Chapter 5

TILLAGE - ITS ROLE IN ESTABLISHMENT AND MANAGEMENT OF PASTURES

S.J. Cook, P.D. Cregan, M.H. Campbell and J.W. Read

Agricultural production, especially that from pastoral areas, has played, and continues to play, a key role in the Australian economy, primarily through its generation of export income. The value of exports from pastoral areas usually exceeds that from crop production. Most of Australia's pastoral production is based on native pastures but, in the areas where improved pastures have been established, this has led to large increases in both pasture and animal production.

Australian native pastures severely limit animal production, both through their seasonal limitations and their overall low production. In many areas the major limitation to animal production on native pastures is the lack of green feed and crude protein during the winter and early spring (Shaw and Bisset, 1955; Roe *et al.*, 1959; Norman, 1963) and the dry material is also unpalatable. This is most marked in north-western Australia (the north of Western Australia and the Northern Territory) and north Queensland because of the long season, which lasts for 5 to 7 months. Similar problems exist on the northern tablelands of New South Wales where low temperatures and frosts during winter depress the growth of summer-growing native grasses (Roe, 1947). The problem of poor forage quality is further compounded by the widespread soil deficiencies of phosphorus and nitrogen.

Pasture improvement overcomes many of the forage quality problems associated with native pastures. In addition, sown temperate species grow better than the natives at low temperatures (Hilder, 1963; Cook *et al.*, 1978b) and sown legumes retain their quality and palatability better than the native grasses during the dry season. Pasture improvement involves either the complete replacement of the native pasture with some legumes and grasses or, in some areas, the supplementing of the native pasture with legumes only. Fertiliser, usually phosphorus and sulphur and sometimes one or more trace elements, is usually required to correct nutrient deficiency.

The role of tillage in the establishment and maintenance of pastures largely depends on the type and intensity of agriculture in the various regions and on the method of pasture establishment. By definition, tillage involves disturbance of the soil by implements involved in seedbed preparation and sowing operations. Tillage also enables placement of seed and/or fertiliser within the soil. However, tillage operations are expensive in terms of both time and energy, especially where the area to be sown is large. Consequently there has been a move to reduce the amount of tillage in the pasture establishment phase. The need to develop land that is too steep and/or rocky for machinery as well as the need to reduce soil erosion, have also resulted in a strong move towards reduced tillage in recent years. This reduction in tillage has various implications for the germination, emergence, growth, survival and management of pasture species, the effects of which are the subject of this review.

METHODS OF PASTURE ESTABLISHMENT

Improved pastures may be established using either cultivated seedbeds or reduced-tillage methods. Reduced tillage involves sowing into a live or chemically killed or partially disturbed sward by surface sowing, direct drilling (sod-seeding) or other minimum-tillage methods. The method of establishment used tends to be related to the class of land being developed, the intensity of agriculture in the various regions, climatic factors, the species being sown and whether or not this species is intended to completely replace or just supplement the existing vegetation.

Cultivated seedbeds, which have probably accounted for the greatest number of sowings of improved pastures in the past, involve from two to ten workings prior to the sowing operation and result in complete disturbance of the surface 4-15 cm of the soil. Ploughing destroys all existing vegetation and is often carried out in order to provide a long fallow that will maximise weed control, store soil moisture and prepare a firm seedbed with a fine tilth. The seed is normally drilled into the soil with the fertilisers. However, many of the tropical grass seeds are light and chaffy and some of the legume seeds contain hooks (e.g. *Stylosanthes* spp.) and will not flow through the normal seed-metering mechanisms. Seeds of these species are often mixed with dry, sieved sawdust and applied through a fertiliser spreader. Light harrows or a roller may then be used to cover the seed.

The practice of cover cropping to help offset the cost of establishment is common in southern Australia, especially where pasture is part of a rotation with cereals. On the other hand, this practice is difficult to justify (Donald, 1963) from the viewpoint of pasture establishment *per se* except in areas where the seedlings need protection from sand or wind blast (Stephens, 1979). Like weeds, cover crops compete with the establishing pasture for moisture, light and nutrients. This results in reduced establishment and yield, both of which can have deleterious long-term effects on pasture production (Donald, 1963). Cover cropping is rarely used in tropical areas.

Direct drilling involves the use of relatively specialised implements capable of penetrating previously untilled soil in existing swards (Breakwell and Jenkins, 1953). Such implements need to be robust in order to be able to drill seed into the existing sward with minimal soil disturbance in a one-pass operation. Although such methods have been used in southern Australia, New Zealand and the United Kingdom, they have not been used in tropical areas except for the establishment of winter forage crops in dairy pastures. On the other hand, 'minimum tillage', and to a lesser extent surface sowing, have been widely used.

Some minimum-tillage methods are quite crude and range from sowing through seedboxes mounted on ploughs to the broadcasting of seed onto partially disturbed areas. Compared with direct drilling, seed placement is often poor and soil disturbance varies depending on the implement used, the number of tillage operations and the physical characteristics of the soil. For example, offset discs operating in a moist sandy soil can, in a one-pass operation, almost completely destroy the existing sward and produce a seedbed equal to many cultivated seedbeds that have had several workings. However, very little disturbance results if the soil is dry and hard, allowing most of the existing vegetation to remain.

Surface sowing, whereby seed and fertiliser are broadcast onto the surface of undisturbed soil, has a long history in Australia. Many of the pastures sown on fertile soils after clearing the temperate forests in coastal New South Wales, Victoria and Tasmania in the 1800s were established by the hand broadcasting of seed into the ashes that remained after the dry timber was burnt (Paton and Hosking, 1970). More recently, similar methods have been used in the

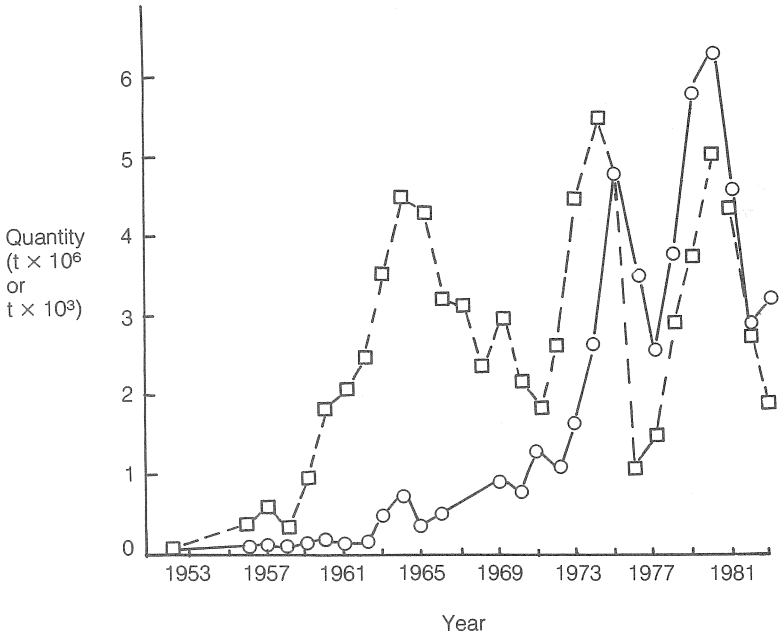

Figure 5.1 Aerial distribution of superphosphate (□, t × 10^6) and pasture seed (○, t × 10^3) in Australia between 1952 and 1983

brigalow areas of Queensland (Coaldrake, 1970). These situations are unique in that the seed is embedded in the ash, thereby conveying many of the advantages of seed drilled into the soil, but without tillage.

The first aerial sowing of pasture seed was conducted in 1940 on the Ninety Mile Plain in South Australia. Surface sowing, and particularly aerial sowing, was soon recognised as being a quick method of establishing large areas of pasture, especially on non-arable land (Gruen and Pearse, 1958). Aerial sowing also had the advantage of being cheaper than conventional methods, particularly where legumes only were to be established in country with dead trees and logs. As a result, the area of pasture established by aerial sowing in Australia increased rapidly until 1964; thereafter, fluctuations (Figure 5.1) depended on the profitability of the rural economy. More fertiliser and pasture seed has been distributed by aerial techniques in New South Wales than in other States (Table 5.1) because of the larger area of high-rainfall hill country in that State. Surface sowing has also been stimulated by the need to control weeds, e.g. *Nassella trichotoma* (serrated tussock) that occur in hill country (Campbell, 1960; 1974).

The main differences between the various methods of pasture establishment are related to the amount of tillage and its effects - the placement of seed and fertiliser, the amount of soil disturbance, and the treatment of vegetative cover and litter.

SEED PLACEMENT

The most critical aspect of seed placement depends on whether the seed is covered by soil or is left uncovered. Where the seed is covered it is able to imbibe water from the surrounding moist soil. On the other hand, seeds that are not covered can only imbibe water through that area of the seed that is in contact with moist soil (Sedgley, 1963). As the exposed seed surface loses

Table 5.1 Percentage of the total amount of superphosphate and pasture seed aerially distributed in Australia, by State

Year	Aerial distribution of superphosphate and pasture seed (%)				
	NSW	Vic./Tas.	Qld	SA/NT	WA
Superphosphate:					
1972–77	59	20	6	5	10
1978–83	69	16	2	4	9
Pasture seed:					
1980–83	53	38	7	–	2

water to the surrounding microenvironment, attainment of the necessary threshold moisture content for germination is controlled by the seed's capacity to balance water uptake against the water loss. The larger the seed, the larger the surface exposed relative to the area in contact with the wet soil. Large seeds are therefore at a disadvantage compared with small seeds when sown on the soil surface (Harper and Benton, 1966) or in open drill rows (Baker, 1977).

