Chapter 7

CROP RESIDUE MANAGEMENT

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Crop residues traditionally have been burnt as the first step towards preparing a seedbed. As early as the 1920s, however, the value of retaining stubbles to reduce wind erosion had been recognised in southern Australia, while their value in reducing water erosion in the northern cereal-growing areas was first appreciated in the 1940s (Chapters 2 and 3). Despite the early recognition of the value of crop residues, they have been retained on a wide scale only in recent years, and then only in summer-rainfall areas. The cost of retention in most cases has clearly outweighed the benefits, at least the benefits perceived by farmers.

Improved soil and water conservation with residue retention has not always resulted in higher crop yields. Indeed, there have been problems with crop establishment and nutrition, pests and diseases, and with weed control in fallows. In view of the strong case for retaining residues, argued elsewhere in this book, there is a need to learn how to manage crop residues in a way that maximises the benefits to be achieved while minimising the problems associated with the practice. The principles involved in effective residue management are discussed in this chapter.

ROLE OF RESIDUES IN SOIL AND WATER CONSERVATION

An important factor in managing residues is the amount needed to achieve the desired result. Reducing the amount of residue to the minimum required, the 'target level', will frequently reduce the problems associated with it. This section examines residue rate in relation to the primary objectives of residue retention - soil and water conservation. Later sections examine the means of achieving this level, and of coping with supra-optimal levels of stubble.

TARGET RESIDUE RATES FOR SOIL AND WATER CONSERVATION

Before tillage and residue management systems can be designed for a particular region, soil type or paddock, an understanding of the physical attributes that influence moisture accumulation and soil erosion is needed. This section discusses the general principles for water and soil conservation in terms of crop residue cover and the combined effects of tillage and residue retention. Wider aspects of soil erosion and soil and plant water relations are considered in Chapters 6 and 8, respectively.

Water conservation

Accumulation of water in the soil profile is the primary role of fallows in regions that depend on stored soil water for subsequent crop growth (Chapter 8). A measure of the effectiveness of fallowing is fallow efficiency - the proportion of rainfall stored during the fallow period as soil water. Fallow efficiency depends on the rates of infiltration and evaporation from the soil surface, both of which can be influenced by residue management.

The traditional fallow is a relatively inefficient way of storing water. On coarse-textured soils this can be as low as 3% (French, 1978) but is usually in the range 15-25% for fine textured soils (Kohn *et al.*, 1966; Fawcett, 1967; Freebairn *et al.*, 1986; J.W. Littler and J.M.T. Marley, unpublished data). Good residue management can increase fallow efficiency by increasing infiltration and in some situations (where rainfall occurs regularly) by reducing evaporation from the soil surface.

Evaporation

Soil evaporation accounts for the major loss of soil water during the fallow period. One experiment over 4 years on the Darling Downs showed that two-thirds of rainfall was lost as evaporation, regardless of residue management (Figure 7.1). In this experiment, retaining stubbles increased fallow efficiency from 21% to 29% but this was achieved by reducing runoff rather than evaporation.

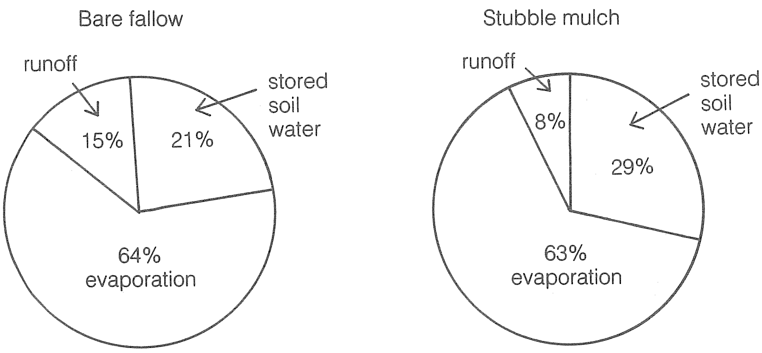


Figure 7.1 Summer water balance for bare fallow and stubble mulch (sweep tillage) at Greenwood 1978/79–82/83 on a grey clay soil with a mean fallow rainfall, December–June, of 440 mm

Results of research from the United States as summarised by McCalla and Army (1961) indicate the general effect of a residue mulch on soil evaporation. Evaporation is reduced only when the soil surface is maintained at a high moisture content by frequent rains or when extremely high rates of mulch (10-15 t ha^{-1}) are applied. A mulch has little value during extended dry periods. The authors' conclusion is supported by data from 0.5 m diameter weighing lysimeters at Toowoomba, Queensland, using a 'brigalow' grey clay soil (Freebairn, 1984). An 80% stubble cover (4000 kg ha^{-1}) reduced soil evaporation over a 5 month winter fallow by only 8 mm. The experiment showed that mulch reduced evaporation slightly for a brief period after rainfall, presumably because of the higher albedo of the stubble, but the cumulative evaporation from both bare and stubble surfaces was similar once the soil surface (10 mm) was dry (Figure 7.2).

In South Australia, Schultz (1972) also found that a straw mulch slightly increased water-storage efficiency, in this case on a red-brown earth soil. The effect of mulch was greater in a wet than in a dry season. At Wagga Wagga, New South Wales, 6 t ha^{-1} of stubble reduced evaporation from a red-earth soil by almost 10 mm in the first 24 hours after simulated rain in February. After 16 days without rain this soil retained no more water than one with no stubble cover (P.S. Cornish, unpublished data).

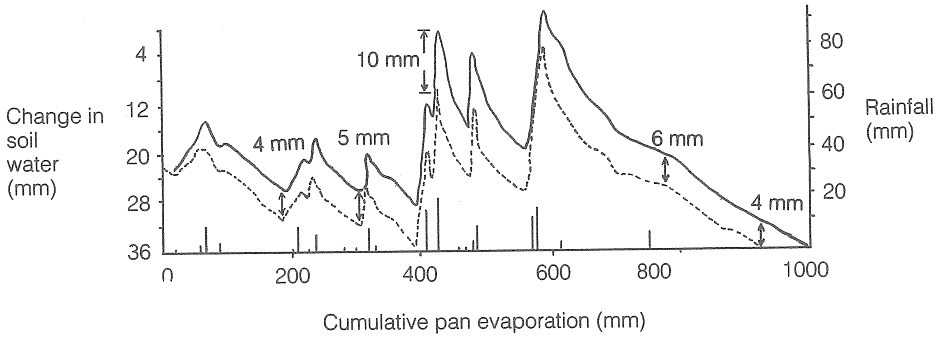


Figure 7.2 Change in soil water due to evaporation for two soil-surface conditions: bare surface (---), and 4000 kg ha^{-1} stubble (——), May–Nov., 1982 (205 days) in a brigalow grey clay soil

Although the effect of stubble on total water storage is usually small, an increase in the water content of the surface soil can affect sowing. Radford and Nielsen (1983) found that stubble levels as low as 2000 kg ha^{-1} extended the time for successful planting (50% establishment) by 2-6 days. The extension of the planting period allows greater areas to be sown at optimal dates.

For the purpose of residue management it is important to know how much residue is needed to minimise evaporation, whether standing stubble or flattened straw is preferred, and if straw of different crops gives a different result. Unfortunately there are almost no data of this kind for Australian conditions, although it seems that high rates will be needed to significantly reduce evaporation and increase total water storage in fallows.

