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Analysis of wheat–sheep farming in southern Australia

16.1 INTRODUCTION

In southern Australia most wheat is grown on farms that also produce sheep for wool and for meat (prime lambs). Successful farming began in this region in the 1800s with wheat grown in an alternating sequence with bare fallow while sheep grazed on separate grass pastures. The legume content of those pastures was low because the soils were deficient in phosphorus and often in molybdenum also. Under that early system, yields of wheat, originally near 1 t ha^{-1}, had fallen to around 0.5 t ha^{-1} by 1900 owing to the loss of soil N and the build-up of soil-borne diseases. Carrying capacity of those pastures was around 2 sheep ha^{-1}, relatively low for the rainfall.

The advantages of introducing legumes into pasture and growing them in sequences (rotations) with cereal crops to increase the productivity of both crop and pasture was recognized by the 1930s. Suitable pasture legumes had been available since the turn of the century but it was not until the 1950s, when wool prices increased, that the widespread use of phosphorus fertilizer became profitable.

The present legume–wheat system continues to evolve in response to changing ecological and economic conditions. A traditional cropping sequence was two to four crops of wheat following several years of leguminous pasture. In recent years, developing markets and acceptable prices for grain legumes (pea, lupin, faba bean) and rapeseed have made it possible to include them in more complex pasture–crop rotations. However, it is rarely possible to replace pasture completely with grain legumes because much of the nitrogen they fix is removed by harvest and also because few soils of the region will tolerate continuous cropping without unacceptable loss of structure, even with minimum tillage. Other benefits to be had from diversification of activities include reduction of risk and more efficient utilization of labor (Chapter 15).

The wheat–sheep system occupies about 50 Mha (Fig. 16.1) in a semiarid region where variable, winter–spring rainfall supports variable plant growth, and where summer is a season of high temperature and predictably low rainfall (Puckridge & French 1983). It has a 'Mediterranean' climate; the dominant agricultural plants were introduced from that zone of ancient agriculture. This Australian farming environment has close parallels in the Mediterranean region (Middle East, North Africa, Spain and Portugal), in California and Oregon, and parts of South America (Chile and Argentina).

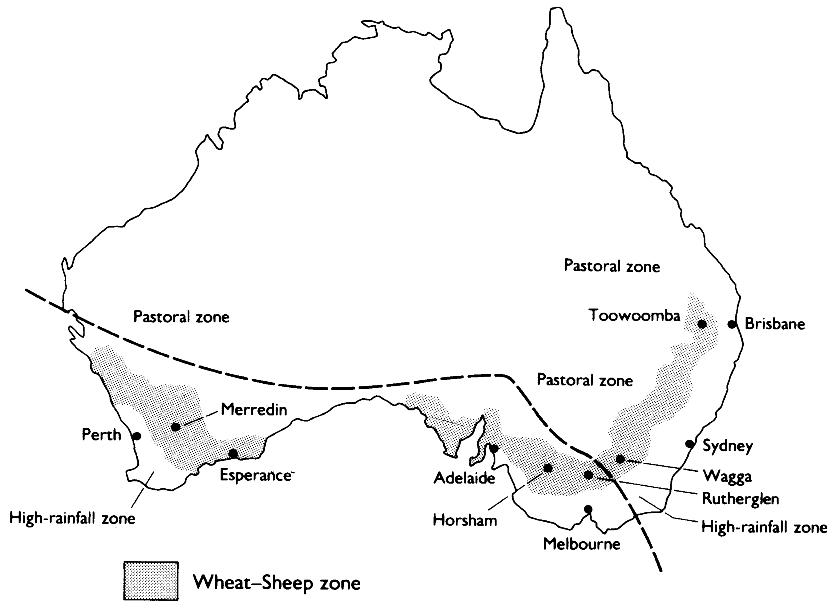

Fig. 16.1. The location of the wheat-sheep zone in southern Australia in relation to annual rainfall. The zone of winter-dominant rainfall is to the south of the dotted line (after Puckridge & French (1983).)

While crop and pasture compete for land, management, and investment, their combination here is mutually beneficial to profitability. Crop productivity is limited by the low and variable rainfall and by the infertility of the soils. Legumes provide a major benefit to the rotation through nitrogen fixation. Other benefits from the rotation include a break for pests, diseases, and weeds that build up during the crop cycle. The wheat crop provides similar benefits for the pastures as well as opportunities for their periodic renewal. In ecological terms, the crop sequence exploits the fertility that has accumulated under the pasture.

The optimum balance between wheat and sheep depends on the complementary production gains from pasture and crop, and on the relative prices for the two commodities which, like the weather, change unpredictably. For this reason, farmers do not follow fixed rotations. Rather, the proportions of crops and pasture are varied tactically according to changing prices of limiting resources such as land, labor, capital, and nitrogen fertilizer to maximize long-term profitability and other objectives.

Management of the system follows the critical principle of concentration of limiting resources of water and nitrogen to maximize plant productivity. The sequence of leguminous pasture accumulates soil organic and mineral nitrogen to a concentration that increases the yield and profitability of subsequent wheat crops. Summer fallows retain rainfall while organic nitrogen mineralizes for autumn-sown wheat, further concentrating the yearly supply of moisture and nitrogen for plant growth during later parts of the year. Crop and pasture species adapted to grow in winter-spring use that water at a time when ET* is low and water-use efficiency is high (Chapter 13).

This chapter outlines the management and performance of a representative farm in northeast Victoria. The analysis starts with the climate, moves to the objectives of the farmer, and then provides an ecological explanation of how the system operates, how it responds to management, and how it might be modified. The principles are appropriate to the wheat–sheep zone generally, although the detail varies across it. But first, a brief explanation of how the wheat–sheep system relates to adjacent agricultural zones.

16.2 RELATIONSHIP TO ADJACENT AREAS

The wheat–sheep zone produces mostly for overseas markets but has economic relationships with adjacent agricultural zones. There is an extensive pastoral zone in the drier regions towards the interior of the continent (Fig. 16.1) that concentrates on fine-wool, 'Merino' sheep. Parts of the drier interior and the drier margins of the wheat–sheep zone produce first-cross ewes (typically Merino × 'Border Leicester') that are used in the higher rainfall parts of the wheat–sheep zone, where they are bred to sires such as 'Southdown' or 'Poll Dorset' to produce prime lambs. The interior zone also provides the Merino wethers (castrated males) that are grazed instead of ewes in the drier extremes of the wheat–sheep zone, and in combination with ewes in wetter parts. Such mixed flocks are able to cope better than ewe flocks with variable feed supply. There is also exchange of feed supplies between zones, in particular hay from the coastal zone for grain from the wheat–sheep zone. In addition, flocks can be transferred from dry areas to pastures rented from farmers ('agistment') in higher-rainfall areas.

16.3 SOILS

Soils of the Australian wheat–sheep zone range from heavy clays to deep sands, but the most extensive, the Red Duplex Soils (Northcote *et al.* 1975), also known as Red Brown Earths (Stace *et al.* 1968), are also the dominant profile type in northeast Victoria. They have a shallow, acidic, loam surface (pH = 4.5 to 5.0) overlying massive clay beginning at about 15–20 cm depth. The subsoil restricts the penetration of water and roots and the surface soil is vulnerable to sealing when it becomes low in organic matter following repeated cropping or loses structure owing to excessive tillage.

16.4 CLIMATE

Sufficient rainfall for plant growth becomes available each year in autumn and ceases in spring (Fig. 16.2). A simple climatological analysis of mean monthly climatic data identifies the months during which rainfall exceeds one-third of potential evapotranspiration (i.e. when $P > ET^*/3$) as those with **effective rainfall** (Trumble 1939). Across the wheat–sheep zone, the months of effective rainfall, are

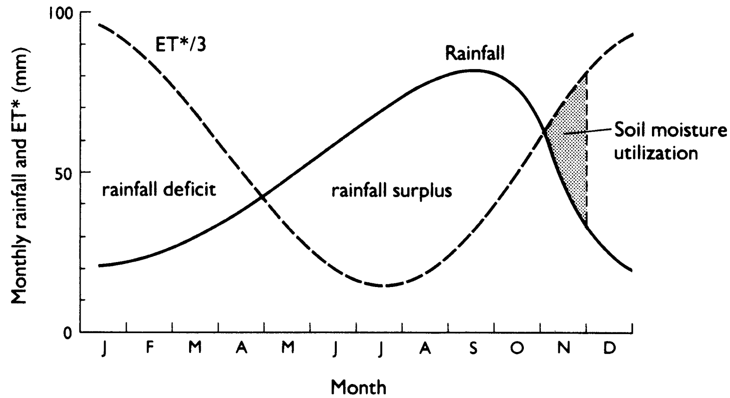

Fig. 16.2 Seasonal relationship of rainfall and potential evapotranspiration (ET*) in the wheat–sheep zone of southern Australia.

generally consecutive and range, with average annual rainfall, from about four to nine but with considerable variation from year to year. The timing of the first heavy rains ('autumn break') and the end of effective rains in the spring (the 'finish') can each vary by up to 2 months, leading to great year-to-year variation in length of growing season and hence in plant productivity.

The climatic conditions relevant to our farm are those for Rutherglen, summarized in Table 16.1. Even though average summer rainfall is not much less than that of winter, its effectiveness for plant growth is negated by the great summer evaporation. The mean period of effective rainfall ($P > ET^*/3$) is 7 months, from April to October. Plant production is restricted by low temperature in June and July.

Low temperatures during winter depress but do not prevent plant growth. Stock are able to graze throughout the year but usually require supplementary feeding with hay during periods of low pasture availability in winter (hay for roughage value) and with grain (for greater energy and nitrogen for digestibility) in summer–autumn as the dry pastures deteriorate.

16.5 FARMING OPERATIONS

Our farm comprises 700 ha of gently undulating land (maximum slope 5%) of which 500 are well drained and arable and 50 are unused or devoted to road reserves, woodlots, stockyards, and buildings. The farm is subdivided into paddocks (fenced fields), mostly according to topography and soil type, ranging in area from 20 to 50 ha. Water is piped to troughs in each paddock, supplied by dams distributed around the property to collect runoff.

The arable land is sown to wheat, oat, and lupin in rotation with pasture containing subterranean clover and annual ryegrass. On average across the farm, the pasture and cropping phases both last around 5 y, and at present there are equal areas (250 ha) of both activities on the arable land. Of the 250 ha crop, there are currently 150 ha wheat and 50 ha each of oat and lupin.

Table 16.1 *Monthly mean climatic data for Rutherglen, Victoria*

Month	Rainfall (mm)	ET* (mm)	Max. temp (°C)	Min. temp (°C)
Jan.	37	265	31.0	14.3
Feb.	37	223	31.0	14.2
March	41	182	27.7	11.5
April	45[1]	99	22.8	8.1
May	52[1]	51	17.7	4.9
June	58[1]	34	13.5	3.2
July	60[1]	29	13.1	3.1
Aug.	62[1]	51	14.7	3.6
Sept.	53[1]	76	18.3	5.2
Oct.	58[1]	127	22.3	7.3
Nov.	42	173	27.4	9.7
Dec.	43	259	30.8	12.7
Total	588	1569		

Note:
[1] Months of effective rainfall (mean rainfall > ET*/3).

The remaining 150 ha are unsuitable for cropping because of shallow soil on the higher ground or, in the case of lower areas, susceptibility to waterlogging in winter. That land carries permanent pasture improved by broadcasting subterranean clover seed and by biennial application of phosphate fertilizer. Two perennial grasses, phalaris (*Phalaris aquatica*) and cocksfoot (*Dactylis glomerata*), were also introduced by sod-seeding into suitable areas. These grasses are important components of improved pastures in higher-rainfall areas of southern Australia. In the Rutherglen area, they produce valuable green feed in the wetter summers and yet are sufficiently drought-resistant to survive the drier ones. Productivity of the permanent pasture on shallow soil is restricted because it dries out early in spring owing to its low water-holding capacity. By contrast, the pastures of the lower areas are usually more productive because the soils are deeper and retain the additional moisture needed to sustain growth longer into the spring. However, growth is restricted there in winter by waterlogging in wet years.

Sheep are the only grazing animals. The flock comprises 750 wethers, 1000 ewes and 30 rams giving an average stocking rate of 6.9 DSE ha^{-1}. The DSE, dry sheep equivalent, is a unit of stocking. An adult wether is 1 DSE; a value of 2 DSE for each ewe covers lambs, rams and non-breeding ewes. On this farm, all replacement ewes, wethers and rams are purchased off the farm.

The workforce comprises an owner–operator and one permanent employee supplemented by contract labor for specialized tasks such as shearing and fencing, and for periods of peak demand during fodder conservation and harvesting.

The present (1990) value of the land, equipment and stock is around A$1 400 000. Income varies unpredictably from year to year, particularly in response to variable yields but also to prices for products. With average yields, annual operating profit, i.e. the return to capital after allowing for owner's labor and management, would be around A$60 000. With above-average yields, operating profit increases disproportionately because the variable costs of production and overheads tend to remain fairly constant per unit of output. In good years, operating profit may rise to A$100 000 or it may fall sharply in poor years to less than A$30 000.

These financial returns are low relative to the size of the investment. Farmers generally accept low return to labor and management and rely upon a few good years and capital gain to cover return on investment. If in the long term, the returns (including capital gain) to labor, managerial skill, and capital do not match those from alternative enterprises (agricultural or non-agricultural), then farmers tend to reinvest elsewhere.

16.6 WHEAT PRODUCTION

Conversion from pasture to crop

The change from pasture to a new sequence of crops requires substantial reduction in the seed bank of pasture and weed species that has built up during the pasture phase. The reduction of that seed bank is accomplished traditionally by tillage that kills establishing seedlings and brings other seed into microenvironments that stimulate germination (Chapter 5). The best control is achieved when tillage begins in spring before the annual pasture species and weeds set seed and is repeated when sufficient seed germinate in response to rainfall, but that usually involves a considerable loss of spring–summer grazing (Fig. 16.6). Other disadvantages of this form of weed control include the high cost of tillage (Chapter 15) and the potential for soil erosion from unvegetated ground (Chapter 12). Cutting hay to prevent seed production and delaying tillage until autumn offers a reasonable compromise even though weed control is less thorough.

