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Harvest and Postharvest Management of Forage Seed Crops

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8.1 SEED HARVEST

8.1.1 Introduction

Not all the seed that is produced can be harvested (Lorenzetti, 1993), because of the range of seed ripeness, the effects of lodging, seed shattering/pod dehiscence, and losses during the harvest process. These losses can be substantial; e.g., in an on-farm survey, Clifford and McCartin (1985) measured harvesting losses in white clover (*Trifolium repens* L.) seed crops of 12–39%, the mean being 200 kg seed ha^{-1}. Similarly in grasses, losses ranging from 20 to 75% are often reported (Andersen and Andersen, 1980; Meijer, 1985; Hampton, 1991).

Hopkinson and Clifford (1993) suggested four stages of seed loss during the time from seed physiological maturity to collection of the seed from the combine harvester:

Stage 1: Environmental losses – the effects of wind, rain, lodging and the ability of a cultivar to retain its seed.

Stage 2: Cutting losses – seed shaken from the seed head during the cutting of the crop, or forced out of the head by wind or rain while in the swath.

Stage 3: Pickup losses – seed shaken from the seed heads during the lifting from the swath for presentation to the combine auger platform.

Stage 4: Separation losses – seed lost because of threshing inefficiency, excessive aspiration draught blowing seed directly over the straw walkers and out the back of the separation chamber, and seed entrapment in the offal deposited on the ground from the straw walkers.

8.1.2 Seed Shattering

Grass and legume cultivars are bred primarily for their forage production, and not their seed production ability. High seed retention is therefore not usually a plant breeding goal. Consequently, because of natural variation, there is a great difference in seed retention among species and cultivars (see Chapters 4 and 10).

Steen (1983) produced a seed shattering index for eight forage grasses, and concluded that Italian ryegrass (*Lolium multiflorum* L.), common meadow grass (*Poa trivialis* L.) and meadow fescue (*Festuca pratensis* Huds.) were species most prone to seed shattering, while Kentucky bluegrass (*Poa pratensis* L.) and red fescue (*Festuca rubra* L.) lost little seed through shattering. However, any forage species will shed seed through shattering if incorrect decisions as to the time of harvest are made (e.g. Table 8.1).

Differences in seed retention among cultivars within a species have been reported (McWilliam, 1980; Elgersma *et al.*, 1988; Simon, 1993). For example, Piccirilli and Falcinelli (1989) found large variation in seed shattering among different ecotypes of cocksfoot (*Dactylis glomerata* L.) and identified differences in genetic resistance to shattering in some of these ecotypes. In tall fescue (*Festuca arundinacea* Schreb.) Falcinelli (1993) found genotypes with delayed shattering which indicates that resistance to seed shattering is likely to exist (see Chapter 10).

Environmental conditions from flowering to maturity play a role in the ability of a crop to retain its seed (Steen, 1983; Elgersma *et al.*, 1988). For example, in perennial ryegrass, dry and warm conditions increase seed shattering; in tall fescue and Yorkshire fog (*Holcus lanatus* L.) strong winds through a non-lodged crop can result in 50–90% seed shattering within 24 h (J.G. Hampton, Palmerston North, 1996, personal communication).

Unfortunately, data on seed shattering of grass and legume species/cultivars are not well documented. This information is pivotal to minimizing harvest losses. The seed shattering potential of a crop influences the choice of harvest method, as well as the time of harvest.

8.1.3 Crop Growth and Conditions of Growth

Lodging

The risk of seed loss in a species which is prone to shattering is greatly decreased if the crop has lodged after anthesis (Ellegaard, 1971a, b; Jensen, 1976). This is because the loss of fertile tiller fresh weight in the latter stages of seed development can result in the upward movement of the crop (i.e. a partial reversal of lodging) just before harvest, and this movement can increase shattering (Andersen and Andersen, 1980).

Alternatively when seed crops are grown in windy environments, some lodging after anthesis can offer protection from the seed shatter which results from wind action.

Table 8.1. Effect of date of harvest on seed yield of meadow fescue. (Adapted from Simon, 1993.)

Date	Seed moisture content (%)	Seed yield (kg ha^{-1})	Seed loss (%) from optimum[1]
29 June	51	1040	—
4 July	41	1221	—
8 July	31	1039	15
20 July	13	808	34

[1]Peak seed yield recorded on 4 July.

Vegetative growth

Once translocation of assimilates to the seed ceases (see Chapter 4), or when lodging allows light to penetrate to the base of the plant, new vegetative growth begins as long as water and nutrients are not limiting. This flush of vegetative growth can in severe cases virtually submerge the seed heads, making direct combining impossible. Even the presence of small amounts of new vegetative growth means that it becomes more difficult to thresh the seeds out of the straw, and threshing losses are increased. Vegetative regrowth in swathed crops may mean that the swath has to be lifted before feeding into the combine, or undercut by mowing. This process is likely to increase seed shattering (Clifford and McCartin, 1985).

Uneven ripening

The indeterminate growth habit of forage legumes means that the seed crop will not ripen uniformly, as flowering may be spread over several weeks. While forage legume seed crop management aims to produce a single peak of flowering (Hopkinson and Clifford, 1993; Chapter 6), a single harvest of a forage legume seed crop will include seed at all stages of development.

Ripening in grasses is usually more uniform, but factors such as varying soil quality, uneven fertilizer application and areas of lodging within a crop can all result in uneven seed ripening.

In a very unevenly ripened seed crop it may be economic to thresh more than once (Arnold and Lake, 1965, 1966).

Sprouting

Seed sprouting (germinating) in the seed head before harvest may occur in wet seasons, resulting in increased difficulties with harvesting, high yield losses and poor quality seed.

8.1.4 Determining the Stage of Development of the Crop

Delaying or advancing seed harvest by only a few days can result in substantial yield losses (Andersen and Andersen, 1975), and it is therefore important to know the stage of development of the crop during the period leading up to harvest. This can be determined in the following ways.

Days after anthesis

For most forage species, the number of days from peak anthesis to maximum seed dry weight (harvest ripeness) is around 30 days (Hyde *et al.*, 1959; Hill and Watkin, 1975a; Hare and Lucas, 1984; Hopkinson and Clifford, 1993; see Chapter 4), although this time period may vary within a cultivar depending upon climatic conditions (Hare and Lucas, 1984). For example, higher temperatures shorten the period from peak anthesis to harvest ripeness (Komatsu *et al.*, 1979).

Harvest decisions based on a grower's local environmental knowledge and previous experience with the time it takes a crop to reach harvest ripeness can be extremely effective. For example, Marr (1990) stated 'as a general rule, when the cocksfoot crop flowers at Methven (Canterbury, New Zealand), there are 28 days until harvest'.

Crop colour

Crop colour has been proposed as a method for determining the stage of development of the crop (Hill and Watkin, 1975a; Andersen and Andersen, 1980), and Steen (1983) developed a scale of five ripeness groups, with a rating for the colour of the stem and spikelets from green to yellow. However, specific climatic conditions and cultivar differences influence the relationship between stem and seed dry matter, seed shattering and colour. This method is rarely used.

Endosperm consistency

Pegler (1976) suggested that endosperm consistency was a reasonably reliable indicator of seed maturity. For grass seeds, growers consider that when the endosperm has passed from the 'milk' to 'dough' stage, there are around 7 days until harvest (Marr, 1990).

Stripping ripeness

The 'stripping ripeness' of a crop was described by Kåhre (1964), i.e. a crop is considered ripe for harvesting when single seed heads can be stripped with a single sweep of the hand from the bottom to the top of the head. This is equivalent to the 'hat test', where a crop is judged to be ripe when seeds drop into a hat swept through the crop (Marr, 1990). This technique is considered especially useful in determining the time to harvest species prone to shattering (Jensen, 1976).

Seed moisture content

Seed moisture content (SMC) is the most reliable parameter for determining harvest timing (Hill and Watkin, 1975b; Klein and Harmond, 1971) provided that first the crop is sampled accurately, and second an accurate method is used to determine seed moisture. Because of differences in seed maturity within a crop, and the tendency to take a few seed heads from the nearest plants rather than a truly representative sample of seed heads from the crop, the SMC of the sample may differ significantly from that of the crop. SMC can be determined accurately by the use of an infrared lamp (Hill and Crosbie, 1966). Portable moisture meters such as those used for cereals cannot be reliably used for forage seed crops, as conductance meters become widely inaccurate at SMC > 20% (M.J. Hill, Palmerston North, 1996, personal communication).

8.1.5 Optimal Harvest Time

The optimal harvest time is that which provides the highest yield of quality seed, but this will depend on the species being grown and the method of harvest. Seed viability is not a factor in determining harvest date, as this reaches a maximum long before seed harvest is even considered. In perennial ryegrasses, for example, maximum viability is reached 14–17 days after anthesis (Hill and Watkin, 1975b; see Chapter 4). However threshing viable seed too early (i.e. when SMC is > 45%) can reduce germination because of physical damage to the seed (Nellist and Rees, 1963).

For forage grasses, the optimum time to begin pre-threshing operations is the point at which the yield of viable seed is maximal (i.e. before seed shattering begins). For perennial ryegrass this is usually at around 42–45% SMC, as seed shattering begins at around 40% SMC. For forage legumes such as white clover which can be managed to produce a single peak of flowering, optimum harvest date is usually from 5 to 6 weeks after peak anthesis (Hopkinson and Clifford, 1993), whereas in a species such as big trefoil (*Lotus uliginosus* Schkr.) where umbels mature over several weeks, the optimum harvest time is when the majority of pods are light-brown (around 30 days after anthesis – Hare and Lucas, 1984).