Infiltration

Residue retention increases water storage even though evaporation is often not significantly reduced, as shown in Figure 7.1. The main benefit of stubble is increased infiltration. A cover of crop residue affects infiltration by reducing the raindrop energy at the soil surface. This results in less detachment of soil particles and disruption of soil aggregates, thus maintaining

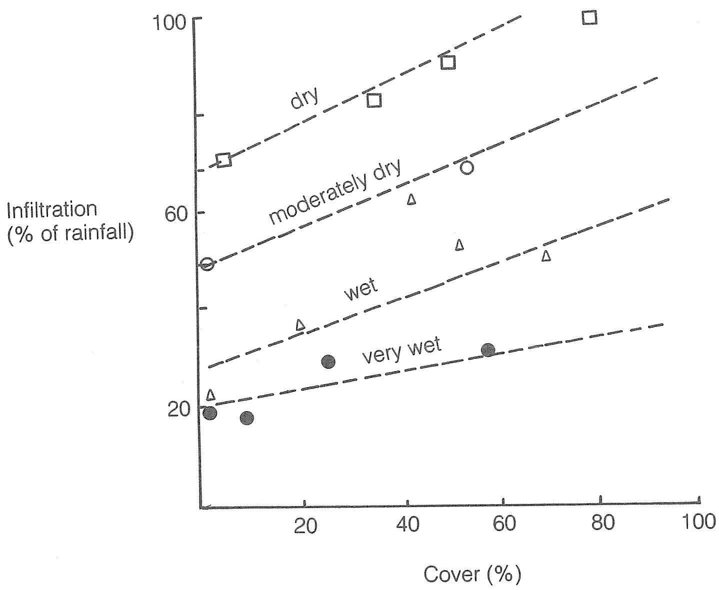


Figure 7.3 Effect of soil-surface cover on infiltration into a black earth for four soil-moisture conditions

the size and number of soil-surface voids for a greater time. The amount of surface cover, either from dead plant residue or a growing crop, influences the rate of infiltration of rainfall (Freebairn and Boughton, 1981). There is an approximately linear relationship between cover and infiltration, but cover becomes less effective as the soil profile fills (Figure 7.3). Infiltration into a wet soil is controlled more by the whole profile than by a limiting layer at the surface. The situation where stubble is almost ineffective often occurs at the end of a fallow, which also coincides with a declining amount of residue from the previous crop. Consequently erosion potential increases in these circumstances and the amount of cultivation becomes an important factor in controlling soil loss.

The results in Figure 7.3 for a black-earth soil show that about 90% cover is needed to maximise infiltration in a dry soil. A cover of 80% was achieved with 4000 kg ha^{-1} of wheat stubble. On a dry red earth soil, 4000 kg ha^{-1} of grazed wheat stubble maximised infiltration of 78 mm of rain received over 5 days (P.S. Cornish, unpublished data). Stubble increased infiltration by 30 mm compared with bare soil. While there is a roughly linear response to stubble in many situations, these limited data suggest that 4 t ha^{-1} of wheat stubble should be the target rate to minimise runoff. This is roughly equivalent to the residue of a 2.5 t ha^{-1} crop immediately after harvest.

Interactions between residue retention and cultivation

The method of stubble retention can influence infiltration and hence both runoff and total water storage. A no-till fallow may result in more runoff than stubble mulching where the soil is cultivated (Figure 7.4). Cultivated soils with the stubble retained primarily on the surface (stubble mulched) have greater surface storage porosity in the top 10 cm than uncultivated soils with the stubble retained. This can result in higher runoff from uncultivated areas. Both give less runoff, however, than burning and cultivation.

Cracks are an important route for infiltration in swelling soils. Cultivation can close these cracks and reduce infiltration. When a soil is dry and cracked, very intense rainfall (> 50 mm hr^{-1}) can infiltrate directly into soil cracks and be quickly redistributed to the bottom of the soil profile. This can be referred to as 'filling up from the bottom'. If a cracked soil is

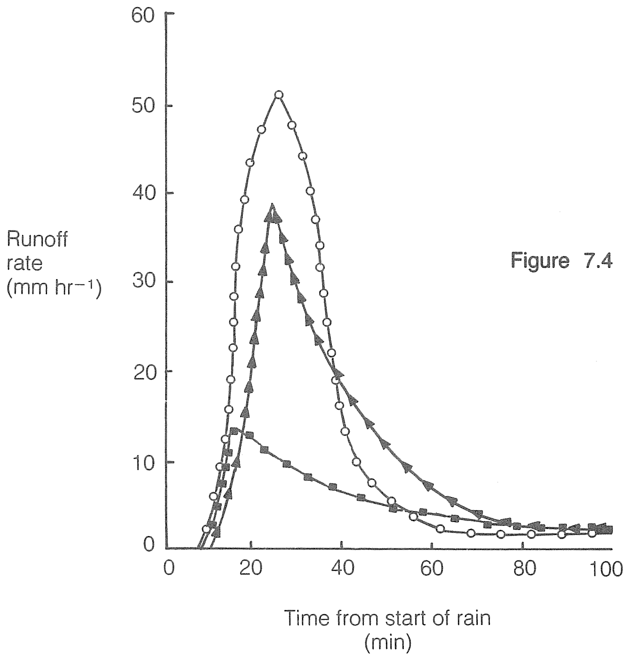


Figure 7.4 Runoff hydrographs after 36 mm rainfall from 0.8 ha catchments with three tillage methods on a brigalow grey clay at Greenwood (Nov. 6, 1981); ○ stubble burn (2% cover), ■ stubble mulch (20% cover), ▲ no-till (26% cover)

cultivated, the pore continuity may be reduced or lost, especially if no stubble residue is available. Once cracks close, even in the surface 30 cm, this mechanism of water entry becomes less important. Rapid infiltration of water via cracks has been observed in 5 out of 6 years since 1978 on the eastern Darling Downs. This process is apparent in the field by the presence of 'sink holes' or residual cracks, with visible overland flow pathways of local runoff water into cracks.

Soil conservation

Soil erosion can be caused by both wind and water and is related directly to land-management practices. Tillage and removal of vegetative cover to prepare a seedbed predispose the soil to erosion by reducing soil structural stability and by increasing runoff.

The susceptibility of the soil to erosion is determined by physical features of the soil and particularly by its management (Rosewell and Marston, 1978). The effect of management on soil erosion and the beneficial effect of retaining plant residues are shown in Table 7.1.

Table 7.1 Effect of cropping practice on erosion at Gunnedah Research Centre, New South Wales (Rosewell and Marston, 1978)

Practice	Relative soil loss (%)
Wheat—long fallow, stubble burnt	100
Annual wheat—stubble burnt	40
Annual wheat—stubble incorporated	14
Permanent pasture	1

Water-induced erosion

The major role of surface cover, whether from growing plants or from residue from a previous crop, is to protect the soil from the impact of falling raindrops and overland flow. Interception of raindrop energy reduces soil detachment and breakdown of aggregates to finer, more easily transported particles. Cover also reduces erosion by reducing runoff and the sediment concentration in that runoff water (Figure 7.4, Figure 7.5).

