40°C shatters stubble into smaller pieces. Considerable varietal differences become evident in the shattering of stubbles of different wheat varieties by conveyor-belt matting or chains (S. Porritt, W.A. Dept. of Agric., pers. comm. 1987).

The maximum-possible amount of cereal stubble cover in contact with the soil surface may be considered to be required for reducing water erosion on cropland in Western Australia (see Section 2.0). A trade—off situation may therefore exist with respect to trash—flow through seeders, between flattening stubble to increase soil contact cover, and leaving more of the stubble standing and therefore anchored for superior trash flow through tillage or sowing machinery.

4.2 Machinery for tilling through stubble

Trash flow characteristics of machinery may vary with soil moisture, particularly as it affects straw adhering to tines in a soil types which become sticky when wet. Several machine characteristics affect the ability of stubble to pass without blockage.

4.2.1 Disc implements

Disc implements generally have greater stubble-clearing ability than tined implements, as observed by the common use of disc coulters (e.g. Koronka, 1973; Choudhary and Baker, 1981). Kushwaha ~ . (1986) found that a 460 mm diameter disc had a greater ability to cut stubble on untilled soil than discs of 360 and 600 mm diameter, with little difference between plain and fluted discs. Freebairn ~ ~J., (1986) report reduced stubble blockage and mud build-up using 550 mm diameter plain discs than smaller discs. Offset and tandem disc cultivators are commonly equipped with scalloped discs, though one-way disc ploughs and culti-trash seeders are almost universally equipped with plain spherical discs.

Discs tend to cut or positively displace straw, enabling stubble to flow past more easily. Hence discs may be placed in gangs, with adequate stubble clearance. Each disc or multiple of discs may still retain a stump-jump ability, as on one-way ploughs, and culti-trash and disc drills.

4.2.2 Tined implements
Tined implements lack the capacity of discs to slice through stubble lying on the soil surface. The tendency of individual tines to catch stubble is further increased when stubble collected by one tine comes in contact with stubble collected by an adjacent tine. An unstable situation may then arise, in which adjacent tines effectively combine to act as a rake, frequently resulting in total blockage of the implement. Tine spacing has therefore been increased, in an endeavour to enhance the flow of stubble.

The distance between tines may be increased by increasing the number of ranks of tines, and spacing them in patterns which maximize stubble flow through a machine, while leaving evenly-spaced ridges.

The shape of a tine also affects its ability to pass through stubble. Hermanson (~1985) report less raking of stubble using vertical tines than tines leaning forward. A tine curved in a semi-parabolic shape, with the point entering the soil at a sharp angle, had superior stubble flow characteristics compared to vertical tines. Stubble tended to be lifted up as the more backward-sloping tine passed, increasing its ability to flow through without clogging.

Tine spacing may also be increased by reducing the number of tines, and using wide sub-surface tools such as blade ploughs and rod-weeders, which till the soil under the stubble mulch. Less shanks therefore flow through the stubble with less possibility of blocking than on a cultivator equipped more shanks with narrower points. The powered, slowly counter-rotating rods of rod-weeders further entangle roots of weed seedlings, dislodging the seedlings, which may then die. However, the 25 mm thick, square or round rods are intrinsically vulnerable to obstructions such as stumps and stones, which effectively confines their potential use in Australia to native grassland which is free of stones in the surface soil. Rod weeders are therefore not used in the Western Australian wheatbelt, where stumps of the original native vegetation may be encountered below the soil surface.

**4.3 Surface stubble remaining after tillage**

The proportion of the original stubble which remains above the soil surface after tillage depends on both the implement used, and the condition of the stubble. Those few authors reporting detailed measurements indicate some variability in percentages of stubble remaining following tillage, even using similar implements. These measurements are summarized below, in order to allow an assessment of likely stubble remaining following tillage in Western Australia.

A higher proportion of 41 cm high wheat stubble remained on the surface than 15 cm high oat stubble, as reviewed by Colvin (~1980), shown on Tables 1 and 2.
Table 1. Residue conservation of tillage implements after one tillage operation on oat stubble 10 months after harvest. Pre—tillage residue was 15 cm high and averaged 2680 kg/ha (from Dickerson—A. 1967).

