CHAPTER 8

CROP ESTABLISHMENT AND MANAGEMENT

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Farming systems in Australia differ according to the climatic (Chapter 2) and soil (Chapter 5) constraints of the environment. In the winter rainfall areas of southern Australia, crop production is confined to the cool season, coinciding with the incidence of effective rainfall. The soils are, to a large extent, structurally fragile and inherently low in nutrients. The production of crops is integrated with livestock production, thus providing through diversification a buffer against economic fluctuations. The combination of pastures and crops in rotation is called ley farming.

In the summer rainfall areas of north-eastern Australia, continuous cropping is more common. Soils are usually better structured and more fertile than in the south. Further, the capacity to grow both rain-fed summer crops and stored-moisture winter crops can provide the biological and economic diversity required for a viable farming system. Soil conservation measures are particularly important because of the erosivity of summer rainfall.

Depending therefore on the location of the field in question, the farmer will need to adapt seedbed preparation methods to the state of the soil which will have been either in pasture, in fallow or cropped the previous growing season.

Tillage Practices

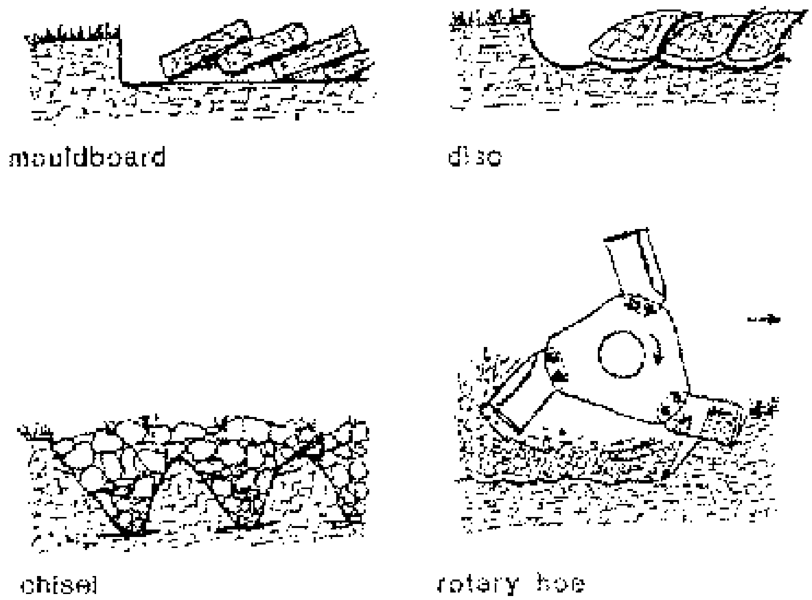
Until the 1970s in Australia, seedbed preparation involved numerous passes with cultivation equipment, resulting in substantial soil physical degradation (Chapter 1). Since that time much attention has been directed towards minimum tillage techniques which preserve soil structure and facilitate crop establishment by enabling the timing of operations to be optimised. Traditional tillage practices are covered in detail by Cornish and Pratley (1987, 1991), who described the effects of cultivation in breaking down organic matter, degrading soil surface structure, increasing erodibility and creating compaction layers at plough depth. A summary of the actions of various tillage implements is given in Table 8.1, and their effect on soil is shown in Figure 8.1. Modern methods rely heavily on herbicides instead of cultivation to control weeds. This is less damaging to soil structure, consequently improving the infiltration of moisture.

Fields coming out of a lengthy pasture phase will normally be compacted to some extent on the surface due to the presence of grazing animals. Unless the soil is particularly well structured, a cultivation with a tined implement is usually necessary to facilitate the subsequent penetration by sowing equipment. Thereafter, weed growth is managed by

Table 8.1 Comparison of actions of various tillage implements (after Orchiston, 1965)

Action	**Mouldboard plough**	**Disc implements (ploughs and harrows**	**Tined implements (chisel ploughs, scarifiers, harrows)**	**Rotary implements (hoes, tillers)**
Wear	Shares require replacement	Superior to all others and remain efficient with wear of discs	Tilting action of stump-jump types wears points – new designs correct this	Comparatively rapid but generally self sharpening
Negotiation of obstacles	Effective if stump-jumping type	With ease without spring loading	Effective with stump-jump action	Effective if spring loaded
Movement of soil	Complete inversion of furrow at normal speeds	Partial inversion of furrow	Narrow furrows no subsoil brought to surface	A cut, slice, lift actin thoroughly mixes soil
Soil resistance	Increases with speed	Increases markedly with speed	Fairly constant all speeds – best for high speeds	Tends to decrease with speed
Grinding or pulverising soil	Very little	Tendency; varies with adjustment – can be substantial	Less than other types	Extensive
Shattering	Completely in all directions	Partial – can be substantial	Partial	Completely; with shield
Compacting at depth of cultivation	Considerable if soil is too moist	Considerable if soil is too moist	Very little	Very considerable if soil is too moist
Fineness produced	Very little	Considerable	Moderate	Very considerable
Surface trash	Well buried at normal speeds	Buries a large proportion	Left on surface	Buries in large proportion
Killing of old crop	Effective	Effective and ideal for scrub clearing	Partial	Effective
Seedbed preparation	Requires secondary tillage	Useful for general ploughing and cultivation. Requires secondary tillage	Ideal for ploughing, crop cultivation and scarifying without making soil too fine	Makes soil fine in one operation
Build-up and conservation of moisture	Effective especially on contour, unless plough pan developed	Effective unless plough pan developed	Well suited to infiltration	Surface mulching
Control of weeds	Unsuited	Excellent	Can be excellent	Excellent
Renovation of crop or pasture	Unsuited	Too severe	Ideally suited	Unsuited

Figure 8.1 A comparison of the effects of primary tillage implements on soil



regular grazing by livestock, and final kill is achieved through non-selective ‘knockdown’ herbicides such as paraquat/diquat mixes and glyphosate. Sowing then proceeds by drilling the seed into the minimum tilled soil. Where soils allow or seasonal conditions dictate, the pastures are sprayed and direct drilled without the cultivation process The timing of the tillage, where practised, also varies. Often the soil is cultivated at the break of season in autumn. Farmers sometimes cultivate in late winter/spring to take advantage of favourable moisture conditions, to prevent weed seed set or to ensure that lucerne plants are killed before they extract too much soil water.

The need for good pasture management in the last year has been described: that is, removal of weeds through winter cleaning, spray-grazing and spray-topping. Also important is the reduction in the carryover of surface vegetation, particularly silvergrass (*Vulpia* spp.) the residues of which have strong allelopathic capabilities and can interfere significantly in the establishment of crops sown into such residue (Pratley, 1989; Pratley and Ingrey, 1990).

With an increase in the use of lucerne in the pasture phase, the challenge for cropping is its destruction prior to the cropping phase. Research has shown that the most successful option is to have a heavy grazing regime in late winter-early spring followed by herbicide application 2-3 weeks after complete defoliation when the direction of translocation is from shoots to roots. The reliability of kill at this stage is higher than spraying in early summer or autumn (Davies *et al*., 2000). Yield benefits for the subsequent crop, usually canola, have been shown to be proportional to the time between lucerne removal and sowing time (Angus *et al*., 2000).

Raised Bed Farming

Waterlogging and poor soil structure are major constraints to crop production. In the higher rainfall areas of Victoria, the duplex soils of Western Australia and the sodosols of Tasmania, and in southern South Australia, raised bed farming has reduced waterlogging by allowing more runoff during wetter periods. There has also been improvement to soil structure. In many cases there has been a reduction in damage to the structure through a reduction in tillage *per se* but also because the soils are not being cultivated at high moisture contents. Increases in crop yield of up to 47% have been achieved in some cases (Bakker *et al*., 2000).

Controlled Traffic

The aim of controlled traffic is to manage soil compaction by restricting machinery movements to permanent wheel tracks uniformly established in the cropped field. Tullberg (2000a, b) reported that field traffic is often more significant than tillage as the driving process of soil compaction. His work showed that half the total power output of a tractor can be dissipated in the process of creating and undoing the compaction effects of its own wheels.

The traffic lanes are established using differential global positioning systems (DGPS) for guidance and are normally untilled and unplanted to optimise traction and trafficability. Soil in the inter-lane beds is managed for high crop performance, uncompromised by traffic.

The advantages of controlled traffic, as experienced by practising farmers (Tullberg, 2000b) include:

- a reduction in time of operations;
- a reduction of material inputs of about 20%;
- elimination of over- and under-lapping and the resultant effects on yield;
- improved timeliness of operations such as sowing and herbicide application because the lanes are more trafficable sooner after rain;
- reduced erosion from extreme events;
- improved soil structure and health.

However, for controlled traffic to be successful, there needs to be uniformity, in terms of tracking, across the spectrum of crop machinery. To fulfil this requirement, each farmer must make a significant investment in guidance technology.

Stubble Management

In fields where crops have been grown in the previous season, an extra management consideration is the treatment of stubbles from that crop. The options available are grazing, incorporation, burning, or retention on the surface. A combination of grazing and another option is the usual practice. In the winter rainfall areas in particular, the high cereal yields produce a high physical stubble burden to manage. A wheat crop yielding 4t/ha of grain also produces of the order of 6t/ha stubble, which usually goes through a dry summer without deterioration and becomes a problem for any mechanical operation that precedes the next crop.