Analysis of soil-erosion experiments conducted over 8 years on the eastern Darling Downs has shown that soil losses were generally less than 5 t ha^{-1} yr^{-1} when a surface cover of 20-30% was

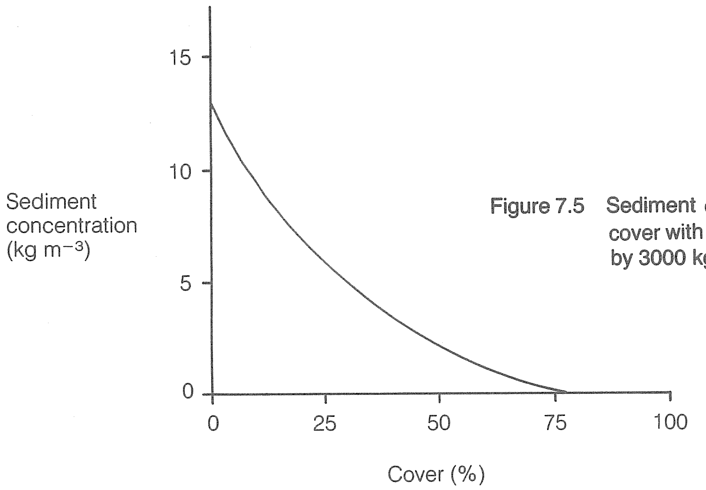


Figure 7.5 Sediment concentration of runoff at flume vs ground cover with stubble mulching (50% cover was obtained by 3000 kg ha^{-1} of stubble)

maintained over the summer rainfall period (October to March), while soil movement from winter crop/bare summer-fallow treatments was 60 t ha^{-1} yr^{-1} (Freebairn and Wockner, 1986).

Although no-till can lead to more runoff than stubble mulching, soil loss is less because sediment concentration is lower in runoff from the untilled soil (Freebairn and Wockner, 1986). No-till offers the best protection against erosion, even when the soil profile is wet and a cover of stubble has little effect on runoff (Figure 7.3).

The amount of stubble required to reduce soil loss to an acceptable level depends on soil type, stubble type and distribution, rainfall duration and intensity, length and steepness of slope and type of land-management practice being implemented. Woodruff *et al.* (1966) used equations to calculate the amount of flattened stubble required to reduce soil loss to specified amounts on different soil types. These data were used by Wingate-Hill and Marston (1980) to indicate the amount of stubble needed to reduce soil loss to 12 t ha^{-1} yr^{-1} on three general soil types on land of 8% slope in northern NSW (Table 7.2). This loss would be acceptable only on deep soils. These results are consistent with those obtained on clay soils of the Darling Downs (Freebairn and Wockner, 1982; 1986). In northern New South Wales and southern Queensland the period in which high-intensity rainfall is most likely is from October to March (Rosewell and Marston, 1978; Rosenthal and White, 1980). Therefore, the desired stubble level for erosion control should be maintained for the period October to March. Examination of historic rainfall records will provide information on the period most prone to runoff and erosion in other areas.

Table 7.2 Stubble amounts required for erosion control on land of 8% slope in northern New South Wales (Wingate-Hill and Marston, 1980)

Erosion type	Soil type	Amount of flattened stubble required (kg ha^{-1})	
		Wheat stubble	Sorghum Stubble
Water	Loamy sand	900	2800
	Silt	1500	4300
	Clay	2000	5400
Wind	Silt	900	2600
	Clay	1600	4800
	Loamy sand	2100	6200

Weight of dry matter and percentage cover are practical measurements of surface cover. Tall, coarse crops provide less protection than close-growing crops because of their more open canopy. For 90% effectiveness of raindrop interception, approximately 2500 kg ha^{-1} of close-growing crops (e.g. wheat) or 4000 kg ha^{-1} of tall, coarse crops (e.g. grain sorghum) are required. At 1000 kg ha^{-1} there is no significant difference in the two kinds of crops; both are about 60% effective (Stallings, 1957). As a general rule wheat stubble retained as a surface mulch at 2000 kg ha^{-1} will provide adequate soil protection against soil erosion.

Wind-induced erosion

Wind erosion is a serious problem in cropping areas on the light-textured soils of Western Australia, South Australia, Victoria and south-western New South Wales. The important management factors influencing wind erosion are stubble orientation and amount, and sheep-stocking rates. Vegetative cover is an important factor in reducing wind erosion. Anchorage, orientation of cover, and density of standing stubble as well as total dry matter present are determinants of the effectiveness of residues.

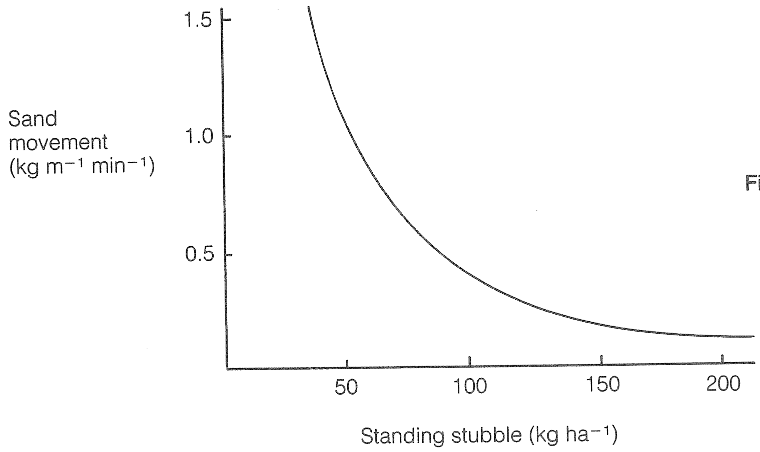


Figure 7.6 Effect of anchored stubble on wind-induced erosion (D. Carter, personal communication)

Standing stubble reduces wind erosion by reducing the wind velocity at the soil surface. Small amounts of standing stubble were found by D. Carter (personal communication) in Western Australia to be very effective in protecting the soil surface (Figure 7.6). The amount of stubble required in this work was considerably less than the calculated amount shown in Table 7.2 using the data of Woodruff *et al.* (1966), reflecting differences in soil texture or management, and the orientation of the stubble.

MAJOR DIFFICULTIES WITH RESIDUE RETENTION

Many factors interact to determine the growth and yield of crops in response to residue retention. The beneficial effects of increased water storage and reduced soil erosion can be offset by less effective or more expensive weed control, incorrect nutrition, reduced crop establishment, reduced soil temperatures and the phytotoxicity of residues. Stubbles can be managed, however, to minimise the risk of these factors reducing yield.

Weed control

The tillage practices used between successive crops in Australia vary from a burn-plough-cultivate system to no-till, in which herbicides fully replace cultivation for weed control and residues are retained. The many alternatives between these extremes can give rise to considerable differences in soil disturbance and the amount of residue present. When cropping intensity and rotations are also varied it is clear that weed flora and populations, and the appropriate control measures will also vary greatly, even within regions with homogeneous climate and soil type.

Pre-sowing weed control in the presence of stubble

Cultivated fallows The presence of crop residues on the soil surface makes weed control more difficult as the cultivated soil dries more slowly and weeds may re-establish. Residues may also wrap around tillage machines, leading to clumps of weeds, soil and straw.

When stubbles are retained, good weed control with tined implements or a blade plough requires drier soil conditions than with a disc plough. Moisture loss from the surface is reduced with stubble mulching, giving weeds a better chance of surviving disturbance if the soil is too moist or if rain follows soon after cultivation. Weeds die slowly in such conditions and the uneven surface makes future tillage operations difficult. Although a disc implement controls weeds better than a tined cultivator or blade plough under wet conditions it buries the residue and leaves the soil unprotected unless initial residue levels are very high.