<table>
<thead>
<tr>
<th>Implement</th>
<th>Percent of pre-tillage residue weight remaining on surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium clearance flex sweeps</td>
<td>75</td>
</tr>
<tr>
<td>High clearance flex sweeps</td>
<td>70</td>
</tr>
<tr>
<td>Rigid sweeps</td>
<td>65</td>
</tr>
<tr>
<td>Chisels</td>
<td>40</td>
</tr>
<tr>
<td>One-way disc</td>
<td>30</td>
</tr>
<tr>
<td>Tandem disc</td>
<td>30</td>
</tr>
</tbody>
</table>

Table 2. Residue conservation of tillage implements after one operation on wheat stubble 10 months after harvest. Pre—tillage residue was 41 cm high and averaged 5880 kg/ha (from Dickerson et al. 1967).

<table>
<thead>
<tr>
<th>Implement</th>
<th>Percent of pre-tillage residue weight remaining on surface</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium clearance flex sweeps</td>
<td>65</td>
</tr>
<tr>
<td>High clearance flex sweeps</td>
<td>65</td>
</tr>
<tr>
<td>Rigid sweeps</td>
<td>55</td>
</tr>
<tr>
<td>One-way disc</td>
<td>55</td>
</tr>
</tbody>
</table>

Further data on surface residue retention after the passage of a wider range of sub-surface and surface tillage implements are shown on Table 3, from Colvin ~t ~J.. (1980).
Table 3. Pretillage residue maintained with subsurface and mixing implements (from V. Woodruff ~., 1966).

<table>
<thead>
<tr>
<th>Implement</th>
<th>Average residue remaining after each tillage operation</th>
<th>Range a</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Subsurface implements:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Blades (914 mm or wider)</td>
<td>90</td>
<td>70 to 113</td>
</tr>
<tr>
<td>Sweeps (610 mm to 914 mm)</td>
<td>90</td>
<td>60 to 112</td>
</tr>
<tr>
<td>Rodweeders — plain rod</td>
<td>90</td>
<td>80 to 115</td>
</tr>
<tr>
<td>Rodweeders — with semi—chisels</td>
<td>85</td>
<td>55 to 105</td>
</tr>
<tr>
<td><strong>Mixing implements:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Heavy-duty cultivator (406 mm to 457)</td>
<td>80</td>
<td>50 to 100</td>
</tr>
<tr>
<td>Heavy-duty cultivator (51 mm chisels apart)</td>
<td>75</td>
<td></td>
</tr>
<tr>
<td>One-way disc (610 mm to 660 mm discs)</td>
<td>50</td>
<td>30 to 90</td>
</tr>
<tr>
<td>Tandem or offset discs</td>
<td>50</td>
<td></td>
</tr>
</tbody>
</table>

a Values greater than 100 percent mean that more residue was brought to the surface than was buried.

Data on amounts of wheat residue remaining after four different fallow tillage sequences of operations are shown on Table 4, from Colvin ~ al. (1980).
Table 4. Amounts of wheat residue remaining after four different summer-fallow tillage sequences (from V. Woodruff g.t ~j. 1966).