Stubble Spreading

The successful management of stubble starts at harvest time. Older headers create a trash trail whereby the straw and chaff passing out the back is concentrated in a width less than a third of that of the machine. This concentration affects the physical handling later and also interferes with herbicide effectiveness.

Most modern headers can spread the straw so that it is less concentrated, but the chaff remains concentrated. The straw spreaders consist of horizontally rotating fingers. Straw choppers can assist by reducing the length of straw while 'straw storms' reduce the straw length and blow the straw and chaff over about two-thirds of the width of the machine. These attachments use more power and slow down the harvest process.

In a separate operation from harvesting, the standing straw can be slashed or mulched into shorter lengths, the only limitation being the risk of fire from these operations at that time of year.

Grazing the Stubbles

Grazing is important in reducing the amount of stubble to be contended with in later mechanical operations. Animals are usually introduced to clean up any spilt grain and weeds but in modern farming the efficient utilisation of stubble has several advantages:

- a source of energy for livestock during a period of the year when feed is lacking;
- the spelling of pasture paddocks to allow species such as lucerne to produce forage for autumn; and
- a reduction in the stubble load for subsequent cropping operations such as spraying and sowing.

Research has shown that stubble utilisation is improved by:

- stocking immediately following harvest, because the stubble feed value is at its highest prior to its deterioration through rain and dew; and
- stocking with sheep initially to enable them to select out the more digestible fractions (Coombe, 1981). Cattle digest lower-quality material better than do sheep and can thus maintain their weight for longer. Mulholland *et al*. (1976) found that sheep could maintain their weight for up to 6 weeks on stubble, whereas cattle maintained their weight for up to 12 weeks on the same stubble. Supplements such as urea, lupin grain and sulfur can improve utilisation and animal performance.

Stubble Incorporation

This procedure involves the mixing of the stubble with the upper layers of soil. Turning stubbles into the soil usually causes short-term nitrogen depletion due to the large carbon:nitrogen ratio of the material, although in the longer term soil organic matter levels benefit. Unsatisfactory decomposition can result in blockages in closely spaced tined implements that may be used in later stages of seedbed preparation.

The time required for decomposition varies with different conditions, but moisture availability is a most important factor. In lower rainfall environments, more time is usually required. Where soil temperatures are unsuitable for microbial action, the rate of decomposition will also be slower. The incorporation usually involves a disc implement, the use of which is discouraged in modern farming practice because of likely detrimental effects to soil structure.

Stubble Burning

This is the most common means of removing a physical problem during crop establishment. Traditionally, stubble was burned in autumn, as soon as conditions and fire regulations allowed. However, the role of surface cover in reducing the rate of evaporation from the soil has now resulted in burning much closer to time of sowing.

Burning is a quick, inexpensive and effective way of removing the physical burden of the straw, particularly where suitable machinery from trash working is not available. The carryover of several stubble-borne diseases is also reduced. The disadvantages of burning include the loss of soil organic matter and the sublimation of nitrogen and sulfur into the atmosphere.

Stubble Retention

This procedure involves the maintenance of the residues from the previous crop on the soil surface with the succeeding crop being sown through the bulk material. The advantage of better soil moisture conditions is important, and the retention of organic matter and protection from raindrop impact are also most important. Because the material is not incorporated, soil nitrogen is not locked up to any significant effect.

However, under the winter rainfall conditions of southern Australian cropping areas, the quantity and toughness of the material at the beginning of the new season create blockage problems for machinery. The passage of tined implements through the bulk of residue is described by Brown *et al*. (1986) as being affected by:

- the quantity of stubble, blockages occurring more readily with the presence of more stubble;
- the moisture content, high moisture raising the mass density of the material, the strength and toughness of the straw, and the tendency for soil and stubbles to intermix;
- the anchorage of stubble providing easier passage;
- the length of detached straw, shorter lengths allowing easier passage because they are less likely to bend (‘hairpin’) around the tines of the implement;

- the trash clearance of the implement, including more underframe clearance; greater horizontal distance between adjacent tines; greater longitudinal distance between rows of tines; and adequate clearances adjacent to the wheels.

Retention of stubble in the southern winter cropping areas has not delivered a consistent outcome in terms of yield responses. A review by Kirkegaard (1995) showed that stubble retention reduced yield in all regions evaluated, most likely due in part to diseases (e.g. eyespot, take-all) and weeds (Heenan *et al*., 1990; Murray *et al*., 1991). Farmers, in order to contend with the bulk of dry material at sowing, have in some cases resorted to wider row spacings which would also contribute to lower yields. Lemerle *et al*. (2002) showed that wheat was affected but peas and canola were largely unaffected by increasing row spacings from 23 cm to 46 cm.

It is not uncommon now for farmers to burn stubbles as close to sowing time as is practicable. This produces a slow, usually incomplete, burn but the benefits of stubble presence in summer and autumn is obtained and the machinery blockage problems are avoided.

Continuous cropping in summer rainfall areas

In the summer rainfall areas of northern Australia, the opportunity exists for the production of rain-fed summer crops and the production of winter crops on fallow moisture. Combinations of winter and summer crops are common. Compared with southern Australia, pastures and livestock play only a minor role in the farming systems, and continuous crop and fallow cycles are practised (Holland *et al*., 1987).

Table 8.2 The effect of soil management practices, soil type and slope on soil loss in south-east Queensland (Cummins, 1973)

Soil type	Soil loss (t / ha / year)		
	Bare fallow	Residue incorporation (average management)	Residue mulch (good management)
Alluvial, fertile, self-mulching clay (1-2% slope)	60	24	12
Colluvial red-brown clay (1-3% slope)	76	31	12 (with contour banks)
Colluvial red-brown clay (5-8% slope)	270	110	10 (with contour banks and crop rotation)

A characteristic of these areas is the high erosiveness of the summer storms, particularly where the soil is in fallow (Marston, 1978a). The need for conservation farming practices of no till and stubble retention has long been realised. The effect of such practices is demonstrated in Table 8.2.

Stubble Management

As in southern Australia, the retention of the stubble from the previous crop is promoted as an important conservation practice. However, it has been more widely adopted in the north for much longer because the soil erosion problem is much greater. The stubble protects the soil surface from raindrop impact and reduces the rate of flow across the surface, both of which aid water infiltration and reduce the extent to which the soil erodes (Shaw, 1971a; Marston and Doyle, 1978; Rosewell and Marston, 1978; Lovett *et al*., 1982).

Unlike the south, the crop residues are present during the wet season and therefore undergo considerable breakdown and cause fewer problems for machinery. However, specialised machinery has been developed for these areas to keep the residues on the soil surface during the fallow.

For primary tillage broad sweep-type implements called blade or sweep blade ploughs are pulled through the soil leaving the surface residues largely undisturbed. The two sweeps of the blade are at angles of about 105^0 and sweep lengths vary from 60 to 250 cm. Chisel ploughs with improved trash clearance are increasingly used because of their versatility (Sweeting and Colless, 1985).

Secondary tillage can be carried out by rod weeders, consisting of a revolving bar or rod, or a chain pulled through the soil just below the surface. Weeds are pulled out by the twisting action of the rods. On heavy soils or on stony ground, however, the sweep plough and rod weeder are not suitable and tined implements are used (Garland *et al*., 1976). Rod weeders are often attached to chisel ploughs, and return some of the trash to the surface after burial by the chisel plough (Sweeting and Colless, 1985).

Increasingly, however, no-till farming is practised in these areas, using herbicides to control weed growth.

Strip Cropping

Many of the soils in the region are black earths, which are fine-textured cracking clays with self-mulching characteristics, often occurring on flat or gently sloping areas. Infiltration rates on these soils during summer thunderstorms can be low due to sealing of the surface, and rainfall runoff rates and hence soil erosion are high (Cummins and Esdaile, 1972; Rosewell and Marston, 1978).

The technique of strip cropping has therefore become increasingly important in these areas as a means of controlling soil erosion. Crops are grown in a systematic arrangement across the slope so as to act as barriers to the flow of water. The water is spread over larger areas, slowing the rate of flow and as a consequence increasing the infiltration of the water into the soil (Kelsey, 1966; Shaw, 1971b). At any one time, therefore, there are strips of crop, stubble or fallow retarding the movement of water, thereby reducing the flow rate over the fallowed strips. The width of the strips is limited to about 100 metres. A typical system has strips of sorghum, wheat stubble and fallow. An example of this system is shown in Figure 8.2.

Figure 8.2 The layout of a strip cropping system at Quirindi, New South Wales. The dark strips represent strips prepared for wheat, the light strips are sorghum stubble. The narrow dark lines represent erosion control earthworks. (Photograph reproduced by permission of Soil Conservation Service of New South Wales)

Strip cropping is usually limited to those areas with a landslope of 1% (1m/100m), although it can be used on landslopes up to 2% with some earthworks to support it (Crawford, 1977). Cultivation approximating the contour in a strip cropping scheme also aids in reducing runoff and increasing infiltration but increases deep drainage and adds to the risk of salinisation.

One problem that is created by a strip cropping program is the location of paddock fences and farm boundaries. In this system it is desirable to have the strips as long as possible, preferably as long as the landslope and other conditions will allow. However, property boundaries are often poorly placed in relation to natural drainage lines and many internal fencelines need to be removed and resited. This will often require cooperation between neighbouring farmers. The removal of internal fences means, however, that the area cannot be stocked unless systems of electric fencing are installed to control the livestock (Crawford, 1977).