Herbicide fallows Herbicides can replace cultivation for weed control during the fallow period and have the advantage of maintaining the level of crop residue on the soil surface. However, herbicide effectiveness may also be reduced by heavy stubbles, which can intercept the herbicide before it reaches the target weed or the soil. Williams and Wicks (1978) refer to a North American study, in which 30% of applied atrazine failed to reach the soil surface during the first 90 days in a no-tillage system with 85% residue cover. Most of the atrazine deposited on plant residues is lost by volatilisation or degradation before reaching the soil surface. Similar problems of herbicide interception can occur with chemicals aimed at weed leaves. There are few Australian studies of this problem, but experience with Glean applied as a pre-emergence spray suggests that the same product should be effective for fallow applications with stubble rates up to 6000 kg ha^{-1} (Herrmann *et al.*, 1984).

While crop residues can sometimes hinder the application of herbicides they may have a role themselves in weed suppression. Heavy residues present a physical barrier to weed emergence and reduce the light available to weed seedlings. Toxins released from fresh stubble may also suppress weed growth (Purvis *et al.*, 1985). Lovett *et al.* (1982) found that residues of field pea, wheat and oilseed rape displayed significant differences in weed-suppressing ability, reducing weed populations by 71%, 53% and 33%, respectively, in a wheat crop.

The advent of non-residual herbicides, originally paraquat, but more recently glyphosate, initiated a trend towards the substitution of herbicides for cultivation. This occurred in the early 1970s in the winter-rainfall areas where crops were direct drilled either several days after weeds were sprayed, or after a short (autumn) fallow using herbicides. Residues from the previous crop had been grazed and usually burnt so that sowing with conventional equipment was usually not a problem. Crops were sometimes direct drilled into light standing stubbles by removing cultivating tines from the combine-seeder. In such cases non-residual herbicides were effective if weed growth warranted their use.

There has been a trend for growers to use herbicides late in a fallow rather than cultivation, even where all previous weed control was by cultivating. This can be an enforced option when the soil is too wet to cultivate, but it is also a quick method of weed control at a time when tractors are required for sowing. It avoids any problem with crop residues interfering with either the application or efficacy of herbicides.

The strategic or non-planned use of herbicides to replace one or more fallow cultivations has increased rapidly since the release of glyphosate. The technique has been used mainly where excessive rainfall has prevented timely cultivation of fallows or to replace a pre-planting cultivation for conservation of seedbed moisture. The present treatment at a low rate of glyphosate (< 1 L ha^{-1}) plus dicamba is effective and cost-acceptable as a 'one-off' operation. The technique has been extensively adopted because it effectively controls a wide spectrum of weeds without producing herbicide residue problems (Marley and Wilson, 1981). However, the benefits of maintaining stubble in the system are usually not a primary consideration of farmers who are most concerned with weed control.

Pre-emergence herbicides These herbicides are used widely in Australia for the control of annual grasses and broadleaf weeds in a following crop. Manufacturers recommend that the most commonly used herbicides, trifluralin and triallate, be applied to, and incorporated into, a cultivated soil free of crop residues. This would appear to prevent their use with direct drilling, stubble retention, and particularly with no-till systems. Recent experiments, however, suggest that pre-emergence herbicides can be used in the presence of plant residues. Bateman and Walker (1980) showed that better than 90% weed control could be achieved using trifluraiin where peanut stubble covered up to 21% of the soil surface. Cocks and Fawcett (1983) found that up to 3 t ha^{-1} of stubble at spraying time did not decrease the efficacy of a number of incorporated herbicides. Good control of wild oats by triallate sprayed onto standing stubble and incorporated by sowing has also been reported (Martin and Felton, 1984). It appears then that pre-emergence herbicides may be effective in stubble retention and no-till systems. Further research is required to establish guidelines for allowable stubble levels with these chemicals, and investigate the usefulness of granular formulations.

If granular herbicides are found to have a place under Australian conditions then other compounds may be formulated in this way. The next step is to examine improved techniques of application. Almost all research into herbicide application has involved hydraulic carriers so there is a need to test alternative methods. An objective of all farmers is to minimise the number of trips over a field so application of granules at sowing or harvest is desirable.

Locating a granule applicator under the comb of the harvester is worthy of consideration. This would have the added advantage of placing the herbicide under the tailings from the header.

Nutrition

Current cereal fertiliser technology was developed for cultivated systems, which until recently contained little or no residue from a previous crop. Consequently, it will be some time before a satisfactory reappraisal is possible for systems where substantial amounts of residue are retained. This will be further influenced by systems where there is also a reduction in soil disturbance. Fawcett (1975), Doyle and Forrester (1980), Fettell (1984) and White (1984) all reported that nitrogen responses were not related to tillage practice but in a longer-term study, J.W Littler and J.M.T. Marley (unpublished data) did find a greater response to nitrogen where stubble was retained rather than burnt. Similar inconsistencies have been obtained in experiments at Tamworth, New South Wales (Chapter 3 and J.F. Holland, unpublished data). At Rutherglen, Victoria, G. Steed (personal communication) has found that a change to retention of wheat stubble reduces the nitrogen available to wheat at sowing at least in the first crop. This has necessitated a change from the recommended rotation of lupins-wheat-wheat to wheat and lupins in alternate years. Similar results have been obtained at Wagga Wagga (A. Taylor, personal communication). While economic factors as well as the crop sanitation value of rotations will dictate the choice between mineral fertilisers, pastures and grain legumes as sources of nitrogen, these results do emphasise that successful stubble retention may require a change in crop rotation or fertiliser practice. The principles of plant nutrition as influenced by tillage practice are considered in detail in Chapter 11.

Residue retention should not make fertiliser application itself any more difficult, except for the application of anhydrous ammonia before direct sowing. This may be inefficient and unreliable because of a lack of soil sealing and therefore loss of gas. Also, the application of high rates (> 30 kg ha^{-1}) of nitrogenous fertiliser at planting requires the fertiliser to be applied in a row that is separate from the seed to avoid poor germination. This may require the addition of extra tines and metering equipment. The application of nitrogenous fertiliser needs further development for new tillage systems.

With respect to residue management the objective is to minimise soil loss to an annual level that will not degrade the physical and chemical fertility of soils. There is a dearth of information from long-term studies monitoring the effects of cropping strategies on soil fertility in Australian agriculture.

Crop establishment and early growth

Many early failures with stubble retention can be attributed primarily to poor crop establishment (e.g. McKeown and McCulloch, 1962; Macadam and Southwood, 1968). Uniform crop establishment and a suitable plant density are essential for maximising crop yield. To achieve this, seed must be placed into moist soil at a uniform depth and spacing, with good seed-soil contact. These conditions are often difficult to achieve where crop residues are present on the soil surface or mixed into the seedbed. Surface crusts, large clods and thick clumps of stubble may reduce seedling emergence. Soil smearing and compacted zones must also be avoided so that root elongation is not restricted. Allelopathic effects may be responsible for poor emergence but poor seed-soil contact and hence variable moisture status immediately around the seed is a more likely reason.

Sowing through crop residues

Traditional Australian sowing equipment has been designed for use on level, cultivated soil, free of crop residues. Seed and fertiliser are sown in rows at 180 mm spacings on two ranks of tines, while a further two ranks of cultivating tines give complete disturbance of the soil surface to aid weed control. These conventional combines work well on clean, cultivated fallows and, with some strengthening, for direct drilling. They are unsuited to those conservation farming systems where residues are retained, the soil surface is often rough and uneven, and the soil may be either wetter than when cultivated, or drier and therefore more difficult to penetrate. Residue may build up around tines, preventing soil flow and leading to uneven sowing depth and blockages. Sowing tines have low 'break-back' strengths and are thus unable to maintain the desired sowing depth in uncultivated soil.