<table>
<thead>
<tr>
<th>Tillage Sequence</th>
<th>(kg/ha)</th>
<th>Percent of pre-tillage residue weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 Pre—tillage</td>
<td>4,035</td>
<td>100</td>
</tr>
<tr>
<td>1 One—way disc</td>
<td>2,220</td>
<td>55</td>
</tr>
<tr>
<td>2 244 cm V—sweep</td>
<td>2,070</td>
<td>51</td>
</tr>
<tr>
<td>3 813 mm sweeps</td>
<td>2,140</td>
<td>53</td>
</tr>
<tr>
<td>4 Rodweeder</td>
<td>1,690</td>
<td>42</td>
</tr>
<tr>
<td>0 Pre—tillage</td>
<td>4,035</td>
<td>100</td>
</tr>
<tr>
<td>1 244 cm V—sweep</td>
<td>3,065</td>
<td>76</td>
</tr>
<tr>
<td>2 813 mm sweeps</td>
<td>2,660</td>
<td>66</td>
</tr>
<tr>
<td>3 Rodweeder</td>
<td>2,460</td>
<td>61</td>
</tr>
<tr>
<td>4 Rodweeder</td>
<td>2,300</td>
<td>57</td>
</tr>
<tr>
<td>0 Pre—tillage</td>
<td>4,035</td>
<td>100</td>
</tr>
<tr>
<td>1 51 mm chisels</td>
<td>2,700</td>
<td>67</td>
</tr>
<tr>
<td>2 813 mm sweeps</td>
<td>2,460</td>
<td>61</td>
</tr>
<tr>
<td>3 Rodweeder</td>
<td>2,545</td>
<td>63</td>
</tr>
<tr>
<td>4 Rodweeder</td>
<td>2,376</td>
<td>59</td>
</tr>
<tr>
<td>0 Pre—tillage</td>
<td>4,035</td>
<td>100</td>
</tr>
<tr>
<td>1 One-way disc</td>
<td>2,220</td>
<td>55</td>
</tr>
<tr>
<td>2 One—way disc</td>
<td>1,575</td>
<td>39</td>
</tr>
<tr>
<td>3 813 mm sweeps</td>
<td>1,740</td>
<td>43</td>
</tr>
<tr>
<td>4 Rodweeder</td>
<td>1,490</td>
<td>37</td>
</tr>
</tbody>
</table>

Indications of percentages of the original stubble likely to remain on the soil surface after the passage of tillage implements in Western Australia, may be obtained from Tables 1 to 4.
4.4 Machinery for sowing into stubble

4.4.1 Disc seeders

Disc seeders, like disced tillage implements, are generally better adapted to sowing into stubble than tined seeders. Culti-trashes and one-way-plough seeders are currently routinely used for sowing particularly lupins, but also cereals into stubble (P. Nelson, W.A. Dept. of Agric. pers. comm. 1987). The seed environment achieved using the International “Colta-disc®” was considered difficult in clumps of stubble (G. Riethmuller, pers. comm. 1987). Baker (1979b) report general principles gleaned from a series of developmental trials of disc—and—tine combinations for improved trash clearance. Plain discs which were not set at an angle by the direction of travel, tended to bury straw, leaving the ends sticking out like a hair pin.

They concluded that disc coulters set deeper than a following sowing tine decrease blockages by burying uncut straw.

A perceived disadvantage of one-way plough seeders, in particular, and to some extent of culti-trashes, is their relatively poor seed placement. Riethmuller (W.A. Dept. of Agric. pers. comm. 1986) has also observed a relatively wide range in the placement of wheat seed with depth by wide tined seeders. Nelson (pers. comm. 1987) suggests that seedling emergence is similar after sowing wheat or lupins using either culti—trash or tined seeders.

4.4.2 Tined seeders

Gravity feed of seed and fertilizer represents a physical limitation to the number of ranks of tines on combines with seed-box delivery mechanisms. Pneumatic delivery of seed and fertilizer allows wider spacing of tines for trash flow than gravity feed systems. The development of pneumatic air-seeders in the late 1960s enabled existing tined cultivation implements such as scarifiers and chisel ploughs to be converted for sowing, provided that a sowing boot could be fitted to each tine.

The number of ranks of tines on air-seeder bars is limited by the feasible length of forecarriage from the tractor drawbar. This is because when the machine skews slightly as a tine on one side hits an obstruction, a rear-rank tine can pull into the furrow made by a front-rank tine. Since there is less resistance in this mode of operation, it remains there. These rows are then double-sown, with double spacing between rows, and various spacings between other rows throughout. The longer the drawbar forecarriage, the less likely a rear tine will track behind a front tine in this manner. Forecarriage length is restricted in practice by the need for some manouvrability of the machine.