Fallowing

Fallowing, the process of maintaining the soil weed-free for an extended period before crop sowing, has been practised in Australia since the early 1900s. Its main purpose is to store moisture from the previous rainfall season for use by the current crop, although nitrogen benefits also accrue through mineralisation. The amount of water stored by the fallow depends on rainfall during the fallow period, the length of the fallow, infiltration capacity of the soil, water holding capacity of the soil and the rate of moisture from the soil.

Fallowing has been an integral part of farming in the lower-rainfall areas of South Australia, Victoria and southern and central New South Wales (Sims, 1977; Ridge, 1986; Poole, 1987) but the increased use of reduced tillage systems, the retention of crop residues and the widespread adoption of annual legume pasture leys have made fallows less important. Nevertheless, on the lighter textured soils of the Victorian mallee, the use of fallow remains an important component of yield stability across years (Hannah and O'Leary, 1995).

French (1963) indicates that in South Australia three conditions need to be fulfilled before benefits in moisture conservation from fallowing are likely to be obtained. The first condition is that the rainfall during the growing season is significantly limiting crop production. In this context, French suggests that rainfall in the April to October growing period for wheat production should be less than approximately 460 mm before any benefits are gained. Research in other areas of Australia has been consistent with this finding (Kohn *et al*., 1966; Tuohey *et al*., 1972; French, 1987a).

The second condition is that the rainfall during the fallow period must be sufficient to wet the soil to a depth of at least 15 to 20 cm to avoid significant losses due to evaporation from the soil surface. This condition indicates how long the fallow needs to be in order to coincide with such rainfall. There is also the need to maintain the areas free from actively growing plants during the fallow to avoid this moisture being lost via transpiration prior to crop establishment.

The third condition is that the physical features of the soil are conducive to water storage. In particular, it is necessary that the subsoil be relatively fine-textured as light soils have low water-holding capacity with the moisture being lost by percolation. Surface soil characteristics have to be conducive to ready infiltration. Ridge (1986) indicates that a clay content greater than 25% is needed for moisture retention in north-western Victoria.

What is also clear from research is that a summer fallow *per se* is not efficient for moisture conservation. Any benefits in moisture content from fallow during that period result largely from minimising moisture loss by restricting transpiration, rather than by gains through rainfall which is largely evaporated in the hot conditions (Wells, 1970, 1971). Nevertheless, in the northern cropping areas a summer fallow is important for the successful production of winter crops.

In traditional farming systems the fallow is cultivated as required to destroy weed growth and improve surface soil infiltration characteristics. The reliance on cultivation for fallow weed control has diminished as concerns for soil erosion and soil structural degradation have increased. This has been replaced through increased herbicide options and the development of no-till (chemical) fallow techniques with consequent water conservation and yield benefits (Cantero-Martinez *et al*., 1998). Herbicides seldom completely replace cultivation, particularly because of cost, but the number of tillage operations is substantially reduced, with the positive effect of lessening the extent of soil structure degradation and erosion. The development of equipment that can discriminate green vegetation from soil or litter (Felton *et al*., 1987) enabled a substantial reduction in the amount of herbicide used and therefore the cost involved. Weed mapping using airborne digital video also shows promise for reducing herbicide use (Lamb and Weedon, 1998). The herbicides chosen should, wherever possible, have a different mode of action from those used for in-crop weed control, to reduce the likelihood of the build-up of herbicide resistance. The presence of glyphosate resistance in this system in northern New South Wales emphasises the need for herbicide rotation (Storrie and Cook, 2002).

Residue retention during fallow periods can also improve infiltration (via channelling) but the main effect is to reduce the rate of evaporation from the soil surface (Lovett *et al*., 1982; Pratley and Cornish, 1985) and to protect the soil surface from raindrop impact.

The levels of moisture conserved vary depending on the environment. In a South Australian study extending over five years, an average of 25 mm of additional water was stored as a result of fallowing in the preceding September (French, 1963). At Wagga Wagga, in southern New South Wales, additional moisture was stored in only one out of four years (Kohn *et al*., 1966). In central western New South Wales, September fallow stored an additional 57 mm of moisture (Fettell, 1977) in one instance. The benefits of a fallow should be appraised in the light of loss of alternative income while the land is in this non-productive condition.

Fallow Efficiency

Because water is the ultimate determinant of yield in dryland farming in Australia, particularly in regions where fallowing is practised, it becomes critical to productivity to maximise the water available to plants. Thus the percentage of rainfall eventually stored in the soil for crop use (the fallow efficiency) is an important criterion for raising yields.

Fallow efficiencies are low relative to water use under rain-fed conditions, being of the order of 15-30% (Cornish and Pratley, 1991). The efficiency is usually reduced by cultivation but improved by residue retention due to a slower rate of evaporation.

BENCHMARKING AND TARGET YIELDS

Crops produce a yield at the end of the season. Such yields fluctuate from year to year, crop to crop and from field to field. The important question to answer is how a farmer evaluates the performance of a crop given the climatic conditions under which the crop might expect to be grown or has been grown. A benchmark is therefore required, a benchmark based on a major factor limiting to productivity.

Australia is an arid continent with two-thirds of the land mass routinely having at least a four-month seasonal drought each year. It is not surprising, therefore, that the efficiency of crop water use has been the focus of the benchmark. Crops use water as a vector for nutrient uptake and assimilate translocation, for plant metabolism, for plant structure and for heat regulation through the transpiration mechanism. What is often overlooked is the role of water in CO_2 uptake through maintaining the stomates open. Crop yield therefore is directly proportional to crop water use, provided other inputs are adequate.

In the 1980s attention was focused on the concept of water-limited potential yield developed by French and Schultz (1984a, b) for South Australia and Cornish and Murray (1989) for Wagga Wagga, NSW, and Mead (1992) for Cowra, NSW. For southern Australia this has evolved to kg grain per mm of growing season rainfall after allowing for in-crop evaporation losses (Table 8.3)

The benchmark is thus provided and a realistic target yield below this can be chosen. The benchmark needs to be adjusted in high rainfall areas such as parts of Victoria where waterlogging will interfere with attainment of these high yields. In summer rainfall areas or in seasons where high autumn rains are received, stored soil water prior to sowing can be significant. It can be estimated for addition to GSR by multiplying the previous July-August rainfall, where fallowed, and the autumn rainfall by 0.3 to allow for high evaporation.

Once a target yield is determined, farmers can then budget their fertiliser inputs to meet the target. In the past farmers have been loathe to provide sufficient inputs in the good years (Figure 8.3) and have thus foregone opportunity of high yields. The increased understanding of the potential yield concept has resulted in a significant increase in field performance of crops across Australia.

Table 8.3 Calculating water-limited yield potential where PY = potential yield, GSR = growing season rainfall, E = in crop evaporation, PCWU = potential crop water use

$$PY\ (kg/ha) = (GSR - E)\ mm \times PCWU\ (kg/mm)$$

Crop	E	PCWU
Wheat	110	20
Barley	90	20
Grain legumes	130	15
Oilseeds	110	15

SOWING

Time of Sowing

While each crop has an optimum sowing time, the date of actual sowing will ultimately be determined by the moisture conditions of the soil. Delays in sowing after the optimum date may be caused by either insufficient or excessive soil moisture. Soil

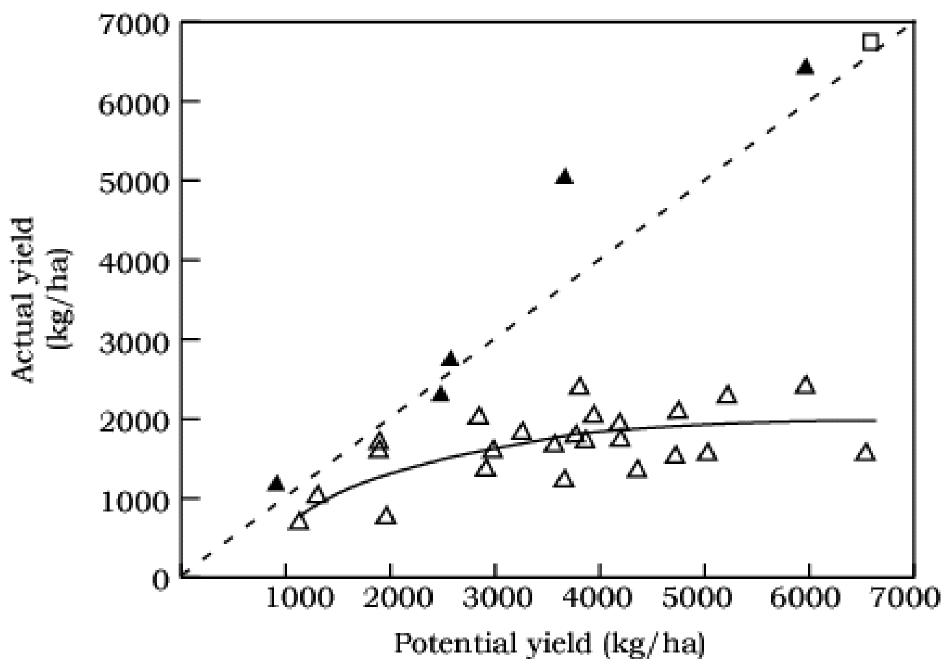


Figure 8.3 District yields for Wagga Wagga (△) compared with predicted potential yields based on rainfall and evaporation at the Agricultural Research Institute, Wagga Wagga, 1960-84 (Cornish and Murray, 1989) ▲ Experimental yields 1980-84; □ 1 ha plot in 1983; - - actual equals predicted potential yield

moisture levels in the period preceding sowing can have an indirect effect on the time the crop is sown. Insufficient or excessive moisture levels may interfere with the timing of tillage and sowing may be delayed until the required number of operations have been

effected. Where direct drilling is used, optimum sowing times are more likely to be achieved because the bearing strength of the soil has not been reduced by previous cultivation.
Irrespective of the presence of a satisfactory seedbed at the optimum sowing date, sowing may be either brought forward or delayed due to particular circumstances. If a seedbed already has a high moisture content and the prospects of further, delaying rains are high, the decision may be made to sow a crop earlier than the optimum time. This will obviate an excessive delay should further rain make the seedbed too wet for the satisfactory operation of sowing implements.