Sowing machinery is being developed to overcome these problems. Combine seeders with six ranks of tines and strong tine assemblies are adequate for direct drilling into low levels of crop residue where the soil surface is reasonably level. For rougher soil conditions and higher levels of residue, specialised machines are required. These should have more underframe clearance, row spacing at least 250 mm, coulters for cutting stubble, rigid tines with high breakout forces for accurate seed placement, presswheels for furrow closure and good seed-soil contact, and independent ground-following ability to ensure uniform sowing depth. A flat coulter followed by a narrow point and a single rib presswheel gives little soil disturbance and has performed well in heavy clay soils with stubble rates of 3000-4000 kg ha^{-1}. Experimental machines of this type have been built (Felton and Smith, 1981) and a small number of commercial units are now operating in Queensland and New South Wales. Micro-seedbed methods, which fully disturb a narrow strip of soil, have potential (Ward and Norris, 1982; Norris and Ward, 1983).

One method of improving the residue-handling ability of sowing machinery is to sow in rows wider than the standard 180 mm traditionally used for winter cereals. There have been no comparisons of row-spacing effects in the presence and absence of stubble. The only guide to row-spacing effects comes from experiments in stubble-free, cultivated conditions. In northern New South Wales, Fawcett (1964; 1967) found no yield reduction at 360 mm spacings in five experiments in one year, but in other experiments grain yields declined by 1-1.8 kg ha^{-1} for each millimetre that row spacing increased above the standard. Doyle (1980) reported that yields at 270 mm were significantly lower than at 180 mm in three years out of five.

In the low-rainfall wheatbelt of central New South Wales, Fettell (1984) compared row spacings of 150, 250 and 350 mm in an experiment where irrigation was used to vary potential yield. The interaction with sowing rate and with the amount of weeds present was also studied. Fettell found that wide row spacings (> 150 mm) reduced yield when the potential yield exceeded 1.5 t ha^{-1}. High sowing rates (2 x recommended) depressed weed growth at all row spacings but did not increase grain yield. The loss in yield due to weeds was not affected by row spacing. In summary, work in residue-free conditions indicates that row spacings up to 250 or 300 mm are acceptable for areas with yield expectations below 2 t ha^{-1}

In one row-spacing experiment in the presence of stubble, Doyle and Felton (1984) found that row spacings wider than 180 mm reduced yield at a low sowing rate (20 kg ha^{-1}) (Figure 7.7). At a high sowing rate (40 kg ha^{-1}) yield was reduced in rows wider than 250 mm. With narrow row spacings the cultivated seedbed gave higher yields than no-till, but this was reversed in wide rows (> 250 mm). Yield reductions ranged from 9.7 to 18.9 kg ha^{-1} per centimetre increase in row spacing and were comparable with those obtained by Fawcett (1967). Further work is required to quantify the interaction between row spacing and stubble rate in a range of environments.

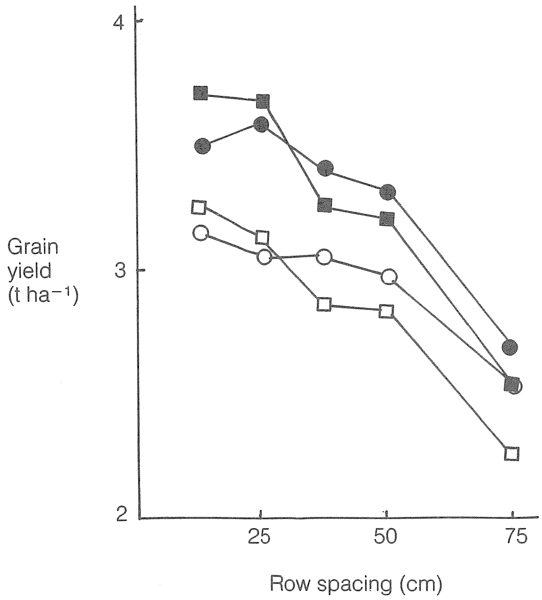


Figure 7.7 Effect of row spacing on grain yield of wheat sown at 20 (□) and 40 (■) kg ha^{-1} after a cultivated fallow and for sowing rates of 20 (○) and 40 (●) kg ha^{-1} after a no-tillage fallow

There is currently substantial experimentation aimed at determining the best method of meeting the requirement of sowing into high levels of crop residue and/or direct drilling. Consequently at this stage it is uneconomic for manufacturers to provide different models to meet all requirements, especially when the requirements cannot be fully specified. Manufacturers should try to provide machinery with maximum flexibility, for example clamp-on componentry with a range of ground-tool and presswheel options. Should particular specifications finally become dominant, it may become economic to design and produce specific-purpose products. Until then there will be an interim stage where most farmers who adopt a programme of increased residue retention will try to modify existing equipment (Mead, 1985). For example, many growers are already equipping cultivators with air seeder and narrow points for sowing into minimum tillage seedbeds where stubble is retained. The high cost of specialised sowing equipment is an important disincentive for the adoption of conservation farming (Chapter 16) and so the continued development of low-cost conversions for conventional equipment should receive a high priority.

The passage of sowing equipment through stubble is aided by the proper treatment of the previous crop at harvest. This involves leaving the straw short (< 30 cm) and ensuring that both the straw and chaff are evenly spread. Methods for achieving this are considered later.

Soil water and temperature effects on establishment and early growth

Water Higher soil-water contents at the soil surface associated with a residue mulch can result in a smaller amount of rainfall being required for sowing. The sowing period can also be extended if a surface mulch is present. In areas of high rainfall the reverse can apply because of reduced trafficability. However, this problem is reduced in uncultivated systems as the soil surface is firmer. A longer interval is usually available for optimum sowing with direct sowing in the presence of stubbles.

Temperature The presence of plant residues on the soil surface can significantly influence soil temperature. Net radiation at the soil surface is reduced, as the albedo of straw is usually higher than that of bare soil. Surface mulches also have an insulating effect, the mulch layer having lower thermal conductivity than uncultivated soil and also some thermal capacity. The result is that diurnal soil temperature amplitudes under residues are much smaller, and that daily average temperatures are cooler in summer and sometimes warmer in winter (Van Doren and Allmaras, 1978). Stubble mulches can improve the growth and yield of summer crops susceptible to high soil temperatures (Lal, 1974; McCown *et al.*, 1980; Holland and Felton, 1983). Soil temperatures during spring, however, are also reduced and the sowing of crops such as sorghum could be delayed. For winter grown crops, mulches may have a deleterious effect. Poor vigour of wheat grown in retained stubble has been attributed to unfavourable temperatures at Rutherglen (G. Steed, personal communication) and near Canberra (Aston, 1985). Maximum soil temperatures (in the 0-50 mm soil layer) were lower for most of the daylight hours where residues remained on the surface.

Phytotoxic effects of crop residues on establishment and early growth

The retention of crop residues may have harmful effects on succeeding crops. Plants affected are generally unthrifty, often yellowed, and with limited tillering, suggesting nitrogen deficiency. However, these symptoms are not necessarily due to nitrogen deficiency, as evidenced by a lack of response to nitrogen fertiliser (Kimber, 1967). Reduced yields have been attributed instead to toxic compounds leached from crop residues or produced by microorganisms during residue decomposition, although the compounds and mechanisms involved are often unknown (Elliott *et al.*, 1978). In the field, wheat yields are usually affected most by stubble when dry summer conditions allow little stubble to decompose between crops (Kimber, 1967). The potential problems are therefore greatest with double cropping and least in areas where fallowing is practised. However, White (1984) found no evidence of phytotoxicity, even with double cropping on the Darling Downs. Residue management plays an important role in minimising phytotoxic effects. High levels of stubble exacerbate the problem and so uniform straw spreading is important. Most of the suspected phytotoxins are rapidly inactivated in soil so that damage occurs only where there is direct or near-direct contact between residues and the crop seedlings (Elliott *et al.*, 1978). Maintaining residues above the soil surface and away from the sowing row should therefore minimise crop damage.