Herbicides are increasingly used to convert pasture to crop. In that case, the procedure commences after the autumn break when pasture and weed seedlings germinate. Heavy grazing of the pasture just prior to herbicide applications exposes the germinating seedlings and improves the effectiveness of the operation. Herbicides provide a number of advantages over full and prolonged seed bed preparation. Soil organic matter is retained better, giving benefits in soil structure and additional grazing that increases animal production. Use of herbicides also allows the farmer to delay decisions about conversion until the last moment and respond to the latest climatic and economic signals.

On the other hand, there are also some disadvantages. Delaying land preparation from pasture until after the autumn break may reduce yield of the first crop because neither water nor nitrate were conserved during the period of preparation. In addition, sowing may be later than optimal. In a wet year it may become impossible to sow wheat as the season progresses, although that is less likely on ground that was sprayed rather than cultivated. In practice, a combination of minimum tillage and chemical methods usually provides the cheapest method of weed control and seedbed preparation.

In many ways, farming with herbicides is environmentally safer than farming exclusively with tillage. There is less damage to soil structure, and the retention of vegetation and surface residues protects the surface soil from the danger of erosion. The use of chemicals does, however, require safe-handling procedures and attention to residual effects within the crop rotation.

Selection of cultivars

Cultivars of spring wheat (long-day plants, no vernalization response) are used in the wheat–sheep system. They have been selected for flowering in October following sowing over a relatively broad period in autumn. October flowering is preferred because it avoids late spring frosts that would seriously damage flowering crops. Late flowering pushes grain filling into the usual conditions of terminal drought, but this pattern of water use maximizes water-use efficiency for the system (see Chapter 13).

Wheat crops are grazed only in emergencies, either in winter during the vegetative phase or towards the end of very dry seasons when crop failure is certain. In this way, wheat may sometimes provide a buffer to feed supply. Sheep can graze cereal crops with least damage in the vegetative phase provided it is done before stem elongation exposes the reproductive apices to consumption.

Additional winter fodder is obtained more efficiently from oat, a crop with excellent winter growth that can be managed flexibly for grazing, grain, or both. Oat fits well into the cropping sequence, being commonly used as a companion crop for undersown subterranean clover in preparation for the return to pasture. Table 16.2 records winter fodder production and spring hay yield for a range of available oat cultivars. The data show that it is possible to make selections for winter vigor and spring regrowth.

Weed control

Weeds can be controlled in wheat crops by pre- and post-emergence herbicides. The advantage of pre-emergence control is that competition is avoided in the seedling stands; the disadvantage is that the need for it may be uncertain. Post-emergence weed control is possible with selective herbicides but decisions have to be taken quickly because effective control requires application of individual herbicides at specified stages, usually during early seedling growth. By the time a weed problem is evident, interspecific competition (Chapter 2) may already have reduced yield potential although weed control is still necessary to prevent further losses.

In this system of mixed farming, annual ryegrass, the valued species of the pasture phase, becomes a serious weed in wheat crops. Ryegrass is a particular problem because, as a grass, it is physiologically similar to wheat and provides strong competition while being difficult to remove from the crop with selective herbicides. Fig. 16.3 illustrates yield reduction in wheat due to a range of ryegrass densities. Crops sown in early May grow rapidly under warmer temperatures of autumn and

Table 16.2 *Herbage production (t ha^{-1}) of oat cultivars*

Cultivar	Winter herbage production: Mid-June	Early August	Total	Spring hay yield
Esk	1.1	2.2	3.3	11.5
Carbeen	0.8	2.2	3.2	9.4
Nile	1.2	1.9	3.1	11.0
Blackbutt	0.8	1.9	2.7	10.9
Cooba	0.9	2.4	3.3	6.0
Coolabah	1.2	1.7	2.9	7.3
Algeribee	1.1	1.8	2.9	5.5
Lampton	1.0	1.3	2.3	6.7
Saia	1.1	1.0	2.1	6.8
Swan	1.2	0.8	2.0	4.5

Source: After Reeves *et al.* (1987).

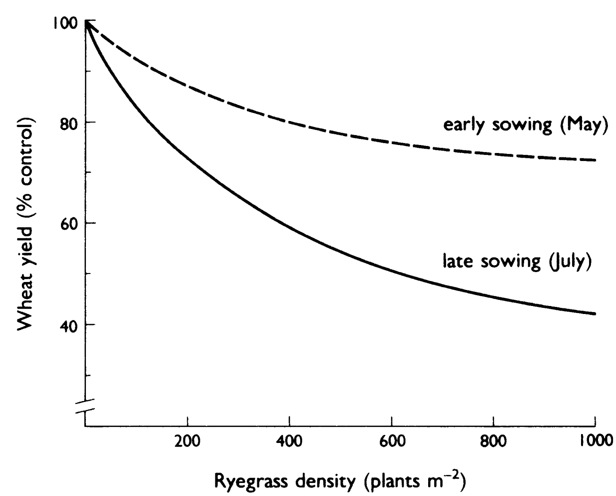

Fig. 16.3. Effect of ryegrass density on the yield of wheat at two times of sowing (after Reeves (1976).)

compete more strongly with ryegrass than do crops sown in July and establishing cover under the cooler temperatures of winter. The effectiveness of control thus varies from year to year depending upon time of sowing and other factors, principally nitrogen fertility which advantages wheat at the expense of ryegrass (Smith & Levick 1974). Ryegrass also serves as an alternative host for certain soil-borne diseases of wheat (Section 16.8). A further problem arises when the pasture legume (subterranean clover) is reseeded under the last cereal crop (usually oat) of a sequence because this restricts the possibilities for chemical control of broad-leaved weeds.

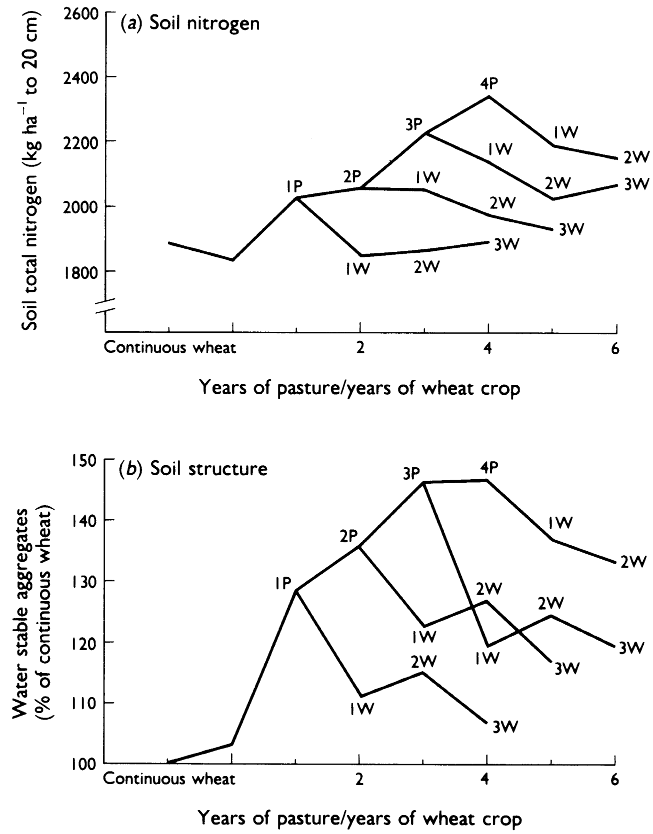

Fig. 16.4. Changes in (*a*) total soil nitrogen content to 20 cm, and (*b*) soil structure, within various crop sequences at Rutherglen (A. Ellington, unpublished).

Length of crop sequence

In individual paddocks, the number of wheat crops grown before returning to pasture depends on how quickly the nitrogen content of the soil is depleted, and on the build-up of soil-borne diseases. It also depends on non-agronomic aspects of the entire farming enterprise, including the returns from wool and lambs relative to wheat. Fig. 16.4 illustrates the changes in soil structure and soil nitrogen content that occur under wheat–pasture sequences using tillage. An important part of the management of these sequences must be directed to preserve the fragile structure of these soils and to maintain adequate nitrogen for crop growth and yield.

More recently, the length of the cropping sequence has been extended by inclusion of crops other than cereals. In northeast Victoria, the grain legume, narrow-leafed lupin, is the most important alternative crop to wheat, but rapeseed is also used. Both crops provide a disease break, and lupin fixes nitrogen some of which remains for an ensuing wheat crop.

On our farm, each ha of pasture on arable land can be expected to add about 40 kg N y^{-1} to the soil reserve, about enough to meet that removed in one average wheat crop (48 kg N in 2.4 t grain ha^{-1} at 20 g N kg^{-1}). Because the nitrogen cycle is 'leaky' (Chapter 8) and the nitrogen harvest index of wheat is near 0.7, more nitrogen than that, about 75 kg N ha^{-1}, must be made available for each crop. Consequently the length of the pasture or grain legume phase needs to exceed that of the crop. In general, pasture should be maintained at least twice as long as the cropping phase.

Stubble management

After harvest, wheat stubbles can provide useful summer feed for sheep because the massive cellulose content of the straw is supplemented by small amounts of grain and volunteer weeds. Sheep are an important element in stubble management because they consume and trample residues so that less tillage is required for the next crop. Without such reduction of stubble, chemical control of weeds is difficult, subsequent sowing of the crop may be delayed, and establishment retarded. One factor that leads to poor establishment of wheat is low soil temperature under surface mulch (see Chapter 7) but there is also the possibility of nitrate depletion, disease, and toxicity from the decomposing stubble.

Stubbles are often burnt after reduction by grazing. Depending upon weather conditions, fire restrictions are lifted in March to April. Despite the loss of nitrogen contained in the stubble (approx. 4 g N kg^{-1}, i.e. 16 kg N in 4 t ha^{-1}), the combustion decreases the C/N ratio in the surface soil, so that microbial growth is restricted and less nitrogen is immobilized in microbial biomass (Chapter 8). Burning also destroys seed in the litter and surface soil and is an effective means of controlling annual weeds, particularly annual ryegrass which is persistent in the crop phase. Burnt stubbles may also conserve more water if the better weed control they afford offsets the higher rate of soil evaporation that occurs in the absence of surface covering (Chapter 9). Farmers in this region are adopting cropping systems involving stubble retention because, on balance, benefits outweigh disadvantages.

Yield

The yield of wheat is related to seasonal water supply and analyses of the relationship are available for Rutherglen (Connor 1975) and related areas (French & Schultz 1984; O'Leary *et al.* 1985; see Section 9.10). The yield distribution function for wheat at Rutherglen presented in Fig. 16.5 is based upon measured water-use efficiencies and the long-term (50 y) distribution of growing-season rainfall.

Wheat yields show substantial variability from year to year. Median yield of wheat is 2.4 t ha^{-1}. One year in ten, yields will exceed 4.0 t ha^{-1} or fall below about 1 t ha^{-1}. Yields less than about 0.8 t ha^{-1} will rarely cover the costs of crop establishment.

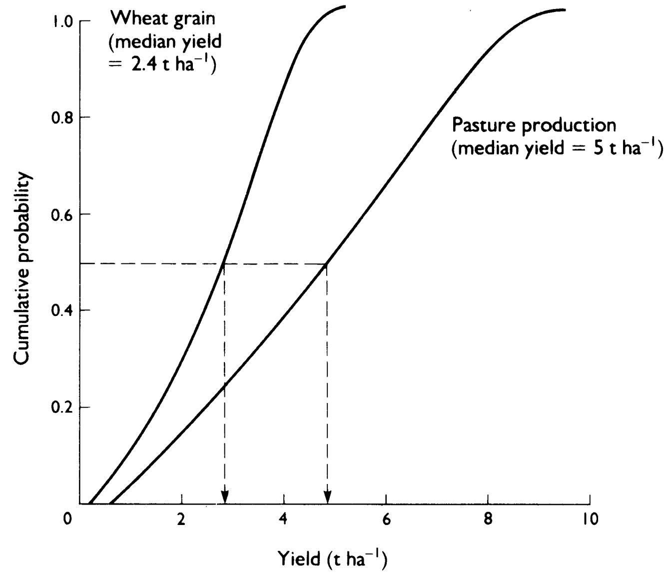

Fig. 16.5. Probability distributions of wheat yield and pasture production at Rutherglen, Victoria.

16.7 ANIMAL PRODUCTION

The health and nutrition of a large flock of sheep is an important concern for a farmer trying to achieve high production by manipulating uncertain feed supplies. The proportion of breeding ewes in the flock and the lambing time determine the seasonal variation in feed requirement through the additional feed for gestation, lactation, and growing lambs. Despite those changes, feed requirements of the flock remain considerably more constant during the year than does pasture production which peaks sharply in spring (Fig. 16.6).

The impact of a shortfall in feed depends upon the timing. Wethers are more robust than ewes and can be managed with less risk. Ewes are most sensitive to low feed supply during gestation and lactation. The penalties for providing insufficient feed for ewes are less production of lambs as well as quantity of wool.

Given this, two of the most important decisions relating to the sheep enterprise that the farmer must make are the **stocking rate** (sheep ha^{-1}) and the **time of lambing**. Others concern the flock replacement strategy because that has implications for seasonal feed demand, genetic improvement, disease control, and cash flow.