Excessive soil moisture at sowing can cause too fast a rate of absorption and seed swelling, resulting in 'bursting' of the seed. In addition, waterlogging of the seedbed during germination results in anaerobic conditions. These can interfere with the physiological processes in the seed and may also favour the development of fungal or bacterial pathogens on the seed.

Sowing time may be delayed beyond the optimum if insufficient moisture is available for germination. For each crop there is a minimum threshold level of available moisture below which rapid and even germination will not occur. This threshold level is influenced by seed size and the absorption capacity of the seeds. High-protein seeds such as the grain legumes require more available moisture than lower protein-containing seeds such as grasses.

Practical considerations may force a farmer to sow a crop even though seedbed moisture is less than ideal. This practice has considerable risk if enough moisture is present to initiate but not complete the germination processes. Rotting of the seed will inevitably occur unless rain falls within a few days of sowing. The risk is not present if the seedbed is very dry in the surface 8 to 10 cm. The difficulty in sowing under these very dry conditions lies in deciding at which depth to sow the seed. A shallow sowing may lead to initiation of germination by a relatively light fall of rain which may be insufficient to carry the seed through to emergence and survival until the next rain. Deeper placement may lead to difficulties in emergence, particularly where rainfall is sufficient to crust or slake the surface soil. More energy is required for seedlings to reach the surface from deeper in the soil.

A major determinant of optimum sowing time for summer crops is soil temperature. For these crops a certain minimum soil temperature is required before germination will take place, so sowing earlier in colder soils again increases the likelihood of deterioration of the seed in the soil. A soil temperature of 18^{0}C, for example, is required for satisfactory germination of maize.

The optimum sowing time is also influenced by the occurrence of frost in relation to the timing of flowering of the crop. For summer crops, the sowing time chosen should ensure that flowering, seed set and maturation are completed before the expected first frost.

For winter-growing crops, the desirable sowing time is one that will result in the crop flowering after the last expected date of a killing frost in spring, but before the onset of the dry period in the summer (Single, 1971, 1975). The period from pre-anthesis, through flowering, into grain filling is one of increasing water demand. At this stage, rainfall is decreasing in the Australian winter cereal areas and evaporation is increasing (Nix, 1975), thus leading to soil water deficits which restrict grain yield. For each area, successful winter crop production depends on a sufficiently long period between these two major constraints for flowering and grain maturation to proceed without significant interference. Within an area, the availability of a range of crop cultivars with inherently different development patterns allows the farmer to choose from a number of optimum sowing dates depending on the availability of moisture at sowing time.

The significance of frost injury is indicated by the impact of two September frosts in 1969 when wheat yields were reduced in New South Wales and Queensland by an estimated 1.36 million tonnes (Single, 1975). The coincidence of frost and flowering impairs the reproductive function and its significance is much greater with determinate than indeterminate crops. In the latter case, where flowering is spread over a period of time, as in lupins, frost may only affect a proportion of the flowers. In determinate crops such as wheat where the whole crop flowers simultaneously, frost at that time virtually eliminates the possibility of a profitable yield.

Delayed sowings generally can be expected to yield less than sowings at the optimum time. Such sowings often experience water deficits from just prior to anthesis through the critical flowering and post-flowering period although good finishing conditions can counteract late sowing in indeterminate crops.

Hocking and Stapper (2001) have shown 25-50% reductions in yield for each month sowing was delayed in canola and wheat. Thompson and Heenan (1994) showed yields of sunflowers to be lowered by 18-37% with a delayed sowing of up to two months. Other crop species have shown similar responses.

Under some circumstances, sowing a particular crop may be postponed to a stage where a change in cultivar cannot compensate for the delay in sowing time. In this situation, a change to a shorter-season crop is warranted. Occasionally, late breaks to the season in the southern Australian wheat belt are associated with an increase in the area sown to barley and a decline in the area sown to wheat. Barley is able to achieve more profitable yield levels in a shorter period of time than wheat.

Rate of Sowing

The rate of sowing for any crop will be determined by the plant populations required to achieve optimum yield in a particular environment. A consideration of the relationship between crop density and yield is therefore necessary.

The potential yields of any crop can only be obtained when the competition for the growth factors such as water, nutrients and light are non-limiting (Donald, 1963) and temperature and soil conditions are favourable. In practice, however, the supply of water and nutrients frequently limits production. This supply of moisture and nutrients and the general conditions of growth will determine the optimum density of a crop in a given situation.

Optimum populations and hence sowing rates are greater under less restricted rainfall conditions, or with irrigation on high fertility soils. Under low-rainfall dryland conditions, in situations where soil fertility is reduced, and in soils with low water-holding capacity, the optimum crop density will be lower. The populations of some field crops grown under dryland and irrigated conditions are compared in Table 8.4.

Table 8.4 Plant populations for some agricultural field crops grown under dryland and irrigation conditions in Australia

	Plant population('000 plants/ha)	
Crop	Dryland	Irrigation
Maize	35 – 50	50 – 65
Sorghum	20 – 60	200 – 250
Soybeans	150 – 300	250 – 350
Sunflowers	20 - 40	50 - 80

Within a defined environment, the yield of grain tends to rise to a maximum as plant density increases and then falls with further increases in density. This relationship for maize is illustrated in Figure 8.4 (Downey, 1971). Therefore, optimum densities for each crop and each environment should be determined by local research.

In addition to effects on crop yield, density changes exert significant influences on individual plant morphology. As density increases, plant height increases and stalk strength decreases. This therefore increases the risk of lodging in high populations. In maize, where the ears are higher on the stalk at high densities (Rutger and Crowder, 1967), the likelihood of lodging is further enhanced because the plant is 'top heavy'. This can also be used to advantage however, because in maize, soybeans (*Glycine max*) and cotton, for example, the height of the lowest ear, pod or boll is also raised, thereby facilitating harvest.

As density increases, tillering or branching of plant declines. In winter cereals, plants can compensate to a degree for lower than optimum plant populations caused by poor germination or disease by producing tillers. In such crops the plant population is perhaps not as critical and the relationship indicated in Figure 8.4 is modified by a flattened peak, a greater range of densities giving maximum yields. Some indeterminately flowering crops respond to lower than optimum densities by producing secondary and tertiary branches.

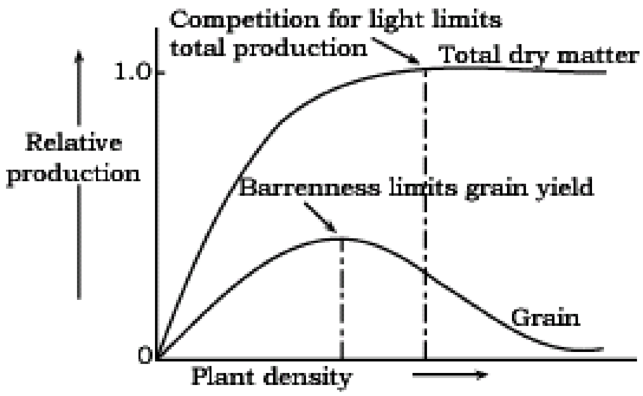


Figure 8.4 Relationship between plant density and grain yield and dry matter production in maize (Downey, 1971)

The size and weight of the ear or seed head is also influenced by density, again in an inverse relationship. This has practical benefits in that smaller seed heads of sunflower, for example, dry more quickly and evenly and facilitate the harvesting process. In maize, however, densities beyond the optimum can increase the incidence of barrenness.

From the previous discussion it should be apparent that at optimum densities, the performance of individual plants within the crop is substantially less than its potential in isolation. Under field crop conditions intense interplant competition is created resulting in high yielding crops being communities of suppressed plants (Donald, 1968).

In considering plant population, crop geometry or distribution is important, particularly in row crop production. Traditionally, many crops have been sown in rows more than 90 cm apart, narrower row spacings being impractical because of the lack of equipment to grow and harvest the crop grown under these conditions. This has been a carryover from the horse-drawn equipment days. Modern machinery now provides flexibility in the choice of crop arrangement for production of row crops. An increase in yield results from the more uniform distribution of plants, plants ‘on the square’ providing minimum competition to their neighbours. Such plants make more efficient use of sunlight, fertility and moisture. In the wider rows much sunlight falls between the rows and is wasted.