Effect of soil moisture on seed germination and seedling emergence

Germination and emergence depend on the moisture content of the soil and the length of time the soil water potential remains above the critical level necessary for germination; slower germinating species require a longer period of favourable moisture than faster species. The surface layers of the soil dry more rapidly than those below and so the conditions for germination and seedling establishment are much harsher near the soil surface. Hence, it is common practice to sow seeds as deep as emergence limitations will permit in regions where the soil surface dries rapidly following rain and/or where rainfall is erratic. However, due to the relatively small size of most pasture seeds (Table 5.2), they need to be sown 25 mm or less below the soil surface. The rapid drying of this part of the soil means that it is often not possible to establish pasture species on moisture stored in the seedbed, even when sowing is carried out immediately after rain (Norman, 1960), germination and emergence being wholly dependent on the rain that falls after planting. In contrast, crops such as wheat (*Triticum aestivum*) and oats (*Avena sativa*) have larger seeds (Table 5.2), which are commonly sown at depths of 50 mm or more below the soil surface; after being sown in a moist seedbed these crops can germinate, emerge and grow without post-sowing rain.

Table 5.2 Weight (g) of 100 seeds of some commonly sown crop and pasture species

Field crops	100 seed wt (g)	Pasture legumes	100 seed wt (g)	Pasture grasses	100 seed wt (g)
Wheat	3.13	White clover	0.07	Perennial ryegrass	0.16
Oats	3.13	Red clover	0.18	Tall fescue	0.20
Barley	4.17	Subterranean clover	0.65	Phalaris	0.14
Grain sorghum	2.00	Lucerne	0.23	Cocksfoot	0.10
Maize	33.33	Barrel medic	0.44	Green panic	0.07
		Townsville stylo	0.23	Rhodes grass	0.03
		Glycine	0.63	Buffel grass	
		Siratro	1.30	(caryopses)	0.06

Rollers and presswheels increase germination, usually by increasing soil-seed contact (Choudhary and Baker, 1980). The advantages of compaction are most evident in sandy or loamy soils, particularly when moisture for germination is limited. On the other hand, compaction appears to be of little benefit with deeper sowings (> 20 mm), or when there is ample moisture for germination (Triplett and Tesar, 1960; Norman, 1960); it may even reduce emergence in clay and clay loam soils by increasing the mechanical impedance of the soil.

The soil surface dries rapidly when high radiation and high temperatures prevail. Rapid drying of the soil surface is therefore common in Australia, and is a particular feature of the tropics (Miller and Perry, 1968; Winkworth, 1969; McKeon and Brook, 1983; Cook, 1984) where favourable conditions for surface germination occur only when low-pressure cyclonic or other rain depressions bring 3 or more consecutive days of rain and overcast conditions. However, once the rain stops and the clouds clear, or when high solar radiation occurs on the day following rain, the soil surface dries to near wilting point (-1.5 MPa) in less than 24 hours (Miller and Perry, 1968; Winkworth, 1969; Cornish, 1983; McKeon and Brook, 1983), unless a temporary water table is present, which is fairly common in winter and spring on the duplex soils of eastern and southern Australia (Cornish, 1983). Large numbers of partially or recently germinated seeds on the surface of the soil (Campbell and Swain, 1973a; McKeon and Brook, 1983), or in open drill rows (Baker, 1980), may die from desiccation. Environmental conditions tend to be less harsh in temperate areas, with the soil surface drying more slowly than in the tropics. Nevertheless, surface sowing in late autumn to allow germination and radicle entry in winter, the season with the highest probability of obtaining effective rainfall, has become the practice in temperate Australia (Campbell, 1963; 1967; Dowling and Smith, 1976).

Rapid drying of the surface of self-mulching clay soils has been shown to reduce the emergence of small-seeded grasses, e.g. green panic (*Panicum maximum* var. *trichoglume*) and Rhodes grass (*Chloris gayana*), from cultivated seedbeds in southern Queensland (Leslie, 1965). Emergence failures resulted from mechanical impedance by dry soil crumbs beneath the surface crusts, which form on these soils, and to the penetration of light into the soil, resulting in the development of the primary leaf of the non-emerged seedlings (Leslie, 1965). This problem can be overcome by using a surface mulch to reduce the rate of drying of the soil surface (Rickert, 1973). A number of crop residues appear suitable but care needs to be taken during seedbed preparation to retain the mulches on the surface where they provide greatest benefit (Rickert, 1973).

Species and depth of sowing

The depth from which seedlings will emerge depends on the species sown and the soil type. Seedling emergence is affected by mechanical impedance, crust strength and moisture content of the soil as well as the energy reserves and growth rate of the seedling. As soil moisture increases, mechanical impedance and crust strength decrease and so the soil becomes easier to deform by the expanding plant organs. Low soil moisture tensions therefore allow rapid seedling emergence at low energy cost, resulting in stronger seedlings and faster establishment. The converse occurs with increasing soil moisture tensions. The relationship between seedling vigour and mechanical impedance becomes more important as planting depth increases, particularly with slower-emerging species (Brock, 1973).

Emergence ability generally increases with seed size (Tadmor and Cohen, 1968; Whiteman, 1968; Ludlow and Wilson, 1972; Crowder and Chow, 1974), the larger organs, which develop from the larger seeds, being able to exert greater force (Barley and Greacen, 1967) allowing emergence from greater depths of sowing than smaller seeds. Germination rate is also considered important

(Heydecker, 1960), particularly for seedling emergence and survival in environments where the soil dries quickly following rain (Whalley *et al.*, 1966; Torssell *et al.*, 1968). For example, the rapid germination of Townsville (*Stylosanthes humilis*) and Caribbean (*S. hamata*) stylos may be a reason for their success in the harsh north-west of Australia. These species are capable of germinating overnight following afternoon thunderstorms (McKeon and Brook, 1983). Speed of germination may compensate for a lack of seed size in the case of these stylos (Torssell *et al.*, 1968) and also of some small-seeded annual grasses such as *Schismus arabicus* (Whalley *et al.*, 1966). On the other hand, too fast a germination associated with a single fall of rain, e.g. a thunderstorm, can lead to death of seedlings in subsequent dry periods (Mott *et al.*, 1976; McKeon and Brook, 1983).

Most pasture species have relatively small seeds (Table 5.2) and an optimum sowing depth of only 10-20 mm (Bogdan, 1961; Sund *et al.*, 1966; Lazenby and Schiller, 1969; Stonard, 1969; Townsend and McGinnies, 1972; Brock, 1973). Increasing the depth of sowing from 0 to 20 mm generally increases germination and emergence, but emergence declines when seed is sown deeper than 20 mm (Figure 5.2), particularly in clay soils, which frequently have a higher mechanical impedance than sandy soils. Thus the optimum sowing depth for clay soils is shallower than that for sandy soils. Conversely, the surface of sandy soils dries more rapidly than that of clay soils (Miller and Perry, 1968), resulting in lower establishment of surface-sown seed, especially of species that are relatively slow to germinate (Mott *et al.*, 1976).

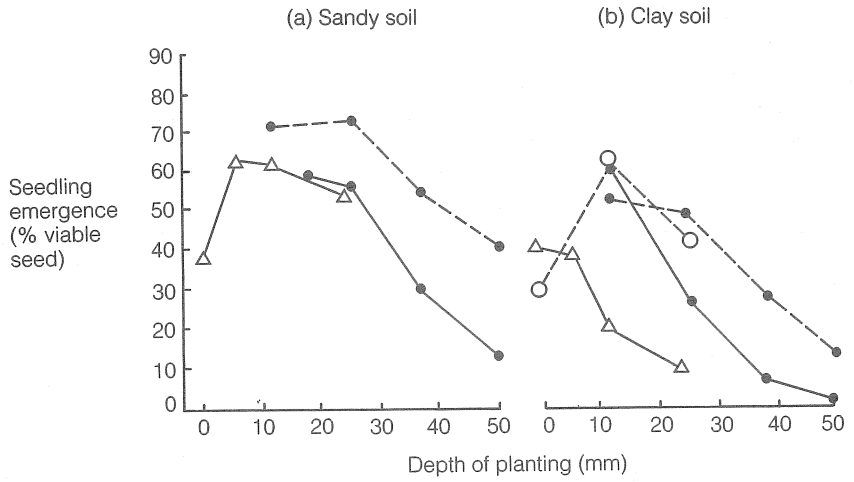

Figure 5.2 Effect of planting depth on seedling emergence from (a) sandy soil and (b) clay soil: ●——● cocksfoot, ●----● lucerne (Sund *et al.*, 1966), △——△ buffel grass (Mutz and Scifres, 1975), ○----○ phalaris (clay loam) (Lazenby and Schiller, 1969)

On coarse-textured sandy soils subterranean clover (*Trifolium subterraneum*) and barrel medic (*Medicago truncatula*), which have larger seeds than many other pasture species (Table 5.2), were shown to establish best at sowing depths between 25 and 37 mm. However, shallow or surface sowing gave better establishment on sandy soils where surface crusts formed (Toms, 1958). *Stylosanthes* spp. have smaller seeds and are incapable of emerging from depths greater than 13 mm (Stonard, 1969; Winkworth, 1969). Their failure to emerge from greater depths appears to be related to the length of the hypocotyl (Winkworth, 1969). Previous work suggested that Townsville stylo did not respond to seed coverage. For example, in experiments near Katherine, Norman (1961) showed that covering the seed by harrowing the seedbed after broadcasting the seed onto cultivated ground reduced establishment. However, this reduction may have resulted from too deep a burial of the seed. Many seeds fall into furrows and depressions when they are sown onto

a cultivated surface (Toms, 1958). Harrowing would then bury many of the seeds at depths greater than 13 mm below the soil surface, leading to poor emergence. The poor soil structure and surface sealing, common on Tippera clay loam soils in the Katherine environment (Mott *et al.*, 1979) are also likely to have contributed to the poor establishment, especially of the more deeply planted seeds.