Recommendations for optimal harvest time vary from species to species and from country to country. A summary of recommendations is presented in Table 8.2 for grasses and Table 8.3 for legumes.

8.1.6 Harvest Methods

The harvesting method is determined by the growth habit of the crop, the climatic conditions, and the availability of machinery for both harvesting and drying.

Legumes

Pre-cutting. The decision to cut crops green is related to herbage moisture, crop bulk and weather pattern stability for drying (Hopkinson and Clifford, 1993). The advantage of additional seed maturation in the swath must be balanced against the likely chance of rain and wind damage in the 7–14 days the crop is on the ground, and the high losses associated with any 'undercutting' requirements (Clifford and McCartin, 1985).

Desiccation using diquat reduces vegetative bulk, but requires precise timing in relation to both crop maturity and stable weather patterns.

Cutting. Mowers are frequently used in all forage legume species (Hopkinson and Clifford, 1993), the main types being: (i) standard sicklebar (17 fingers per metre); (ii) double reciprocating knife (17 knife sections per metre); and (iii) a range of rotary types. In white clover, seed losses were 10%, 5% and 27% for (i)–(iii) respectively (Clifford and McCartin, 1985). Windrowers are used for large fields.

Pickup. Lifters used in association with the combine reel guide the crop over the combine knife and onto the auger platform. Murphy pickups are counter-rotating beaters which ensure centre feed to the auger platform. They are predominantly

Table 8.2. Optimal harvest time in grass seed crops.

Crop	Swathed before threshing	Direct combined
Cocksfoot	Morphological ripeness* – 3,4–3,6[1] Moisture content – 44%[5]; 35–40%[1]	26–30 days after peak anthesis[2] Endosperm consistency – cream cheesy/cheesy[2]
Meadow fescue	Morphological ripeness – 3,5–4,0[3]; 3,0[1] Moisture content – 40–50%[3]; approx. 43%[1]	17–29 days after peak anthesis[4]; 18–26 days after peak anthesis[2] Morphological ripeness – 4,0–4,8[3]; 3,4–3,7[1] Endosperm consistency – cream cheesy/cheesy/hard[2] Moisture content – 25–35%[3]; 27–50%[4]; approximately 35–40%[1]
Red fescue	Morphological ripeness – 4,0–4,5[3]; 4,0[1] Moisture content – 30–45%[3]; 25%[5]; approx. 35%	24–38 days after peak anthesis[4]; about 30 days after first anthesis[6] Morphological ripeness – 4,5–5,0[3] Moisture content – 20–30%[3]; 24–40%[4]; about 35%[6]
Tall fescue	Moisture content – 35–41%[9]	29–30 days after peak anthesis[2] Endosperm consistency – cheesy[2]
Smooth meadowgrass	Morphological ripeness – approx. 3,3[1] Moisture content – 28%[5]; approx. 23%[1]	About 23 days after first anthesis[2] Moisture content – about 35%[6]
Hybrid ryegrass		Moisture content, approx, 40%[8]
Italian ryegrass	Morphological ripeness – 3,0[1] Moisture content – 40–45%[3]; approximately 45%[2]	28–32 days after anthesis[10]; 28–30 days after peak anthesis[2] Morphological ripeness – 3,3–3,4[1] Endosperm consistency – doughy to solid[10]; cheesy[2] Moisture content – 30–40%[3]; approximately 37–40%[1]
Perennial ryegrass	Morphological ripeness – 2,5–3,5[3]; 2,9[1] Moisture content – 40–50%[3]; 40–47%[11]; 35%[5]; min. 37%[1]	Approx. 30 days after first anthesis[6]; 28–30 days after peak anthesis[2]; 23–34 days after peak anthesis[4] Morphological ripeness – 3,0–4,5[3]; 3,0[1] Endosperm consistency – cheesy[2] Moisture content – 25–35%[3]; 25–46%[4]; 20–25% in lodged crop[12]; 30–40% in un-lodged crop[12]; approx. 42%[6]; 40–47%[11]; approx 30%[1]
Timothy	31–35 days after peak anthesis[12] Morphological ripenesss – approx. 3,6[1] Moisture content – 46–47%[11]; approx. 40%[12]; approx 37%[1]	33–38 days after peak anthesis[2] Endosperm consistency – cheesy/hard[2] Moisture content – 23–31%[11]; below 30%[12]

Morphological ripeness (Andersen and Andersen, 1974): completely green inflorescences, 1; not completely green or completely yellow, 3; completely yellow inflorescences, 5.
[1]Steen, 1983; [2]Pegler, 1976; [3]Andersen and Andersen, 1975; [4]Anonymous, 1972; [5]Klein and Harmond, 1971b; [6]Hebblethwaite and Ahmed, 1978; [7]Komatsu *et al.*, 1979, [8]Williams, 1972, [9]Andrade *et al.*, 1994; [10]Komatsu *et al.*, 1971; [11]Hill and Watkin, 1975a; [12]Ellegaard, 1971; [13]Roberts, 1969.

Table 8.3. Optimal harvest time in legume seed crops.

Crop	Swathed before threshing	Direct combined
Red clover	Approximately 6 weeks after peak anthesis[1]	Approximately 6 weeks after peak anthesis, if desiccated[1]
White clover	Approximately 21–26 days after peak anthesis or optimal bee visits in the field[1]. At least 25% brown flowers on average per head[1]	
Lucerne	The crop should be swathed during periods of high humidity or when leaves are wet with dew after two-thirds to three-fourths of the seed pods have changed to dark brown. High proportion of green but fully formed, plump pods[2,3]	A chemical desiccant is usually used when all pods are nearly ripe. Combine within 3–10 days as soon as pods and leaves are 15–20% (wt/wt) moisture to avoid shattering[2,4]
Lotus	Swath when a majority of the pods are yellow-brown to brown. Do not delay until pods are black or swath early when a majority of pods are purple to green[5,6]	

[1]Borggaard *et al.*, 1991; [2]Jones, 1952; [3]Smith and Melton, 1967; [4]Bunnelle *et al.*, 1954; [5]Anderson, 1955; [6]Pieroni and Laverack, 1994.

used in white clover, with minor use in red clover and lucerne (Hopkinson and Clifford, 1993). Drapers are counter-rotating belts with bars and/or fingers attached to ease the crop from the ground to the auger platform. They are best used in bulky crops.

Direct-combining. Normally only desiccated upright crops such as red clover and lucerne are direct-combined.

Grasses

Cutting. For grass seed crops the two basic machines are top-hat rotary mowers and windrowers (Hopkinson and Clifford, 1993). Cutting the crop and laying it in a swath has the following advantages:

1. Seed ripeness is more likely to be uniform.
2. Seed dry down in a swath is relatively rapid.
3. Seed losses from wind are minimal (cf. a standing crop).
4. If required the crop may be lifted or turned to aid drying.
5. Drying costs are lower (cf. direct combining).

A crop such as perennial ryegrass would be cut at 43% SMC and either:

1. Left to dry for 2–3 days in the swath to 25% SMC, then threshed and artificially dried to 14% SMC or
2. Left to dry for 4–6 days in the swath to 14% SMC, then threshed.

For method (1) there is a necessity for artificial seed drying and some risk of seed loss from the swath as a result of inclement weather. Method (2) is the least expensive (no artificial drying) but the most risky, as seed may shatter and losses from environmental damage can be large.

Pickup. Counter-rotating tined belt pickups in a range of designs are used for grass seed crops (Hopkinson and Clifford, 1993). Major attachment concerns are: (i) the angle of incline to the auger platform and (ii) ensuring that there are no gaps where shattered seed can be returned to the field. Counter-rotation speed is adjusted to the combine forward speed to ensure that no windrow 'bunching' or 'stripping' occurs.

Direct-combining. Seed crops may be direct-combined at around 43% SMC, and then artificially dried to a storage moisture content of < 14%. This method minimizes the time a crop is in the field, and is most appropriate when the crop is prone to shattering, bird or insect damage is a problem, or when there is a risk of weathering damage induced by adverse weather. Disadvantages may include the high cost of artificial drying, and potential damage to seed; because the seed is still 'wet', a high drum speed and narrow concave setting need to be used to remove the seed from the seed heads, and this can bruise and/or crush the seed, reducing germination (physical damage) and vigour (physiological damage).

Threshing and separation mechanisms

Usually, large quantities of plant material have to pass through the combine harvester when seed crops are threshed. The moisture content of this material is often high, and in some years the material may be 'stringy'. As the seeds are small and light, heavy demands are made on both the knife and threshing equipment in combine harvesters primarily designed to thresh cereals and/or large seeded legumes, not forage seeds.

The threshing mechanism consists of a slotted concave, against which the plant material is beaten by a rotating barred drum. For forage legumes (e.g. white clover), plates are frequently attached to the concave wires to improve threshing efficiency (Hopkinson and Clifford, 1993). Threshing efficiency is the interrelationship between drum speed and distance from the concave in relation to crop bulk and moisture content. Too harsh a threshing damages seed, both physically and physiologically (Hampton, 1990), leading to lowered germination and vigour. It may also damage adhering structures on seeds of undesirable weeds, thereby reducing the ability to remove them during seed cleaning (Hartley, 1980; see Chapter 9). Incorrect air-blast settings can blow seed out of the combine.

While it is not possible to supply 100% clean seed directly from the combine, correct adjustments will provide a well-threshed raw product which has a high proportion of pure seed and an acceptable seed weight.