Stocking rate

Pasture production varies seasonally and from year to year depending upon climatic factors, principally rainfall. Stocking rate cannot be set to the level of the most

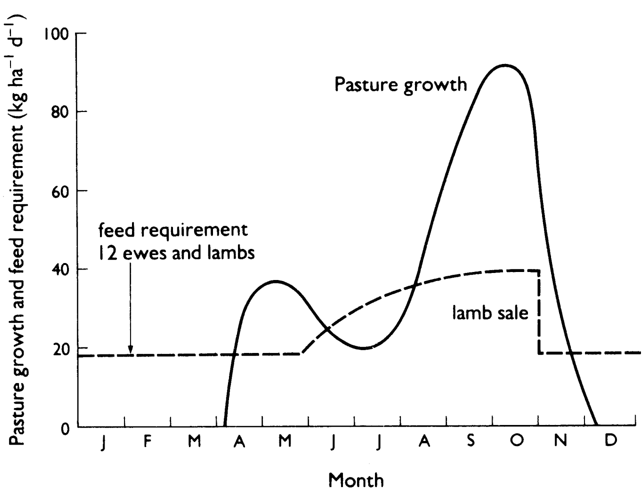

Fig. 16.6. Seasonal pattern of pasture production and flock fodder requirement in the wheat–sheep zone of southern Australia.

productive year nor to the most productive season. A balance must be struck, based on long-term rainfall expectancies and the state of development and level of management of the farm, that will allow fodder reserves (standing fodder, hay and grain) or funds to meet seasonal and annual feed deficits (Fig. 16.6) at acceptable risk. As stocking rate is increased, the danger and onset of a feed deficit is greater and earlier, so more seasonal and drought reserves are needed but there is then less surplus fodder to conserve.

It is possible to make a general calculation about the annual feed requirements of a sheep flock as a basis for understanding stocking rate. An annual allowance of 400 kg of medium-quality dry forage per adult wether (1 DSE) and 800 kg for each ewe plus lamb and associated stock (rams and replacement ewes) (2 DSE) allows for the mismatch between times of production and consumption. If the efficiency of grazing utilization is 60%, then the 400 ha of pasture on our farm must produce around 1800 t dry forage annually or an average of 4.6 t ha^{-1} over permanent and rotational pasture for the flock of 750 wethers and 1000 breeding ewes. This forage requirement is just below the median annual pasture production at Rutherglen (5 t ha^{-1}; see next section). In the mixed farming system, sheep gain additional feed each year from grazing stubbles and from forage and grain crops (e.g. oat and lupin) sown for that purpose.

Time of lambing

The time of lambing strongly influences the seasonal feed requirements of the flock. In this region, lambing in autumn provides the best match with the availability of green herbage in winter and the 'flush' of spring growth (Fig. 16.6). The alternative is to lamb in early spring. This fits better with the reproductive cycle of the sheep, and lambing percentage is greater. In addition those lambs come to market when prices are usually higher. However, supplementary feed, fodder crops, or special pastures (e.g. alfalfa) must be provided to 'finish' spring-born lambs. Spring lambing is possible on these mixed farms but the decision to implement it requires careful economic evaluation.

16.8 PASTURE PRODUCTION

Pasture composition

The improved pastures of the wheat–sheep zone are dominantly mixtures of annual grasses and legumes, although perennial grasses are important in some areas as for example on the uncultivated areas of this farm. The preferred grass is annual ryegrass and the legumes are various cultivars of subterranean clover or medics (*Medicago* spp). All are native to the Mediterranean region, have long-day requirements for flowering (Section 5.3) and are well adapted to the Australian wheat–sheep zone. The cultivars are chosen by individual photothermal requirements to match the length of growing season. The medics are better suited to a short growing season and alkaline soils than subterranean clover. At Rutherglen, ryegrass and subterranean clover (cvs. Woogenellup and Trikkala) are the preferred pasture species.

Several other species are voluntary invaders of pasture. The most important are also introduced species, barley grass (*Hordeum leporinum*) and storksbill (*Erodium botrys*) from the Mediterranean region and capeweed (*Arctotheca calendula*) from South Africa. All are undesirable because they have shorter growing seasons than ryegrass and subterranean clover and are consequently less productive. In addition, the burrowing seeds of barley grass and storksbill damage the eyes and hides of sheep. Capeweed is common on high fertility sites, invading the pastures when the nitrogen level has been raised. Both barley grass and capeweed are stronger winter growers than ryegrass and subterranean clover, and either can come to dominate pasture.

The 150 ha of pasture on this farm that cannot be cropped were improved by broadcasting subterranean clover seed and by biennial applications of superphosphate. The species content is comparable to that of pastures that are managed through the cropping sequence but with valuable perennial grasses (phalaris and cocksfoot) and overall a greater proportion of less desirable, weedy species. In this case, carrying capacity is 50% of the rotational pastures on the farm.

Managing pasture composition

Pasture management requires attention to interspecific competition during the growing season, especially as it affects seed production because the composition of the soil seed bank and the germination responses of the component species determine what mixture emerges at the next break of season. The timing of the autumn break is important and can have overriding effects on pasture composition, causing the grass, clover, and weed composition to vary considerably from year to year. Clover tends to be dominant when the break comes early, grass when it is late, and capeweed after a long dry summer. During the growing season, grazing, mowing, and applications of fertilizer and herbicides control species composition and ultimately the annual seed set.

The success of legumes depends upon the application of phosphorus. It is in limiting supply and is readily fixed into sparingly soluble forms in these soils by aluminum and iron. Annual applications of about 10 kg P ha^{-1} to the pastures are most common, but practice varies. Some farmers rely on applications made to the wheat crops during short rotations to carry over to pasture, others apply phosphorus during the pasture phase for greater benefit to fodder production. In pastures established for over 20 y, the application of 10 kg P ha^{-1} may be made in alternate years. Phosphorus fertilizer is an important tool in pasture management because it can be applied to increase clover content and hence the nitrogen fixation rate and overall productivity of the pasture.

Successful management of pasture composition by grazing requires flocks of a size that can quickly reduce pasture biomass in individual paddocks when required. In this way, timely defoliation can be effected, for example to limit seed set in capeweed or barley grass. Pastures are grazed lightly in the first year to ensure establishment of plants at a satisfactory density. Once established, heavy grazing favors short-stature clovers, medics, and capeweed over grasses. Light grazing favors the taller grasses. Time of grazing is also important. Spring grazing, as with mowing for hay, can be used to control seed production of all species. Ultimately, grazing determines the composition of the pasture.

Some of the surplus spring forage (Fig. 16.6) is commonly mown and conserved as hay. The traditional storage is in small, rectangular bales in sheds but increasingly, for reasons of quality and economy, large (round) bales are made and usually stored without cover. The ideal time to cut pasture for hay is when the grains of the grasses are still immature and the biomass and nutritive quality are high. Consequently, mowing reduces grass seed production and causes significant shifts in pasture composition. For that reason, mowing is restricted to older-established pastures while young pastures are allowed to seed freely without hay production or heavy grazing. The last pasture in a sequence is commonly used for hay production in order to reduce the seed load and hence competition during the subsequent crop sequence. Mowing is a particularly effective means of restricting dominance of barley grass because little of its seed persists over more than one summer.

Herbicides can also be used to manipulate species composition but they are expensive compared with management by grazing or hay making. However, some cheap options are available. For example, control of capeweed can be achieved by a subtoxic dose of a herbicide that slows growth causing sugar content to increase. In this condition capeweed becomes especially palatable and sheep will selectively graze it. A new and valuable use of herbicides is in 'pasture topping'. The pasture is sprayed while still green in late spring, causing rapid senescence. There is no residual effect of the herbicide on rumen activity, animal metabolism, or meat quality. Labile carbohydrate and nitrogen contents of the dry forage remain high during the summer and as a secondary effect, seed set is prevented. This effectively enhances the nutritive value of dry standing feed during the summer and also controls grass weeds, e.g. barley grass. It is especially useful in the last year of a pasture sequence as a weed control treatment prior to cropping.

Soil seed bank

The stability of annual pastures depends upon the ability of the component species to reestablish each autumn from the seed bank in competition with invading species. With uncertain rainfall, each species must set seed in most years and in sufficient quantity to maintain a place of dominance in the seed bank in the topsoil. That bank must be large enough to tolerate depletion by ill-fated germination after early rains ('false breaks') that occur prior to the main wet season.

For subterranean clover and annual ryegrass, seed dormancy, including hardseededness (Section 5.6), ensures that a substantial seed supply remains in the topsoil following false breaks, and even after seasons with low seed-set due to drought or heavy grazing. Most cultivars of subterranean clover produce hard seed that will persist in the soil for many years. Subterranean clover germinates in wheat crops; although it does not compete strongly, sufficient seed remains for re-establishment after the cropping phase. When pastures fail to re-establish after cropping, the cause is usually failure of inoculation due to decline in rhizobia population. Undersowing inoculated seed with the last wheat crop of a sequence ensures rapid re-establishment of a productive pasture. In drier areas of the wheat–sheep zone with shorter and more opportunistic crop sequences, the persistence of pasture legume seed through the crop phase lowers the cost of pasture re-establishment, contributing to the profitability of cropping at lower yield levels than are achieved in northeast Victoria.

Over the summer, seed, especially of subterranean clover, form an important part of the sheep diet. Their high content of nitrogen (32% crude protein) aids sheep in digesting the low quality roughage that is usually on offer at that time. Annual production of subterranean clover seed can reach 500 kg ha^{-1}.

Disease control

The pasture phase provides an important break in the reproductive cycle of soil-borne pests and diseases that build up under continuous cropping. In northeast Victoria, on acid soils, the important fungal diseases of wheat are take-all (*Gaeumannomyces graminis* var. *tritici*), eyespot lodging (*Pseudocercosporella herpotrichoides*) and speckled leaf blotch (*Septoria tritici*). In other parts of the wheat–sheep zone, on neutral and alkaline soils, rhizoctonia root rot (*Rhizoctonia solani*) and the cereal cyst nematode (*Heterodera avenae*) cause serious losses in wheat yield, often in combination. Table 16.3 presents observations made on yield, grain nitrogen content, and disease incidence in wheat grown in various sequences with lupin at Rutherglen. The responses reveal that lupin provides an important disease break in addition to greater available nitrogen.

Table 16.3 *Yield, grain nitrogen content, and disease incidence of wheat in the third year of various wheat–lupin sequences at Rutherglen*

The diseases of wheat were *Gaeumannomyces graminis*, *Fusarium* spp. and *Pseudocercosporella herpotrichoides*.

Rotation	Grain yield (t ha^{-1})	Nitrogen content (%)	Disease incidence (%)
W–W–W	2.58a	2.31a	36a
L–W–W	3.00b	2.51b	2b
W–L–W	3.34b	2.65c	1b
L–L–W	3.41b	2.73c	1b

Note:
Within columns, values followed by different letters are significantly ($p < 0.05$) different.
Source: Adapted from Reeves *et al.* (1984).

The effectiveness of pasture as a disease break is reduced by the presence of grasses that provide inferior but alternative hosts to diseases and pests of wheat. Pure legume pastures offer disease control comparable with that of grain legumes, such as lupin and pea, or the oilseed crop, rapeseed, and are now a practical option with the use of herbicides. They are recommended in some areas of the wheat–sheep zone, but not currently in north-east Victoria.

Cropping and pasture rotations also provide the basis for controlling internal parasites of sheep, particularly worms. The crop sequence provides a longer break in disease cycles than is possible by rotational grazing of pastures themselves. Rotational grazing is usually not sufficient to control internal parasites at the stocking rates concerned and is supplemented by drenching with anthelmintics.

Pasture productivity

Pasture productivity depends upon the establishment and maintenance of LAI over the season. A pasture of low LAI will never 'grow away' from sheep, so the advantage to pasture production that accrues from closing some paddocks after an early autumn break ('deferred grazing') can be considerable. The penalty is a temporary but significant decline in animal production because after a dry summer the stock are in condition to respond to green pasture, even a small amount, to supplement the dry standing feed that remains. Until the rainy season is established, however, it is probably better to graze what grows in response to early rains, given that feed is scarce and if not eaten may desiccate and blow away.

Because grazing can reduce green cover below that needed for maximum growth rate, rotational grazing of paddocks plays an important role in allowing LAI to increase towards the level needed for high production. In practice, however, farmers stock at rates that result in overgrazing of some paddocks in most years.

Pasture production is closely related to growing-season rainfall. We can again use a yield versus ET relationship (Section 9.10) to analyze the variability of annual pasture production. The distribution of annual pasture production presented in Figure 16.5 was estimated from growing-season rainfall and water-use efficiency determined for vegetative growth of wheat (Connor 1975; O'Leary *et al.* 1985) but appropriate to the growth of C3 pastures. The distribution function emphasizes that pasture production, like wheat yield, varies considerably from year to year. Median annual production is 5 t DM ha^{-1} but the range is wide. One year in ten will have pasture production above 8 or below 1.5 t ha^{-1}. Fodder reserves of grain (oat and lupin) and pasture hay provide for feed transfer from years of high to years of low production.

Nitrogen fixation and cycling

Pastures that accumulate 5 t ha^{-1} dry forage at a nitrogen content of 25–30 g N kg^{-1} contain about 140 kg N ha^{-1}. That translates to 875 kg crude protein ha^{-1}. Not all of that nitrogen will be obtained from symbiotic fixation because the pastures are not pure legume, and because legumes utilize inorganic nitrogen when it is available. Uptake of mineral nitrogen by legumes would occur particularly in the seedling phase when soil nitrate levels are high following the summer drought.

The cycling of nitrogen through the soil–plant–animal system is complex (Chapter 8). When pastures are grazed, the major portion of the nitrogen consumed is excreted by the animals and returned to the pasture in urine and feces. Perhaps 50% is lost by volatilization with the remainder returning to the soil. That means that nitrogen is rapidly recycled through the pasture during the rainy season and more slowly in the dry season when pasture growth is small.