Survival of perennial grass seedlings depends on the development of nodal or secondary roots (Hyder, 1974). Seedlings that fail to develop these roots grow slowly after germination because of moisture stress; they only survive a few months, even when subsoil water is available (Wilson and Briske, 1978; Cornish *et al.*, 1984). Nodal root development is inhibited by low soil water potentials at the crown of the plant; about 3-4 consecutive days of moist conditions are needed for root development to proceed (Wilson and Briske, 1978; Cornish, 1982). Seedlings from shallow or surface sowing, with their crown at or near the soil surface, may have difficulty developing nodal roots because of the rapid drying of the soil surface. Species differences can influence seedling behaviour under such conditions, e.g. surface-sown phalaris (*Phalaris aquatica*) seedlings produced no nodal roots despite daily watering of the soil to field capacity, whereas 67% of the perennial ryegrass (*Lolium perenne*) seedlings developed nodal roots (Cornish, 1982).

Limitations of planting equipment

The majority of the seed drills used for sowing pastures have been designed for crop species where sowing depth is not so critical and so they are not capable of sowing with precision placement at the shallow depths required for small-seeded pasture species. Rather than placing the seed at say a depth of 13 mm, they tend to distribute the seed throughout the top 13 mm of soil. Many seed drills are also adapted for use with pasture seed by the fitting of a small-seeds box. Seed is either directed into the sowing boots or onto the soil surface behind the machine, relying on light harrows and/or rollers to cover the seed. Variable planting depths result, with a portion of the seed not being covered. Furthermore, few seed drills are capable of controlling the depth of the individual coulters so that even small ridges or depressions in the surface of the soil can result in relatively large variations in sowing depth.

Even though it is difficult to relate the placement of seed at a specific depth in direct-drill situations to that in cultivated seedbeds (Campbell, 1985), precise seed placement has been shown to be just as important when direct drilling as when sowing into conventional seedbeds (Barnhart and Wedin, 1983; Campbell *et al.*, 1983). For example, when direct drilling red clover (*T. pratense* cv. Pawera) in New Zealand, Campbell *et al.* (1983) observed considerable variation in coulter depth. Close to 90% emergence was obtained where coulter depth was controlled at 13 mm below the soil surface. Significantly fewer seedlings appeared (48%) where the coulter skimmed the surface. Sowing deeply also reduced numbers, with just over half the seed emerging, the rest germinating but dying below ground.

Direct-drilling machines that place seeds in open drill grooves with little or no soil coverage, namely those based on the dished disc, triple-disc and hoe coulters (Figure 5.3), also tend to result in a relatively poor seedling emergence when compared with seeds sown with optimum soil coverage. The winged 'chisel' coulter developed at Massey University in New Zealand (Baker, 1976) was designed to improve seed germination and seedling establishment by retaining a soil and litter cover over the seed. This coulter is designed to create minimal disturbance at the soil surface but produces considerable sub-surface shattering, leaving an inverted 'T'-shaped groove (Figure 5.3) with better moisture retention properties than the 'V'- and 'U'-shaped grooves created by the triple-disc and hoe coulters. Such effects are particularly important where moisture is marginal for seedling establishment (Baker, 1980) and rapid soil drying

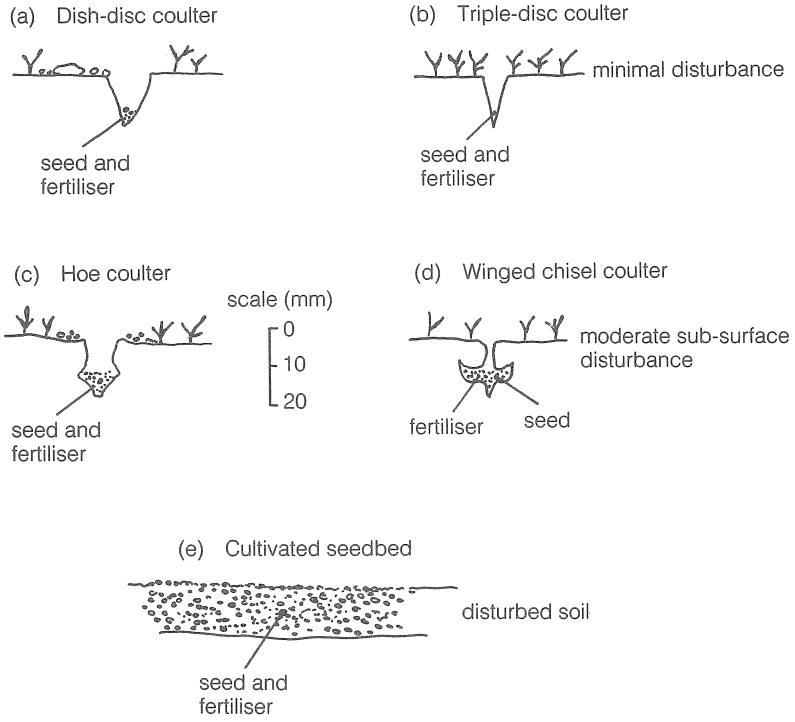

Figure 5.3 Groove geometry and relationship between seed and fertiliser placement for a range of pasture-sowing coulters

follows rain. However, such advantages are lost if coulter depth is not controlled on uneven ground, allowing the coulter to ride out of the soil in low patches and sow too deeply on ridges (Campbell, 1985).

Sowing methods that place seeds on or within 5 mm of the soil surface, either intentionally or through inaccuracies of planting equipment, are likely to result in a significantly lower germination and establishment than methods that precision-place seed 10-20 mm below the soil surface. This applies in almost all sowing situations, irrespective of whether the seedbed has been cultivated, unless the moisture conditions are highly favourable for the full period of germination and establishment. Since few machines are capable of placing small-seeded pasture species with the degree of precision required, seed placement should be given a high priority in programmes developing planting equipment.

The precision placement of seed of a number of important tropical species is almost impossible with the machinery that is currently available because of the nature of their seeds. Problems associated with metering these seeds need to be overcome, either by pelleting the seeds or redesigning the metering mechanisms, before any attempt at seed placement can be made.

Poor germination and emergence resulting from variable planting depths or seed coverage is likely to remain a problem with pastures established by direct drilling or in cultivated seedbeds unless machinery is specifically designed or adapted for use with small-seeded pasture species. In particular there appears to be a need for precision depth control of individual coulters, or at least small groups of coulters.

FERTILISER PLACEMENT

Fertiliser may be broadcast on the soil surface, drilled in rows in contact with the seed, or drilled in bands placed either beside and/or below the seed. All three methods of fertiliser placement may be used in cultivated seedbeds and direct-drilling situations, but with surface sowing, application is limited to surface broadcasting.

The most important aspect of fertiliser placement, as with seed placement, is whether the fertiliser is broadcast on the surface or is drilled into the soil. Drilling the fertiliser with the seed, or banding it close to the seed, are generally more effective than broadcasting it on the soil surface (Jackson, 1966). For example, Flemons *et al.* (1963) showed that for a given amount of superphosphate applied, drilling the fertiliser with subterranean clover seed was as effective as using double the amount of fertiliser when broadcast, although such effects were confined to the establishment year. Similarly, Scott (1973) showed that dry matter yields of barrel medic (cv. Jemalong) were higher when superphosphate was placed at either 5 or 10 cm depth as opposed to surface banding or broadcasting. The effects were still evident in the second year and also resulted in higher seed yields. Cornish and Myers (1977) attributed the low productivity of pastures on some soils of the southern Tablelands of New South Wales to the common practice of broadcasting superphosphate.