MANAGEMENT TO MAXIMISE BENEFITS AND MINIMISE PROBLEMS

Target stubble levels

'Critical' or target stubble levels should be determined at the beginning of any fallow period so that management strategies can be adopted to achieve the desired dry matter or stubble cover.

The target may be, for example, to maintain at least 30% cover at the end of the high-risk period for storms in order to reduce erosion. Alternatively, the target may be to reduce stubble levels to 1000 kg ha^{-1} by planting so that a particular planter will operate without blockage. The choice of management strategies to achieve the target level requires a knowledge of stubble breakdown rates due to tillage and biological degradation, as well as limitations of equipment, the purpose for retaining stubble, and the rate needed to achieve that purpose. The management strategies include treatment of the residue at harvest, management in the intercrop period and at sowing time.

When the amount of stubble remaining after harvest is greater than necessary, it can be reduced by the appropriate management options. These include grazing, slashing, hay removal, partial burning (e.g. burning of stubble after windrowing) or tillage that incorporates a substantial proportion of the residue. On the other hand, if only a moderate crop is grown, then grazing may be undesirable, slashing not necessary, and tillage operations performed with implements that incorporate a minimum amount of residue, e.g. a blade plough or rod weeder.

Treatment at harvest

At harvest the most important considerations are the following:

* To operate the header comb at a height (less than 300 mm) that will leave the anchored straw short enough to allow subsequent operations without obstruction. The development of a header with a second cutter bar to shorten the straw length without increasing the volume of material being threshed is a possibility for tall crops.

* To spread the tailings from the header evenly across the field. This should include the chaff as well as the straw in heavy crops and a chopper attachment on the harvester should be used under these conditions.

* If excess stubble is present, and alternative uses for stubble exist, removal or partial removal of available stubble can be considered. Some alternative uses are considered later in this chapter, but retention of anchored straw during the major erosion-risk period should be the main aim of all farmers.

Residue treatment

Grazing In many cereal-growing areas the grazing animal is an integral part of the farm operation. Grazing of stubble has the dual role of reducing stubble levels while providing some weed control. This is particularly the case in the winter-rainfall areas. Grazing may also have a role in summer-rainfall areas, especially in marginal-cropping situations where rainfall is less, slope negligible and the need for erosion protection is less critical. However, it is undesirable to have stock in cropping areas after rain, especially on clay soils. Compaction as a result of this practice is recognised but the consequences are not fully appreciated (Packer *et al.*, 1985).

Slashing Slashers or mulchers that cut crop residue into shorter lengths speed stubble breakdown, while enabling easier flow of stubble through machines. It should be noted that when stubble is moist, the stubble-handling ability of most equipment is reduced.

Burning Burning is not a recommended management option immediately after harvest. If stubble levels are excessive for available equipment then burning may be the only option available, but should be delayed as long as possible. Burning should only be carried out when the moisture and soil conservation aspects are considered together with possible disease occurrence and machinery limitations. Partial or late burns, close to sowing, are important management options. There is reduced erosion risk associated with burning stubble in May in the northern cereal belt, where 80% of the erosive rain occurs in the October to March period (Rosenthal and White, 1980).

In southern winter-rainfall regions there also appears to be no justification for burning early in the fallow period. Even cereal-ley pasture rotations can result in excessive soil erosion (Adamson, 1978) because tillage usually coincides with the period of most erosive rainfall - February and April. As in summer-rainfall areas, if burning is necessary it should be carried out as close as possible to sowing.

Tillage Tillage methods predominantly control the amount and orientation of stubble. Farmers have some control over the amount of stubble retained by varying the implement type and frequency of cultivation (Table 7.3).

Table 7.3 Reduction of surface stubble by a one-way disc, chisel and sweep plough on a black earth

Implement	Incorporation per operation (%)
One-way disc	50–60
High-clearance chisel	25–35
0.95 m sweep	15–20
Rod weeder	5–10

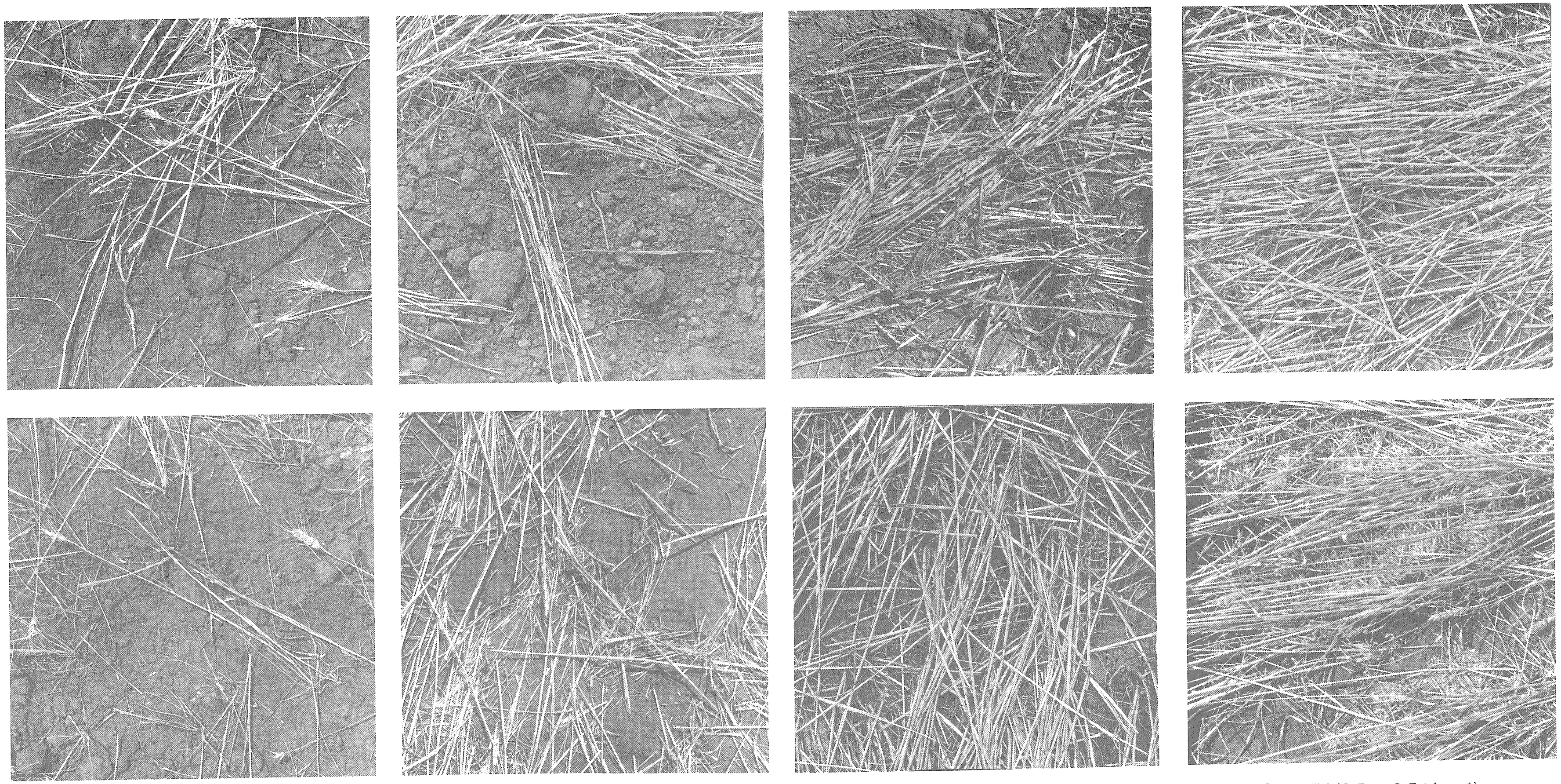
Some tillage equipment is capable of effective cultivation through stubble levels of up to 8000 kg ha^{-1}, e.g. a 1.8 m blade plough, whereas high-clearance chisel ploughs operate in 4000-6000 kg ha^{-1} stubble levels. Therefore even substantial amounts of residue can be manipulated between crops to a level that can be sown into while maintaining erosion protection.