8.2 SEED DRYING

8.2.1 Introduction

The moisture content of seed is one of the most important factors affecting seed quality and longevity in storage. For most forage species, a seed moisture content (SMC) of between 8 and 12% is considered 'safe' for storage, and therefore for freshly harvested seed, SMC may have to be reduced from 40 to 45% (e.g. direct combined grasses) or 14 to 20% (desiccated red clover) to the desired storage SMC. Failure to reduce SMC promptly and adequately, or incorrect use of seed dryers, leads rapidly to heat damage which can ultimately result in seed death.

8.2.2 Heat Damage

Field heating in wet seed

When seed is harvested at SMC > 15% it is generally dry on the outside, but has a wetter interior. If this moisture is not removed, the moisture difference begins to 'even out', and the seed lot is referred to as 'going through a sweat' or 'wetting back' (Hill and Johnstone, 1985). At the same time, the humidity of the inter-seed space increases rapidly, creating an ideal environment for heat production (as a byproduct of metabolism) and increased activity of a range of microorganisms already present in or on the seed. The principal agents are *Aspergillus* and *Penicillium* fungi (see Chapter 9), and their activity can raise the temperature of the seed lot to around 55°C (Hill, 1975), at which point germination losses occur. The rate of deterioration in seed quality increases with increasing heat and with increasing time of exposure to high temperatures. A seed lot can be killed in 12–15 h (Hill, 1975).

Field heating in dry seed

Even when seed is not harvested until it is at a 'safe' SMC (e.g. 13–14%), heat damage can still occur. This is because when seed is threshed from the windrow on a hot, sunny day, it will invariably contain radiant heat, so that the seed temperature may be 10–12°C higher than ambient air temperature (Hill and Johnstone, 1985). This effect is greatest on hot, clear days, is reduced by cloud, and ceases at sunset (Hill and Crosbie, 1966).

If 'hot' seed is stored in bags, further heating does not occur because heat loss into the surrounding air occurs reasonably rapidly. However if such seed is stored in bulk, the insulation properties of seed result in heat retention in the mass, and subsequent seed damage through microbial activity (Matthews and Hill, 1967).

Artificial drying

Forage seeds are hygroscopic, meaning they can gain or lose water depending on the amount of moisture in the air around them. They also exhibit varying degrees of heat sensitivity, being more easily damaged by high temperatures and particularly when SMC is high. Drying conditions combining high temperature, high SMC and a fast drying rate are particularly injurious. High temperatures when drying moist seed rapidly remove free surface moisture, and this rapid evaporation removes heat from the seeds fast enough to keep the actual seed temperature depressed. As the SMC drops, however, the supply of moisture for evaporation is less readily available, and actual seed temperature will increase. Under these conditions, seed injury can occur (Hill and Johnstone, 1985).

8.2.3 The Drying Process

Drying occurs when there is moisture movement out of the seed and into the surrounding air. For this to happen, the relative humidity (RH) of the air must be reduced to a level which establishes the movement of moisture from the seed surface into the surrounding air. This evaporation process continues until the SMC and moisture in the air reach a balance. This point of equality is known as the equilibrium moisture content (EMC).

The SMC at EMC will differ for different species. For example, with drying air of 70% RH, the SMC at EMC is 8.2% for lucerne, 11.0% for cocksfoot, 9.3% for birdsfoot trefoil, and 12.8% for perennial ryegrass (Dexter, 1957). Such variations in EMC between species are mainly attributable to differences in composition, a range of forage seed examples being presented in Table 8.4.

Artificial drying is simply a way of accelerating the rate of natural movement (diffusion) of water from the inside of the seed to the surface where it is available for removal by evaporation. Diffusion rate depends on seed size and composition, speed of surface evaporation, temperature, initial moisture level, seed coat permeability and time (Hill, 1982).

Table 8.4. Equilibrium moisture content of seeds of a range of forage grasses and legumes at relative humidities from 15 to 85%. (Adapted from Harrington, 1968; Dexter, 1957; Justice and Bass, 1978.)

	Relative humidity (%)								
	15	30	45	55	65	70	75	80	85
Grasses									
Bromegrass	6.6	9.0	10.5	11.5	12.5	13.1	13.7	16.1	18.4
Browntop	6.2	8.6	9.6	10.0	10.7	11.0	12.5	13.5	15.0
Canary grass	6.6	8.8	9.8	11.4	12.0	12.5	13.5	14.7	15.7
Cocksfoot	6.0	8.0	9.1	9.8	10.5	11.0	12.0	13.4	14.9
Fescue	6.5	8.7	9.4	10.5	11.9	12.5	13.2	15.0	17.3
Ryegrass	6.5	8.6	10.7	11.0	12.1	12.8	13.4	14.9	16.6
Timothy	6.7	8.9	9.9	10.9	11.8	12.5	13.6	14.6	16.1
Legumes									
Lotus	4.8	5.6	6.2	7.1	8.8	9.3	11.7	15.9	18.9
Lucerne	4.5	5.2	6.0	6.5	7.1	8.2	9.3	14.5	18.3
Red clover	4.7	5.7	6.3	7.6	8.6	9.1	11.2	15.6	18.7
Sub. clover	4.3	5.1	6.0	6.9	7.8	8.7	11.0	15.0	17.8
White clover	4.6	5.4	6.5	7.2	8.4	9.0	10.9	15.4	18.0

Table 8.5. Maximum safe drying temperature without germination loss at different levels of seed moisture content. (Adapted from Hill and Crosbie, 1966.)

Seed moisture content (%)	Maximum drying temperature (°C)
> 20	32
18–20	34
14–17	37
11–13	40
9–10	42
< 10	43

Drying temperature

No single temperature can be quoted beyond which it is unsafe to heat seed during drying, because many factors are involved. These include the type of seed, maximum heat tolerance, SMC, duration of temperature rise and drying rate (Hill and Johnstone, 1985). However the drying temperatures provided in Table 8.5 are considered safe for forage seeds (Hill and Crosbie, 1966).

Drying systems

Low temperature dryers. The simplest artificial drying system is one which operates by increasing airflow through the seed bulk by means of a fan. Ambient air is used, and the seed gradually reaches a SMC in equilibrium with the RH of the air. Cool night air is often used, the aim being to cool the seed to within 1–2°C of ambient air temperature reasonably quickly (Crosbie, 1972).

If the air RH is around 70%, then seed can be dried to 'safe' SMC by this method. If air RH is > 70%, raising the air temperature will lower the RH (by approximately 4.5% RH for every 1°C increase in temperature).

Medium temperature dryers. Warmed air is blown through a bed of seed of controlled depth. The drying process stops before equilibrium SMC is reached. A temperature rise of up to 14°C above ambient will produce moisture extraction rates of up to 1% per hour. As each batch of seed dries, a moisture gradient develops from the bottom to the top layer. The heat is switched off and ambient air blown through to reduce the seed temperature and prevent possible subsequent condensation.

High temperature dryers. These subject the seed to a high temperature for a short period of time. The seed loses moisture, but does not come into equilibrium with the air RH which is very low. Wet seed passes through the dryer and emerges dry in 30–60 min. The process is continuous, the amount of moisture removed being determined by the air temperature and the time of exposure of the seed. In a continuous flow dryer with 30 min per pass, perennial ryegrass seed at 15–20% SMC can tolerate a dryer temperature of up to 46°C with no detrimental effects on germination, but an operating temperature of 43°C is recommended (Hill and Johnstone, 1985).

For a discussion of the advantages and disadvantages of various dryer types see Justice and Bass (1978).

It is important to understand the principles of seed drying to ensure a high quality product is obtained. The market acceptability of poorly dried seed is often low, resulting in downpricing due to its appearance and low germination. Such factors as scorching, heat damage, mould activity and cracking can all be important in affecting the quality of dried seed, and particularly the ability of seed to retain germination capacity even under the best storage conditions.

Perhaps surprisingly, seed drying damage is not usually reflected in a loss of germinability in seed lots tested immediately after drying. However, the subsequent and often rapid deterioration of damaged seed is shown in an often substantial loss of viability within a short time, even if seed is stored under supposedly 'ideal' conditions. This is a commonly observed but not generally understood situation; the cause being more commonly focused on the 'inadequacy of the storage system' than on the pre-storage drying history of the seed lot.

There is no doubting the importance of controlled drying systems in affecting seed quality and longevity. However, many seed processing systems do not focus on seed drying as an important seed quality control issue, suggesting it is one of the least understood and least appreciated aspects of seed production.

8.3 SEED PROCESSING

The success in meeting seed lot purity and any size standards for a particular harvested crop relies on a knowledge of the principles of seed separation in terms of size, weight, shape, texture and colour. Of equal importance is processor interpretation of these relationships as they affect the efficient use of the range of commercially available seed-cleaning equipment (Hartley, 1980). Where any contaminant species that share the same separation characteristics as the sown species are liable to occur, their removal prior to sowing the crop (see Chapters 5 and 6) is imperative.

8.3.1 Primary Equipment

Air screen cleaners

The combination of separation principles allowing sample differentiation in terms of weight and general sizing make these machines a basic component of any seed processing operation. Most air screen cleaners have three distinct sample separation operations; a coarse and a fine aspiration separated by screening.

Aspiration. The initial operation is a coarse aspiration or controlled airflow removal of particles based on differences in weight, specific gravity or density; akin to the age-old practice of winnowing. This initial step still remains a quick and inexpensive way of removing dust, small weed seeds and chaff (large unit area per unit of weight) from the sample. The removal of the chaff fraction helps increase screen efficiency. This coarse pre-screening operation does not require the

air-column length of aspiration post-screening. For the latter aspiration, screen sizing has produced a more homogeneous remainder which needs greater column length for a much finer separation based on terminal velocity. Manipulation of the air-column velocity to gain the best separation is initially through fan speed adjustment. Further refinement beyond fan speed is by way of similar adjustment to the fan air intake.