Estimation of the contribution of legume nitrogen to the rotation is difficult. The available data for these pastures suggest a mean net nitrogen fixation of about 40 kg ha^{-1} y^{-1} with a range of 20–80 kg ha^{-1} y^{-1}. The amount varies with growing conditions and pasture productivity and declines as mineral nitrogen and organic matter accumulate under the pasture. Natural additions by lightning, rainfall, dust, and free-living organisms are about 2 kg ha^{-1} y^{-1} and therefore minor. Symbiotic fixation is the major source for the entire system since nitrogen fertilizer is rarely used.

The 250 ha of rotational pasture on our farm have the capacity to bring 10 t N ha^{-1} y^{-1} into the system. The portion of this nitrogen that has accumulated at the end of a pasture sequence influences the performance and determines the possible length of the ensuing cropping phase.

16.9 NUTRIENT BALANCE OF THE SYSTEM

Table 16.4 summarizes some components of the macronutrient balance of the farm. Fertilizer practice aims to correct phosphorus deficiency which limits plant growth, especially of subterranean clover. Using superphosphate, that also adds substantial amounts of calcium and sulfur but much of the added phosphorus becomes fixed in relatively unavailable forms so that annual additions are necessary even though they

Table 16.4 *Annual nutrient balance (kg) of a 700 ha wheat–sheep farm, Rutherglen, Victoria*

50 ha are unused.

	N	P	K	Ca	S
Inputs					
Pasture (250 ha rotational pasture)[1]	10 000	2500	—	5250	3050
Pasture (150 ha on non-arable land)[2]	3000	750		1570	920
Wheat (150 ha)	—	1500	—	3150	1840
Oat (50 ha)	—	500	—	1050	610
Lupin (50 ha)[1]	2000	500	—	1050	610
Products					
Lambs (1000 @ 35 body wt = 35 t)	980	240	60	440	135
Wool (1750 @ 5.0 kg cap^{-1} = 8.8 t)	865	1	1	—	230
Wheat (150 ha @ 4 t ha^{-1} = 600 t)	7200	1080	1510	720	900
Oat (50 ha @ 3 t ha^{-1} = 150 t)	2000	300	420	200	250
Lupin (50 ha @ 1.5 t ha^{-1} = 75 t)	3300	390	1080	160	145
Balance					
Oat and lupin sold	+665	+3740	−3070	+10 550	+5370
Oat and lupin consumed	+5955	+4430	−1570	+10 910	+5765

Notes:
[1] All N inputs are net gains from legume–rhizobia symbiosis.
[2] Pasture on non-arable land is fertilized in alternate years.

exceed annual removal. Potassium is not commonly added but removal in wheat grain (0.42%) is high, totalling 1.5 t. It can be expected that potassium deficiency will eventually become widespread on land that is consistently cropped. The system uses no nitrogen fertilizer but relies on nitrogen fixation by subterranean clover during the pasture phase. The budget shows that the system is closely balanced. The estimated annual addition on the rotational system of 12 t (based on 40 kg ha^{-1} for lupin and pasture) would be exceeded by removals if the fodder grains (oat and lupin) were sold. The wheat harvest removes the major proportion, 7.2 t. Stock transfer some proportion of the nitrogen fixed on the non-arable pasture to the cropping system but the real difficulty in constructing the budget is that the actual rate of nitrogen fixation is uncertain. Despite the uncertainties, the estimates illustrate, however, the critical role that nitrogen plays in continuing productivity. The complexity of the nitrogen cycle and the difficulties of measurement were discussed in Chapter 8.

Most of the nitrogen fixed by the lupin crop is harvested in the grain. This is characteristic of the nitrogen balance of grain legume crops and contrasts strongly with the accumulation of nitrogen under leguminous pasture.

The balance provides the overall summary for the farm. For individual paddocks there is a build-up of nitrogen fertility during the pasture phase that is then used during cropping. In ecological terms, stability involves cyclic rather than static nutrient levels.

16.10 ECOLOGICAL STABILITY

A key feature of agricultural systems that affects their long-term stability is the removal of nutrients in harvested products (Chapter 12). Phosphorus and nitrogen are critical elements in the wheat–sheep system; their levels are attended to by phosphorus fertilizer and symbiotic nitrogen fixation. In the future it may be necessary to add other nutrients, particularly macronutrients such as potassium, that are removed in large quantities in wheat grain and lambs. At the present time, however, it is becoming apparent that, for continued productivity, the wheat–sheep system must solve or adapt to two additional changes that it is imposing on the land. The first is dryland salinity, which affects low-lying parts of some topographical sequences, and the second is increasing soil acidity. Both reduce productivity, but do so in different ways. Salinity operates at a scale that is larger than the individual farm so its solution will require cooperative action. Acidity operates at the level of individual paddock and is under the control of the farmer.

These two processes are important ecological issues affecting the long-term stability of agricultural ecosystems. Agricultural fields are maintained for high productivity as disclimax communities that are prevented from successional return to natural vegetation. They are maintained by management, but can management always prevent undesirable change?

Dryland salinity

The original woodlands and shrublands of the wheat–sheep zone were dominated by evergreen perennials, mostly of the genus *Eucalyptus*. Those communities were as active in summer as the water supply would allow. The result was maximum use of all water by drought-resistant communities tuned by evolution to erratic, winter rains. Their characteristic was substantial drying of the soil by a deep root system over summer and autumn. The change to annuals that use less water has had a major effect on the hydrology of the landscapes.

Subsoil moisture has increased under annual crops and pastures because the root systems are shallow and are inactive during the summer. Over a number of years there has been a significant rise of the watertable in some parts of the wheat–sheep-zone from that established under natural woodland. The subsoils contain large quantities of salt leached from the surface layers in earlier times. Because $P < ET^*$ in this region, salt has not leached to the ocean. With rising watertables, it is brought to the surface in seeps, or to within the capillary zone, at low points of the topography. Some catchments are connected by regional watertables so that a change in land use in one area may lead to saline seepage many kilometers away.

Salinity initially reduces the productivity of crops and pastures, then causes their replacement by salt-tolerant species, and, if sufficiently severe, by bare, erodible ground. Because salts have been brought to the surface, a larger fraction can enter surface waters and streams with deleterious effects on wildlife and water supply. This problem is widespread in the wheat–sheep zone, particularly outside northeast Victoria, and is estimated to affect to varying degreees 3–4 Mha in the Australian wheat–sheep zone and to be expanding. Similar scenarios are evident in other youthful, dryland farming systems around the world, e.g. in Montana (USA). On the other hand, in very old systems of the Near East, the uplands are now salt-free but the lowlands are completely salinized unless drained.

The solution is conceptually simple. To prevent seepage reaching the lowland, and to redress the problem that already exists, it is necessary to remove the salt from the seepage areas in the low-lying land. This could be achieved by drainage, which would also export salt from the region to the ocean or to salt sinks, or alternatively by increasing evapotranspiration on the uplands that would reduce the quantity of salt mobilized towards the seepage zones.

Saline water can be drained to the sea or to inland evaporation pans. Both processes occur naturally in this zone but the issue here is if they should be expanded by engineering. Such projects are expensive and with complex socioeconomic consequences. It should, however, be possible to regain and thereafter preserve the agricultural productivity of the entire landscape. Desalinization of the Imperial Valley (USA) was achieved in 20 y. Despite the cost and complexity it should be considered as the principal planning option for the maintenance of long-term agricultural productivity.

The alternative of living with salt will also involve considerable, but continuing, cost to lower the saline watertable below the root zone. Perennial plants might be used to achieve this as they did in the native vegetation. There are some candidates among herbaceous agricultural species such as alfalfa and the grasses, phalaris and cocksfoot. These could maintain summer transpiration but would provide little grazing because of the need to maintain high LAI to be effective. Another avenue involves the introduction of native or exotic trees into the landscape. The problems to be resolved are: What species? Where in the landscape? What density? Would it work indefinitely? The evaluation of alternative pasture species and agroforestry systems for hydrologic control of salinization is now under way in southern Australia.

Whatever combination of techniques is adopted to manage salinity, the selection and breeding of salt-tolerant cultivars of present and alternative agricultural species may be a useful associated objective but will not in itself provide a solution. Salt-tolerant plants have inherently low productivity and reliance on them would inevitably worsen the problem to greater salt concentration levels from which land may be irrecoverable. Many are attracted to plant breeding as the way to solve the problem; ecological analysis teaches us otherwise.

Soil acidification

There is now considerable evidence (see Fig. 16.7) that the soils have continued to become more acid (up to 1 pH unit) under the wheat–sheep system and that the change has already reduced productivity. It was once thought that phosphate fertilizer, despite its high calcium content, was the cause of increasing acidity. It is now apparent that it is increased production, particularly by legume pasture, and associated grazing that accelerate the change (Chapter 7).

Increased soil acidity reduces plant growth, in part, through changes to chemical

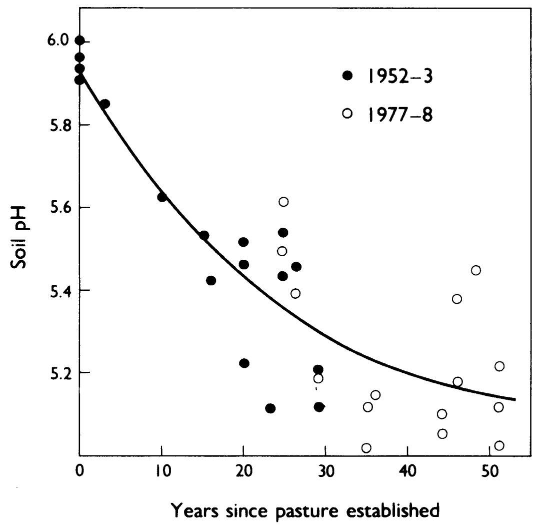

Fig. 16.7. The relationship between age of subterranean clover pasture and pH (1:5 in water), 0–10 cm. Measurements made in two periods, 1952–3 and 1977–8 (after Williams (1980).)

balances leading to aluminum and manganese toxicity and often a deficiency of molybdenum. In addition, the symbiosis between rhizobia and clover, which is the cornerstone of the system, is independently affected. The persistence of the bacterium in the soil and its capacity to form effective nodules with clover are both reduced.

As with the salinity problem, solution to soil acidity cannot rely upon the development of tolerance. More acid-tolerant cultivars and species are an interim objective. Some progress has been achieved in the development of acid-tolerant grasses (e.g. phalaris), but legumes remain a major difficulty. The limiting factor at present lays with the symbiosis because nodulation fails at higher pH than that at which the growth of the clover is affected. Soil acidification is an inevitable process under vegetation with leaching, particularly with agriculture (Chapter 7). On susceptible soils, the long-term management strategy must be to slow down and/or correct acidification of the soil profile. Concentration on the development of tolerant species may allow conditions to worsen to a point from which recovery is not economically feasible.

Acidity can be corrected by the ancient practice of adding lime, a technically feasible but expensive option. Treatment can be sustained when the expected yield increases of wheat and pasture promise sufficient return relative to the cost of lime. This is now the case in some fields in the Rutherglen area (Coventry 1985).

16.11 SUMMARY

Wheat is the principal cash crop in this mixed farming system. Inclusion of leguminous pasture in rotation with wheat provides the nitrogen needed for wheat production. It also provides weed, pest, and disease control so that wheat production can be managed in relation to the limiting resource, variable rainfall. It also provides diversification of income and distribution of labor requirement over the year.

The close interaction between crops and animals in this system shows how production depends upon an appreciation of both scientific and economic principles. Present farmers cope well through acquired experience but the range of interactions is great suggesting that thorough analyses, to assist in explanation and in the development of more sophisticated management, are needed. The development of comprehensive simulation models based on both agronomic and economic principles could be especially beneficial.

Although the present system was developed for a high degree of stability, particularly in terms of nutrient balance and water use, environmental problems require attention. No agricultural system, even the most primitive, can be easily managed to remain unchanged over time. As a human activity, agriculture needs attention to maintenance to adapt to internal change as well as to changes imposed upon it from outside.

16.12 FURTHER READING

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17

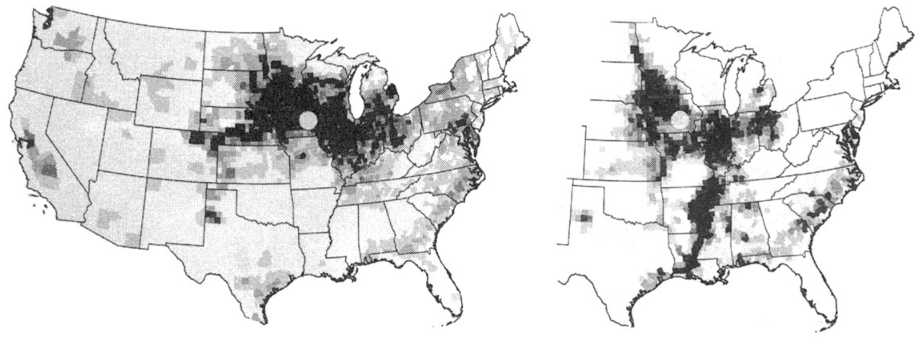
Mixed farming in the North American Corn Belt

17.1 INTRODUCTION

Farming systems of the North American Corn Belt contrast sharply with Victorian wheat–sheep farms. Cropping in an extensive area centered on the states of Iowa, Illinois, and Indiana (Fig. 17.1) is dominated by maize and soybean. Leguminous forages, oat, wheat, and pasture are also found within the region. The abundance of superior feed grains and forages leads to a strong emphasis on production of swine, beef cattle, and dairy products. The climate is too cold and the growing season too short for subtropical crops such as rice, cotton, sugarcane, and citrus. A number of fruits and vegetables can be grown but competing regions such as California generally produce those with higher quality and with less risk and less cost.