Target levels

No hard and fast rules can be applied to target levels of residue for all situations. However, as a guide, Woodruff *et al.* (1966) demonstrated the principles (Table 7.2). These data refer to a slope of 8% and obviously must be considered in relation to erosion risk. The stubble levels in Table 7.2 are those required to reduce soil loss to 12 t ha^{-1} yr^{-1}, or about 1 mm of topsoil. This may be an acceptable short-term loss for deep soils but would be excessive for shallow soils.

The determined amounts of stubble are required during the whole period in which high-intensity rainfall may occur. In Queensland and northern New South Wales this is from October to March. In order to achieve this protection, and allowing for reduction due to cultivation, approximately 6000 kg ha^{-1} of straw would be required at the start of a wheat fallow if stubble incorporation were to be practised on a clay soil. If stubble mulching were practised, the amount would be 3000 kg ha^{-1} under similar conditions (Marston and Doyle, 1978).

The amount required will also vary depending on the type of machinery used and the number of cultivations necessary during the fallow. Therefore, it is critical to assess the amount of stubble available and plan a tillage programme accordingly.



Class I (0 to 0.6 t ha^{-1}) Class II (0.6 to 1.2 t ha^{-1}) Class III (1.2 to 2.5 t ha^{-1}) Class IV (2.5 to 3.5 t ha^{-1})

Class V (greater than 3.5 t ha^{-1})

Figure 7.8 Estimation by eye of the quantity of stubble present. Note: Each photograph is 50 cm × 50 cm of flattened wheat stubble and is at the upper limit of the weight range. Two photographs in each class illustrate different distributions of the same amount of stubble.

Class I (less than 0.6 t ha^{-1}) offers little protection to the soil from wind, especially when it is flattened.

Class II (0.6 to 1.2 t ha^{-1}) encompasses 1.0 t ha^{-1}, which is the figure research indicates is sufficient to minimise wind erosion, assuming good management.

Class III (1.2 to 2.5 t ha^{-1}) will protect the soil during the majority of high-velocity wind storms.

Class IV (2.5 to 3.5 t ha^{-1}) offers good protection to the soil but requires good stubble-retention techniques if 1.0 t ha^{-1} is to be retained by sowing.

Class V (greater than 3.5 t ha^{-1}) is the amount of stubble required before long fallowing a paddock with tined implements if 1.0 t ha^{-1} is to be retained by sowing.

As a guide, approximately 1500 kg ha^{-1} of wheat straw and 1000 kg ha^{-1} of sorghum straw remain for each tonne of grain harvested. Therefore, a 3 tonne wheat crop would leave 4500 kg ha^{-1} of stubble after harvest.

A guide to the visual estimation of stubble cover is given in Figure 7.8 (Leys and Semple, 1984). These photostandards provide a quicker method than cutting or estimating percentage cover from point quadrats.

Natural breakdown rates

The breakdown rate of stubble other than by tillage varies with the type of stubble and the weather. Radford and Neilsen (1983) found that dry-matter weights of wheat stubble did not decrease significantly in 6 months while levels of sorghum stubble decreased by 50% in the same period.

Stubble becomes more susceptible to physical shattering by tillage implements after several months of weathering, especialy when substantial rain falls during this period. This becomes important when considering which implement is capable of working effectively for a given stubble level. More data are required on maximum levels of stubble that various machines can handle and how this varies as the season progresses.

Achieving target levels with tillage

Primary tillage

Residue retention by incorporation can be achieved most effectively by implements that invert the surface soil and bury the residue (Table 7.3). Mouldboard ploughs are still commonly used for this purpose in Great Britain but disc ploughs are favoured in Australia.

Although sales of disc ploughs have declined considerably in recent years there are many farmers who still use a disc implement at the initial working. In wet conditions the disc plough is regarded in some areas as being better than a tined implement. In the Victorian Mallee, for example, the traditional use of the disc plough for fallowing has proven to be effective in moisture conservation. Where wet conditions prior to harvest have resulted in a large volume of weeds, particularly vining types such as wireweed (*Polygonum aviculare*), a disc implement is often the only means of ploughing. Tined implements soon become blocked in these conditions.

The early years of stubble retention farming in Australia saw the use of large numbers of blade ploughs and chisel ploughs for primary tillage. More recently, sales of blade ploughs have declined dramatically while the sales of chisel ploughs have increased. Blade ploughs provide excellent performance from the point of view of maintaining a high level of crop residue on the soil surface, but they have several disadvantages:

* The structural requirements of the wide blades require greater amounts of lift of soil as it passes over the blade than is needed by chisel-plough sweeps. This can restrict the range of soil conditions in which the blade plough will operate satisfactorily.

* The wide cut of each blade assembly results in the bottom of the cultivation being almost level, unlike the bottom of the narrower-spacing tine cultivation, or disc

cultivation, where significant irregularity is normal. The level bottom can lead to extreme soil erosion due to mass flow of saturated soil on sloping ground.

* Blade ploughs are generally not provided with any 'stump-jump' capability, and their wide blade width makes such provision difficult. This has restricted the application in many areas.

On the other hand, the superior performance of blade ploughs in leaving surface residue in place has found them a secure place in marginal sandy-soil areas where protection from wind erosion is the dominant consideration. Some American manufacturers have adapted airseeders to allow sowing in conjunction with the blade plough.

Chisel ploughs provide significant advantage in their flexibility. They will operate successfully in a wide range of soil types and conditions. They can be used at greater depth to break up compacted soil layers. A wide range of points is available to meet varying requirements of penetration ability, soil disturbance, residue flow, and weed control.

Chisel ploughs inherently provide high levels of residue-handling capabilities. Coulter attachments are becoming available to improve this capability where required.

Recent chisel ploughs have increased the tine spacing from the traditional 30 cm to 35 cm to provide further improvement in residue handling, as well as some reduction in draught-force requirement.

Some Australian machines offer hydraulic loading of their stump-jump mechanisms. This feature provides a reduction in load on tine components when tine breakout occurs. More importantly it provides a ready capability for the operator to select the tine breakout force to match field conditions.

Secondary tillage

Control of weeds and seedbed preparation after the primary tillage operation can be achieved by a wide range of disc, tined, blade or rod implements. Each leaves a varying proportion of the residue on the surface (Table 7.3) and exerts variable degrees of fracturing of the soil.

Tandem discs are able to operate with very high levels of residue and can accelerate the rate of breakdown of residues if this is required.