Screens. Arranged between the coarse and fine aspiration columns are reciprocating inclined screens to promote seed-material separation on the basis of width or diameter. The main screen types are square or oblong holes woven in wire and slotted oblong or round holes punched in metal. Due to the roundness of wire this type has a greater ability to set grass seeds on edge for sizing. At the lowest end of the scale the gradient in hole size is very small to cater for fine differences. Sizing can be in metric (mm) or imperial (64ths) units. Graduation increase at the smallest sizings is by 0.1 mm from 0.5 mm upwards or by 0.25 64ths from 1.25 64ths. Air screen cleaner manufacturers present very comprehensive tables relating sown species/weeds to scalping and grading screen size requirements. Because of the wide cultivar variations that can occur, let alone those resulting from the seed production environment, these tables act as very useful guides only. Screens are normally used in pairs, fixed one above the other in cradles or boats. The size of the upper sieve diameter is such that it removes all material of greater width than the sown seed: the process is known as scalping. The lower sieve is chosen to just retain the sown seed on the screen surface with the smaller material falling through: this is called grading. Samples and rejection material are checked early on to ensure the desired separations are occurring. In air-screen cleaners used to produce a final product, a series of two boats is frequently used to ensure fineness of width separation. The depth of sample presented to the top of the screen is no more than that which will reduce to the height/diameter of the sown seed prior to leaving the sieve.

To ensure maximum area use, screens are continually cleaned by balls or brushes. Ball cleaning relies on a reasonable oscillation speed and is more effective on larger holed screens. Brushes work well for small screen sizes. Cleaning the brushes between cultivars and species is very important, to ensure contamination does not occur.

Indented cylinder separator

This piece of equipment may be needed where the sample has to be stratified in terms of length. Should this be the case, the cylinder follows in sequence after the air-screen cleaner. Because indented cylinder throughput is slower than that of the air-screen cleaner, several may have to be run in parallel if forming part of a continuous process.

The major principles involved are the revolving of a cylinder punched with pockets of distinctive shape and size, at a speed which is sufficient to retain the length/s of components until gravity, at a point above the collection trough, more than offsets the applied centrifugal force. At this point the component/s are removed. Depending on their length differential either species or contaminant may be indented. As for screens, indent size may be given either in metric or imperial units.

Examples of weed seed separation from grass seed using indented cylinders are *Avena fatua* L. (wild oats), awned goose grass (*Bromus mollis* L.) and hairgrass (*Vulpia* spp.), field madder (*Sherardia arvensis* L.) and docks (*Rumex* spp.) (Hartley, 1980). Sheep sorrel (*Rumex acetocella* L.), knotted clover (*Trifolium striatum* L.), clustered clover (*T. glomeratum* L.), plantain (*Plantago lanceolata* L.), Scotch thistle (*Cirsium vulgare* (Savi) Ten.), Californian thistle (*C. arvense* (L.) Scop.) and fathen (*Chenopodium album* R. Br.) can be separated from clovers.

Specific gravity table

This machine may be used to give very fine and often final separations as an adjunct to an air-screen cleaner or cylinders.

Separations are mainly by weight and texture differences in the seed sample being stratified as it travels over a vibrating shallowly inclined fabric surface which has an airblast applied to the underside. The relative fineness of fabric mesh size ensures uniformity of air throughput across the whole deck, while ensuring that the sample is retained on the fabric surface. Separations can be further enhanced through deck cloth choice to give the friction coefficient which promotes the greatest separation level. Lightest seed travels the shortest distance with largest separation levels being associated with maximizing the length of the deck used.

For legumes, impurities such as fathen, field madder, chickweed (*Stellaria media* (L.) Vill.), catchfly (*Silene gallica* L.), earth particles and cracked, damaged and broken seed can be removed (Hartley, 1980). Separations of ryegrass and cocksfoot can also be achieved.

Velvet roller mill

Roller or Dodder Mills are another alternative for sample separation based on texture. In this process the seed is fed into the groove created between two gently sloping counter-rotating velvet-covered rollers. The smooth seed gradually moves along this groove to be collected at the far end. In contrast, rough-coated seeds such as dodder (*Cuscuta* spp.), dock, sheep sorrel or even inert material get constrained by the downy surface of the velvet. This constraint lifts them through the sample mass finally to be deposited on the other side of the rollers.

Spiral separators

This technology is very important in separating components which have similar terminal velocities, widths and lengths. In this case shape, as it varies in reaction to centrifical force, is the separation element. For example, white clover is virtually impossible to separate from tetraploid *Lotus uliginosus* either by screens or aspiration. Their only exploitable dissimilarity is shape. Whereas lotus seed is predominantly spherical, that of white clover is flattish to oval and heart shaped. When this mixture is fed into the top of an inclined spiral, friction effects based on contact area will modify the terminal velocity of the two sample components. The greater friction coefficient of the white clover reduces the terminal velocity to contain these seeds close to the spiral axis. In contrast, the lack of seed surface contact due to the roundness of lotus enhances its terminal velocity. Travelling at higher speeds down the spiral creates a greater tangential movement imposed by centrifugal force to allow it to be thrown onto an outer spiral, and exit through a separate spout.

Colour sorters

This technology is expensive and as a consequence used only occasionally within the highest forage seed grade. Further adding to the cost is slowness of operation. Seed is channelled in as a single column for passing over a colour background similar to its own. Any major divergence away from the background colour activates the seed removal mechanism.

8.3.2 Secondary Equipment

Depending on harvest conditions, differences in species/cultivar, physical seed characteristics and end use, additional seed processing options may be needed.

Seed polisher

This machine performs a range of options on grasses and legumes. Seed is fed in at one end of the machine to be abraded by brushes rotating against a woven wire screen, with the seed plus screenings exiting at the opposite end. Intensity of abrasion can often be adjusted by alteration of brush speed, distance between brushes and screen, and throughput rate. For de-awning or de-hulling grass seed this machine is the initial processing step prior to the first aspiration of a pre-cleaner or air-screen separator. Where a species such as cocksfoot needs to be 'shelled' to improve uniformity of spread during aerial oversowing then this process is carried out immediately prior to sowing. For de-awning, brush-type polishers are not suitable for all grasses, as evidenced by the development of a flame-removal technology to de-awn prairie grass (*Bromus willdenowii* Kunth.) in order to stop seed bridging in the drill.

For legumes, polishers can perform two different functions which are carried out near or at the end of the cleaning process. Where a proportion of seed has not been cleanly threshed from its attendant floral parts, this sample is polished prior to a final aspiration. The major use of polishers for legumes, however, is for 'clean-seed' abrasion (scarification) to reduce hard seed and increase germination to a commercially acceptable level.

Dehullers

Some legume seeds such as sainfoin (*Onobrychis viciifolia* Scop.), sulla (*Hedysarum coronarium* L.) and serradella (*Ornithopus sativus* Brot.) are enclosed in a thick husk. At sowing, particularly where moisture limitations for germination occur, husk removal prior to sowing is advantageous. These machines use a much higher level of abrasion than polishers and vary in design. De-hulling is done prior to sowing, or in batches to service the species' seasonal sowing requirement, as long-term, germination levels can be impaired.

An alternative grass seed use in New Zealand has been with grazing brome (*Bromus stamineous* Desv.) cv. Grasslands Gala for seed coat smoothing to aid seed drill-flow characteristics.

8.3.3 Quality Verification

For certified seed, strict procedural requirements are imposed by the Certifying Authority to ensure that seed authenticity is maintained from the harvest field through to the final processed product (Anon., 1994). Field storage containers used for transport to the seed processing plant are field labelled and bulk inward weights of the seed lot taken. Final processed weight is recorded for the allocation of the exact tag numbers for baggings or containers. In New Zealand these figures must contain the kind and class of seed, registered number of the grower who produced the seed and a unique reference number. All certified seed must be labelled and tagged prior to sale.

8.3.4 Seed Treatment

The concepts and technologies of selected seed treatments as reviewed by Taylor and Harman (1990) comprise a very extensive subject. As only a brief discussion will be presented in this section, refer to Taylor and Harman (1990) for further information.

Simplistically, the seed is used as the most efficient vehicle for transport to the sowing site and intimate placement of a range of materials for its own betterment. This added cost of treatment, however, must be balanced by an increase in income. Forage seeds, in contrast to vegetable and flower seeds, have a much lower expectation of return. Therefore, apart from the more specialized amenity grass market, only relatively minor cost increases above that of bare seed can be supported. That forage seed treatment is a viable entity is evidenced in the amount of commercial investment into process and product development. As a consequence there is an exclusivity level through patent rights which, in some cases, detracts from exact knowledge of processing and product technology.

Fungicide and/or insecticide application

Machines originally developed for applying slurry or liquid cereal seed treatment to curtail seed-borne diseases are also used for forage seeds, either to control seed-borne or soil-borne pathogens, or insect pests; for example, captan formulations to protect grass and legume seedlings against damping-off fungi (e.g. *Pythium* spp.), and imidacropyrid and furathioicarb to control grass grub (*Costelytra zealandica* Wh.) larvae and Argentine stem weevil (*Listronotus bonariensis* L. Kuschel) respectively. The technology involved has to ensure a desired dosage of chemical is uniformly spread over a unit weight of seed.