Further benefits from more evenly distributed plant populations include better weed control and better moisture utilisation. The crop competes more efficiently with weeds because the canopy develops much earlier, thereby restricting light to the weeds in the inter-row spaces. As the crop shades the ground earlier, the evaporation of soil moisture is likely to be reduced, making more moisture available to the crop. Disease incidence may also be reduced because the plants within the rows are further apart and hence there is less contact between plants to facilitate disease spread.

The change of management with narrower row spacings is important. Greater dependence on herbicides for weed control is required since post-emergence mechanical cultivation is likely to cause damage to the crop. Wider row spacings may be necessary in weedy paddocks than in clean paddocks to enable inter-row cultivation to be undertaken. Fertiliser dressing and pesticide spraying, where necessary during the growing period of the crop, may be more satisfactorily carried out by aeroplane, thus avoiding damage to the crop.

In decreasing the distance between the rows it is important to note that the distance between the plants within the row will need to be increased if the same plant population is to be achieved. The effect of different row spacings on the intra-row spacing of sunflowers is illustrated in Table 8.5.

Table 8.5 Effect of row spacing on the number of plants per metre of row for different populations of sunflowers (assuming 85% germination)

	Plant population (plants/ha)						
Row spacing (cm)	50 000	67 500	75 000	87 500	100 000	112 500	125 000
35	20	26	31	36	41	46	51
53	30	38	46	53	61	68	76
72	41	51	61	71	81	91	102
85	44	54	65	76	87	98	109
90	52	65	78	91	104	118	130
100	58	73	87	102	116	131	145
105	61	76	91	107	122	137	153

Apart from consideration of plant density and plant distribution, seed quality and time of sowing need to be taken into account in choosing a sowing rate. Seed quality is of particular importance. Seed should have a high germination percentage. Differences in seed size between different batches of seed also need to be taken into consideration. The number of seeds per kilogram may vary considerably between seasons, being influenced by the growing conditions in the year of production. Where large seed is used, sowing rates need to be higher because there are fewer seeds per kilogram. The effect of seed size on the rate of sowing of sunflowers is shown in Table 8.6.

The rate of sowing is also influenced by the timing of the sowing operation. In circumstances where sowing is delayed, sowing rates are generally increased. This partially compensates for the expected reduction in yield as a result of a reduced period in which branching and tillering can take place.

Table 8.6 Effect of seed size on sowing rate (kg/ha) of sunflowers grown in 35 cm rows (assuming 80% germination of seed) to establish required plant populations

Plant population (plants/ha)	Number of plants per 30 cm of row	Seeds/kg		
		15 000	20 000	25 000
25 000	28	2.2	1.6	1.3
37 500	42	3.3	2.4	1.9
50 000	56	4.4	3.2	2.5
67 500	70	5.5	4.0	3.1
75 000	84	6.6	4.8	3.8
87 500	98	7.7	5.6	4.4
100 000	112	8.8	6.4	5.0

The range of sowing rates for a number of field crops is given in Table 8.7.

Table 8.7 Range in sowing rates for some agricultural field crops under dryland and irrigation conditions in Australia

	Sowing rate (kg/ha)	
Crop	Dryland	Irrigation
Wheat	20 – 120	100 – 135
Oats	20 – 120	100 – 135
Barley	20 – 120	100 – 135
Rice	-	110 – 160
Lupins	60 – 130	60 – 130
Field peas	60 – 170	120 – 170
Linseed	20 – 30	40 – 60
Canola	3 – 6	5 – 9
Safflower	9 – 16	20 – 30
Sunflower	2 – 4	5 – 8
Soybeans	35 – 60	50 - 70
Cotton	-	15 – 40
Peanuts	-	30 – 50

Undersowing In south-eastern Australia, pastures are resown at the end of the cropping phase. The resowing usually takes place under the last crop.

This is a compromise between a loss in crop yield and successful establishment of the undersown pasture, since competition between them is inevitable. Dear (1989) demonstrated the effect of undersowing subterranean clover to wheat at Wagga Wagga (Figure 8.5) where a reduction in wheat sowing rate reduced wheat yield, but it is necessary if the required seed production of about 400 kg/ha of the clover is to be obtained for productive regeneration and maximum winter yield of the pasture in the following year.

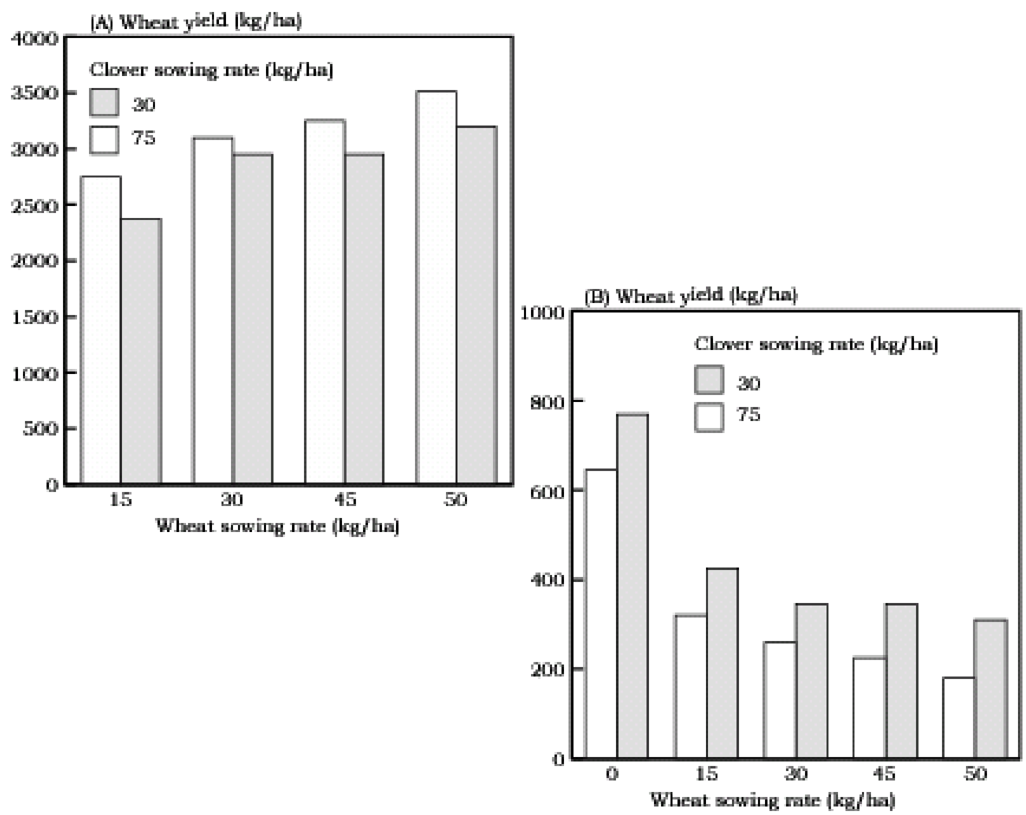


Figure 8.5 The relationship between a wheat cover crop and undersown subterranean clover at Wagga Wagga (Dear, 1989); (a) The effect of wheat and clover sowing rate on wheat grain yield, 1987; (b) The effect of wheat and clover sowing rate on clover seed yield, 1987

The effect on pasture establishment can be expected to be greater as rainfall declines due to competition for moisture. The impact is also greater on perennial pasture species such as lucerne which have to survive the first summer.

Poor pasture establishment results in a poor pasture phase, reducing the ability of this phase to assist the recuperation of soil fertility and soil structure and to provide high-quality feed for livestock. Farmers must therefore be prepared for lower yields in the final crop if the productivity of the whole rotation is to be enhanced.

In Western Australia and South Australia the short rotations traditionally followed provided for the natural regeneration of the annual legumes. This depends on high seed set at the end of the previous pasture year with sufficient hard-seededness to carry through the cropping year. Factors identified by Thorn (1989) which interfere with this practice include:

- using herbicides which prevent seed production by the pasture legume;
- extending the cropping phase, which has the effect of reducing seed reserves, particularly in subterranean clover;
- poor pasture years or high-pressure grazing not allowing adequate seed production (the effect is greater on subterranean clover than on medic pastures);
- hard-setting surface soils brought about by excessive tillage;
- tillage practices which bury the seed too deep for emergence; and
- high burdens of crop straw carryover.

The trend towards extended cropping phases in these areas precludes dependence on natural regeneration.

Depth of Sowing

The selection of the correct depth of sowing for any crop is based on the conflicting needs to plant deeply enough to protect the seed from desiccation within the surface layer of soil, yet shallow enough to permit easy and rapid emergence of the shoot (Donald and Puckridge, 1975). The factors that influence seed desiccation and shoot emergence need to be considered.

The risk of desiccation is obviously related to availability of soil moisture. Under low levels of soil moisture, sowing should be deeper than normal in an endeavour to locate the seed adjacent to the moisture deeper in the profile. The soil moisture/seed relations are also influenced by soil type, the lighter soils having a lower moisture-holding capacity. In these soils, therefore, deeper sowing is justified when compared with heaver soils with their higher moisture-holding capacities.