Much of the original vegetation in this region was tall-grass prairie and oak savannah on level to gently undulating glacial till, loess, and alluvium. When farming began in 1830, tall-grass prairies presented a rather hostile environment. Traditional wooden plows were inadequate for breaking sod and shortages of wood for fencing and fuel were a concern. John Deere's steel plow (1840) pulled by heavy oxen opened the land; invention of a practical barbed wire (1870) allowed development of mixed farming with livestock; and invention of elevator grain storage buildings facilitated handling and shipping of grains by rail and barge. Technological change has continued to be a fundamental feature of Corn-Belt farming. Hybrid maize resistant to stalk rot (1930), soybean as a new crop (1935), low-cost ammonium fertilizer (1950), herbicides (1950), and chisel plows (adopted in the 1970s) are recent innovations that have brought dramatic change to crop production.

Diffusion of new technology was sometimes very rapid and sometimes slow. Transition to hybrid maize was 99% complete in 10 years but the combine harvester, invented in Michigan in 1840 and widely used in California and Washington since 1870, was not scaled to the Iowa farm until the 1930s. Innovation came from within the system as well as from outside. The Parson trencher, developed in Grinnell, Iowa, for installation of subsurface drainage, came to worldwide use, and immigrant Dutch and German farmers introduced legume rotations.



Maize Soybean

Fig. 17.1. Maps of continental USA illustrating the concentration of maize production (left) in a 'Corn Belt' across various counties in upper midwest states. Soybean (right) has a similar distribution except that it is also found in the lower Mississippi Valley (bottom center of map) and along the Atlantic coastal plain. A total of 32 Mha is given to maize and 26 Mha to soybean. Maize and soybean production also extend into Ontario, Canada. Location of the example farm is indicated by a white circle. (From Bureau of the Census (1984).)

Farming in Iowa

An analysis of farming in Iowa provides insights into the character of the Corn Belt. Evolution of the Iowa systems was as strongly influenced by the knowledge, energy, and culture of the pioneer settlers (English, German, Dutch and Scandinavian) as it was by the great fertility of prairie soils. The land was settled in homestead grants of 65 ha and is privately owned as family farms. In the American survey system of sections, a square-mile section (640 acres, 259 ha) was subdivided into 40-acre (16.2 ha) units; four of these, a 'quarter-section' (160 acres, 64.8 ha), constituted a homestead grant. The change from animal power to tractor power significantly increased the productivity of labor and thus the possible size of a family farm. Combined with greater incomes from urban jobs, that has caused farm population to decline since 1940 while farm size has increased (Loomis 1984). Farms are now fewer and farm families smaller, in part because mechanization reduced the advantage from child labor.

Most farms were once involved in raising both cattle and swine for market. Swine production is still a major activity in Iowa but it is restricted now to a small number of intensively managed operations. Beef production and with it areas of land given to pasture and forages have declined sharply in recent years. High prices for grain during the 1970s, consumer concerns about dietary cholesterol, and increased competition from the Great Plains contributed to making small-scale beef operations less profitable in Iowa. Since 1960, new pump-irrigation systems have been introduced in the Plains states. These produce low cost grains close to cattle ranches and have led to the development of large, highly efficient, feedlots. With the loss of that traditional source of feeder cattle, beef production in Iowa is now mostly in

Table 17.1 *Agricultural statistics for Iowa in 1987*

Iowa farms				
Size class		*Number*		*Area*
0–20 ha		18 960		
20–72 ha		66 630		
>72 ha		19 600		
All farms		105 200		12.8 Mha
Total area of state				14.6 Mha
Estimated value and income		*Mean*		*Total value*
Land		US\$2340 ha^{-1}		US\$29.9 × 10^9
Value of equipment		US\$58 400 farm^{-1}		US\$6.1 × 10^9
Gross income		US\$99 000 farm^{-1}		US\$10.8 × 10^9
Expenses		US\$77 500 farm^{-1}		US\$8.5 × 10^9
Net income		US\$21 400 farm^{-1}		US\$2.3 × 10^9
Livestock products marketed		*Total amount*		*Total value*
Swine		21.3 × 10^6 head		US\$2.7 × 10^9
Beef cattle		2.9 × 10^6 head		US\$1.4 × 10^9
Dairy		1.6 × 10^9 l		US\$0.4 × 10^9
Poultry				US\$0.1 × 10^9
Harvested crops		*Production*		
	Area	*Mean*	*Total*	*Total value*
Maize (grain)	4.0 Mha	7050 kg ha^{-1}	28.2 Mt	US\$1.8 × 10^9
Soybean	3.2 Mha	2620 kg ha^{-1}	8.4 Mt	US\$1.6 × 10^9
Oat	0.3 Mha	1540 kg ha^{-1}	0.4 Mt	US\$42.0 × 10^6
Hay	0.8 Mha	7500 kg ha^{-1}	6.3 Mt	US\$0.3 × 10^9
Other crops[1]	0.3 Mha			
Not harvested[1]	1.5 Mha			
Other land[1]	3.3 Mha			
Fertilizer use		N	P	K
Total state (t)		840 700	68 200	420 100
Per ha cropland (kg)		98	8	49

Note:
[1] 'Other crops' are mainly wheat and rye; 'not harvested' includes approximately 32 kha of crop failure and 1.4 Mha of new seedings in set-aside and CRP programs; 'other land' includes established CRP, woodland, farmsteads, farm roads, and pasture.
Sources: From Iowa Agricultural Statistics (1988); Bureau of the Census (1984).

areas having permanent pastures on soils marginal for farming. Elsewhere, cash sales of grain for export have replaced cattle feeding. Engaged as they are in bulk production of low-value commodities (maize and soybean), net income per ha for most Iowa farms is small. In addition, commodity prices and land values have been unstable in recent years.

Data presented in Table 17.1 illustrate the present character of agriculture in Iowa. Maize and soybean acreage now seeded to grass in government-sponsored conservation reserves accounts for much of the 'not-harvested' area shown in the table. In Iowa, the numbers of large and small farms are both increasing gradually while the total number of farms is declining. The smallest farms (18% of total farms) average about 8 ha in size and occupy only 1.1% of the arable land. Most small farms consist of surplus homesteads and marginal farm land sold from large farms. They can be viewed as an urban extension because the principal employment and income of these 'weekend farmers' comes from urban jobs. In contrast, more than half of the arable land is held by farms larger than 200 ha.

An example farm

We will analyze an imaginary farm located along the North Skunk River in Jasper County, Iowa (70 km east of Des Moines at 41° N, 93° W). The analysis is based in part on information about yields and crop and livestock management obtained from local farmers. The farm consists of 400 ha extending from flatlands in the river floodplain, over hill lands of the river breaks (5–18% slopes), to undulating uplands (Fig. 17.2). Extensive, low-cost methods of production are used and yields are average for the region (i.e., about 0.6 of local record yields). The distribution of cropland and pasture is dictated by spatial patterns of soils and topography. All of the principal crops of the region (maize, soybean, oat, and legume forages) are grown on the cropland. The farm does not have swine or dairy cattle. Swine production is found on one-third of farms in this county but dairying, for local markets, is a specialized activity on only 2% of farms. Whereas most of northern and western Iowa are given to grain production, farms on hilly loess soils in southern portions of the state are still involved in beef production. This farm possesses elements of both systems.

17.2 CLIMATE

The Corn Belt climate is midcontinental and temperate with cold winters and a limited frost-free season (140–170 days). Summers are warm (July mean near 24 °C with diurnal amplitude of 4 °C) and humid; 70% of the moderate annual rainfall (700–1000 mm) is received during the growing season from May through September. Our farm averages 160 days of frost-free weather and 840 ± 150 (SD) mm of precipitation. Humidity limits daily total radiation to 20–23 MJ m^{-2} d^{-1} in midsummer. Crop ET during summer averages 5 mm d^{-1} whereas rainfall is only about 3.5 mm d^{-1}. Therefore, most crops also depend upon soil moisture that accumulates from spring rains and snowmelt. Severe drought, hail from strong storms, early frost in fall, and difficult conditions in spring (too dry, cold, or wet) are the principal environmental risks. Drought is not uncommon and crops would sometimes benefit from supplemental irrigations but supplies of surface and ground waters are limited and capital costs of standby sprinkling equipment are large. Maize (determinate development) is most susceptible to drought at anthesis while soybean (indeterminate), given the absence of an early frost, can compensate for loss of early flowers.

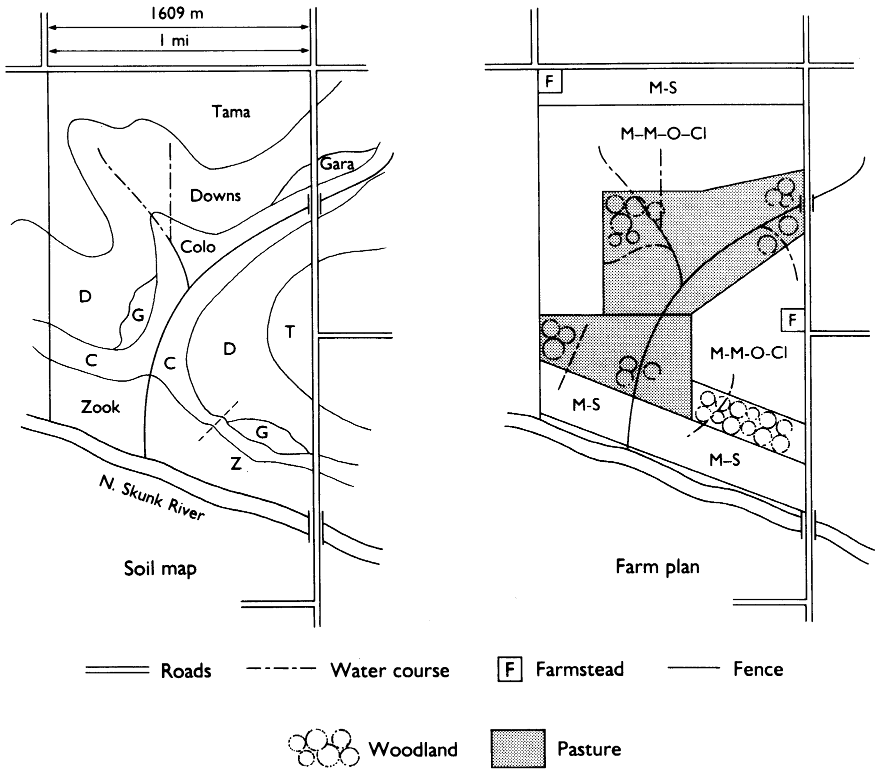


Fig. 17.2. Map of soil types, field boundaries, and land use for the example Iowa farm. M–S, maize–soybean rotation on level land; M–M–O–Cl, maize–maize–oat–clover rotation on sloping land. Pasture and woodland areas are shaded. The distribution of area is given in Table 17.2. The soils are described by Nestrud & Worster (1979).

17.3 SOILS

Glaciation during the Recent Quaternary Period was a dominant factor in landscape and soil formation in this region. Compared to Australian soils, Corn Belt soils are all young and relatively unleached of their original nutrients. Early extensions of the Canadian glaciers ('Nebraskan' and 'Kansan' periods) deposited 5–10 m of till over most of the region. During the most recent, 'Wisconsin', glaciation (14 000 BP), ice lobes extended into central Iowa (the 'Des Moines lobe') and northern Illinois, and soils in those areas formed on gently undulating till. Surface drainage is poor and marshes and lakes are common. South of those lobes, paleosoils of the Kansan till (29 000–14 000 BP) were covered by as much as 15 m of silty loess blown from glacial outwash during the Wisconsin Period. In both regions, fire served to maintain grasses in the prairie and oak-savannah while protected areas supported mixed hardwood forest. In places, river valleys have cut through the over-mantles of loess and till, exposing earlier tills and paleosoils, and creating alluvial plains. Mollisols

Table 17.2 *Land utilization and production on the example Iowa farm*

Production figures are given as dry mass. Normal moisture levels are: maize, 0.15; soybean, 0.13; oat, 0.11; hay, 0.12. Nutrient contents of the crops are adapted from National Research Council (1982).

Crop	Area (ha)	Yield (kg ha^{-1})	Production (t)	Nutrient content (kg kg^{-1}) N	P	K
Maize: grain	130	7000	910	0.016	0.0029	0.004
stover		6000	780	0.009	0.0010	0.015
Soybean	50	2350	118	0.068	0.0065	0.018
Oat	40	2100	84	0.021	0.0038	0.004
Forage	40	6000	240	0.025	0.0025	0.016
Pasture	100	4000	400	0.020	0.0034	0.020
Set-aside	13	—	—	—	—	—
Uncropped	27	—	—	—	—	—
Total	400		2532			

(FAO, Chernozems) dominate grassland sites, while Alfisols are found with woodland influence.

Our imaginary farm lies southeast of the Des Moines lobe and its soils were formed mostly on loess (Nestrud & Worster 1979; Fig. 17.2). Well-drained, Tama silty clay loam (Mollisol on loess with grassland) and Downs silt loam (Alfisol on loess with oak–savannah) are found on uplands. Patches of Gara loam (Alfisol on Kansan till paleosoil with woodland) occur on lower slopes. Colo silt loam occurs on alluvial fans, and Zook silty clay loam in alluvial river plains. Colo and Zook soils are both Mollisols, formed under poorly drained grassland. Tama, Downs, and Gara soils are all subject to erosion. Water courses on the slopes are provided with subsurface drains (perforated plastic pipe) and are permanently grassed. Farming is done in approximate contour strips with permanently grassed headlands for turning. Conservation rotations with a sod–crop phase are practiced on the steeper (6–14%) slopes. Colo soils receive runoff and seepage from the uplands and are mostly left in permanent pasture. The level Zook soil is also wet and subject to occasional flooding; it is provided with subsurface drainage and cropped continuously.