The advantages of placing fertiliser in the soil as opposed to surface broadcasting appear to be three-fold. Firstly, the surface layers of the soil dry more rapidly than those at depth and the fertiliser is therefore unavailable to plants for longer periods than if it were placed deeper in the soil (D'Aoust and Taylor, 1968; Scott, 1973; Cornish and Myers, 1977). Such effects may be less important in higher-rainfall areas, where the surface layers of the soil stay moist for extended periods and where certain nutrients may be leached into the root zone. However, they are likely to be a significant factor over large areas of both temperate and tropical Australia and where superphosphate is the main fertiliser applied. Secondly, fertiliser placed in the seedling root zone is more readily accessible to the roots of the developing seedlings. Young seedlings have only a limited root distribution so nutrients placed in the soil close to their root zone are more readily taken up (Tesar *et al.*, 1954), resulting in a more rapid seedling growth and development (Wagner, 1956). Thirdly, banding of phosphorus in the vicinity of the root maximises its availability in strongly fixing soils, although more phosphorus may eventually be lost to unavailable chemical forms (Holford, 1976).

The importance of adequate nutrition during the early stages of seedling development has been demonstrated by McWilliam *et al.* (1970). They showed that fertiliser phosphorus was absorbed as early as 4 days after the start of imbibition. Lucerne (*Medicago sativa*) and subterranean clover seedlings grown in perlite and sand under conditions of controlled environment, and receiving nutrients, were significantly heavier than those receiving only distilled water as early as 5 days after starting imbibition. Phalaris and perennial ryegrass seedlings showed a similar response 6 days after the start of imbibition and the differences in growth of both the legume and grass seedlings increased markedly with time. When nutrients were withheld, a reduction in root elongation was evident 5 days after the beginning of imbibition. Furthermore, under field conditions Cook and Ratcliff (1985) showed that, one day after seedling emergence, Siratro (*Macroptilium atropurpureum*) seedlings fertilised with superphosphate and nitrogen at sowing were larger than those receiving no fertiliser. Such results demonstrate that young seedlings are capable of utilising external nutrients within the first few days of emergence under favourable conditions. This, together with the fact that the bulk of the endogenous seed reserves, at least in ryegrass seedlings (McWilliam *et al.*, 1970), appears to be utilised by about 10 days after germination, suggests that fertilisers need to be placed where they are readily accessible to the young seedling in order to gain maximum benefits in growth rates following emergence.

The lack of a local supply of phosphorus must be a major disadvantage of surface-sown seeds, partly explaining their slow establishment compared with a cultivated seedbed. It does not appear to be related to survival in the absence of competition, however, because the extension of main roots into the subsoil is insensitive to P-supply in many pasture species (Cornish, 1986).

Problems with germination and nodulation can occur where fertilisers are drilled in contact with the seed (Jackson, 1966), especially where nitrogen and potassium fertilisers are used (Wagner, 1956). Superphosphate is toxic to *Rhizobium* bacteria and there is also evidence that the germination of pasture species such as subterranean clover (*Trifolium subterraneum*), lucerne (*Medicago sativa*) and phalaris (*Phalaris aquatica*) is inhibited by contact with superphosphate, especially in sandy soils (Jackson, 1966). In cultivated seedbeds it is therefore often recommended that superphosphate be drilled into the seedbed in the last working prior to sowing, although less benefit may be obtained than if the fertiliser were banded in close proximity, yet separate from the seed (Wagner, 1956). Basic or reverted superphosphate, mixtures of lime and superphosphate, or lime pelleting are often used to overcome toxicity problems associated with *Rhizobium* survival (Jackson, 1966).

Where soil acidity causes nodulation problems and restricts the general growth of pasture species, either directly or indirectly through effects such as aluminium toxicity, application of lime may be necessary, the amount and method of application depending on the soil pH and the species concerned. In cultivated seedbeds lime is best applied during seedbed preparation so that it becomes mixed with the soil during the various tillage and planting operations. Surface application of lime is not as effective as incorporation (Cregan *et al.*, 1979). Banding may be useful in overcoming initial nodulation problems, but the effects may only be local with limited benefits outside the band area (Graven and Theron, 1970). Lime is therefore difficult to effectively apply in surface-sowing and direct-drilling situations and it may be necessary to select more acid-tolerant species where these establishment methods are to be used.

Band placement of fertiliser separate from the seed has been hindered by the lack of machinery capable of performing the task. However, where grain drills are fitted with a small-seeds box as well as a fertiliser box, the seed and fertiliser may be directed down separate delivery tubes. It is possible to direct the seed into furrows above the fertiliser, which is placed in bands at a deeper level in the soil by the normal sowing boots (Wagner, 1956). However, it is difficult to control seed placement and seed coverage when using this technique of banding. Furthermore, while this method of fertiliser banding may be feasible in cultivated seedbeds it would generally not be feasible for direct drilling, at least with the machines currently available. Grain drills or combines are generally not sufficiently robust for direct drilling into undisturbed pasture swards (Breakwell, 1957) and few of the specialised sod-seeders based on either the triple-disc or hoe coulters are capable of banding the seed and fertiliser separately. One exception is the winged 'chisel' coulter discussed previously (Baker *et al.*, 1979a). It places the seed and fertiliser approximately 10 mm apart in the row (Figure 5.3) and offers many possibilities for banding fertiliser at sowing time, especially in relation to the application of nitrogenous and potassic fertilisers in direct drilling operations.

EFFECT OF SOIL DISTURBANCE

Pasture establishment is generally proportional to the amount of soil disturbance and so establishment from sod-seeding or other minimum-tillage methods tends to be intermediate between that of surface sowing and fully cultivated seedbeds (Norman, 1961; Watkin and Vickery, 1965; Clatworthy and Thomas, 1972; Grant, 1976). The disturbance created by tilling the soil can affect pasture establishment in a number of ways: disturbance may change the physical and

chemical characteristics of the soil and also modify or destroy the habitats of various pests and diseases. Cultivation is also one of several means of modifying the existing vegetative and litter cover, which are considered later in this review. The degree to which each of these factors is changed depends on the soil type, past land use, the climate of the area and the extent of the soil disturbance.

Effect on soil physical and chemical characteristics

Root growth through the soil depends on the availability of soil pores of sufficient size to allow penetration, or alternatively on the ability of the roots to create their own pathways by deforming the soil (Russell, 1977). The latter depends on the mechanical resistance or strength of the soil, which in turn depends on bulk density and soil water content (Taylor and Gardner, 1963). Soil disturbance generally increases the percentage of large pores in the soil, which reduces bulk density and improves aeration and water infiltration (Russell, 1977). Any reduction in bulk density is more likely to benefit root growth under low rather than high soil water contents (Cornish *et al.*, 1984). Many soils are inherently strong, such as the surface of red and yellow podzolic soils in northern New South Wales where root growth may cease at relatively high soil water potentials. In one such soil, Cornish *et al.* (1984) found that perennial ryegrass root extension ceased at a soil moisture potential of only -0.3 MPa (bulk density, 1.3 g cm^{-3}), well above the -1.5 MPa that is usually considered permanent wilting point. Any such reduction in root extension is likely to limit nutrient uptake (Cornish *et al.*, 1984), especially of phosphorus and other immobile nutrients. Seedlings may also die from water stress if their rate of root growth does not keep pace with the downward movement of the drying front in the soil. Seedling growth and survival may therefore be reduced in surface sowing, direct drilling and other minimum-tillage situations, either because of induced nutrient deficiency or an insufficient rate of vertical root penetration (Plummer, 1943; Cornish, 1979; 1982).

Radicle entry into the soil is a critical phase in establishment where seeds are sown on the soil surface. Radicles exposed on the soil surface are susceptible to desiccation (Dowling *et al.*, 1971; Campbell and Swain, 1973b) and losses during this phase of establishment can limit the success of surface sowing (Campbell, 1968a). Since radicle entry is favoured by increasing the heterogeneity and decreasing the strength of the soil surface (Campbell and Swain, 1973a) any soil disturbance during sowing favours establishment. Possible exceptions are where soils form seals following tillage and where the tillage machinery compacts or smears the drill groove. For example, in moist clay soils, triple-disc coulters, because of their shape and subsequent wedging action, tend to smear and compact the sides and base of the drill groove. Even on soils that do not smear, compaction at the base of the triple-disc groove can reduce radicle entry (Baker, 1976). Nevertheless, seeds sown with triple-disc seeders are still likely to establish better than if they were broadcast on the soil surface (Dowling *et al.*, 1971).

There is conflicting evidence on the effects of soil disturbance on plant growth, with both increases and, more usually, decreases having been recorded where minimum tillage has been compared with conventional cultivation. The causes and consequences of reduced early growth in direct-drilled crops are discussed in Chapters 2, 6, 8 and 15.

Mineralisation of nutrients tends to be greater in ploughed soils than in undisturbed soils (Baeumer and Bakermans, 1973) and mobile nutrients such as nitrate tend to accumulate in conventional fallows (Chapter 11). In low-fertility soils in Australia the small increases in available nitrogen resulting from soil disturbance are likely to stimulate seedling growth, particularly during the first weeks after emergence when root distribution is limited, provided there is no plant competition.

Pest and disease control

Special precautions may be necessary to control pests and diseases where complete cultivation is not practised. Direct-drilled and surface-sown pastures are prone to damage from pests and diseases that are often destroyed when the soil is ploughed. Seed-harvesting ants can take large quantities of surface-sown seed if conditions remain dry after sowing (Campbell, 1966; Russell *et al.*, 1967; Johns and Greenup, 1976a; 1976b). Pre-treating seed with dieldrin, bendiocarb or permethrin (Campbell, 1966; Campbell and Gilmour, 1979), or pelleting it in lime (Russell *et al.*, 1967), can substantially reduce seed theft by ants.