The emergence of a seedling will depend on the characteristics of the seed and the soil conditions. Small-seeded species, such as canola, have small food reserves and therefore restricted elongation potential. This necessitates much shallower sowing depths of 1 to 2 cm than is the case for larger seeds with much greater food reserves, such as soybeans, which are normally sown at depths of 3 to 5 cm. The effect of depth of sowing on emergence is more critical for the smaller seeded species but sowing practices have been generally less exacting for small seeds, perhaps because of the lack of suitable machinery. Such species, including many pasture species, are sown from a pasture seed box through swinging droppers and are covered to variable depths by trailing harrows. A more precise placement of small seeds by drilling would undoubtedly result in more even emergence and establishment and thus higher crop yields. In contrast, the placement of larger seeded species is carried out more accurately. For each set of conditions, an optimum sowing depth for any given crop exists. Sowing practices should take this into account. Sowing depths for field crops are given in Table 8.8.

Table 8.8 Average depths of sowing for agricultural field crops

Crop	Depth of sowing (cm)
Wheat	2 – 4
Oats	2 – 4
Barley	2 – 4
Maize	3 – 5
Sorghum	3 – 4
Lupins	2 – 4
Field peas	3 – 4
Soybeans	2 – 4
Safflower	3 – 5
Sunflower	2 – 4
Canola	1 – 3
Linseed	1 – 2
Peanuts	2 – 7
Cotton	2 - 4

The ability of a crop to emerge from the soil is influenced by the type of emergence of the seed. In crops such as soybeans which exhibit epigeal emergence (in which the cotyledons are brought above ground), the depth of sowing needs to be more shallow than for crops such as peas. The latter has an equivalent seed size but exhibits hypogeal emergence (in which the cotyledons remain below ground). The cereal crops have an advantage over many other crops because of their hypogeal emergence, together with their slender coleoptile. With the advent of semi-dwarf cultivars, however, the coleoptile length is reduced, thereby restricting the depth from which these cultivars can be successfully established.

Soil characteristics also influence emergence. In lighter soils, seeds can be sown deeper than in heavy soils because less resistance is offered to the progress of the seedlings. In poorly structured soils or where soil compaction and surface crusting are likely, emergence is impaired (McIntyre, 1955; Millington, 1959; Stoneman, 1962). In such conditions, a light surface harrowing following sowing may be necessary to break up the crust.

Seed Preparation

In field crop production, the seed sample produced by commercial harvesting machinery is seldom satisfactory for sowing another crop unless prior preparation is undertaken. This preparation is most important as it affects the results to be obtained in crop establishment.

The objectives of seed preparation are:

- to produce seed with a prospect of high percentage germination by the removal of small or cracked grains;
- to remove weed seeds; and
- to apply chemical seed dressings, or 'pickles' to control seed-borne pathogens, or to protect stored seed from insect infestation.

These objectives are accomplished by the use of an array of seed grading machinery. The choice of a particular grading machine will depend on the crop species and the species of weeds contaminating the sample. The final operation in most seed graders is the application of dusts with fungicidal or insecticidal properties.

Grain to be prepared as sowing seed is usually selected from a batch with good appearance. Weather-damaged grain or grain that has obviously been damaged by incorrect threshing techniques are avoided where possible. The batch to be graded and dusted will also need to have low moisture content levels to survive the storage period.

The most common types of grading machinery used in Australia are designed to clean cereal seed. These use perforated metal screens with round or slotted holes separating the larger seed from the small (de Silva, 1977a). Indented disc separators may also be employed in series with the screens to remove seeds of different sizes. When cleaning seed of crops other than cereals, equipment which separates seeds with different resistance to airflow may be needed.

The gravity table, or more correctly the specific gravity separator, will divide seeds of differing weights and size and may be useful in removing noxious weed seeds from the seed sample. Equipment is also available to separate seed on the basis of surface roughness, shape and colour.

Concurrent with the grading process, many seeds are subject to treatment peculiar to their particular morphology. Barley seed requires de-awning, cotton seed is delinted and hard-seeded legume seeds are scarified to promote water imbibition.

Chemical seed dressings are applied as a dry dust. These may be used to control seed-borne or soil-borne diseases, such as 'damping off', where the seed rots in the soil. The smut diseases of wheat are usually controlled by fungicidal dusts, as most wheat cultivars are not resistant to these diseases. Some chemicals may affect the storage life of seed and this needs to be taken into account. The effect may be more severe in some cultivars (Kuiper, 1974).

For grain legume seed, peat cultures of suitable *Rhizobium* strains are mixed with water and the resultant slurry mixed thoroughly with the seed. Methyl cellulose is often used to increase adhesion to the seed and prevent desiccation. This operation is usually restricted to less than 48 hours prior to sowing to ensure a high survival of the inoculum. Alternatively, an attachment to the sowing implement can spray the inoculum into the furrows in close proximity to the seed, avoiding the need for inoculating the seed.

Correct crop agronomy dictates that the efficiency of the seed preparation processes should be assessed. This involves a laboratory test for germination. Seed prepared for sale is usually subject to minimum germination and purity standards set by government legislation under different state Agricultural Seeds Acts. A knowledge of the germination percentage is essential. Adjustment of sowing rates to ensure optimum plant populations is made on the basis of this.

Crops which may be attacked by insects in the seedling stage are sometimes treated with systematic insecticides immediately prior to sowing. The application is usually by spraying the material on the seed while it is agitated. This application will afford protection to the crop until the plant is sufficiently developed to withstand attack. An example of this is the treatment of canola with dimethoate to enable the young seedling to withstand attack by red-legged earth mite (*Halotydeus destructor*).

Stored seed should always be kept in a cool, dry place. Seed deterioration is greatest under warm, humid conditions. In cotton and soybeans, such conditions can cause significant loss of viability in two or three months. In these circumstances seed may need to be stored in moisture-proof bags, provided that the seeds are already dry enough for sealed storage.

Sowing Methods

The method of sowing a crop depends on a number of factors including the crop to be sown, the condition of the soil and the system of production used. The methods for sowing seed fall into two categories: surface sowing, and drilling the seed into the soil.

Surface sowing involves the broadcasting of seed on the surface of the soil by ground machine or from the air. Sowing by this method is generally inferior to placement of the seed in the soil, largely because the conditions are less conducive to good germination and establishment, with seedlings at greater risk of desiccation. Theft of seeds by ants and birds is also a problem. Aerial sowing, however, is a common method of establishing rice (*Oryza sativa*). The seed is pre-germinated before being dropped into water. This method has the particular effect of advancing the growth of the crop by up to ten days and therefore is advantageous in situations where sowing is delayed or in areas with a shorter growing season such as the Murray Valley in southern New South Wales. However, crop damage by bloodworms and ducks is increased (Woodlands *et al*., 1984).

The most common method of sowing is by *drilling* the seed into the soil at a prescribed depth. The winter cereals and many small grain crops are usually sown by a *combine*, a grain drill with a fertiliser box attached, thereby resulting in the seed being placed in the soil adjacent to a band of fertiliser. From the seedbox the seed passes through a metering device, commonly a fluted wheel or a double run, into droppers which extend to a prescribed depth in the soil behind furrow openers. The fertiliser follows a similar procedure although the metering system is different, usually being a 'star' feed. The furrow openers vary, there being single disc, double disc and tine types.

Traditional tine drills have poor plant residue handling capabilities and blockages occur unless the residues have been fragmented, are dry and are in small amounts (Kamel, 1975; Brown *et al*., 1986). This is important for stubble retention farming, necessitating a change in tine geometry to greater trash clearance both within the tine row and between rows of tines. Tines are also less useful under heavy wearing conditions such as sandy soils. Problems arise where disc openers are used under conditions where soil is likely to adhere to the discs (Kamel, 1975).

Many combines have a small seeds box attachment preferably in conjunction with a band seeder through which pasture seed or small seeded crops such as canola are sown by mixing them with the fertiliser, providing consideration is given to likely fertiliser germination damage.

Combines sow the crops in rows approximately 18 cm apart although this can be varied in multiples by blocking the appropriate seed openings. The metering systems in conventional combines are not particularly precise and considerable variation in sowing rate and fertiliser rate both within and between rows is frequent. In many crops, however, this is relatively unimportant, but in the case of concentrated fertiliser, small differences represent considerable variation in actual nutrient supply.

Many combines have sets of cultivating tines or discs ahead of the furrow openers to allow the farmer a final cultivation during the sowing process.

In recent years in Australia, higher horsepower tractors capable of pulling cultivating and sowing equipment much wider than the traditional combine have become available. Typical 'wideline' implements may cover a span of 8 to 14 m in one pass. These implements often are combined with seed and fertiliser metering equipment to allow very rapid sowing. The usual arrangement consists of a large capacity wheeled hopper trailing immediately behind the tractor. The wide span machine is attached to the rear of the hopper. After metering, the seed and fertiliser are blown along flexible plastic tubes to the sowing tines. The fan providing the pneumatic propulsion is driven either from the tractor power takeoff shaft or a separate motor. To allow this system to be used to its maximum, the seed and fertiliser are handled in bulk, being augered or elevated from large truck-mounted bins. A major difficulty with wide span machinery is obtaining consistent depth of sowing on unlevel ground.