17.4 FARMING OPERATIONS

Of the 400 ha (1000 acres) on the example farm, 270 are arable, 100 are permanent pasture, and 30 are given to farmsteads, grassed headlands and watercourses, and woodland. An additional 300 ha are farmed for a retired neighbor under a share-cropping arrangement. That operation is not included in the present analysis. Permanent streams supply water for cattle in the pastures; deep wells service the house and cattle lots. The present cropping plan and normal production levels are given in Table 17.2.

The arable land is subject to two different rotations based on low-cost methods of production. Level lands are in a maize–soybean rotation (MS) while a maize–maize–oat–forage (MMOCl) sequence is used on sloping land. The basic forage crop is a mixture of red clover (a short-lived perennial) and smooth bromegrass. Alfalfa and birdsfoot trefoil (both perennials) are included when the sod is to be maintained beyond the second year. Forages are seeded in spring with oat as a companion crop. The unimproved permanent pastures evolved under grazing and are dominated by common perennial bluegrass with an understory of trefoil.

The cattle herd consists of 120 cows and 5 bulls. On average, 114 calves (95% yield) are reared each year.

The work force consists of father and son as owner–operators. Present value (1990) of land, farmsteads, equipment, and stock is near US$1 700 000. Investments in machinery are significant. The main tractor (225 kW (300 HP), four-wheel drive, diesel) is supported by two 100 kW (133 HP) machines. These tractors are about 30% more powerful than are needed for the annual work of the farm and share-cropped land. Smaller machines would suffice if tillage were done in fall but this farm needs crop aftermaths for grazing during winter and sloping lands need a protective cover of residue. Most of the tillage is done during a short period in spring when the land is sufficiently dry on less than 50% of the days. Timeliness is important and a powerful tractor pulling wide tools at moderate speed represents an efficient means for risk reduction. The main tractor is matched with 8 m chisel plow and tandem disk and an 8 m field cultivator. It can cover 5 ha h^{-1} with the chisel plow on medium soils, and 3 ha h^{-1} on heavy soils. Other major implements include a self-propelled combine harvester (with a row-crop head for maize and cutter-bar head for oat and soybean), baler, cultivators, mowers, grain trucks, hammer mill (for grinding grain), and feed mixer.

Income varies widely from year to year depending on yields and prices (which tend to be negatively correlated) and success in marketing. Gross sales from the 400 ha with average yields range from US$190 000 to US$230 000 per year with about 50% of that from sale of stock. Annual profit (after allowance for owner's labor and management and all costs, including maintenance, depreciation, and land tax), as was the case in Australia, is only 1–2% on capital. That small rate of return explains why almost all American farmland is and will continue to be held in family farms rather than by investors.

Farm operations and income are affected strongly by several government programs. Current programs are responses to world-wide commodity surpluses that have undercut the Corn Belt's traditional role in export trade of maize and soybean. If a farmer agrees to certain acreage limitations on maize production (crop land is 'set aside' and planted to grass) and certain conservation practices, government will accept harvested maize as collateral for short-term loans and provide 'deficiency' payments for the difference between the loan price and a 'fair' price based on costs of production. In addition, erodible crop land may be leased to the government for 10 y periods in a 'conservation reserve program' (CRP). CRP lands must be maintained in grass or planted to trees and, like the set-aside, may not be grazed or harvested for forage.

Set-aside and CRP programs have brought commodity surpluses to manageable levels and have elevated and stabilized farm incomes but not without some negative effects. Rotations are disturbed because farmers feel pressured to maintain large areas in row crops (maize and soybean) in order to meet set-aside requirements. One result is that soybean, which leaves little protective residue, is sometimes planted on erodible land. In addition, the floor under grain prices has made livestock production less profitable.

17.5 MAIZE AND SOYBEAN PRODUCTION

Tillage systems

This farm employs conservation tillage using a chisel plow (Chapter 12). Sloping lands that need protection against erosion with surface residues are plowed in spring. That allows grazing of maize residues ('stover') by cattle during winter but it is difficult to achieve timeliness in spring operations of seedbed preparation. Early planting of maize is important in this region to minimize damage by the European corn borer (*Pyrausta nubilalis*) and corn rootworm (*Diabrotica longicornis*) which begin activity in early summer, and to reduce the risk of injury from drought or high temperatures at anthesis. Soils warm too slowly with no-till for timely planting of maize and that method is used by only a few farmers and only for soybean. To ease the burden of spring operations, our farmers chisel the flatlands in fall.

During land preparation, residues of sod crops (forages) and maize sometimes need to be cut with the heavy disk before chiseling. Soybean offers only light residues and preparation for the following crop of maize is accomplished with disk or field cultivator. Fertilizers impregnated with pre-emergence herbicides are spread by contractors and incorporated with disk or field cultivator during spring tillage.

Maize crop

Maize is the principal crop in this system. Commercial, single-cross cultivars of a '120-day' maturity class are planted, beginning in late April when temperatures can be expected to remain above 13 °C (maize is a C4 species and subject to chilling injury). The crop is drilled with 5.7 grains m^{-1} in 0.76 m rows for a final population of 75 000 ha^{-1} (30 000 $acre^{-1}$). If cold, wet weather delays planting into May, an earlier-maturing cultivar may be used, or, in emergencies, the land may be diverted to soybean. That substitution is not possible, however, where fertilizer and pre-emergence herbicides are already in place.

The normal phenological advance for maize in Iowa is illustrated in Fig. 17.3. Progress is slow during cool weather in spring but in summer, high average temperature and small diurnal amplitude cause a relatively rapid rate of development. As a result, the effective grain-filling period is generally only 38–40 calendar days. In contrast, at Davis, California, in a semiarid environment with nearly the same mean temperature but twice the diurnal amplitude of Iowa, effective grain-filling periods for the same cultivars are 44–48 days. The growth and partitioning

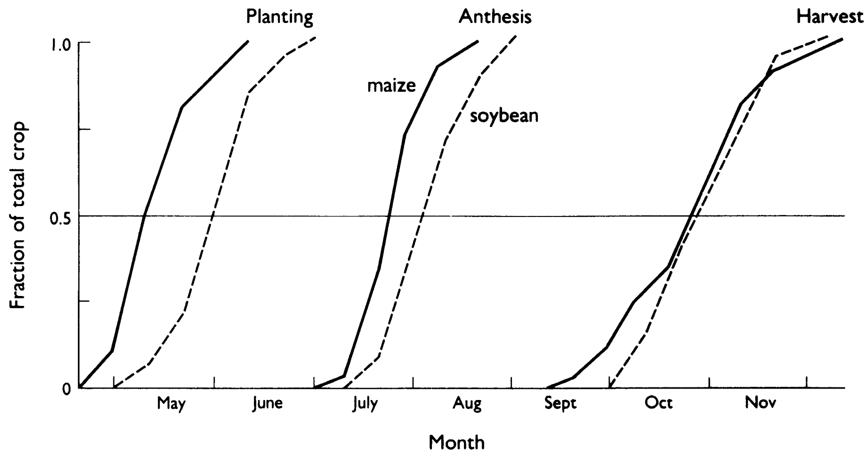


Fig. 17.3. Average seasonal phenology of maize and soybean crops in the western Corn Belt. The graphs depict cumulative occurrence of planting, flowering, and harvest. Distortion in the maize harvest curve occurs when it is interrupted to harvest soybean. Individual years vary from these patterns by as much as several weeks. At the example farm, timing of events falls at about the 50-percentile level. (Redrawn from Iowa Agricultural Statistics (1989).)

patterns for maize presented earlier in Fig. 2.1 are representative of those seen on this farm. The canopy closes about 40 days after emergence and thereafter crop growth rate is nearly constant for 70 d at 150–170 kg ha^{-1} d^{-1}. Peak leaf area index is near 4; assuming 80% interception, radiation-use efficiency is about 1 g biomass MJ^{-1}.

Maize grain contains 0.013 to 0.016 N. With expected yields of 7 ± 1.5 t ha^{-1}, 120 kg N ha^{-1} as granular urea are used on this farm for maize after maize and maize after bean. After forage, 90 kg N ha^{-1} are applied. Our farmers also apply 25 kg P and 75 kg K ha^{-1} for each crop of maize.

Diseases are not a major problem for maize production in Iowa and fungicide treatment of seed is the only general practice. Conservation tillage with surface residues results in a greater frequency of foliar diseases and *Diplodia* and *Gibberella* stalk rots than occurs with moldboard plowing. Resistant cultivars, rotation, and adequate nutrition are the main elements in control. Rootworms and stalk borers are the principal insect pests. Present cultivars offer adequate resistance to borers and insecticides are employed only with severe infestations. Rootworm is controlled mainly by rotation. In maize–maize (MM) sequences, evidence of root lodging in the first year of maize is the basis for banded application of insecticide at planting of the second crop, or for altering the rotation. A population of the northern corn rootworm with an extended, 2 y diapause is an increasing problem in the maize–soybean (MS) rotation. This farm occasionally has problems with other soil insects, particularly after the sod phase in the MMOCl rotation, but no controls are employed.

Weeds offer a serious challenge to maize production, particularly after sod. Intense competition and repeated mowing provide general weed control in the oat–

forage sequence, and herbicides are employed in maize portions of the rotation. Control by those means is significantly less effective, however, than the alternating sequence of maize and soybean herbicides plus tillage found in the MS rotation. The preplant herbicides employed with maize (EPTC or cyanazine and alachlor) usually provide effective suppression of the principal annual grass (foxtail, *Setaria* spp.) and broadleaf species (lambsquarters, *Chenopodium album*; ragweed, *Ambrosia artemisiifolia*). Post-emergence herbicides (2,4–D and dicambia or tridiphane and atrazine) are directed at other dicots including cocklebur (*Xanthium canadense*), pigweed (*Amaranthus* spp.) and perennial bindweed (*Convolvulus arvensis*). Cocklebur has an interesting two-seeded fruit. One seed germinates after one winter, the second has extended dormancy and tends to germinate in the following year. Control of other perennials such as hemp dogbane (*Apocynum cannabinum*), Canada thistle (*Cirsium arvense*), on the other hand, is poor because they tend to escape damage by the chisel plow. The wide sweeps of the field cultivator are effective on perennials but our farmers find it useful to also mechanically cultivate maize with sweeps once after emergence and to spot spray thistle and other persistent weeds with specific herbicides.

Maize grain maturity, indicated by formation of a black layer at the base of the grain, occurs at a rather high moisture content (*ca.* 0.23). The crop can be left standing to dry naturally to a safe storage level (0.15) but that involves exposure to weather and lodging damage, particularly when harvest is delayed by rain. Yields are less and risks are reduced only a small amount with early maturing cultivars. The general practice in the Corn Belt is to combine-harvest the grain wet (0.18 to 0.22 moisture) and dry it artificially. Elevator companies provide that service. Our farmers are able to do it more cheaply, however, with a 500 t storage building equipped with a propane-fired drier plus two 500 t storage units for dry grain. This practice also allows more flexibility in marketing. Part of the crop is sold and part is fed to the growing cattle.

Soybean crop

The soybean cultivars grown in this system have shorter life cycles than maize (Fig. 17.3). That distributes spring field work more evenly because beans are planted in early May after maize operations are completed.

Soybean is grown only in the MS rotation and tillage consists of heavy disk (if needed) followed by chisel plow and field cultivator. This tillage system leaves insufficient residues for erosion protection on sloping land, however, and the MS rotation is limited to level soils. Locally grown seed of commercial cultivars is drilled in 0.76 m rows with a final stand near 325 000 ha^{-1} (130 000 $acre^{-1}$). Use of the same row spacing for both maize and soybean simplifies planter adjustments to change of plates and depth control and eliminates the need to adjust wheel spacings of tractors during post-emergence cultivations.

Farmers in this region do not apply rhizobia inoculum to soybean because the soils are populated with rhizobia and there is no measurable benefit from specific inoculum. Small 'starter' applications of nitrogen (*ca.* 40 kg N ha^{-1}) are employed by some farmers but are omitted from our budgets. Soybean establishes full cover in about 45 days and eventually reaches LAI 4 or more. During the period of full cover, crop growth rates are nearly constant (Hanway & Weber 1971) and, for our crop, would average 14 g m^{-2} d^{-1} for about 45 d. Radiation utilization with 80% interception is near 0.9 g biomass MJ^{-1}. As was the case for maize, our farmers' yields are about average for the Corn Belt (2400 ± 500 kg ha^{-1} at 0.12 moisture). Attainable yields at the best locations exceed 4000 kg ha^{-1}.

No serious insect or disease problems interfere with soybean production in this part of Iowa. No seed treatment is used and insect control is limited to suppression of spider mite in dry years.

Weed problems with soybean are similar but generally less severe than those encountered with maize. If the maize program is successful, then the bean ground will be relatively clean. Preplant applications of alachlor or metolachlor herbicides are incorporated with the field cultivator and followed by a post-emergence herbicide (usually chlorimuron), if needed, and cultivation. Tall weeds and volunteer maize that emerge from the canopy are sometimes attacked with glyphosate herbicide from an overhead 'wick' boom. The height of the boom is set to contact foliage of plants that emerge above the crop.

Soybean is also combine-harvested. In this case, grain is delivered directly to the elevator since none is consumed on the farm. Marketing can be delayed if storage fees at the elevator are met. Because soybean is more subject to lodging and shattering losses than maize, the crop is harvested when mature in early October; maize harvest is worked around that of soybean (see Fig. 17.3).

17.6 OAT AND FORAGE PRODUCTION

The forage needs of this farm are significant. With a base of 120 cows, the minimum annual feed requirement is more than 700 t dry matter of which nearly 200 t is legume–grass hay (Table 17.3). This is produced in the sod phase of the MMOCl rotation. After 2 y of maize, erodible lands are disked and broadcast seeded in early spring to legume and grass forages with oat as a companion crop. Improved cultivars of each are used. Farmers sometimes save their own oat seed, one of few such examples remaining in the Corn Belt. The seed are incorporated with the field cultivator or light disk harrow. These simple methods generally provide good stands of both oat and forage providing care is given to achieving an even distribution of a high rate of forage seed. Variations in legume stands, in addition to lowering forage yield and increasing opportunities for weeds, cause spatial variability in the supply of nitrogen to subsequent crops. No herbicides are used for weed control during the two years of the oat–forage sequence.