Other pests including crickets and slugs (Charlton, 1978; Byers *et al.*, 1985) can reduce survival of white clover (*Trifolium repens*), red clover (*T. pratense*) and subterranean clover, lotus (*Lotus pedunculatus*) and lucerne seedlings in reduced or no-tillage situations. The presence of dead surface cover provides an ideal environment for these pests as do the drill grooves created by direct drilling. Charlton (1978) showed that less than 10% of a range of legumes survived to 6 weeks where slugs were present. Seedlings in the early stages of development (germinating seed to cotyledon stage) were most vulnerable, whereas once the seedlings reached the one-to-five true leaf stage there was little further mortality. However, coating the seed with methiocarb greatly increased seedling survival (Charlton, 1978). Byers *et al.* (1985) also showed that methiocarb bait, either alone or in conjunction with carbofuran, increased lucerne and red clover seedling survival. It may be possible to reduce slug and insect populations by reducing the existing surface cover, but this is likely to be at the expense of seed germination, radicle entry and soil-conservation considerations and so does not appear to be a practical solution. Slugs are not a problem in the hotter, drier areas of the tropics.

TREATMENT OF VEGETATIVE AND LITTER COVER

Surface cover includes both the standing vegetative cover that is still attached to plants and the litter on the soil surface. Its treatment is one of the most powerful means of influencing establishment, primarily through its effect on the water relations of seeds and establishing seedlings. Surface cover can either increase or decrease establishment, depending on the environment in which the pasture is being established, the nature and type of cover present, and whether the cover is living or dead plant material. The amount of surface cover retained depends on the amount of soil distubance, previous grazing pressure and the use of other management practices such as use of herbicides and fire. Minimising trash at planting in order to reduce clogging problems with tine-based planters is also a common objective of conventional seedbed preparation. The amount of surface cover is often reduced by burning and/or heavy grazing prior to the initial working. The surface cover remaining is then mixed with the surface soil during ploughing. Subsequent workings are designed to control weed growth and hasten the breakdown of plant material already incorporated into the soil.

Conventional seedbeds tend to destroy all or most of the surface cover and leave a bare soil surface, which, in certain situations, is very susceptible to the formation of surface seals (Bridge *et al.*, 1983; Chapter 6). Infiltration is reduced and runoff increased. Soil erosion may be increased, particularly in tropical areas where thunderstorms of high intensity are a feature of the environment. Surface sealing can also reduce establishment by reducing seedling emergence (Arndt, 1965; Leslie, 1965; Greenland, 1971; Mott *et al.*, 1979). On the other hand, surface cover protects the soil surface from raindrop action, increases infiltration and reduces soil erosion problems (Chapter 7).

Effect of surface cover on seed germination and seedling emergence

Surface cover affects seed germination primarily by increasing the moisture retention of the soil surface and that of the microenvironment surrounding the seed (Harper and Benton, 1966; Mott *et al.*, 1976; Dowling and Gilmour, 1983). Cover also increases the number of microsites available for radicle entry (Harper *et al.*, 1965; Dowling *et al.*, 1971) and reduces the diurnal fluctuations in soil temperature (Baeumer and Bakermans, 1973).

The importance of surface cover for germination and emergence largely depends on the weather accompanying and following the germinating rains, being most important when hot sunny or dry conditions follow rain (Baker, 1977; Cook, 1984; McIvor and Gardener, 1985). Under these conditions the surface cover shades and protects the germinating seed and the soil surface from direct radiation and the hot drying conditions it creates. The rate of drying of the soil surface is therefore reduced by cover (Mott *et al.*, 1976; Dowling and Gilmour, 1983), especially if it is dead (Cook and Dolby, 1981). Maximum soil surface temperatures in sub-tropical and tropical areas commonly exceed 65° C where the surface is bare, but are up to 20° C lower in the presence of surface cover (Mott *et al.*, 1976). Furthermore, after 2 days of heavy rain the surface of a sandy soil, where the cover had been burnt, dried from field capacity to -1.5 MPa within 48 hours of the rain stopping. In contrast, live grass cover kept water potential above -0.1 MPa for 72 hours. Under such conditions the germination of Townsville stylo surface sown into unburnt pasture was up to three times that in burnt areas (Miller and Perry, 1968). Species such as the shrubby stylos (*Stylosanthes scabra*), which germinate more slowly than Townsville stylo, are even more susceptible to the rapid drying of the soil surface (Mott *et al.*, 1976). In temperate areas, surface-sown grasses germinate more slowly than legumes and are more susceptible to surface drying (Dowling *et al.*, 1971).

Apart from their drying effect, high soil temperatures can also kill any partially imbibed surface-sown seed that has not germinated (Murtagh, 1970). Many seedlings also die at the stage of radical emergence under bare soil conditions as a result of dehydration (Campbell and Swain, 1973b; McKeon and Brook, 1983). In the absence of surface cover, the period of germination is often restricted to the overnight period following afternoon storms in tropical areas, except where rainfall and cloud cover continue into the following day.

Surface cover is less important for germination and emergence where evaporative conditions remain low for extended periods, such as when rain events extend over several days (Cook and Dolby, 1981; McIvor and Gardener, 1985), or during the winter in temperate areas (Campbell and Swain, 1973b). Nevertheless, Dowling (1978) has shown that surface cover improves establishment of surface-sown seed at all times of the year at Glen Innes on the northern tablelands of New South Wales.

Treatments that reduce or destroy cover, such as burning and, to a lesser extent, heavy grazing, can reduce germination of surface-sown seed when hot sunny conditions follow rain. Burning denudes the soil of almost all surface cover, destroying both vegetative cover and litter. Although heavy grazing creates conditions less severe than burning, by retaining or increasing litter cover due to the trampling action of the animals, establishment may still be reduced because cover height is more important than cover weight (Dowling and Gilmour, 1983). The nature or botanical composition of the vegetative cover can therefore be important in determining the effects of cover on germination and emergence.

Dead vegetative cover and litter can reduce germination and emergence in some circumstances and Naylor *et al.* (1983) cite a number of such instances relating to the establishment of grasses

and cereals in the United Kingdom. The problem appears to be related to the release of phytotoxic substances from decaying plant residues and to herbicide leachates (Marshall and Naylor, 1984a; 1984b) and occurs particularly during wet autumns (Naylor *et al.*, 1983). Furthermore, any lowering of soil temperatures by surface cover where low temperatures already limit germination may further reduce the rate of germination and increase the risk of fungal infection. Dense litter layers can also reduce establishment by preventing seeds reaching the soil surface (McIvor and Gardener, 1981). Vegetative cover that collapses onto the soil surface when it is killed with herbicide can cause similar problems. For this reason dead plant cover does not assist establishment in areas infested with nitrophilous weeds (Campbell *et al.*, 1985).

Dense litter or trash on the soil surface can make depth control difficult when seed is direct drilled. In some situations, even disc coulters may not cut through the trash and the seed is placed on the surface of the litter or in the trash layer (Naylor *et al.*, 1983). Alternatively, the trash may be pressed into the slot with the seed, leading to poor soil-seed contact (Marshall and Naylor, 1984b) or preventing the closure of the drill slot and allowing the soil surrounding the seed to dry (Choudhary and Baker, 1980).

Effect of surface cover on seedling growth and survival

The seedling growth and survival phase starts once the radicle has entered the soil and root growth has started. In many situations litter and dead vegetative cover could be expected to favour seedling growth and survival by reducing heat and water stress as in the germination phase, especially in tropical areas. Dead vegetative cover has the advantage of reducing water requirements of seedlings by partially shading their leaves from direct radiation (Scott and Archie, 1976). This is considered particularly important in tropical areas when seedlings have only a small root system. Unshaded seedlings display severe heat and water stress during sunny hot conditions, even where the soil surface is quite moist. Seedlings with the protection of dead standing cover did not show such symptoms (S.J. Cook, unpublished data). However, shading from too dense a cover can reduce seedling root growth (Ludlow, 1978) or morphological development (Cornish, 1982). Dowling (1978) found that establishment of surface-sown seed of both grasses and legumes on the northern tablelands of New South Wales increased as cover increased from less than 1000 to about 5000 kg ha^{-1}; however, establishment declined when cover exceeded 6000 kg ha^{-1}.

Live vegetative cover, while providing similar protection to dead cover, has the disadvantage that it competes with the establishing seedlings for water, nutrients and light. In some temperate and sub-tropical areas, where the existing vegetation is comprised mainly of summer-growing species, it is possible to minimise the effects of this competition by sowing temperate species during the late autumn and winter when the existing vegetation has stopped growing or is dormant (Grimmett, 1967). However, tropical pastures, because of their temperature response and the distribution and reliability of rainfall in the Australian tropics, have to be sown during the late spring or summer months, the time when competition from existing swards is greatest.