Seed coating

This term as defined by Taylor and Harman (1990) covers a range of processes of which, for forage seeds, 'film coating' and 'pelleting' are the most important. Film coating is the application of material dissolved in a liquid adhesive to the seed surface. Seed weight increase from this process can be up to 10%. In contrast, seed pelleting usually involves the use of a solid inert material and may increase weight–size relationships well beyond that of film coating, depending on requirements. For example, pelleting can be used for seed sizing of highest grade seeds for precision sowing to ensure maximum seed yield per seed number sown. For small seeds such as browntop (*Agrostis capillaris* L.) ballistic capacities to promote a greater uniformity of spread at sowing are considerably improved by pelleting. Even colour has been incorporated in coating materials to promote easy assessment of white clover sowing depth (Hopkinson and Clifford, 1993).

Materials appended to seed cover a broad spectrum. These include fungicides and insecticides for disease and pest control, trace elements and bird repellants. Probably the most important legume seed treatment had been inoculation with *Rhizobium* spp. to promote nitrogen fixation. To be effective the *Rhizobium* spp. must be compatible with the species to be treated. It is also of note that product acceptability and dosage rate of chemicals can vary from species to species.

Priming

Seed priming, matriconditioning or osmoconditioning describe technologies associated with a pre-sowing hydration treatment intended to improve seedling establishment. The aim of this technology is for an earlier more uniform emergence particularly at lower temperatures. These technologies relate mainly to the vegetable industry, and are not generally used for forage seeds.

8.4 SEED STORAGE

8.4.1 Introduction

Once forage seed has been harvested, it must be stored for a short, intermediate or extended period of time. Immediately after harvest, short-term storage may be necessary before seed drying, or between drying and processing. Forage seeds moving in international trade are often stored for various periods of time in warehouses and custom houses before overseas shipments. Seed supply in any one season may exceed demand, and seed lots may be stored for sale in the following season. Small seed lots may be kept in storage for many years as a means of maintaining cultivars or in order to preserve genetic resources. The common objective of all seed storage practices is to maintain the original seed quality, particularly viability and vigour, and to protect it from damage.

Literature on seed storage and various factors affecting seed viability and seed deterioration has been reviewed in general by Barton (1961), Roberts (1972a, 1979), Kozlowski (1972), Heydecker (1973), Doerfler (1976), Justice and Bass (1978), Bass (1979), Bewley and Black (1982) and Priestley (1986). Special reference to the storage of forage seeds has been made in reviews by Gunn (1972) and Bass *et al.* (1988).

8.4.2 Inherent Factors Affecting Seed Viability

Species and cultivar

The ability to maintain seed viability differs among species and cultivars. Justice and Bass (1978) devised a 'Relative Storability Index'. They classified those plant species for which 50% or more of the seeds could be expected to germinate after 1–2 years of storage under favourable ambient conditions (Category 1), after 3–5 years (Category 2) and after 5 or more years (Category 3). Many forage plants were in Category 1. Generally, legumes appear to retain germinability better than grasses (Hanson and Moore, 1959; Rincker, 1983).

Interactions between species and long-term storage conditions with regard to maintaining viability have been reported by Canode (1972b). In short-term storage experiments Luczynska (1980) found tall oat grass (*Arrhenatherum elatius* (L.) Presl.), Kentucky bluegrass and Italian ryegrass to be more sensitive to high RH than red top (*Agrostis alba* L.), timothy and perennial ryegrass.

Cultivar effects that have been observed in other species (Justice and Bass, 1978) have not yet been reported for forage crops, although they are likely to occur, considering the differences in seed volume between diploid and tetraploid cultivars of *Lolium* and *Trifolium* species, for example.

Seed maturity

Maximum longevity can only be expected when seeds are fully mature at harvest. Immature seeds have not only a higher initial SMC, but may also be less developed, lighter and, as a consequence, less viable than mature seeds. Gaspar *et al.* (1981) have shown that lighter weight seeds in a seed lot have lower germination and shorter longevity than heavier seeds.

The weather conditions during the pre-harvest period, such as extremely high temperature, drought or excessive rainfall, can also seriously affect seed quality and storability (Bass *et al.*, 1988).

Seed dormancy and hardseededness

Harvested seeds may remain dormant for a certain period of time. A phenomenon particularly in leguminous species is hardseededness, due to the impermeability of the seed coat. Dormancy of seeds has been treated very extensively by Bewley and Black (1982). Dormancy is greatest when the seed is physiologically ripe. It decreases with ageing at a rate that depends primarily upon the temperature and moisture conditions of the storage facility (Nakamura, 1962; Kendall and Stringer, 1985). In Kentucky bluegrass and many other grasses, dormancy usually vanishes within a few weeks after harvest (Delouche, 1958). Kentucky bluegrass seed grown in Norway, however, expressed significant dormancy even after 10 years' storage under warehouse conditions (Aamlid and Arntzen, 1993).

Hardseededness in relation to seed storage has been reviewed by Justice and Bass (1978). The temperature and RH of seed storage facilities have a pronounced effect on hardseededness of clover species (Kendall and Stringer, 1985). Low temperature and high humidity conditions during storage favour the softening of hard seeds, although the rate of softening differs among species and sources of seed.

Moisture content

The initial SMC of a seed lot at harvest may vary tremendously with maturity, atmospheric moisture, species and cultivar, and contamination with excessive fresh foreign plant material such as leaves, stems and seeds (see Section 8.1). Since

SMC during storage is the most influential factor affecting seed longevity, it is important to harvest mature, relatively dry seed or to reduce the SMC of high-moisture seeds soon after harvest (Justice and Bass, 1978; see Section 8.2). High SMC combined with high temperature causes most seeds to lose viability rapidly (see Section 8.2).

The effects of different initial SMC on germination of timothy and meadow fescue seed after 3 years' storage in a warehouse have been demonstrated by Roberts (1959). In timothy, when the initial SMC was 7.7%, germination decreased from 98 to 73%, but if the initial SMC was 13.5%, germination dropped to 33%. In meadow fescue the germination at 8.9% SMC fell from 96 to 77%, but to 3% at 16.6% initial SMC. As a rule of thumb the storage life of seed is doubled for each 1% decrease in SMC in the range from 5 to 14% (Harrington, 1960). Data for the most appropriate SMC for various kinds of seeds and storage conditions were reported by Nakamura (1975). Roberts (1972b) developed equations to predict the viability of seeds after any storage period under a wide range of conditions including initial seed quality, RH and temperature. These formulae were later revised by Ellis and Roberts (1980).

Endophytes

Seeds of *Festuca*, *Lolium*, *Poa*, *Agrostis* and other grass species may contain fungal endophytes of the genus *Acremonium* (see Chapter 9). These endophytes may cause both beneficial effects to the host plant and detrimental effects to grazing livestock and insect herbivores (Rolston *et al.*, 1993).

The endophytes can be transmitted only by seed. Therefore, from a livestock production point of view, it is usually desirable to establish a pasture with endophyte-free seed. Various procedures have been proposed to reduce viable endophyte in the seed without impairing germination. Seedborne infection can be reduced by treatment of the seed with fungicides or heat (Welty *et al.*, 1987). It has been shown that endophyte viability in perennial ryegrass decreased to zero just by storing the seed in calico bags under ambient warehouse conditions for 12 months, and that the endophyte declined more rapidly than germination (Rolston *et al.*, 1993). Welty *et al.* (1987) found the most rapid decrease of endophyte in tall fescue and perennial ryegrass at SMC between 14 and 24%. The optimum reduction of endophyte with least reduction of germination occurred at 10°C and 19% SMC in tall fescue. In perennial ryegrass, under these conditions, endophyte decreased by 50% while germination was maintained above 95%. Endophyte viability can be maintained for many years when seed is stored at SMC < 10% and temperature < 5°C (Rolston *et al.*, 1993).

8.4.3 Effects of Harvesting and Processing

Mechanical damage during harvesting, handling and processing may influence the viability of seed in storage. Improper adjustment of harvesting or cleaning equipment contributes to such damage (Bass *et al.*, 1988; see Sections 8.1 and 8.3). Damaged seeds do not store as well as intact seeds. According to Moore (1972) small and hidden injuries in seeds may not cause immediate loss in germination, but they can become increasingly critical with ageing of the seed. Scarified seed loses its ability to germinate at a significantly greater rate than unscarified seed (Brett, 1952).

Drying

The SMC of herbage seeds coming off the combine may vary from 13% to more than 40% (Simon, 1993; see Section 8.2). In contrast, seed is considered safe to remain in bulk after threshing only if the SMC is below 12%. As a general rule, seed especially of grasses must be dried soon after harvest in order to reduce the moisture content to the appropriate safe maximum for the species. If freshly harvested grass seed is kept in bulk at ambient temperature without drying, temperature rises sharply resulting in a dramatic decline of germinability (see Section 8.2).

Seed treatment

Fungicide and ultrasonic treatment, and coating and pelleting of seeds may affect longevity. The results of pertinent investigations are at variance depending on the type of treatment, species and environmental conditions. Seeds of lucerne, ladino types of white clover and red clover were not adversely affected when treated with various fungicides after storage for 30 months at 25°C (Kreitlow and Garber, 1946). Hafenrichter *et al.* (1965) reported that treatment with 2% ethyl mercury phosphate reduced the viability of grass seed. Ultrasonic treatment increased the germination percentage and reduced the level of hard seeds in a number of small-seeded forage legumes (Kövics-Tatár and Nagy, 1984).