The companion oat crop is combine-harvested in midsummer (yields average 2100 kg ha^{-1}). The straw is normally baled and saved as bedding for livestock. Developing stands of forages are left alone during the remainder of the first year unless mowing for weed control seems desirable. Some grazing is done in dry years when bluegrass pastures are unproductive. In the second year, the forage is cut three times, sun-cured, and put up in round, 600 kg bales. The bales are stored on high

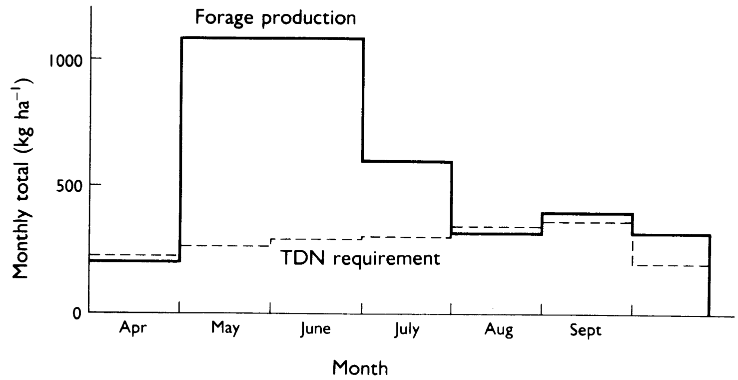


Fig. 17.4. Monthly patterns of dry matter production in bluegrass pastures, and TDN requirements of 1.25 cow–calf units per hectare. The factor 1.25 adjusts for stocking rate. Because the TDN value of the forage is only 0.7, hay must sometimes be fed in late summer and fall. (Data from Littlefield (1980).)

ground in field margins where they can be accessed in winter. Storage losses of 5–10% can be reduced by wrapping the bales in polyethylene but that practice is not common. In the third year, the sod is normally returned to maize.

Forage mixtures vary. Red clover and smooth brome are the principal components on this farm but alfalfa and birdsfoot trefoil are also included. Digestibility of the hay by cattle is low (about 0.55) but palatability and intake are good. The market value of such hay is low and while surplus supplies can be sold locally, intensive dairies in adjacent states (Wisconsin, Minnesota) turn in emergencies to high quality alfalfa produced in the Great Plains. Our farmers prefer clover to alfalfa because of a smaller risk of winter injury but that problem is less with new cultivars and pure stands of alfalfa (with or without the oat companion) are now used on some farms in this area.

17.7 PASTURE PRODUCTION

The 100 ha perennial-bluegrass pasture is the least intensively managed portion of the farm and, in some years, is its weakest link. These pastures evolved from prairie communities dominated by big bluestem grass with native bluegrass as only a minor component. The pastures are now dominated by Kentucky bluegrass, which seems to be of Eurasian origin and to have migrated through North America with settlers and wild animals.

Growth resumes in spring as temperatures rise in late April. The seasonal pattern of production is illustrated in Fig. 17.4 along with the forage requirements of the herd. Calculations in Table 17.3 reveal that the herd will need only 246 t of the 400 t dry forage produced in average years and forage is surplus in late spring but frequently in short supply in late summer. Such mismatches plague most grazing systems. The size of the cow herd is balanced optimistically to normal years. Palatability and digestibility (0.7) of the young forage are excellent but quality declines if the grass is undergrazed. Some rest is desirable for rhizome growth in bluegrass to insure stand vigor. The pastures are fenced in units to allow rotation during the season but most rhizome growth occurs during the undergrazed period in spring.

Nitrogen dressings (40–80 kg N ha^{-1} y^{-1}) increase the yield of bluegrass and extend its production later into summer but generally are not economic. Birdsfoot trefoil produces well in late summer and also is a desirable component of the sward for its nitrogen contribution and its tolerance of wet soil (Colo in this example). Pastures can be improved by seeding trefoil into narrow, tilled strips but the expense is generally not justified by returns. Cropping to maize or oat as a basis for reseeding with superior grasses and legumes is impractical because of slope, wetness, and water courses.

Bluegrass and trefoil are intolerant of acid soil. The pastures are amended occasionally with lime because the soils tend to acidify under grazing due to base metal extraction and leaching. The pastures are usually mown once in summer for weed and brush control. The original savannah was maintained by fire. With elimination of fire, the tendency for succession to brush and trees is very strong. Canadian thistle is a special problem requiring spot sprays of herbicides.

17.8 CATTLE OPERATIONS

Annual plan

The beef herd consists of 120 head of cross-bred English cows (Angus × Hereford breeds, black with white face) and five European bulls (Limousin, Charolais, and Simmental breeds). The cows and bulls are purchased from other farmers who engage in purebred programs with the various breeds. The farm employed a local strain of large, purebred, English Shorthorn cattle during its first 100 y, and this new herd represents a sharp change in animal husbandry. The principles underlying the crossbred cows are to have small (500 kg, 1100 lb) animals for minimum feed requirement yet hardy of severe winters. In addition, the Angus strain carries with it a trait for small-headed calves (fewer calving problems). The bull breeds also favor small head size. More important, they throw 36 kg calves of high growth rate with a good size at weaning (190 kg at 5 months), a slightly greater dressing percentage to red meat, and a smaller fat content than traditional English breeds.

The general plan of cattle operations is as follows. The cows are turned to pasture for calving when grass growth begins in April. Calving extends over an 8–10 week period during which bulls are segregated from the herd. The animals have access to mineral supplements while on pasture. Calves are weaned in November (after crop harvest) and put in the feeding lot on hay with supplements of grain and minerals. Feeding is done on a concrete platform where the growing calves have ready access to feed, shelter, and water. The cattle are vaccinated and wormed at various times in the year. The male calves are castrated by pinching when young. All animals are deliced in the fall, and calves are given hormone implants when they enter the feedlot.

At weaning, the cows are culled, based on pregnancy tests, condition, and age, and turned into stalk fields with access to shelter from severe winter storms (sheds and woodlands serve as windbreaks). Between 10 and 15% of the cows are replaced each year. The supply of maize stover, including a small amount of lost grain, averages 6000 kg ha^{-1} with digestibility near 0.6. Grazing in stalk fields is limited by snow cover, wetness, and by the need to retain about 4000 kg residue ha^{-1} until the beginning of spring tillage.

Feeding of the calves begins in earnest in January when the hay ration is reduced and concentrate (ground corn mixed with soybean meal, antibiotics to optimize rumen flora, and mineral supplements) is supplied *ad libitum*. The TDN factor for the ration is near 0.85. The calves remain on full feed until their sale in September at 500 kg live mass (1100 lb).

Feed requirements

The annual pattern of TDN and dry matter use by the cattle operation is summarized in Tables 17.3 and 17.4. For simplicity, rations were calculated on a TDN basis (total digestible nutrients; the mass equivalent of DE in Table 1.3), rather than net energy (NE); TDN values tend to underestimate the merit of hay and overestimate that of concentrate. Given the seasonal movement of animals and diets common in this area, Table 17.3 was constructed by using TDN requirements assembled by Littlefield (1980). In Table 17.4, the amounts of hay and concentrate are increased by 10% to 194 t and 200 t, respectively, to accommodate waste in feeding. The critical role of forages in ruminant diets is apparent. The annual requirement of 468 t TDN is met 70% from roughage and 30% from concentrate. Only 10.5 t or 1.5% of the 711 t is purchased oil-seed meal. For simplicity, stover consumption from stalk fields is shown only during late fall (October–December). In practice, cows and bulls are left there as long as a supply of feed remains in order to minimize their maintenance cost. The 60 t of stover consumed translates to 462 kg ha^{-1} of the 6000 kg supply.

This budget uses 194 t of the normal annual supply of 240 t hay. That seems like a generous margin but, with losses in storage and the need to supplement pastures in drought years, hay is sometimes in short supply. The option of additional use of stover adds a margin of safety, however. The animal-carrying capacity of this farm could be increased significantly through pasture improvement (e.g. by fertilizer) and through expansion of acreage given to forages. That route is likely with a further decline in grain prices because cattle would then provide greater added value to the maize. The grain base would also support a return to swine production; our farmers have avoided that because of the large capital and labor requirements. Instead, they buy additional feeder cattle (weaned calves) at local markets when prices are favorable.

The average gain per animal in the feedlot is 310 kg (500 kg finish − 190 kg at weaning) providing a total gain of 35.3 t for the 114 animals on feed. A total of 247 t of feed (36 t hay + 211 t concentrate) is used to achieve that. That ratio, 247/35.3 = 7

Table 17.3 *Feed requirements for a 120-cow beef herd and for feeding the 114 calves produced each year*

Data are for the example Iowa farm. TDN requirements are from Littlefield (1980); TDN factors are from the National Research Council (1982). The patterns of feed sources employed are typical for central Iowa; H, hay; P, pasture; and S, maize stover.

Month: Cows on:	Jan H	Feb H	Mar H	Apr H–P	May P	June P	July P	Aug P	Sept P	Oct P–S	Nov S	Dec S–H
TDN requirements, kg animal^{-1} day^{-1}												
Cow	3.68	3.81	4.13	6.08	6.67	6.67	6.67	6.08	5.40	4.80	3.54	3.59
Calf	—	—	—	0.18	0.50	1.00	1.50	2.00	2.81	3.68	—	—
Lot-fed	4.45	4.68	4.95	5.18	5.40	5.63	5.86	6.08	6.31	—	3.95	4.19
Bull	4.31	4.31	4.31	4.31	4.31	4.31	4.31	4.31	4.31	4.31	4.31	4.31
Number of animals												
Cows	120	120	120	120	120	120	120	120	120	120	120	120
Calves	0	0	0	60	116	115	114	114	114	114	—	—
Lot-fed	114	114	114	114	114	114	114	114	114	—	114	114
Bulls	5	5	5	5	5	5	5	5	5	5	5	5
Total TDN/d	970	1012	1081	1353	1496	1579	1661	1673	1710	1017	897	930
Days	31	28	31	30	31	30	31	31	30	31	30	31
TDN/month	30 070	28 340	33 530	40 580	46 380	47 370	51 490	51 860	51 300	31 520	26 900	28 840
TDN sources												
Hay	16 120	15 010	17 800	13 310	2440	2360	1770	1770	1710		8378	16 529
Stover										15 760	13 400	7000
Pasture				11 280	26 620	27470	30 790	30 360	29 710	15 760		
Feed	13 960	13 330	15 720	15 990	17 330	17 540	18 930	19 730	19 870		5130	5300

Table 17.4 *Summary of feed consumption (t y^{-1}) by the beef herd*

Source	TDN	TDN factor	Dry matter	Waste allowance	Total feed
Hay	97	0.55	176	18	194
Stover	36	0.60	60	—	60
Pasture	172	0.70	246	—	246
Grain	154	0.85	182	19	200
Soybean meal	9	0.85	11	—	11
Total	468	0.69	674	37	711

kg feed kg^{-1} gain, is better than the Iowa average (8 ± 1kg kg^{-1}) reflecting the small (190 kg) entry mass and the high proportion of concentrate in the ration. The average daily gain, 0.93 kg (2.04 lb), is also within the range found in an Iowa survey. In southern Iowa, greater returns are obtained by moving calving to March and April, placing calves on full feed in fall, and marketing in late spring. At our location, however, the Colo soil is too cold in early spring for the grass growth needed in that practice. On a herd basis, total feed consumption of the herd (711 t) divided by total gain of calves (114×500 kg = 57 t) is 12.5 kg feed kg^{-1} gain.

17.9 HYDROLOGY

ET* of maize crops in this environment, provided with adequate water supply, is near 610 mm and that of soybean about 560 mm. Annual precipitation (840 mm) exceeds those levels but summer rainfall is only about 450 mm and the balance of crop requirements must be met from soil moisture that accumulates during the fallow period. Drought is a principal factor limiting yields of crops and pastures to moderate levels; brief periods of drought occur in most summers and severe drought is experienced one year in 10.

The soil freezes in winter, and fall tends to be dry, therefore most profile replenishment occurs in spring. In addition to some sublimation of snow during winter, rapid snow melt coupled with spring rains result in significant runoff; runoff also occurs with heavy summer rains. The cropland averages 130 mm annual runoff. Runoff from pasture is less but its complete cover tends to be offset by steepness and 50–60 mm loss is common. With an undulating landscape, runoff–runon patterns occur and lower lands tends to receive too much moisture and generally must be protected by diversion channels constructed along the base of hills. Subsurface drainage is also needed for successful crop production.

Approximate hydrologic budgets for the various crops are presented in Table 17.5. The risk of drought is apparent: consumptive use by good crops of maize and soybean amounts to 70% or more of annual precipitation and the standard deviation for precipitation is 150 mm. The marked increase in drainage under cropping is a general phenomenon in agriculture since the duration of green cover is less than with natural vegetation. This contributes to the need for subsurface drain lines.

Table 17.5 *Approximate annual hydrologic terms for various crops in central Iowa*

Crop	Precipitation (mm)	Runoff (mm)	Winter ET (mm)	Summer ET (mm)	Drainage (mm)
Maize	840	125	30	610	75
Soybean	840	125	30	560	125
Pasture & other	840	85	30	700	25

Source: Personal communication of R. Kanwar & E. Taylor, Iowa State University.

17.10 NUTRIENT DYNAMICS

As was the case with the Australian farm, operations on this farm reveal the importance of considering nutrient dynamics on a farm basis. Our focus on nitrogen cycling begins with calculation of amounts of nitrogen consumed by the animals and amounts that can be recycled in manure.