Scarifiers and chisel ploughs have been adapted for sowing in Queensland. Their superior trash-flow, when compared with the traditional combine or cultivator bar (Ward and Robotham, 1986) and generally higher break-out forces (Robotham and Norris, 1986; Robotham ~ 1983) make them suitable for nu—till cropping with stubble retention. A converter is available commercially, with sowing tubes and 30 mm wide spear points.
or 100 mm wide duck—foot points for scarifier or chisel—plough tines (Brian Kulp, Connellan Castings, pers. comm, 1987) (see Plates 10 and 11).

The recent trend to stubble retention for conservation farming has also resulted in increased tine spacings on combines. A stubble seeder has been developed by Mead and Wedd (1982). Some tine configurations and their requisite clearances are discussed by Colless (1985). The traditional four ranks of tines have been increased to six, with three ranks of cultivating tines preceding three ranks of sowing tines. The complete removal of cultivating tines has also allowed sowing tines to be spaced over more ranks, facilitating the flow of stubble through the machine.

Narrow chisel, spear or winged points on existing combines or air seeders or scarifiers may therefore represent an economically viable method of reducing tillage and retaining stubble. Minimal additional outlay of capital would be required for such machinery adaptations, while maintaining or increasing crop yields.

4.4.3 Tine—and—disc combination seeders

A disc coulter may be located directly in front of each tine in order to slice straw and facilitate its flow through the machine, particularly on untilled soil. Scalloped discs were found to be more effective for minimizing “hair-pinning” of straw by pushing it below the seed zone by (Baker ~ 1979a), Freebairn ~ (1986) report adequate sowing through evenly-spaced stubble of up to 6 t ha~ at 250 mm row spacings, using a 550 mm diameter smooth coulter in front of a 30 mm wide spear point with sowing boot attached. Disc coulters may be required in front of tines under heavy stubble conditions even where a narrow path has been cleared at approximately 400 mm row spacings by a powered, rotating finger rake (Hyde ~ ~., 1979).

A seeder using sowing boots on single stump-jump discs, attached behind a widely—spaced tined cultivator for enhanced stubble clearance has been assembled by Mr Derek Morrell at Moonyoonooka, near Geraldton. A spraying boom is also mounted on the frame ahead of the tines, in order to apply and incorporate herbicides, and sow in a one-pass operation (Plate 12).
Plate 12. Pneumatic seed and fertilizer delivery to sowing boots, attached to single stump-jump individually-mounted discs behind a cultivator with widely-spaced tines for stubble-clearance, in order to achieve uniform depth of sowing.

4.4.4 Press wheels on seeders

Metal or rubber press-wheels may be used to apply pressure to the seed zone (Plate 13). Metal press wheels significantly increased emergence of barley on non-wetting sands (Crabtree, W.A. Dept. of Agric. pers. comm. 1987). Ward and Norris (1982) report beneficial effects using a single-ribbed pneumatic press-wheel on wheat sown in heavy clay soils. They attributed these effects to possibly increased soil cover and seed-soil contact on heavy clay soils, though seedling vigour was reduced on a poorly-structured soil. Radford (1986) reported increased establishment of wheat on heavy clay soils, though not on a sandy loam. Seedling establishment increased from 74 per cent to 88 per cent at a sowing depth of 46 mm using a loading of 5.6 N per millimetre width of press wheel on a black earth (Ug 5.15, Northcote) and from 55 per cent to 89 per cent at 85 mm (Radford and Wildermuth, 1987).
Plate 13. A press—wheel with variable spring loading and a loose rubber “zero-pressure” tyre, which reduces mud build-up in sticky clay soils.

Improved development of secondary roots has been observed under some conditions using press-wheels on heavy clay soils in Queensland (Norris and Ward, 1983). Where wheat crops could be reliably established without press wheels, yield advantages were not necessarily observed. A primary function of press-wheels is to compact moist soil around the seed, in order to enhance the establishment of seedlings for future growth on sub-soil moisture, in an environment in which no rainfall may occur during an entire growing season. They report the successful establishment of a wheat crop 89 days after the last significant rain, for example, which they attribute to the beneficial effects of press-wheels. Freebairn \~. (1986) recommended the use of a large smooth-disc coulter and spear point opener with press wheel for sowing without tillage in Queensland.