Seed pellets of white clover and bermudagrass (*Cynodon dactylon* (L.) Pers.) developed with kaolin clay and polyvinyl alcohol retained excellent germination when stored for up to 6 months (Smith and Miller, 1987). The effects of various coating materials and minerals on the germination of seeds of five forage plant species were studied by Lee *et al.* (1987), who found differential responses among formulations and species.

Seed handling

Seed should be handled carefully in order to minimize mechanical damage. Harvesting, cleaning and transportation may injure seed to some extent. The degree of damage depends on how well harvesting, processing and transport equipment was adjusted. The effects of mechanical damage are minimized under favourable storage conditions, i.e. low temperature and RH (Bass *et al.*, 1988).

8.4.4 The Storage Environment

Temperature and RH are the most important environmental factors affecting the viability of seeds during storage. An intricate relationship exists between the RH of the surrounding air and the SMC, resulting after a certain period of time in a moisture equilibrium (see Section 8.2). Both RH and SMC are governed by temperature. Any increase in temperature decreases RH and vice versa. The effects of temperature and air/seed moisture on the viability of seeds have been discussed in detail by Roberts (1972a), Doerfler (1976) and Justice and Bass (1978).

Temperature

The effect of temperature on the viability of seeds has been studied by numerous authors. As a general rule, the longevity of seeds increases as temperature decreases. According to the rule of thumb proposed by Harrington (1960), the lifespan of seeds is halved for each 5°C increase in seed storage temperature within a temperature range from 0 to 50°C. The detrimental effect of increased temperature is more rapid at high RH and SMC. Rincker (1983) reported that 260 seed lots from 26 cultivars of nine forage species retained germinability for 20 years when stored in cotton bags at −15°C and 60% RH. Similar results were obtained by Canode (1972b) and Acikgöz and Knowles (1983) in grass seed, Bass (1978) in crimson clover, Hafenrichter *et al.* (1965) and Hanson and Moore (1959) in a number of forage species, and Nienhuis and Baltjes (1985) in different field crop and grass seeds.

Relative humidity of the atmosphere

The RH of the surrounding atmosphere affects seed quality in two ways (Doerfler, 1976):

1. The ambient RH is directly related to the SMC which has been shown to be the most important factor for the preservation of viability of seeds.
2. Infestation, growth and reproduction of storage moulds and insects increases with increasing RH and SMC.

RH is particularly important when seeds are stored in open or porous containers (Bass *et al.*, 1988; see Section 8.2)

Dexter (1957) and Harrington (1968) published data on equilibrium moisture contents of seeds of grasses and small-seeded legumes at 23/25°C (see Table 8.4). Relative humidity values of 30, 45, 65 and 85% correspond with approximately 8–9, 10–11, 11–12, 16–18% SMC in grass seed, respectively. In comparison with grasses the moisture equilibrium in small-seeded legumes is generally 1–3% less. Although RH is influenced by temperature, a change of temperature has little effect on SMC and RH in practice (Justice and Bass, 1978).

8.4.5 Effects of Pests

Stored seed is endangered by the activity of many harmful organisms. Certain fungi, insects and rodents may cause seed deterioration.

> Saprophytic and parasitic seedborne fungi remain dormant during seed storage unless SMC increases greatly. Storage fungi are principally *Aspergillus* and *Penicillium* spp. (see Chapter 9). They invade and destroy seeds at 4–45°C and 65–100% RH. Their activity is largely determined by the physical condition, vitality and moisture content of the seed and the ambient temperature and RH of the storage area. Under favourable conditions deterioration of seeds can occur in a few days.
> (Kulik, 1978).

Microflora and seed deterioration have been reviewed by Christensen (1972). Mills (1986) described insect, mite and mould characteristics associated with stored grains. Howe (1972) reviewed insects attacking seeds during storage.

8.4.6 Packaging of Seeds

A detailed review of types, material and problems of seed packages has been published by Justice and Bass (1978).

A large variety of packages and packaging materials are available. The type to be used depends on the kind and amount of seed to be stored, the storage time, the storage temperature, the relative humidity of the atmosphere, the geographical area, transportation facilities and transportation distance (local, overseas), and whether the seed is moved from the grower to the processing plant, or destined for wholesale, retail, or for special purposes such as storage for plant breeding programmes, seed testing, plant variety control agencies, or gene banks.

Bulk seed, as it moves from grower to the processing plant (Fig. 8.1), is usually stored in wood or steel pallet boxes (Fig. 8.2). The capacity of these boxes is approximately 500–1500 kg. Subsequent storage may be in such boxes, in holding bins or in sacks. Forage crops and turf grass seed for wholesale is usually marketed in bags of 25 kg capacity (Fig. 8.3). Turf grass seed for retail is often sold in smaller units packaged to appeal to the purchaser.

Packages for processed seed may be bags from burlap, cotton, paper or plastic/foil materials, fibreboard boxes, metal cans, glass jars or containers made of various combinations of materials. Seed stored under cool and dry conditions for a short time will retain good viability in porous fabric or paper containers, but seeds stored under humid tropical conditions will lose viability rapidly without moisture protection. Justice and Bass (1978) differentiate between moisture-proof materials such as metal and glass containers, and moisture-resistant materials such as polyethylene and polyvinyl films, cellophane, pliofilm, aluminium foil, and laminations of many of these and other materials. The construction and source of 18 flexible packaging materials tested for suitability as moisture barrier seed packages is listed by Justice and Bass (1978). These authors summarized the results of

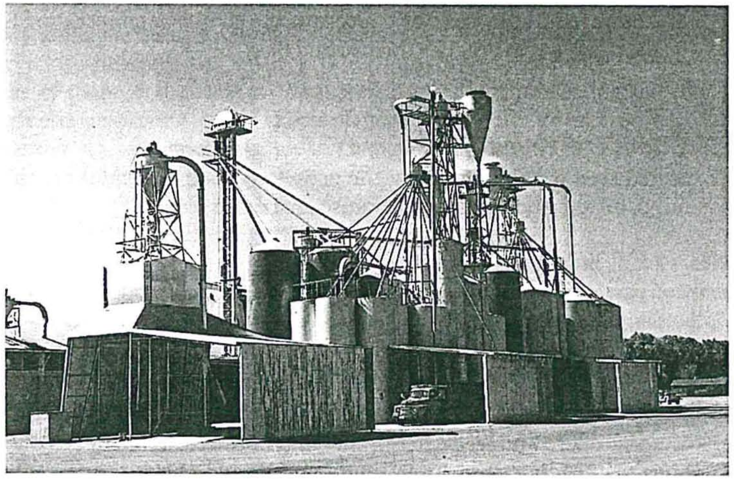

Fig. 8.1. Seed processing plant, USA.

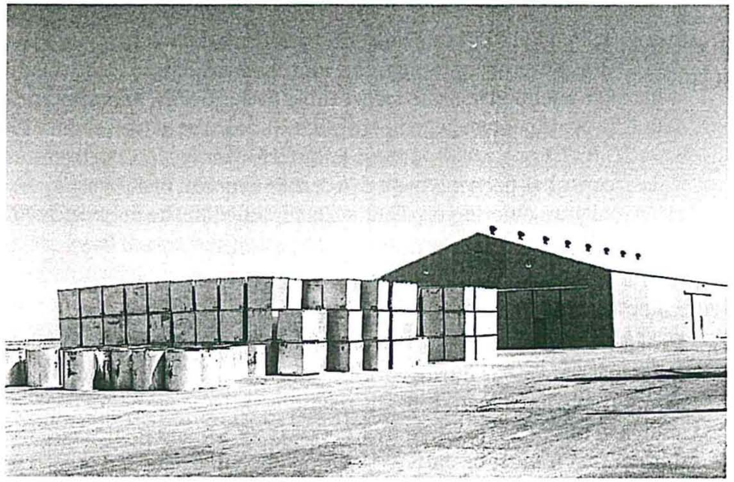

Fig. 8.2. Steel pallet boxes used for storage of forage seeds after processing.

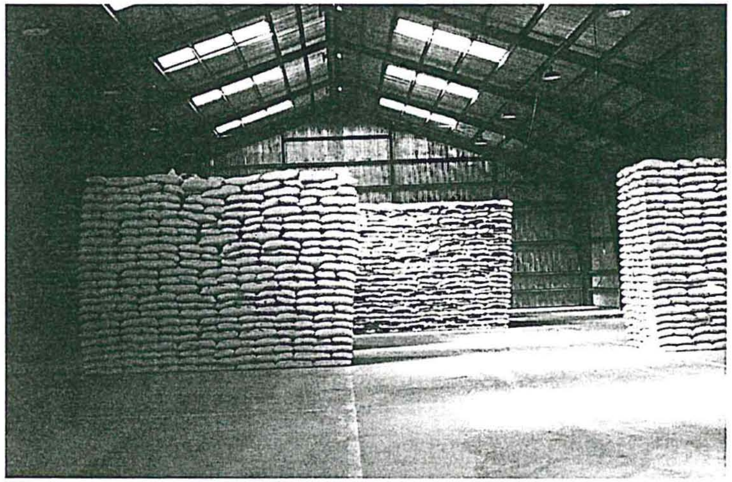

Fig. 8.3. Processed seed stored in 25-kg multiwall paper bags.

experiments with grass and forage legume seeds under porous and moisture barrier conditions at different levels of temperature, SMC and RH. It can be concluded from this and other information (Bean *et al.*, 1984; Bekendam and van Pijlen, 1987) that simply sealing seeds in moisture-proof containers does not necessarily guarantee safe long-term storage: 'Adequate drying before sealing is absolutely essential for safe storage of seeds in airtight moisture-proof containers' (Justice and Bass, 1978). In general, a maximum of 6% is considered to be safe for the long-term storage of seed in airtight containers although for both grasses and forage legumes, up to 10% SMC is safe. Under optimal conditions seed can retain germinability for a very long time. Evidence is provided by the report by Aufhammer and Simon (1957) on barley and oats seeds which had lain in the foundation stone of the Nuremberg city theatre and retained germinability for 123 years. The seeds were enclosed in sealed glass tubes at 7.3% SMC in barley and 8.0% SMC in oats. The average storage temperature was calculated by Roberts (1972b) to have been 10.6°C. For special-purpose long-term storage in sealed containers, the use of desiccants has been advocated; a certain amount of a drying agent like calcium oxide, calcium chloride or silica gel is included in the container. For adequately dried seeds a desiccant may not be necessary (Justice and Bass, 1978).