Competition and pasture establishment

Competition from existing vegetation is a major factor limiting the survival of seedlings established by surface sowing, direct drilling and other minimum-tillage methods in both temperate areas (Charles, 1962; Cullen, 1966; Campbell, 1968b; Dowling *et al.*, 1971; Campbell, 1974; Squires *et al.*, 1979) and tropical areas (Cook and Dolby, 1981; McIvor and Gardener, 1981;

Cook, 1982; Thomson *et al.*, 1983; Cook, 1984). Grasses are more susceptible to competition than legumes and, in most situations, it is almost impossible to establish improved pasture grasses by these methods unless the existing vegetation is severely disturbed by cultivation or killed by herbicides.

Survival depends on the size of the plants when stress is encountered. Bigger plants (Wagner, 1956; Hoen, 1968; Cook, 1984) with larger (Plummer, 1943) or deeper (Cornish, 1982) root systems survive. Competition from existing vegetation may restrict growth to such an extent that the seedlings subsequently die from water or temperature stress (Cook and Dolby, 1981; Thomson *et al.*, 1983). The effects on the seedling of plant competition, water and temperature stress appear to be additive, suggesting that competition acts as a form of stress. Such an effect has been observed for the tropical legume Siratro which, though capable of withstanding either moderate water stress (Peake *et al.*, 1975) or competition (Cook, 1980), is less able to cope with the combined effects of the two. Seedling growth rates following emergence are therefore critical in affecting seedling survival (Cook and Ratcliff, 1985).

Tillering in grasses (Cook, 1984) and the number of leaves of Siratro were useful indicators of seedling growth and ability to survive. Siratro seedlings were particularly vulnerable to stress until the first trifoliate leaf emerged. This generally occurs from 10 to 21 days after germination, depending on growth conditions and the amount of competition present (Cook, 1980). Cook (1984) found that the majority of grass plants surviving 10 months after germination possessed from three to six tillers and were 8-10 cm tall 140 days after seedling emergence while the majority of plants which died had only one tiller and failed to exceed 4 cm in height.

In a relatively open sub-tropical native grassland dominated by speargrass, Cook and Ratcliff (1984) found that competition between the existing native sward and green panic seedlings was associated mainly with the root rather than the shoot component. Similar results were obtained in a subsequent experiment where competition for light was also shown to be of secondary importance to root competition for the growth of both green panic and Siratro seedlings, even under irrigated conditions. However, Siratro grew better than green panic in the presence of both root and shoot competition, yielding about 11 times the yield of the green panic 29 days after seedling emergence (Cook and Ratcliff, 1985). Removal of shoot competition increased the average dry weights of green panic seedlings five-fold and that of Siratro six-fold, whereas the removal of root competition increased yields 73- and 10-fold for the green panic and Siratro seedlings, respectively (Figure 5.4); removal of both root and shoot competition increased growth of green panic and Siratro 143- and 16-fold, respectively.

The fact that legumes are better able to compete with native grass swards than grass seedlings (Figure 5.4) and can be established successfully by direct drilling, surface sowing and other minimum-tillage techniques (Cook, 1980) suggests that competition for soil nitrogen is a major factor limiting grass seedling growth. In situations where soil nitrogen levels are higher, either because of natural soil fertility, fertiliser application (Cook, 1985), or nitrogen build-up under the influence of legumes and fertiliser, introduced grasses are better able to compete with the resident vegetation, making establishment by reduced-tillage methods possible (Tothill, 1981). However, legume establishment by reduced tillage in areas of higher fertility may be less reliable, even with the aid of soil disturbance or herbicides, because of intense competition from annual nitrophilous weeds (Campbell and McDonald, 1979).

Even though legume establishment in the presence of native-pasture competition is possible (Cook and Dolby, 1981; McIvor, 1983), the probability of successful establishment is still low (Cullen, 1966; Dowling *et al.*, 1971; Cook, 1984), especially for perennial species. Greater reliability in establishment in the presence of native-grass competition has been achieved with

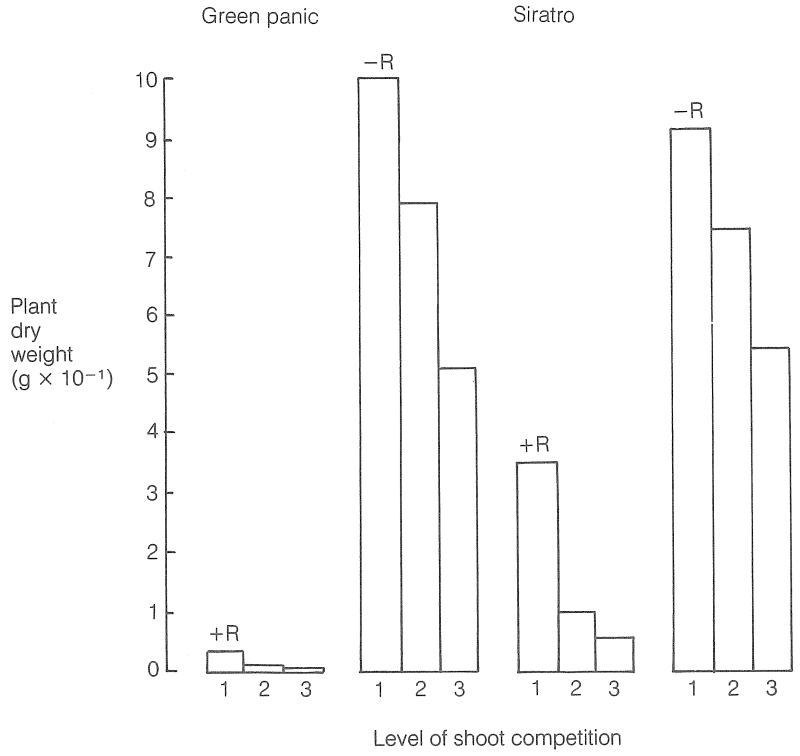

Figure 5.4 Dry weight of green panic and Siratro seedlings 29 days after seedling emergence when grown in the presence (+R) and absence (−R) of root competition under three levels of shoot competition:
Level 1—pasture maintained at height of 3–5 cm by clipping; yield of 520–1180 kg ha^{-1}
Level 2—pasture maintained at a height of 10–15 cm by clipping; yield of 1780–2950 kg ha^{-1}
Level 3—unclipped control, height of 40–60 cm; yield of 2500–4900 kg ha^{-1}

annual species such as subterranean clover (Campbell, 1968b; 1976a), Townsville and Caribbean stylos (Miller and Perry, 1968; Edye and Gillard, 1985), especially in areas where rainfall reliability during germination and establishment was relatively high. The slower establishment of some perennial legumes, when combined with erratic rainfall and competition from existing vegetation, makes establishment a more risky procedure.

Competition for light is considered less important than root competition in most Australian native grasslands where growth is limited largely by the low fertility status of the soils in which they grow. The sward canopies are relatively open, allowing good light penetration, even under continuously wet conditions (Cook and Ratcliff, 1984; 1985). Nevertheless, positive responses in establishment to burning (Anning, 1980) and clipping (Gillard, 1977) have been claimed for *Stylosanthes* species, which are known to be sensitive to low light levels (Sillar, 1967). On the other hand, few experiments have been reported in which adequate control treatments (e.g. burnt versus unburnt) have been included. Nor is it clear whether the benefits of burning were due to a reduction in competition for light or to a reduction in root competition, especially in view of the relative growth response of Siratro, which is also considered to be sensitive to light levels (Whiteman *et al.*, 1974), and to root and shoot competition. Competition for light reduced the growth of green panic and Siratro seedlings in speargrass swards by reducing leaf and tiller production, but the effect was substantial only in the absence of root competition (Figure 5.4).

Control of plant competition

Herbicides, burning and grazing have been used with varied success to control plant competition in reduced tillage (Cook, 1980). The reasons for this variation contribute to the uncertainty often associated with reduced tillage. However, a major reason for the variable and unpredictable response is likely to be the general lack of understanding of the nature of the competition at which the control measures were being directed. Control treatments that work in one situation may not work in another where the circumstances are different.

Burning and heavy grazing have both been shown to reduce the subsequent growth of native grasses (Smith, 1960), especially when carried out at critical times in their growth phase (Jones, 1933; Norman, 1965; Stocker and Sturtz, 1966; Cook *et al.*, 1978a). Species such as *Sorghum plumosum*, *Themeda australis* (Smith, 1960) and *Sporobolus elongatus* (Shaw, 1957) appear particularly susceptible to burning whereas *Chrysopogon fallax* (Smith, 1960) and black speargrass (*Heteropogon contortus*) (Shaw, 1957) are quite resistant. If the dominant native species in the pasture are resistant to fire then only a limited reduction in root competition might be expected following burning. Conversely, if the dominant species are susceptible to fire, as was the case of the annual *Sorghum intrans* seedlings of Stocker and Sturtz (1966), then a considerable reduction in root competition could be expected. Burning can therefore be expected to give only a small relief from root competition in the majority of native pastures in tropical Australia in which black speargrass and *C. fallax* are important species. On the other hand, burning may reduce the amount of other grasses and forbs that tend to occupy the spaces between the tussocks of the black speargrass (Tothill, 1983), leading to a reduction in root competition. Such an effect may be the reason for the positive response to burning but lack of response to clipping in the establishment of Siratro when it was surface sown into black speargrass pasture (Cook, 1984). However, small reductions in root competition, while of some benefit to legumes in favourable situations, are of insufficient magnitude to enable legumes to establish in less favourable situations, or to allow improved grasses to establish in almost any situation (McIvor and Gardener, 1981; Cook, 1984).