The few known instances of the use of press—wheels in Western Australian wheat-growing have met with mixed success. Seedling establishment has been adequate using the International “Colta-disc”® on an experimental seeder on moist loamy soils (G. Riethmuller, pers. comm. 1987). Seedlings sown using a Noble® press-wheel drill in loamy sand at first throro but later lagged behind those sown using a conventional tined seeder. This may have been caused by the relatively high pressure of 19 kg per
centimetre width of press-wheel, compared with the 10 kg per centimetre width used by Ward and Norris (1982), and 5-15 kg per centimetre used in their subsequent work (C.P. Norris, South Australian Dept. of Agriculture, pers. comm. 1987). Further trials of press—wheels on farm and experimental seeders are proposed. Increased seed—soil contact using press-wheels offers the prospect of less patchy establishment of wheat in stubble on loamy soils. (J. Blake; G. Riethmuller; W. Crabtree; W.A. Dept. of Agric. pers. comm. 1987).

4.5 Harrows

Harrows are frequently attached behind tined implements in Western Australia, in order to further uproot weeds and spread clumps of stubble, achieve and flatten ridges to achieve a more even sowing depth, and a smoother surface at harvest and for future pasture years. A range of harrows are used.

4.5.1 Tined harrows

Light, stump-jump tined harrows are also available in a heavier form for higher speed operation. They may clog in heavy stubble, as indicated by their traditional use in fire harrowing for burning scattered stubble, or as a hydraulically-operated rate for burning stubble in windrows. Tined harrows may be attached to combines (Plate 3), or used independently on a light, wheeled harrows frame.

4.5.2 Finger harrows

Light coiled fingers have been attached to tined seeders in order to level ridges or increase soil coverage over seed. Finger harrows may also be located behind each tine in order to decrease soil coverage. Stubble tends to hook around the fingers, reducing their effectiveness, and sometimes resulting in their acting as a rake in heavy stubble. Angling the fingers backwards improves their stubble—handling ability, but reduces their levelling effectiveness.

4.5.3 “Connor Shea”® Horizontal revolving harrows

Toothed harrows which can rotate horizontally on forward motion, also level ridges and uproot weeds, though they may become blocked with straw in heavy stubble.

4.5.4 “Flexicoil”® harrows

Triangular steel bars arranged helically in the shape of a roller of approximately 0.5 m diameter, readily clear stubble and smooth ridges. Increased seed-soil contact and reduced wind erosion are sometimes attributed to the slight compaction effect of flexicoil harrows.

4.5.5 Chain harrows
Chain harrows are typically a length of chain mounted in bearings at the extreme edges of a seeder so that it rotates on forward motion. They have a smoothing action on ridges following tillage, providing a more even depth at sowing. Rolling chain harrows have heavy-link chain with ends mounted in bearings. Steel spikes may be welded on both sides of each link, for more effective spreading of clumps of stubble collected by tined seeders.

4.5.6 “Phoenix”® rotary spike harrows

Patterns of interlocking, bent steel rod strung together as a chain sometimes with a central thick steel rope for increased weight and rigidity, are termed rotary spike harrows. More robust than a simple rolling chain, rotary spike harrows may be mounted at the rear of combine or air-seeder frames, or independently on wheeled bars (Plate 14). They smooth ridges and clumps of stubble and may retrieve part of any stubble buried by tined seeders.


4.5.7 Bar harrows

Overlapping trailing lengths of steel bar, such as railway iron cause loose soil to fall in and cover seed in the groove, as well as provide a scuffing and smoothing action on the surface of untilled soils (Baker 1970).
5 Relevance of Reduced Tillage and Stubble—retention
Machinery in Western Australia

Cropping with the minimal soil disturbance consistent with maintaining yields reduces water erosion, particularly on sloping loamy soils in medium and higher rainfall areas of Western Australia. Stubble—retention is also desirable to reduce water erosion on cropland, including during high-intensity storms on sandy soils in low rainfall areas. Machinery systems for cropping with reduced water erosion must therefore be capable of preparing a satisfactory micro-seedbed with minimal soil disturbance, and/or of sowing into stubble.