8.4.7 Field Performance of Stored Seed

A loss of seed vigour during storage may result in a reduction in the yield of the plants grown from such seed. The relationship between age or deterioration of seed and yield has been reviewed by Roberts (1972a) and Justice and Bass (1978). In this context it must be emphasized that chronological age of seed within certain limits is not usually correlated with viability or vigour. Deterioration of seed may affect the yield of the crop derived from it in two ways: the crop may be reduced due to a decreased plant population, and a reduced vigour of the seedlings may result in weaker plants.

Several investigations have shown that normal forage crop yields have been obtained from seed that has been stored for a prolonged period of time, provided that the initial germination and vigour of the seeds and the storage conditions were good. Plants of perennial ryegrass derived from seed lots stored for 20 years did not differ in growth habit from plants derived from 1-year-old seed (Griffiths and Pegler, 1964). However, the seed setting capacity of the plants from old seeds was markedly reduced. Rincker (1981) reported the results of experiments with lucerne, red clover, alsike clover and birdsfoot trefoil grown from 14- to 18-year-old seed stored at −15°C and 60% RH. He concluded that forage yields would not be affected by long-term subfreezing of seed if the seed had maintained good germinability during storage.

8.5 POSTHARVEST SEED CROP MANAGEMENT

8.5.1 Introduction

Many perennial forage grass and legume seed crops are harvested more than once in their lifetime. To ensure continued seed production, appropriate management of the newly harvested crop is important. Following seed harvest in late summer, preparations must begin immediately to remove crop residue and then stimulate new vegetative growth before the winter.

In perennial grasses, particularly those that require vernalization, reproductive tillers for the next season's harvest are produced in the autumn and early winter (see Chapter 2) and accumulated straw, debris or stubble from the previous harvest can seriously impair new tiller development, thereby lowering seed yields. With many perennial legumes, the stand density may increase, because of volunteer plants growing from fallen seed and regrowth of old plants, to a level where too much interplant/interstem competition will reduce seed yields (Hare, 1992). Cultural practices aimed at reducing crop density may be required in the postharvest period (Hare, 1992).

In grasses, shading can seriously reduce new tiller development. In timothy (*Phleum pratense* L.) and cocksfoot, tillers may either fail to initiate, or fail to become reproductive (Ryle 1961, 1966). Ryle (1967) similarly reported that shading inhibited tiller production in meadow fescue and perennial ryegrass. Langer (1972) showed that perennial ryegrass tiller numbers per plant declined continuously as natural light was reduced from 100 to 5%, but once shade was removed they resumed tillering at the same rate as plants that were not shaded. However, in tall fescue Hare and de Ruiter (1993) found that plants that had been shaded, tillered eight times more than the unshaded plant rate once shading was removed. Also, if sunlight penetrates to the plant base after harvest, more tillers emerge before the autumn (Ensign *et al.*, 1983). Where animals form an important part of the farming system, quick regrowth of plants after harvest is necessary for autumn forage production (Hare, 1993).

Removal of harvest stubble and straw also helps to control pests and diseases which can seriously reduce seed yield in grasses such as perennial ryegrass, Kentucky bluegrass and creeping red fescue (*F. rubra* L.) (Chilcote *et al.*, 1980) and in legumes such as lucerne (Pedersen *et al.*, 1972). Some methods of postharvest management also control weeds (Mueller-Warrant *et al.*, 1994a) and prevent thatch build-up (Chilcote *et al.*, 1980).

8.5.2 Postharvest Management Practices

Burning

Burning of grass seed crop residues began nearly 40 years ago in the USA (Hardison, 1976) for the control of the fungus *Gloeotinia granigena* (Quelet) Schumacher which causes blind seed disease in perennial ryegrass. Burning then became a common practice in many grass seed crops to dispose of residue, control diseases and weeds and, in particular, to enhance seed yields (Youngberg, 1980). In the USA open-field burning of perennial ryegrass seed crop residues nearly always produces better seed yields than non-burn methods (Chilcote, 1969; Canode and Law, 1975, 1979; Chilcote *et al.*, 1980; Ensign *et al.*, 1983; Hickey and Ensign, 1983; Young *et al.*, 1984a).

A more open canopy after postharvest burning allows more vigorous tillering in perennial grasses, and better flower induction and higher panicle production in the spring (Chilcote *et al.*, 1980). In the USA, burning stubble and straw as soon as possible after harvest increased tall fescue seed yields by more than 20% compared with baling and removing the straw (Youngberg, 1980). However, by contrast in New Zealand, burning tall fescue straw and stubble immediately after harvest produced similar seed yields to cutting or grazing (Hare, 1993). These contrasting results may be explained by the different climates. In Oregon, where most of the published work on burning has been carried out, the dry summer results in little growth of perennial grasses after harvest. The grasses are almost dormant (Youngberg, 1980). It is not until the autumn rains that tillering commences in Oregon, whereas in the North Island of New Zealand, the moist summer and autumn enables tillering to commence immediately after harvest.

In creeping red fescue seed crops in New Zealand, Hare *et al.* (1990) found that burning produced similar seed yields to cutting. In the USA, however, autumn tillering in burned plots of creeping red fescue began earlier and at a greater rate than tillering in unburned plots (Chilcote *et al.*, 1980). The tillers on burned plots were exposed to a longer period of low-temperature induction, resulting in more reproductive tillers. Furthermore, tillers on burned plots received more light during the winter because of reduced canopy cover, and thus were more receptive to vernalization. Subsequently, they initiated spikelets and florets earlier which lead to a longer period of differentiation. This generally results in a larger number of florets per spikelet, more spikelets per tiller and more seeds per tiller, although the response has not been consistent in all trials involving burning (Chilcote *et al.*, 1980; Young *et al.*, 1984a, b; Hare *et al.*, 1990).

It seems that burning of perennial grasses is an advantage over other postharvest practices in places with a dry summer and autumn, but not in places which have a moist summer and autumn. If burning is practised it must be completed as soon as possible after harvest and before autumn regrowth commences. Late burning has resulted in seed yields being reduced by 12–35% compared with mid-summer burning (Youngberg, 1980). Similarly, autumn burning of creeping red fescue seed fields in New Zealand has lowered seed yields by 14% in one cultivar and 66% in another (Hare *et al.*, 1990).

Burning of legume seed crop residues has not been well documented. Generally, legumes will not tolerate as much burning as grasses, and so burning should be quick. Large windrows which burn slowly will cause excessive plant death.

Burning will control some diseases and pests in the fields. Stubble and weeds should be removed and burned from around seed crop edges, as these are potential sites for overwintering pests such as aphids.

Field burning as a practice in many seed production areas in the USA and Europe is being phased out gradually for environmental reasons, i.e. concerns over air pollution, public safety and human health from smoke inhalation (Mueller-Warrant *et al.*, 1994a). In addition, many areas that have very dry summers and autumns have very strict laws for fear of fires getting out of control. Permits to burn must be obtained from local councils and wide firebreaks must be ploughed around the fields to be burned. In some areas the fire risk may be so high as to impose a total ban on open fire burning for several weeks. For these reasons, systems of removing crop residues by mechanical means or by grazing animals, combined with herbicides to control weeds, have been developed.

Cutting

Cutting grass seed crop stubbles to approximately 25 mm can give seed yields nearly equal to those obtained following burning (Chilcote *et al.*, 1980; Young *et al.*, 1984a; Coats *et al.*, 1990). However, some species respond better to cutting than others species (Table 8.6).

In creeping red fescue fields, close-clipping (early or late) maintained seed yields (Table 8.6), but more volunteer seedlings established which could cause rejection of fields from certification (Young *et al.*, 1984a). In Kentucky bluegrass fields, close-clipping also gave yields equal to burning, but in perennial ryegrass, burning was the only treatment capable of maintaining seed yield over several years. In these trials (Table 8.6), cutting resulted in increased weed seed content in the grass seed crops compared with burning (Young *et al.*, 1984b).

In the North Island of New Zealand, where regrowth commences within days of harvest, cutting creeping red fescue stubble to 10 mm after harvest and removing the straw, and cutting tall fescue stubble to 100 mm after harvest and removing the straw, produced seed yields similar to burning the stubble (Hare *et al.*, 1990; Hare, 1993). In contrast, cutting creeping red fescue seed fields to 10 mm in early autumn significantly reduced seed yield (Hare *et al.*, 1990), but cutting tall fescue seed fields three times in the autumn to 100 mm and leaving the cut forage to decompose on the field did not affect seed yield (Hare, 1993).