In the absence of complete weed control by tillage the best control of plant competition has been obtained from the use of herbicides (Dowling *et al.*, 1971; Campbell, 1974; Cook, 1984) that control both root and shoot competition. In fact the development of effective herbicides with few residual effects, namely paraquat and glyphosate, was partly responsible for the rapid development of direct drilling as a means of renovating and establishing pastures in New Zealand, the United Kingdom and the United States in the 1960s and 1970s. Both paraquat and glyphosate are inactivated on contact with the soil. However, some herbicide residue may remain in the dead cover (Campbell, 1976b) or in the leachates arising from the cover (Marshall and Naylor, 1984a), especially in cool temperate areas and/or where the dead cover collapses onto the soil around the seedlings. In these areas it is therefore recommended that 10 to 20 days be allowed between spraying and sowing to permit breakdown to occur (Campbell, 1976b). However, no such problems have been evident in sub-tropical areas (S.J. Cook, unpublished data), even when spraying and sowing have been conducted in the same operation. The higher levels of radiation and higher temperatures in the tropics may lead to a more rapid breakdown of the herbicide.

There is an important difference in the mode of action of paraquat and glyphosate. Paraquat is a contact herbicide, which can desiccate green foliage within 2-3 days, whereas glyphosate is a systemic herbicide, which is slower acting, taking up to 14 days to kill the sward. The translocating action of glyphosate may also tend to dilute the effects of the herbicide in band-spraying situations (Baker *et al.*, 1979b). Higher concentrations of herbicide may be required when banding than where blanket spraying is used. The rapid action of paraquat is sometimes considered to be an advantage during seedling establishment but the competition

control is short-term in nature where the existing vegetation is comprised mainly of perennial species. Paraquat rarely kills perennial species and regrowth may be rapid, especially where temperatures exceed 15-20° C. In most situations the best establishment is attained from the herbicide treatment that gives the most complete control of weeds for the longest period (Campbell *et al.*, 1981).

Despite the advantages of herbicides such as glyphosate in controlling both root and shoot competition there is still a reluctance to use herbicides on large areas because of the cost involved. However, techniques such as band spraying have the ability to reduce herbicide costs in direct-drilling situations (Squires *et al.*, 1979). When considering the use of herbicides for competition control, it is necessary to consider the type of competition control required. Narrow bands 4 cm wide were assessed by Baker *et al.* (1979b) to provide better conditions for seedling growth than no spraying at all, but they suffered in the longer term in comparison with blanket spraying. In contrast, studies in south-east Queensland showed that herbicide bands 10 cm wide gave little advantage over no spraying in terms of grass seedling survival, despite a complete kill of the native grasses within the sprayed area (S.J. Cook, unpublished data). Bands needed to be at least 25 cm wide in order to provide sufficient competition control for satisfactory growth and survival of grass seedlings. Presumably root encroachment from plants outside the band area was responsible for negating the effects of the narrower bands. If root competition is as important in temperate areas, as has been demonstrated by Cook and Ratcliff (1984; 1985) for sub-tropical areas, then it is doubtful whether bands only 4 cm wide could sufficiently control root competition. The assumption that competition for new seedlings is minimal while the bands are visible (Baker, 1980) must also be questioned.

PASTURE MANAGEMENT

The method of pasture establishment has important implications for management, not only for the individual pasture but for the farm as well. Moreover, weed management in pastures is an integral part of conservation farming in southern Australia.

Management flexibility

Methods of establishment based on direct drilling or surface sowing allow more flexible management than on conventional seedbeds because less time is involved in seedbed preparation, the land is out of production for a shorter time, and it is possible to sow or use machinery on wetter soils. Decisions on whether to sow can also be delayed until the sowing date. With conventional seedbeds a commitment to sowing, or at least a commitment of resources, must be made some time in advance, when seedbed preparation starts. Direct drilling and surface sowing also allow for greater flexibility in management of crop-livestock enterprises. Aerial or surface sowing also offer a means for developing non-arable hill country and aerial sowing is well suited to the development of partially cleared country.

Grazing management to assist pasture establishment

Grazing management to optimise pasture establishment has not been studied in detail for either temperate or tropical Australia. In the absence of such information it is assumed that the management requirements are similar to those for established pastures, albeit that grazing

should not begin until the plants are firmly rooted and cannot be pulled from the ground. This is usually associated with the development of secondary roots in grasses. Grazing management is particularly important during the early stages of pasture development. The main objective in the management of new pastures should be to ensure adequate flowering and seed set. This is particularly important in annual species to ensure regeneration at the start of the next growing season. It is better to delay grazing rather than to graze too early.

Subterranean clover seed set is reduced by shading and responds positively to defoliation until flowering (Collins, 1981). Similarly, where legumes are oversown into existing swards by reduced-tillage methods, light to moderate grazing during the establishment phase is often beneficial, especially in tropical areas. However, while grazing can increase the competitive ability of the legume (Norman, 1965) by reducing shading in tall-growing pastures, it is unlikely to be sufficient, on its own, to give adequate control of root competition as well. The legume also benefits from the fact that cattle tend to preferentially graze the competing grasses rather than the tropical legumes early in the growing season. However, it is best to destock the pasture when diet selection changes to preference for the legume during the early autumn period (Stobbs, 1977). This usually coincides with the main period of seed set. In the tropics this is also a time of feed surplus thus allowing increased stocking rates on other areas of the farm.

INTEGRATING PASTURES AND CROPS IN CONSERVATION-FARMING SYSTEMS

The role of pasture management in conservation-farming systems in southern Australia has been reviewed by Pratley and Cornish (1985). They stressed the need for weed management to be implemented during the pasture phase, and drew attention to the implications of pest carryover, of livestock management and annual pasture regeneration where direct drilling of crops is practised.

Weed management

Early planning of weed control strategies during the pasture phase in a rotation system allows the inexpensive and highly effective techniques of spray-grazing and spray-topping to be employed. Weeds that are difficult or costly to control in-crop can therefore be controlled by low rates of chemicals in the seasons preceding cropping activity. This is environmentally and financially desirable. In the case of annual grasses, which are alternate hosts to several cereal diseases, control in the pasture phase provides a break in disease build-up and reduced incidence in the cropping phase (Chapter 14). In all cases the production of desirable species in the pasture phase is enhanced, as is the associated animal production. Although the techniques have been available since the early 1970s (Pearce, 1972; Pearce and Holmes, 1976) and practised in Western Australia for many years, their incorporation into farming programmes on a regular basis in eastern Australia is relatively recent.

Spray-grazing This technique enables control in pastures of broadleaf weeds, such as Paterson's curse (*Echium plantagineum*) and capeweed (*Arctotheca calendula*), which have a rosette habit of growth. Low rates of phenoxy herbicides such as 2,4-D and MCPA are sprayed on the rosettes and the hormone action mobilises the sugars in the plant, thereby making the forage 'sweeter'. The growth of the plants is also distorted, making the leaves more easily prehended by the grazing animals, which are introduced to the area about 10 days after spraying.

Spray-topping Low rates of paraquat, Spray.Seed or glyphosate are applied in spring at the time of seedhead emergence to restrict the formation of viable seed in annual grasses and *A. calendula*. Grazing management becomes important in the period preceding spraying because the greatest effect is achieved where the crop of seedheads is evenly developed. Livestock can be returned to the spray-topped area the day following spraying or at any time after, as required.

In addition to the curtailment of viable seed-set two other advantages are obtained. Firstly, the application of the chemical has the effect of stopping the quality deterioration of the forage generally associated with plant maturation (ICI Australia, unpublished data). Secondly, where annual ryegrass is the main species being topped, it is likely that the risk of annual ryegrass toxicity is substantially reduced.

The effectiveness of the technique is reduced where a mixture of annual grasses occurs due to the range of maturity times of the different species. Barley grass (*Hordeum leporinum*) will normally flower first, followed by soft brome (*Bromus mollis*), silver grass (*Vulpia* spp.) and finally annual ryegrass. If one of these species dominates the pasture it becomes the target species for the spray-topping programme. Where two or more are present, each in substantial proportions, it may be necessary to use the 'hay freezing' technique of applying higher rates of paraquat earlier in the spring to stop the development of all species at that time (ICI Australia, unpublished data).

Pest carryover

Some reports indicate difficulties with pasture pests infesting crops in the first year of direct drilling. These pests include red-legged earthmite (*Halotydeus destructor*), lucerne flea (*Sminthurus viridis*), blackheaded pasture cockchafer (*Aphodius tasmaniae*) and the pasture webworm (*Hednota* spp.) (Allen, 1982), and require the application of insecticide with the pre-sowing herbicide spray. In South Australia the cereal curculio (*Desiantha caudata*) has also caused severe damage to direct-drilled crops (Grierson and Allen, 1977) although this can be minimised by removal of barley grass during the pasture phase (D.L. Rowell, personal communication).