In view of the currently depressed economics of wheat-growing, and the high cost of capital, modifications to machinery systems for immediate application on farms should preferably require little additional capital outlay in order to be acceptable to the majority of farmers, (Ward ~t~. 1987). Inexpensive modifications to machinery already available on farms, will therefore be more readily adopted by the farming community than expensive new machinery.

Variable costs and cash flow are altered by factors such as the increased use of herbicides required under reduced tillage. Machinery costs and cropping rotations may also need to be changed. Economic benefits of erosion—reduction systems may only be fully realized in the long term (Ward ~ ~. 1987). Sweeting (1985) and Freebairn ~ ~ (1986) stress the importance at new management skills in no-tillage cropping. Reduced tillage and stubble—retention cropping must therefore be considered as a whole—farm system.

Agronomic research has identified some of the principles governing the degree of soil disturbance required for satisfactory seedling establishment and yield on particular soil types (e.g. Jarvis ~ ~. 1986). Increased crop yields over minimal soil disturbance cropping have been shown to occur on sandy soils following surface disturbance over the complete width of sowing, particularly in low rainfall areas,. Stubble retention is therefore important for reducing water erosion on such sandy soils during occasional intense storms following sowing in late autumn or early winter.

In view of the large amount of stubble cover required after sowing relative to the usual initial stubble levels (1.5 to 2 t ha~, Freebairn and Wockner, 1986b), working through stubble should preferably be confined to the sowing operation alone. Therefore additional weed control, if required, must be achieved using herbicides.

A limited range of narrow points may currently be fitted to existing tined seeders, with little additional capital outlay. The stubble handling ability of many existing combines on farms is inferior to that of newer combines and air seeders with higher under-frame clearance and more widely—spaced tines. Sowing is easier in stubble which has been broken into shorter lengths by lower harvesting, using choppers and spreaders on headers, or by slashing or breaking up and flattening after harvest, facilitates sowing. Stubble-handling should therefore be considered as a system which begins at harvest.
Scarifiers and chisel ploughs have been adapted for use as minimal-soil-disturbance seeders for improved stubble handling in Queensland by fitting converters with spear points to tines (Ward and Rowbothani, 1986). Similar converters could be used in Western Australia, though closer row spacings than the 300 mm typically available on chisel ploughs, may be necessary for achieving optimum yields (Burch, 1986). Doubling the number of tines may therefore be required, with an increased number of ranks to maintain stubble handling ability. Press-wheels may further enhance seedling germination and establishment in stubble or on clayey or loamy soils, and non-wetting sands.

Gypsum applied at rates of up to 5 t ha\(^{-1}\) may be used to profitably enter a minimal—soil—disturbance system of cropping responsive soils, whose structure has been degraded (Howell, 1987).

Approximately 4 million hectares of the 6 million hectares cropped in 1986 in Western Australia followed annual pasture, which is typically closely grazed prior to sowing. Requirements for sowing following pasture include providing a weed-free micro-seedbed for adequate plant establishment and yield. Soil erodibility is reduced if the initial knock—down of weeds is achieved chemically using herbicides rather than mechanically by tillage, both by prolonging the interval before tillage loosens the soil and by reducing the intensity of tillage at sowing.

Sowing with complete surface soil disturbance using existing machinery without prior tillage, improves soil structure under continuous cropping on loamy soils. Sowing then requires little if any seedbed preparation on loamy soils, particularly in medium and high rainfall areas of Western Australia (Jarvis, 1986). The stage is set for ultimately reducing soil disturbance to a minimum, in order to reduce erodibility while maintaining crop yields.

Optimum sowing depth can be achieved by raising or angling the sowing boot, so that seed and fertilizer are placed after some loose soil has fallen into the groove created by a narrow point. Shallow sowing behind a deeper, seedbed-forming tine may alternatively be achieved by using either a separate sowing point of disc following immediately behind. Narrow winged or chisel points with raised boots, may currently be fitted to existing combines and air seeders for reduced soil disturbance. Though modern combines and air seeders are generally capable of penetrating moist undisturbed soils in Western Australia, higher break-out forces may be required when using deep-vaned points for tillage below the seed zone.