No published research comparing cutting and burning has been conducted on legume seed crops. Good quality hay can be made from legume seed-crop straw if it is baled immediately after combine harvesting, when the vegetation is still green and before too much leaf has been lost. Very stemmy vegetation can still be baled, as it is useful as bedding for animals or as compost and mulch. Some stemmy hay may not be palatable to sheep and dairy cows, but may be ideal for goats and deer. The residue from seed crops that have been chemically desiccated usually cannot be used for hay following the seed harvest.

Where livestock are an important part of the farming system, crop residues can be conserved as hay or straw or grazed 'in situ'. Even if baling or grazing crop residues does not give a seed yield equal to burning, the increased animal output and performance, combined with a lower seed yield, may still give a better economic farm return than a higher seed yield and lower animal performance.

Table 8.6. Effect of differing postharvest management on seed yield of three perennial grass species. (Adapted from Young *et al.*, 1984a.)

	Seed yield (kg ha^{-1})		
Postharvest	Perennial ryegrass[1]	Smooth meadowgrass[2]	Red fescue[3]
Close-clip[4]	579	828	298
Burn[5]	713	798	305
Flail-chop[6]	588	692	261
Late close-clip[7]	595	806	328
Late flail-chop[7]	603	709	278
LSD ($P < 0.05$)	56	51	44

[1]Mean yield 1979–1982.
[2]Mean yield 1980–1982.
[3]Mean yield 1980–1982.
[4]Cut to 25 mm and straw removed.
[5]Mobile field-sanitizing machine.
[6]Cut to 75 mm and straw removed.
[7]After autumn regrowth.

Grazing

There has been very little work on the effectiveness of immediate postharvest grazing compared with burning or cutting. Hare (1993) found that using sheep (1000 ha^{-1}) to graze tall fescue stubble to near ground level (30–50 mm) after harvest produced seed yields similar to burning or cutting. Hare *et al.* (1990) also found that immediate postharvest grazing was just as effective as cutting or burning in creeping red fescue seed crops. In contrast, Coats *et al.* (1990) found that ungrazed stubble areas of Kentucky bluegrass outyielded grazed stubble areas. These authors did comment though that farmers generally found grazing to be better than not grazing. However, proper precautions should be taken with grasses infected with the endophyte fungi (*Acremonium* spp.) because of their association with animal health problems that include staggers and heat stress, resulting in low animal growth rates (see Chapter 5; Hoveland *et al.*, 1983).

Legume seed crop stubbles often contain high quality residues which provide good livestock feed. However, grazing livestock should be closely monitored in legumes such as lucerne because of the anti-quality factors associated with ruminant bloat (see Howarth, 1988). On the positive side, grazing lucerne stands after seed harvest can remove a high portion of overwintering aphids (*Acrythosiphon* spp.) (Penman *et al.*, 1979) and reduce the number of sitona weevil adults (*Sitona* spp.) laying eggs (Trought, 1981).

Cultivation

With age, grass seed crops can become overpopulated with tillers and an excessive tiller population can lead to a drop in seed yield, as intertiller competition reduces seed yield per tiller. With legumes, seed yields can decrease due to interplant and interstem competition.

Edes (1968) stated that after seed harvest, severe harrowing or gapping of tall fescue effectively reduced the density of the stand. Bean (1978) also considered that tall fescue appears to benefit from gapping in second and subsequent harvest years. Some grass crops drilled in rows less than 60 cm apart have benefited more from gapping than crops planted in wider rows. Cocksfoot seed yields, for example, have been increased 33% when 30 cm of grass was removed every 30 cm of drill row, in crops originally drilled in rows 30 or 60 cm apart (Lambert, 1963). However, when cocksfoot was grown in 91-cm rows, removing 30 cm of grass from the row reduced seed yield by 29% (Canode, 1972a).

Gapping does not benefit all grass species. Large 'clump-like' grasses such as tall fescue and cocksfoot appear to derive some benefit from it in their second and subsequent harvest years, but seed yields of timothy and meadow fescue have been reduced by gapping (Lambert, 1964). Gapping has increased seed yield of Kentucky bluegrass at low rates of nitrogen but decreased it at high nitrogen rates (Evans and Canode, 1971).

Gapping is usually done by rotary cultivators. However, herbicide spraying can also be used. Some tall fescue seed crops in New Zealand have been sown in 15-cm rows and once established have been hand sprayed with glyphosate at right angles (spray 10 cm, leave 15 cm), with no loss of seed yield (Hare *et al.*, 1990).

In legume seed crops, inter-row cultivation or gapping has improved seed yields of white clover, lucerne and big trefoil (Table 8.7). Timing of inter-row cultivation is important. Hare (1992) found that the most successful method was to inter-row cultivate in both spring and early summer (Table 8.7). If cultivation was only done once in mid-winter, the rows usually closed up again with the vigorous spring growth of stolons or rhizomes. Hare (1992) did find that both inter- and cross-row cultivation of the same field reduced seed yields 33% below that of uncultivated fields.

Table 8.7. The effect of inter-row or gapping cultivation on seed yields (kg ha^{-1}) of white clover, lucerne and big trefoil.

Crop	Inter-row or gapping	Cultivation method	
		Cultivated	Non-cultivated
White clover cv. Kent[1]	8 cm cultivated and 30 cm of plant left Cut both ways	338	275
White clover cv. Nesta[1]	8 cm cultivated and 30 cm of plant left Cut one way	339	316
Lucerne[2]	60 cm rows. Every 75 cm of row left, 45 cm of row removed	1271	1166
Lucerne[2]	91 cm rows. Every 15 cm of row left, 30 cm of row removed	1305	1166
Big trefoil cv. Grasslands Maku[3]	45 cm rows. 47 cm strips cultivated across rows, 13 cm of plant left	177	64

Adapted from [1]Lewis *et al.*, 1984; [2]Jones and Pomeroy, 1962; [3]Hare, 1992.

In lucerne inter-row cultivation or thinning has produced seed crops that are shorter, lodge less, are less susceptible to frost injury, flower earlier, have more upright growth allowing bees greater access to flowers, and have increased nectar secretion and concentration resulting in better pollination (Pedersen *et al.*, 1959; Pedersen and Nye, 1962; Pedersen *et al.*, 1972). Thinned plants of lucerne also have higher root carbohydrate reserves and produce more seed, more pods per stem and seeds per pod than non-thinned plants which have less carbohydrate (Dobrenz and Massengale, 1966).

Using herbicides in strips across a field or using an inter-row precision sprayer (de Lacey, 1986) will reduce white clover density and remove volunteer plants. Band spraying white clover seed crops in Wales has given a mixed response. Creosote and glyphosate sprayed in strips increased flower production by 70% (Lewis *et al.*, 1993) but further work with ethofumesate and TDA with dicamba, and MCPA and mecoprop, decreased seed yield (Marshall and James, 1986). Herbicides used in strip spraying must be chosen with care, as any systemic herbicide will lower seed yields in the unsprayed strip unless a cutting disc is used at spraying (de Lacey, 1986).

Herbicides

Herbicides sprayed in strips to reduce crop density have been discussed in the previous section. In this section the application of herbicides where open field burning is not practised will be discussed. Preliminary efforts in the USA to control weeds without field burning met with disappointing results (Mueller-Warrant *et al.*, 1994a). Some of the agressive chemicals, such as atrazine, often destroyed stands or reduced yields, while gentler treatments failed to control volunteer crop seedlings and weeds. In New Zealand though, broadcast spraying of atrazine (2.0 kg a.i. ha^{-1}) in mid winter increased seed yields of big trefoil 119% above non-sprayed treatments (Hare, 1992) and in tall fescue an atrazine rate of 3 kg a.i. ha^{-1} in the autumn initially reduced tiller numbers, but subsequently had no effect on seed yield (Hare, 1993). In the USA, simazine (0.5 kg a.i. ha^{-1}) has been used to reduce stand density of mature lucerne seed crops (Peters and Peters, 1972).

However, in recent years, countries with strict herbicide registration requirements have withdrawn many herbicides, such as atrazine, simazine and chlorprophan, from use on forage seed crops (Mueller-Warrant *et al.*, 1994a). Recent studies (Mueller-Warrant *et al.*, 1994a) have shown that in perennial ryegrass seed crops where stubble was cut after seed harvest, an application of metochlor before weeds or seedlings emerged, followed by oxyfluorfen postemergence, gave the best weed control. When both weed control and seed yield were considered in non-burned treatments, while pendimenthalin was the best pre-emergence herbicide, it still required applications of postemergence herbicides, such as diuron or oxyfluorfen, to reduce competition from volunteer perennial ryegrass seedlings and maintain seed yields (Mueller-Warrant *et al.*, 1994a). If appropriate herbicide combinations are used, the seed yield and seed quality of perennial ryegrass from non-burned residue systems are usually similar to those from burned systems in first-year stands, and can be slightly greater in second-year stands (Mueller-Warrant *et al.*, 1994b).

Nevertheless, the effect of herbicides varies greatly from site to site, depending on species, crop age, soil type, weeds present and rainfall. For example, many of the herbicides used by Mueller-Warrant *et al.* (1994 a,b) have not proven very effective in controlling seedling perennial ryegrass in second-year stands in New Zealand (R. Maxwell, Palmerston North, 1996, personal communication). Herbicides are discussed in further detail in Chapters 5 and 6.

Irrigation

In areas which have very dry summers, irrigation applied after crop residues have been removed is often an advantage. Irrigation will help to maintain plant vigour, rot away any debris left and germinate fallen seeds which can then be eradicated by inter-row cultivations or herbicide application. Irrigation enables seed crops to regrow quickly and provide autumn grazing where livestock are a part of the farming system.

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