Livestock requirements

The extra grazing provided by weeds or pasture in autumn when crops are direct drilled can have a significant effect on animal production (Godyn and Brennan, 1984). Conversely the animals are also important in managing the amount of vegetation so that an effective kill can be achieved by the knockdown herbicides prior to sowing. Where the cropping area on individual properties has been increased because of financial needs, the number of stock available for grazing is necessarily reduced as is the ability to have livestock-orientated weed management. In southern New South Wales, for example, it is not uncommon for one-third of the farm to be cropped. This proportion allows for double stocking rates on cropped areas if necessary. However, where two-thirds of the property is cropped, only half the normal stocking rate can be achieved on the cropped area. This is not adequate to control the weeds that flourish in wet autumns, and has reduced and in some cases negated the effect of pre-sowing herbicides. Consideration of the whole farm implications before the event would allow remedial measures to be taken.

Although great significance has been made of the benefits to animal production from a swing to direct drilling in southern Australia, there is evidence that these advantages are not being realised. In the higher rainfall wheat-sheep zone of New South Wales, Simpson (1984) claimed

that, after 5 years of being promoted, conservation farming had failed to integrate farming practices with livestock enterprises. Since the concept of direct drilling was introduced to farmers in the late 1970s, no real attempt has been made to demonstrate the advantages that a conservation farming system can offer to livestock production. Consequently, the majority of landholders have continued with the same livestock management pattern that existed with a conventional farming system.

According to Simpson (1984), on most properties where direct drilling or a similar practice has been adopted the only major difference in the livestock grazing pattern is that sheep are no longer grazed on fallow paddocks during autumn. Instead, they are run at various stocking intensities on proposed cropping paddocks, according to the pre-spraying grazing recommendations for the particular herbicide to be applied prior to sowing. Grazing prior to herbicide application is acknowledged to be a vital part of the conservation-farming system. Sheep are preferred to cattle and dry sheep are more effective than ewes and lambs. Where cattle are the only animals available, high stocking rates may be needed to control growth. This aspect is unlikely to appeal to the average beef producer who likes his cattle to be in good condition at all times.

These recommendations automatically place limitations on the type of sheep to be used for grazing prior to herbicide application. For example, a sheep reproduction cycle involving a spring joining for an autumn lambing is unlikely to fit in with a conservation-farming programme. Winter lambing and conservation farming are the most successful combination. Joining occurs in February/March when the bodyweight of ewes is high and often increasing with grazing on freshly harvested stubble. The post-joining period, when nutrition is not as critical, coincides with the need for autumn grazing in preparation for herbicide application and sowing. The pre-lamb build-up and lambing can be undertaken on a range of grazing crops and pastures. Finally, the natural spring flush ensures that ewes have an abundant milk supply for their lambs. Weaning can be carried out at the end of spring, with weaners having sufficient wool to be shorn so as to prevent losses caused by grass seed. In any case, the grass-seed risk should already have been reduced by spray-topping activities.

In livestock production, the advantages that a winter lambing-conservation farming combination offers to producers may require a change in the lambing time. Although sheep producers are often reluctant to alter time of lambing, those who wish to adopt successfully a whole-farm approach to conservation farming will need to consider the complementary nature of this combination.

Pasture regeneration

Most research emphasis has been on the cropping aspects of conservation farming with little attention paid to the contribution of the pasture phase. In particular, the establishment of pasture species and the regeneration of annual legumes following a direct-drilled cropping phase need to be clarified. It can be argued that the improvement in soil structure may facilitate the process of burr burial and radical entry - it may conversely be argued that the firmer, relatively undisturbed soils may inhibit these processes, particularly in the early years of a direct-drilling programme where surface soils have previously been degraded under intensive cultivation. If the latter is the case, not only will seed ecology and seedling re-establishment be affected, but a high proportion of seed is at risk of being consumed by animals during the summer.

More research attention must also be given to pasture establishment by direct-drilled methods in the cropping zone, especially the role of stubble retention and cover crops. Direct-drilled

crops, with their slower early growth (Cornish, 1985) may be less competitive to establishing pasture seedlings and therefore more effective as cover crops.

Tillage has implications for the bank of hard seed of annual legumes on which many farmers depend for pasture regeneration (Carter *et al.*, 1982). Conventional tillage, particularly where disc ploughs are used, buries a high percentage of legume seed and therefore reduces the breakdown rate of hard seed. This seed, however, would remain below the depth from which emergence occurs until a proportion of it is raised by subsequent tillage to near the surface where it is more likely to become soft and have a potential for regeneration (Taylor, 1980). Intensive tillage also tends to increase soil strength at the surface and makes the emergence of annual legume seedlings more difficult.

Consideration needs to be given to appropriate species and cultivars that are better suited to the requirements of conservation farming in particular districts. While weed management of pastures by herbicides can control both broadleaf and grass weeds, caution is needed to prevent a reduction in seed set by subterranean clover and annual medic.

PASTURE ESTABLISHMENT AND MANAGEMENT PRACTICES - THE FUTURE

The method of pasture establishment used will continue to be determined by the intensity of agriculture in the region, climate, topography, land-use and the profitability of pastures sown by the various methods. In the long term, development of hill country in temperate regions is likely to result from greater pressures from cropping or a resurgence in pastoral profitability. Pastures will be established on these areas by direct drilling or surface sowing in order to minimise erosion.

In the more extensive areas of the tropics, land holdings are large and pasture improvement is not often considered a viable option. However, pasture improvement in these areas allows more stock to be carried on smaller areas, facilitating better herd management (Edye and Gillard, 1985). It is generally considered that if pastures are to be sown in these areas then it will be mainly by sowing seed onto the soil surface after heavy grazing or burning (Thomson *et al.*, 1983). If this is the case, then pasture improvement will be restricted to the use of legumes and the risk of establishment failure will be high. Establishment is likely to vary from year to year, and from sowing to sowing within years, depending on the amount of competition present and on weather conditions. The efficiency of establishment is also likely to be low, with subsequent pasture production depending heavily on a build-up in the population of the sown species from the seed set. While such establishment methods may be appropriate when seed prices are low, they become less appropriate when seed prices are high.

Minimum-tillage techniques that involve one or more workings with a machine, but provide poor seed placement and variable competition control, are of dubious value. They have almost the same high cost structure of the cultivated seedbed, yet still involve a degree of uncertainty and risk because of poor seed placement and lack of adequate competition control. Where such establishment methods are planned, either a fully cultivated seedbed, or strip, or band sowing methods should be considered. Various methods aimed at improving the reliability and efficiency of establishment, but at the same time minimising the costs, have been developed. These have included strip planting (Graham, 1963; Spain *et al.*, 1985) and herbicide banding techniques (Cook, 1982). Such methods aim to reduce establishment costs by only treating 20-30% of the area

with seed and fertiliser and to establish a nucleus population of pasture plants, which will then spread throughout the rest of the pasture, as currently happens with surface-sown pastures. A more efficient establishment is obtained by increasing germination, either by placing the seed into cultivated grooves, or at least placing it on the surface of cultivated soil. A more reliable establishment is achieved because plant competition is controlled, either by the use of herbicides (Cook, 1982), or by mechanical means (Graham, 1963; Spain *et al.*, 1985). The control of root competition also leads to faster seedling growth and faster pasture development, a major factor influencing the economics of pasture improvement (L. Wicksteed, personal communication). To date these methods have not been evaluated on a large scale, but they warrant careful consideration.

Despite the costs involved, the cultivated seedbed is the best and most reliable method of pasture establishment. This will still be the most appropriate method for establishing improved pastures in the more intensively developed areas, especially where there are advantages in sowing both grasses and legumes. Band and narrow strip establishment techniques are considered most useful for renovating old pastures, particularly where one of the components (e.g. the legume) has failed and the other is still abundant.

Good grass-legume pastures can be established by surface sowing provided competition is controlled by herbicides (Campbell, 1968b; 1974; Cook and Dolby, 1981). However, the high cost of blanket spraying with herbicides will limit the application of this technique to high-value land in hilly areas that is either too steep and/or contains too many rocks for machinery.

One of the main problems relating to the introduction of new establishment technology with more sophisticated machines, particularly in tropical areas, is that most landholders involved primarily in grazing enterprises tend to have only a limited knowledge of pasture sowing equipment and a limited interest in acquiring and using it, unless they have had previous experience in cropping enterprises. The more technologically advanced seed boxes on sod-seeders, based on either the triple-disc, chisel or hoe coulters (Baker, 1976) are rarely used, except for special-purpose forage crops in the dairy industry. This has led to a situation where many of the machines are simple and crude, with various types of seed boxes mounted on disc or chisel ploughs or offset discs. A conventional combine, with its tines just scratching or clearing the soil surface, is sometimes used to sow seed after the soil has been ripped with a chisel plough. As these machines are relatively inexpensive to buy second-hand in cropping areas, and are relatively easy to use and maintain, some agronomists have actively promoted their use in an attempt to encourage pasture improvement among landholders. However, the variability in results obtained by using such methods has sometimes had the reverse effect. Furthermore, machinery costs are not excessive when compared with the cost of tropical pasture seed. Poor seed metering and placement can be costly, especially if combined with poor competition control. Research and extension agronomists in both temperate and tropical areas should therefore aim to develop, evaluate and promote new or improved pasture establishment technology that will achieve a more efficient use of seed and fertiliser, reduce the time for the attainment of maximum pasture production, with less risk of failure.

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