Relatively high wear rates of chisel points and winged openers which provide considerable sub-surface tillage may be reduced in future developments using a combination of disc and wings, after Baker (197gb). However, the considerable weight required for penetration of hard soils by machines such as the “Bio—Blade” or triple-disc drill (up to 125 kg per opener) makes them more vulnerable to damage caused by underground obstructions, and increases their cost. The application of metallurgical improvements which have reportedly doubled the life of excavator bucket teeth may reduce wear rates of points.
Minimal-soil-disturbance cropping with stubble retention may be achieved within the present economic constraints of grain—growing, by removing cultivating tines (if any) and fitting inexpensive winged, winged-and-vaned or chisel points on more widely spaced sowing tines on existing air seeders and combines. More exotic developments such as experimental disc seeders, or disc—and—tine combinations, should be investigated for effects on crop establishment and soil erodibility, as sowing implements currently available on farms require replacement in the longer term.
6 References


Robotham, B.G. and Norris, C.?. 1986. Commercial scarifier and cultivator tines an engineering comparison, Queensland Dept. of Primary Industries, Information Series Q1 85020.


7 Acknowledgements

The contributions of the following people in making available information noted in the text, is gratefully acknowledged:— Barber, Richard farming at Macalinden, near Collie, Western Australia;

Clarke, P.J. Sales Manager, P. & D. Duncan Ltd., 204 St Asaph Street, Christchurch, New Zealand;

Johnson, W. Concept Engineer, Ralph McKay Limited, 36-46 Hampstead Road, Maidstone, Victoria 3012;

Morrell Derek farmer of Moonyoonooka, Western Australia 6532;

Norris, C.P. Agricultural Engineer, Department of Agriculture, Kadina, South Australia 5554

Ritchie, W.R. Associate Research Officer, Agricultural Machinery Research Centre, Massey University, Palmerston North, New Zealand;

Williams, Harry farmer, of Nungarin, Western Australia 6490;

The following personnel of the Western Australian Department of Agriculture also contributed as noted:Blake, N.J. Adviser, Division of Resource Management, South Perth;

Booth, W. Manager, Merredin Research Station, Merredin 6415;

Burchell, K. Manager, Avondale Research Station, Beverley 6304;

Carter, D.J. Research Officer, Division of Resource Management, South Perth 6151;

Crabtree, W. Adviser, Esperance District Office, Esperance 6450;

Doyle, R. Machinery Adviser, Dryland Research Institute, Merredin 6415;

~Fels, H.E. Adviser, Plant Research Division, South Perth 6151;

Fosbery, G. Officer-in-Charge, Three Springs District Office, Three Springs 6519;

Gilbey, D.J. Senior Research Officer, Weed Agronomy, W.A. Department of Agriculture, South Perth, 6151;

Jarvis, R.J. Senior Research Officer, W.A. Department of Agriculture, South Perth, 6151

Laing, I.A.F. Adviser, Division of Resource Management, South Perth 6151; Nelson, P. Adviser, Geraldton District Office, Geraldton 6530;
Pearce, G.A. then Principal Research Officer, Plant Research Division, South Perth 6151;

Perry, M.W. Senior Research Officer, Plant Research Division, South Perth 6151;

Porritt, S.E. Adviser, Dryland Research Institute, Merredin 6415;

Riches, J.R.H. Senior Adviser, Division of Resource Management, South Perth 6151;

Riethmuller, G. Engineer, Dryland Research Institute, Merredin 6415;

Sweetingham, M. Plant Pathologist, Plant Research Division, South Perth, 6151.

The advice of many farmer-inventors and landholders together with other colleagues and personnel in the farm machinery industry was greatly appreciated in carrying out this review. Glen Riethmuller, Steve Porritt, Bill Crabtree and Ron Jarvis also contributed helpful comments on the manuscript.