The *sodseeder* is very similar to the combine but there is no cultivation, the seed and fertiliser being introduced into an undisturbed soil. The sodseeder places the seed and fertiliser in a narrow slit in the soil which falls back over the seed immediately following the operation. The success of sodseeding depends on soil type and soil moisture at planting. This technique is used for sowing rice, but requires heavy grazing to leave the area as bare as possible. Following germination of the rice seedlings, the area can be grazed by sheep between irrigation 'flushings' before permanent water is applied. The rice plants are less palatable than the associated species and are therefore avoided. Alternatively, the competitive herbage can be removed by non-residual contact herbicides.

Row crop *planters* are used for sowing of row crops which require wider row spacings than small grain crops, there being a separate seed hopper for each row. Row crops require more accurate seed placement within the rows than, for example, wheat, the metering device in this case commonly being a revolving plate with notches to hold a single seed of specific size. The plate revolves as the planter is drawn forward, releasing single seeds at precise intervals. Different crops can be sown by changing the plates and the row spacings.

After the seed is placed in the soil by the combine or planter, it must be covered by sufficient soil to ensure germination. Some covering may occur with soil displaced by cultivating tines, or by the soil flowing around the sowing tine itself. However, trailing harrows are usually fitted behind the sowing implement to smooth out the ridges, and so cover the seed at the bottom of the furrow. Increasingly, press wheels are used to firm soil around the seed (Sweeting and Colless, 1985). This can aid the establishment of seedlings considerably where conditions for germination are difficult, such as where the soil is drying out (de Silva, 1977b). Press wheels are also useful in improving seed-soil contact where the seedbed contains a large amount of crop residues or is in a rather cloddy state (Kamel, 1975).

The establishment of tobacco (*Nicotiana tobacum*) and sugar cane (*Saccharum officinarum*) warrants special mention because these crops are substantially different in culture to most agricultural crops.

Tobacco seed is extremely fine and is planted in nursery seedbeds. The seedbeds have movable covers of plastic or canvas which are used for protecting seedlings from adverse weather conditions and for seedbed fumigation. In late spring or early summer the seedlings are transplanted into the field and normal cultural operations proceed.

The production of sugar cane is confined to the subtropical-tropical regions of Australia. The plant is a perennial, and up to four crops may be obtained from the one planting. The first crop, known as the 'plant' crop, takes from 8 to 24 months to be ready for harvest; the ratoon (or subsequent) crops are harvested annually thereafter.

The crop requires high soil fertility and high soil organic matter, so often a green manure crop is used just prior to planting in order to build up the organic matter. Soil preparation is very important because it is only done about once in four years. A poor preparation may result in three poor crops.

Because the crop is grown in tropical-subtropical conditions, weed growth is prolific and early management of a crop consists of intensive weed control.

The crop is propagated vegetatively with cane cuttings, or setts, being planted mechanically by a 'cutter-planter'. This machine cuts the cane into setts, plants the setts in drills and applies fertiliser, all in the one operation. If conditions are favourable and the setts used are sound, shoot emergence should be uniform and rapid. However, some gaps often occur in the plantation, caused by non-emergence of setts. Gaps in the rows greater than about 0.5 m are replanted as soon as possible, a procedure known as 'supplying'. Whilst supplies rarely catch up to the original crop, they do provide the useful function of ground cover, thereby preventing weed growth.

POST-SOWING MANAGEMENT

Post-sowing management for most agricultural field crops grown under dryland conditions is confined largely to the control of weeds and pests, much of which is discussed in Chapters 9 and 10 and attention to nutrient needs as discussed in Chapter 6.

Weed and pest control is done by using herbicides and insecticides which are applied by ground boom sprays or by aeroplane. The latter avoids any physical damage to the crop, the amount of damage increasing with age of the plants. Early spraying of herbicides enables lower rates to be used more effectively on weeds, which are generally more susceptible when young. Maximum crop benefits are achieved by early spraying.

Fertilisers may also be applied, particularly if a nutrient deficiency becomes evident during the course of growth of the crop. The most common uses of fertilisers, however, are split applications of nitrogen fertiliser in wheat (at sowing and at completion of tillering) to raise grain protein, and an application for rice at panicle initiation for yield response.

Under some conditions, winter cereal crops may need grazing to arrest their development. This need for grazing most commonly occurs when early sown crops make rapid growth under mild winter temperature conditions. This practice ensures that flowering of the crop does not take place while frosts are likely to occur. Grain yield is usually reduced by grazing, although the reduction is far less than in severely frosted crops (Dann, 1976). In the non-cereal winter crops, grain yield reduction is particularly severe (Dann *et al*., 1977) and the practice is not recommended. However, the winter wheats, oats and barley are particularly valuable for winter forage, and specific cultivars have been bred to give maximum forage production and grain production. If these crops are to be used to obtain high grain yields, the grazings have to be lenient and completed before ear initiation of the crop in late winter (Dann *et al*., 1983).

In tobacco crops an additional process is required. Because the leaf is the economically important part of the plant, management aims at maintaining the crop in the vegetative phase. This necessitates topping, which removes the flowerheads, and suckering, which removes suckers that develop in the leaf axils following topping, as the plant endeavours to complete its reproductive cycle. Chemical control of suckers has replaced what was a tedious, labour-intensive and hence costly task.

HARVESTING

Maturity

The harvesting process for each crop occurs at a particular stage of maturity of the crop. It is important to note the distinction between *physiological maturity* and *harvest maturity*.

Physiological maturity refers to that stage of a crop where the seed reaches its maximum dry weight. In general, grains cease the accumulation of dry matter at approximately 40% moisture. Harvesting crops prior to physiological maturity can be expected to lower the quality of the seed and produce shrivelled grains that have low test weights.

Harvest maturity refers to the stage of development of the crop at which harvesting will produce the best combination of yield and quality. The important factor is the moisture content of the grain. The appropriate moisture content will depend in particular on the crop grown and to some extent on the machine being used.

The problems of harvesting after physiological maturity but before harvest maturity include:

- spoilage in storage if drying facilities are not available. The maximum moisture contents suitable for grain storage are given in Table 8.9;
- mechanical damage to kernels which are high in moisture and swollen;
- an inefficient harvesting process, the machinery being unable to effect total harvest because of ‘green’ growth.

Delaying harvesting beyond the harvest maturity period will generally cause a reduction in yield and quality. Yields can be affected by lodging and shattering, although the degree will depend to a large extent on prevailing weather conditions and on the crop to be harvested. Quality usually deteriorates under excessively wet conditions, commonly resulting in lower test weights. Sprouting and colour loss may also occur and seed crops may lose their germinability. In wheat, rain on the mature grain causes production of α-amylase enzymes which seriously damages baking quality (Simmonds, 1989).

Table 8.9 A summary of the moisture contents for storage of grain of some agricultural field crops in Australia

Crop	Moisture content (%)
Wheat	12
Oats	12
Barley	12
Maize	14
Sorghum	13
Rice	16
Lupins	12
Field peas	12
Soybeans	12
Safflower	9.5
Sunflower	9
Rapeseed	8
Linseed	10
Peanuts	12

Extremes of temperature can also affect grain quality. In rice, sun-cracking may occur if very dry grain is exposed to very low or very high temperatures under alternate wetting and drying conditions (Blakeney, 1984).

The date of harvest of some crops, notably cotton, can be advanced by using chemicals which defoliate or desiccate the plant; this may not, however, be the overriding reason for their use. Cotton grade is assessed on colour, fibre character and trash content. Much of the leaf harvested is large and leathery and is easily cleaned in the ginning process, and therefore presents little problem. The quality of the product declines if the powdered, dry leaf and bracts are present. This is called ‘pin trash’ or ‘leaf pepper’. Sappy green leaves in a harvest sample caused significant staining of the cotton fibre (Swann, 1971). Defoliants have the advantage of removing leaves, which would otherwise block the spindles, add trash, or stain fibre. Only mature leaves are successfully removed by defoliants and therefore in rank crops and crops containing considerable second growth, desiccants must be used. Harvesting, however, must be done before the leaves begin to crumble, otherwise pin trash will be increased (Swann, 1971). Premature use of either defoliants or desiccants may also cause serious loss in yield and quality.

Grain drying overcomes the problem of storage deterioration through high moisture contents. However, several precautions have to be noted in the grain drying process. Where the grain is to be used as seed for future crops, the drying temperature should not exceed 43^{0}C. Where the grain protein content is important in processing, such as wheat for bread manufacture, high temperatures cause a degree of denaturation of the protein and product quality consequently suffers. Under these conditions drying temperatures should not exceed 60^{0}C. The maximum recommended temperatures for drying grain are shown in Table 8.10.

Table 8.10 Maximum temperatures (^{0}C) for drying grain

Grain	Grain for seed	Grain for commercial use	Grain for stock feed
Maize	43	54	80
Grain sorghum	43	60	80
Wheat/oats	43	60	80
Barley	40	40	80
Soybeans	43	49	80
Oilseeds	-	46	-

Harvesting Methods

Two general categories of harvest operations can be described although within the categories the requirements of crops may differ considerably.

Direct Mechanical Harvesting

In this method of harvest the economic yield of the plant is gathered and processed by suitable machinery in one operation. For most seed and grain crops, the all-purpose header or harvester removes the seed heads, threshes the seed from the seed head, separates the grain from leaf and stem material, and discards the trash.