The tandem disc with an airseeder is suitable where sowing with a disc implement is desired, such as planting under high levels of surface residue or with the Western Australian preference for planting lupins with disc implements. The implements are available in a wide range of variable specification - disc diameter, disc spacing, weight per disc, and overall width.

Tined implements are most popular for secondary tillage. The ability to fit sweeps to chisel ploughs provides versatility, a feature that appeals to farmers. Residue-handling capability of a chisel plough is greater than with scarifiers or cultivators, which have more tines in closer configurations. The disadvantage with sweeps is that the soil surface is left rough if this type of implement is used immediately prior to sowing. The fitting of a dead rod or harrows can overcome this problem but this can only be done successfully where stubble levels are low, probably less than 1000 kg ha^{-1}. There has been a trend towards the use of a single-tined implement (a chisel plough) for primary and secondary cultivations. Some farmers use this implement with an airseeder for sowing, thus reducing the outlay for equipment.

Accuracy of depth control has become a primary consideration in the design of cultivators, where they are used as a sowing machine in conjunction with an airseeder. The ability of the implement to follow uneven ground across the width of the implement requires reduction in the width, or the use of a flexible frame. The ability to follow uneven ground in the direction of travel has resulted in availability of an improved facility to disconnect the hitch of the implement from the implement frame (where the implement is fitted with front and rear wheels) so that those wheels on each section of the implement can control the pitch attitude of that section.

The resurgence of interest in trash disc undercarriages for sowing has led to the availability of such undercarriages under wide cultivators to be used in lieu of the regular tine assemblies.

A wide range of attachments are offered for use in conjunction with cultivators - spring-tooth harrows/rolling harrows/mulch treaders/ridge levellers/ridge aligners - to meet the wide range of requirements for improved weed kill, uniform depth of seed cover, level (or not) resultant 'finish'.

The main attribute of the rod weeder is maintaining crop residue on the soil surface but there has been a restricted range of conditions in which they work satisfactorily. Durability in rougher conditions has been a problem. Australian developments have aimed at reducing this disadvantage by providing shorter length (1 m) modules that are self-contained with respect to their drive and depth-control requirements. The main application for this implement in Australia will probably be as an attachment to other implements such as chisel ploughs and tine sowing machines to provide improved weed kill, reinstatement of some residue to the soil surface, or a levelling and firming action.

ALTERNATIVE USES FOR CROP RESIDUES

Grain production from cereal crops totalled almost 23 million tonnes in Australia during 1979/80 and, by applying appropriate harvest indices, Mulholland *et al.* (1984) calculated that almost 60 million tonnes of crop residue remained, 42 million tonnes of this being wheat straw. This resource may be used in a number of ways depending on the relative economic advantages of residues for conservation farming, and in the production of animal or industrial products. These alternative uses may not be competitive where residue production is greater than that required for the protection of soil from wind and water erosion.

Stubble for grazing

For large areas of southern Australia crop residues from winter cereals provide a major source of food for sheep and cattle over the summer period. Animal production from these areas depends on unharvested grain and weed growth in the stubbles. Where spilt grain or weed growth are present, sheep select intensively for these components and usually maintain or even gain weight. Where grain or green herbage is not available, the more nutritious leaf and ear fractions of the dead plants are selected from the total crop residue (Mulholland *et al.*, 1984). Consequently, only a small part of the crop residue is actually utilised by grazing sheep. In a series of experiments, Mulholland *et al.* (1976) found that 36% of the dead material (at most) disappeared during grazing. This was equivalent to 25% of the total straw available at the beginning of grazing. Another 50% of the total straw disappeared due to other factors such as decomposition, being blown away and treading by stock. This required stocking rates far above those likely to be applied in practice except on small areas of crop. At a lower stocking rate, only 14% of the stubble lost was accounted for by animal intake.

Cereal-crop residues are poor-quality roughages in digestibility and deficient in soluble carbohydrate, protein and some minerals. Intake is often below maintenance requirements, and animals fed solely on residues may suffer severe weight losses. Supplementation with urea and minerals has generally produced little benefit in grazing sheep, but marked responses to protein supplements have been observed (Mulholland *et al.*, 1984).

The evidence suggests that grazing of stubbles and stubble retention cropping may not be incompatible. The stem component of crop residue is of least value to grazing animals and the most resistant to microbial decomposition. The spilt grain, weed growth and dead leaf material of most value for animal production is not required for erosion protection. Hence short periods of grazing by sheep should not greatly reduce stubble cover, as the stem component is only likely to be decreased by trampling. Where residue levels are above the 2 t ha^{-1} required for erosion control on sloping clay soils (Woodruff *et al.*, 1966), grazing pressure could be used to reduce residue levels and control weeds, provided care is exercised to minimise soil compaction.

Harvesting for fodder

The efficiency of utilisation of crop residues may be increased by harvesting the bulk of straw from stubble paddocks. The grazing value of the stubble areas would not be greatly diminished in the short term at moderate stocking rates (Coombe and Axelsen, 1984). The poor nutritive value of harvested residues has led to the development of a range of pretreatments to improve their utilisation. Grinding, to reduce particle size, generally increases animal intake although digestibility may be slightly reduced.

Chemical treatments with alkalis result in a substantial improvement in the nutritive value of cereal straw (Ibrahim and Pearce, 1983). Sodium hydroxide can be applied in an operation using a forage harvester (Kellaway *et al.*, 1978) or a pick-up baler (Mulholland, 1981). Large round or square bales may also be treated using a spear technique (Stephenson *et al.*, 1984) or by pumping ammonia into plastic-covered stacks. The use of treated stubble by farmers will depend on the cost of the treatment and the price of alternative feedstuffs, particularly pasture hay. Mulholland *et al.* (1984) concluded that, unless there is no surplus pasture available, as in a drought, the present commercial methods of using treated straw are not competitive economically with the production of pasture hay. Losses from cereal straw products stored outdoors may also be higher than from pasture hay.

CONCLUSIONS

The amount of residue needed to significantly reduce evaporation and increase moisture accumulation in a fallow is too high to manage practicably. The amount of residue required for erosion protection is less, and residues should therefore be treated to maintain this rate. The amount of residue required probably depends on the type of residue and the interval between crops, but there are almost no data of this kind for the range of Australian conditions.

Where cultivation is eliminated, soil loss is less because the sediment concentration in the runoff water is lower. On surface-sealing soils, no-tillage can result in more runoff than stubble mulching, but soil loss is still less. No-tillage offers the best protection against water erosion when the soil profile is wet and stubble cover has little effect on runoff.

Rainfall records can be used as a guide to identify periods of high-erosion risk and residue management programmes should aim to maximise residue retention during these times. Until more information becomes available, 2000 kg ha^{-1} of wheat stubble should be retained to provide adequate erosion protection. This amount of stubble should not pose problems in establishing a subsequent crop.

Crop residues can affect strategies for weed control but herbicides have been shown to be as effective in the presence of stubble, and some weeds are in fact suppressed by the stubble.

Results so far indicate that successful stubble retention programmes may require a change in crop selection and fertiliser practice. Grain legume crops or legume-based pastures are likely to become even more important in a system where stubbles are retained.

Low-cost conversions of conventional sowing equipment have received high priority during the transition from conventional to no-tillage cropping. Such equipment performs satisfactorily at low levels of residue but more specialised planters are being developed to handle large quantities. Uniform distribution of residues is essential so there must be a move towards better straw- and chaff-spreading attachments to harvesting equipment.

Selecting the appropriate management strategy to retain a target level of residue requires experience. A knowledge of degradation rates, equipment limitations and suitable cropping sequences is needed to achieve this goal.

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