The principle of the header-harvester (Figure 8.6) is now described. The stems of the standing crop are cut by a reciprocating knife and are swept or dragged into an elevator by a revolving reel or auger. This elevator conveys the material to a threshing drum which revolves at an adjustable controlled speed, usually between 500 and 1500 revolutions per minute. A stationary concave (a curved open grate) is fitted around the lower half of the drum. The clearance between drum and concave is adjustable. Metal rasp or rubbing bars are fitted to the drum and concave. As the crop material passes between the drum and concave, most of the grain is threshed out of the seeds or pods. This grain and chaff fall through the concave onto the grain pan underneath.

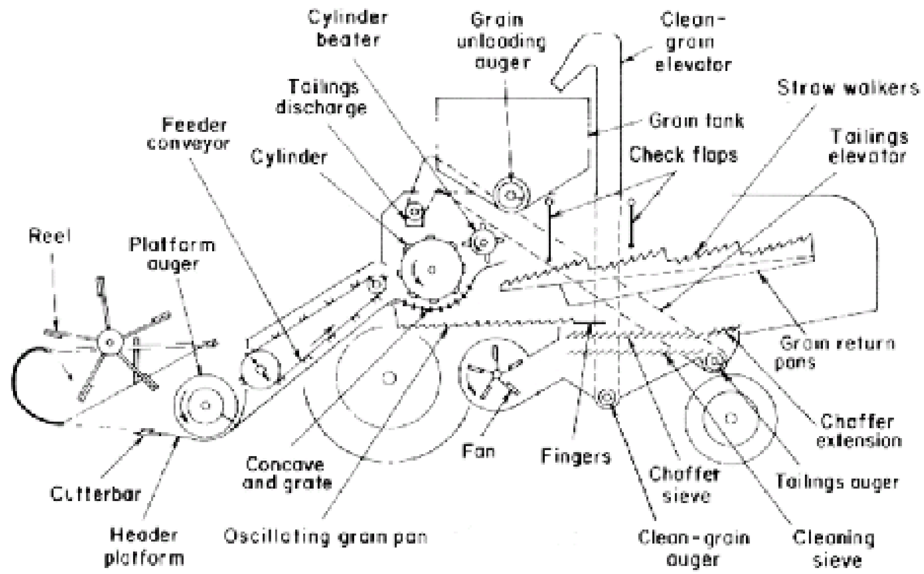


Figure 8.6. Schematic diagram of a typical header-harvester (adapted from Kepner *et al*., 1982)

Behind the drum is a revolving beater, which assists in removing straw from the drum, at the same time removing grain carried in the straw. Any grain thus removed falls through a grate, also onto the grain pan. The threshed straw passes on to the straw walkers, which have an oscillating motion that carries the straw out to the back of the harvester. The need for straw-spreading mechanisms has previously been described. Any unthreshed or partly threshed heads or pods fall through the straw walkers on to chutes which return to the grain pan.

The mixture of grain, chaff and partially threshed material on the grain pan is carried to an oscillating top riddle or sieve and travels towards the rear of the harvester. An air blast passes upwards through the riddle, blowing the chaff out of the rear of the machine. Unthreshed heads or pieces, called ‘gleanings’ ride over the riddles and fall off the rear into a repeat auger which conveys them back to the drum for rethreshing. The free grain falls through the top riddle onto a lower one with smaller openings, where further chaff is removed by the blast of the fan. The grain travels backward on this lower riddle, and is dropped on to an inclined plane and so conveyed to the grain auger. From this auger it is fed to the grain elevator and lifted into the grain box on top of the header. The grain box is discharged when full through a built-on auger.

Successful harvesting requires wide experience. However, the following broad principles apply. The ground speed of the header should be such that only that amount of material which will give efficient separation is allowed to enter the header. High speed in heavy crops does not provide sufficient time for separation to occur and grain losses can be considerable. The clearance between the rasp bars and concave should be adjusted to give maximum threshing with minimum grain damage. The speed of the drum can also be altered to achieve this objective. The volume of the air blast is controlled by varying the fan speed. Excessive blast will blow grain out of the machine, while insufficient will result in a chaffy sample. Correct sieve type and sizes must be chosen for each crop to ensure a clean sample.

For maize, a specialised picker-sheller is used whilst particular harvesting equipment is required for crops such as sugar cane and cotton.

The *sugar cane* harvest takes place in the cooler months of the year when the cane has a high content of sugar. Customarily, much of the trash is removed from the crop by burning shortly before harvest. The harvest is done with a 'chopper', a machine which cuts the cane into lengths and transfers these into bins which are then transported quickly to the mill. The need to process the cane as soon as possible after harvest by chopper machines is due to the increase in the number of cut ends in the cane. Rapid deterioration of cane can result due to the entry of the *Leuconostoc* microorganism into the cut ends of the cane. Mechanical harvesting, however, has created problems of stool damage and soil compaction when harvest has taken place under wet conditions (Sturgess *et al*., 1976).

The *cotton* crop is ready for harvest 7 to 10 days after defoliant sprays have been applied. The crop is picked by 'cotton pickers', machines which straddle the cotton rows. They have barbed spindles which pick the seed cotton from the bolls after which suction pipes blow the cotton into a storage bin. The storage bins are compressed into modules which can be left in the paddock until convenient to transport them to the gin. Growers aim to harvest 70 to 90% of the crop at the first picking, which should be completed before frosts (May-June); the balance of the crop is harvested at a second pass three to four weeks later. Once the harvested material reaches the gin, the ginning process removes the fibre, or lint, from the seed; most of the seed is then transported to oil extraction plants.

Indirect Mechanical Harvesting

This method requires more than one operation before the economic portion of the crop is obtained. The most common example of this method is where the crop is cut and windrowed prior to being picked up by a header for threshing. This method is useful where crops are close to the ground as in the case with *field peas* or with crops that have lodged. It is also common in canola, where shattering losses can be high, particularly if uneven ripening occurs. In crops with a high green weed component, excessive moisture levels may be imparted to the grain and increased losses may occur through blockage of the machine with normal harvesting. Under such conditions, windrowing will be a sound proposition, as the cut weeds can be allowed to dry in the swathe before harvesting.

In crops such as *soybeans*, desiccants are sometimes used to hasten the maturation process, particularly where a bad weed problem exists. However, it predisposes the crop to weather damage and is usually more expensive than grain drying (McInerney *et al*., 1991).

The harvesting of *peanuts* requires several operations. The crop should be cut and pulled when the greatest number of nuts show darkened veins on the inside of the shell. Two-row or four-row mid-mounted cutter bars are passed under the nut clusters of the peanut plants to cut the taproot and loosen the soil around the plants. The cutters are followed by rear mounted pullers that compress the tops and raise the plants at the same time. After the plants have wilted but not dried out, it is usual to combine two to four plant rows into a windrow using a side delivery rake. Extreme care is needed in all operations to minimise losses. Once windrowed, the peanuts are left to cure for two to five days before threshing, drying and bulk handling. Threshing is carried out with pick-up peanut threshers which either deliver into bulk bins or into bags. The moisture content of the pods is usually high, thus requiring artificial drying immediately following threshing. Where such drying facilities are not available the farmer may have to leave the crop in windrows for 7 to 14 days or longer.

THE NEED TO MONITOR

The need to improve productivity in order for farmers to survive financially is ever present. Increased managerial skills are required, and the need to keep records of both physical and financial aspects is a necessary component. The physical records involve regular monitoring of the crop's performance so that, between paddocks or over time, comparisons can be made. Decisions can then be made about what went wrong or what went right, so that continual adjustments can be made to each succeeding year's crop program.

This requirement is emphasised in New South Wales where monitoring programs are in place for various crops. These programs (for example, Wheatcheck, Ricecheck, Soycheck, Canolacheck) involve the close monitoring of crops by groups of farmers, so that key factors influencing yield and quality can be identified within a season by comparisons of data from different farms.

Regular testing for soil nutrient and pH status, the presence of herbicide resistance and measuring groundwater levels provide a firm basis for the determination of the level and type of inputs necessary to achieve a particular target yield.

PRINCIPLES

- Farming systems in the south are commonly in association with a pasture phase. Continuous cropping is more common in the north.
- Tillage is generally harmful to the soil. Reduced tillage systems involving knockdown herbicides in seedbed preparation are commonly used.

- Raised bed farming and particularly controlled traffic farming help to overcome the issues of waterlogging and soil compaction respectively.
- Crop residues need to be managed so that machinery can progress through them at seedbed preparation and sowing times. Options include grazing, burning, incorporation and surface retention or a combination thereof.
- Retention of stubbles on the surface is important for reducing soil erosion, particularly in summer rainfall areas, and reduced soil evaporation, particularly in the south.
- Benchmarking provides the opportunity to evaluate on farm performance. Crop water use efficiency provides a useful guide.
- Sowing on time provides the best chance of achieving highest yields. Ideal sowing time is influenced by the ideal flowering and seedfill conditions.
- Rates of sowing are influenced by sowing time, environmental conditions and seed size.
- Crop emergence and establishment will depend on attention to seed preparation and quality.
- Harvest needs to take place at correct moisture contents of seed to enable proper storage and minimal harvest damage to the seed.
- Monitoring of field performance is essential in order to improve outcomes. Lack of records inhibits improvement.

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