To estimate amounts of nitrogen in dung and urine, feed intakes from Table 17.4 were converted to N by using factors for the N content of the feeds (Table 17.2). The annual intake of the herd is 14.3 t N (Table 17.6). Calculations of amounts of nitrogen entering the feedlot and exiting to market were done by using a gut-fill regression from the Agricultural Research Council (1980) and nitrogen-content coefficients for empty-body and carcass masses from Garrett & Hinman (1969). Nitrogen in gut fill was estimated from data on digesta in cattle and sheep (Table 9–1 in Church (1976)). Export per marketed animal was:

Live mass	500 kg	
Gut fill	66 kg	
Empty-body mass (EBW)	434 kg	
N in EBW (0.027 × EBW)	11.7 kg	
N in gut fill	0.2 kg	
N per animal	11.9 kg	
N per dressed carcass	7.4 kg	(0.017 of EBW; 0.025 of carcass)

Total export then is 114 animals × 0.0119 t N animal^{-1} = 1.36 t N of which 0.84 t is in red meat. Similar calculations indicate that 0.11 t of that nitrogen was accumulated during gestation, 0.39 t during grazing on pasture, and 0.86 t in the feed lot. It is assumed that the nitrogen content of cows sold is matched by that of replacement cows. Therefore, 4.91 t N intake from pasture (Table 17.6) − 0.39 t N exported with cattle = 4.52 t N deposited in dung and urine in pastures; for the lot, 5.55 t N in feed (Table 17.6) − 0.86 t N exported = 4.69 t N deposited in manure. For field and shelter areas, 3.73 t N were consumed, 0.11 t N exported, and 3.62 t N excreted.

Nitrogen in dung and urine deposited by animals grazing pasture and stover recycle (or is lost) in the same fields. It is assumed that 30% of the nitrogen deposited during grazing is lost through volatilization of ammonia. Manure gathered from winter shelters where hay is fed, and the feedlot, is collected and

Table 17.6 *Annual intake (t) of feed and its content (t) of N, P, and K by the beef herd on the example Iowa farm arranged by sources of feed and place of feeding*

The example follows from Table 17.4 for a 120-cow herd producing 114 calves a year. The nutrient content factors came from Table 17.2.

	Source of feed					
	Hay	Pasture	Stover	Maize	Meal	Total
Total feed:	194	246	60	200	10.5	711
Place of feeding and total nutrient content						
N pasture	—	4.91	—	—	—	4.91
N field	—	—	0.54	—	—	0.54
N shelter	3.19	—	—	—	—	3.19
N lot	1.67	—	—	3.20	0.67	5.55
Total N	4.86	4.91	0.54	3.20	0.67	14.19
P pasture	—	0.83	—	—	—	0.83
P field	—	—	0.19	—	—	0.19
P shelter	0.40	—	—	—	—	0.40
P lot	0.08	—	—	0.58	0.07	0.73
Total P	0.48	0.83	0.19	0.58	0.07	2.15
K pasture	—	4.85	—	—	—	4.85
K field	—	—	0.92	—	—	0.92
K shelter	2.58	—	—	—	—	2.58
K lot	0.57	—	—	0.74	0.23	1.54
Total K	3.15	4.85	0.92	0.74	0.23	9.89

applied as an external input to cultivated fields. Some composting occurs with the lot manure. We assume, optimistically, that about 40% of the nitrogen deposited in shelter areas ($0.4 \times 3.20 = 1.28$ t N), and 50% of that deposited in the lot ($0.5 \times 4.69 = 2.35$ t N), a total of 3.63 t N, can be recycled and added to soils in cultivated fields. The balance of the nitrogen deposited in shelter areas and lot (4.25 t N) seems to be lost mainly to the atmosphere. Runoff losses (mostly as suspended organic matter) have been increased slightly for the grazed areas and manured fields. Support for the assumption that runoff of mineral nitrogen is small comes from estimated total runoff (area in Table 17.2 × runoff per ha in Table 17.5) and observations that nitrate concentrations in the Skunk River decline sharply when runoff dominates stream flow (Baker & Johnson 1976). Because only 1 t of NO_3-N would bring its concentration in total runoff from this farm (*ca.* 200 000 m^3) to 0.36 mM, it seems that any significant loss through runoff would have to be in organic forms.

Phosphorus and potassium are not subject to gaseous losses and therefore survive better in manure than does N. Loss of P by leaching and runoff after spreading is less than for N while that of K is greater. About 1 t P and 4 t K are deposited in collectable manure on this farm.

Construction of nitrogen budgets for various fields (presented in Table 17.7) is

Table 17.7 *Estimated average annual nitrogen fluxes in the Iowa crop rotations ($kg\ ha^{-1}\ y^{-1}$)*

System:	MS		MMOCl				
Crop:	Maize	Soybean	Maize-1	Maize-2	Oat-Cl.	Grass–clover	Pasture grass–clover
Area (ha)	50	50	40	40	40	40	100
Supplies to soil							
Deposition[1]	15	15	15	15	15	15	15
Mineralization	80	80	90	80	45	25	20
Residue, previous crop[2]	44	48	80	48	48	40	50
Symbiotic fixation	0	120	0	0	30	130	12
Manure[3]	27	13	5	20	10	5	32[4]
N fertilizer	120	0	90	120	0	0	0
Total supply	286	276	280	283	148	215	129
Removals from soil							
Plant uptake	160	204	160	160	106	170	100
Immobilization	80	80	80	80	50	30	20
Volatilization	2	0	2	2	0	0	14[4]
Runoff	6	4	6	5	4	2	2
Leaching	5	5	5	5	3	2	1
Denitrification	9	7	4	5	3	2	4
Total removal	270	300	257	257	166	206	145
Balances							
Crop removal[5]	−112	−160	−112	−112	−44	−150	−4
Losses[6]	−22	−16	−17	−17	−10	−6	−21
Total output	−134	−176	−129	−129	−54	−156	−25
External input[7]	162	148	108	155	55	150	25
Annual balance[8]	28	−28	−21	26	1	−6	0
Cycle balance		0				0	0

Notes:

[1] 8 kg N ha^{-1} in rain and 7 kg as dry deposition and free fixation.

[2] Residue N is the net of residue and manure from stover grazing.

[3] Manure supplies 3.63 t N net to soil distributed equally to maize after soybean and maize after maize for an average of 40 kg $ha^{-1}\ y^{-1}$. Availability of this nitrogen is distributed with the decay series 0.5, 0.25, 0.125, and 0.125 over successive years (Midwest Plan 1985).

[4] 70% of manure N deposited during grazing is cycled to the soil; 30% is shown as volatilization.

[5] Harvested crop × N content given in Table 17.2; meat export from pasture is explained in text.

[6] Sum of volatilization, runoff, leaching, and denitrification.

[7] Sum of deposition, fixation, manure from external sources, and fertilizer.

[8] Imbalances within and between years include undecomposed manure and residues plus some mineral N.

rather subjective because only a few of the fluxes can be estimated closely. Average crop yields and fertilizer applications are known but rainfall (and thus runoff and drainage), yields, nitrogen contents of produce and residues, nitrogen fixation, and nitrogen processes in soils are all subject to considerable spatial and temporal variation. No allowances have been made for differences in the yield potential of various soils and only slight differences in their nitrogen dynamics are shown. For simplicity, the set-aside is not included in the rotations.

Observations of nitrogen deposition through precipitation in this part of Iowa range from 4 kg ha^{-1} N y^{-1} (in 1985–7; personal communication, National Atmospheric Deposition Program) to 12.5 kg N ha^{-1} y^{-1} (in 1971–3; Tabatabai & Laflen 1976). Dry deposition is not known. The difference in these observations may reflect nearness of the collection stations to sources of cattle (more than 5 kg ammonia-N ha^{-1} y^{-1} is lost from manures on this farm), or changes in cattle numbers between the 1970s (12×10^6 cattle in Iowa) and the late 1980s (4×10^6). To be conservative, we have been generous in estimating inputs; the present analysis uses 8 kg ha^{-1} for wet deposition and takes 7 kg as an additional allowance for dry deposition and fixation by free-living bacteria.

Mineralization of nitrogen in tilled soils was assumed to equal 0.012 y^{-1} of total organic nitrogen content typically found in the surface layer (0.3 m) of these soils under cropping; that corresponds to about 0.03 y^{-1} of an active stabilized fraction of the organic matter (Chapter 8). Smaller values were assigned to sod crop and pastures. In the real farms that served as models, yields and fertility practices have changed little in 15 y so we assumed that organic matter formation equals mineralization. Carry-over N in residues was set to the N content of residues at harvest. The fixation flux for soybean was set at 58% of plant uptake, in line with observations on moderately fertile land (Fig. 8.5) (Diebert *et al.* 1979), while that for clover was set to balance plant uptake within years and over the cycle. Fixation inputs, like those for rainfall, residue, and manure, are generous yet within the range of common observations.

Variables considered in the analysis to this point involve relatively large fluxes. The magnitudes of volatilization, leaching, and runoff fluxes are smaller and are not estimated easily. The total of such losses was obtained by difference from the other numbers; the distribution was made with help from observations reported by Kanwar *et al.* (1988*a*, *b*), with adjustments for soil type and position in rotation. Those estimates can be compared with observed concentrations of NO_3-N in drainage waters by placing the leaching estimate into the expected depth of drainage given in Table 17.5. The 5 kg N ha^{-1} (357 mol) for soybean would be diluted into 1250 m^3 of drainage yielding a 0.3 mM effluent (i.e. 4 ppm NO_3-N); with maize, 5 kg would be diluted into 750 m^3 and the effluent would be 0.5 mM (7 ppm NO_3-N). Waters from wells, tile drains, streams, and lakes in Iowa range from 0.2 to over 1.0 mM NO_3-N; the approximate annual average observed for the Skunk River in 1972 was 0.7 mM (Baker & Johnson 1976).

Complex models of this sort deserve analysis of their sensitivity to important underlaying assumptions. To illustrate the frailty of this model, a decline in the nitrogen content of maize grain from 0.016 to 0.015 reduces nitrogen export in grain by 7 kg ha^{-1}; those 7 kg would allow for large increases in the estimates of nitrogen losses in Table 17.7. One obviously must be careful about placing confidence in small numbers estimated from differences between large, uncertain variables. Confidence in the present analysis is reinforced by the general agreement between calculated and observed concentrations of nitrogen in drainage waters. In contrast to the fields, the nitrogen fluxes calculated for the cattle herd from feed requirements agree remarkably well with farmer and research experience. Farm management would be a much easier task if crops and soils behaved as predictably!

17.11 ASSESSMENTS

Production efficiency

This farm has only a small efficiency in the conversion of short-wave radiation to chemical energy in plant material. The maize crop converts 0.9% of the radiation received during its growing season to above-ground biomass but only 0.5% to grain. The pasture is the least efficient component with an efficiency of only 0.2% conversion to forage. Water-use efficiency, by contrast, is reasonably good: 21.4 kg biomass ha^{-1} mm^{-1} ET and 11.5 kg grain ha^{-1} mm^{-1} ET for maize. The pasture produced only 5.7 kg forage ha^{-1} mm^{-1}. Total above-ground production on cultivated land and pasture is 2870 t y^{-1} or 7970 kg ha^{-1} y^{-1}. Average ET is 648 mm y^{-1}; therefore production is 7970/648 = 12.3 kg ha^{-1} mm^{-1}. That production corresponds to about 1400 t of human-edible grain equivalents or enough for 2800 people. Because of rotations and manure transfers, nitrogen-use efficiency is most meaningful on a whole-farm basis. The farm exported 22.6 t N or 66% of the 34.1 t that it received; 5.9% of the 14.2 t N consumed by all cattle and 9.4% of that fed in the lot were exported in meat (Table 17.8).

Interesting measures of efficiency could also be constructed for other nutrients, for the use of fuel, and for amounts of total external energy embodied in fuel, machines, land improvements, and labor.

Erosion

Control of erosion is an important goal of the cropping plans on this farm. With conservation tillage, the MMOCl rotation is capable of limiting erosive movement to less than 1 t soil ha^{-1} y^{-1} on 6–8% slopes of the Downs soil (calculated with USLE; see Chapter 12). Cropping on contours with alternate strips of forage and maize and retention of at least 35% cover by residues after planting are necessary features of the system. The slopes form a confused pattern, however, and contour cropping is only approximate. In addition, considerable care is needed to retain 35% cover after tillage. Maize stover provides more than 70% cover in fall but a single pass in spring with disk or chisel can reduce that below 35% in some cases. Slopes steeper than 6–8% need as much as 50% cover by mulch after planting for erosion protection. That can be achieved in no-till systems if one accepts their disadvantages. Alternatives for steep slopes include a longer sod phase, terracing, or conversion to grass.

Table 17.8 *Import–export nitrogen balance for the Iowa farm*

Input in seed is ignored. The total for volatilization assumes that most of the loss from manure occurs in that manner rather than by denitrification.

Inputs to the farm		Outputs from the farm	
Deposition	5.4	Maize sold	11.4
Symbiotic fixation	13.6	Soybean sold	8.0
Fertilizer	14.4	Oat sold	1.8
Soybean meal	0.7	Cattle sold	1.4
Total input	34.1	Sales	22.6
		Volatilization	5.4
		Denitrification	2.3
		Runoff	1.3
		Drainage	1.3
		Losses	10.3
		Hay reserve	1.2
		Total output	34.1

Nitrogen

Large losses of nitrogen occur on this farm despite reasonable care of manure and minimum use of fertilizer (Table 17.8). A surprising finding is that annual losses of nitrogen from manure (4.3 t from feeding stations + 1.4 t from grazing = 5.7 t) are greater than those from cropland (3.9 t). In addition, it seems that most of the total loss of 10.3 t is to the atmosphere through volatilization of ammonia and denitrification in manure and soil. One benefit of those processes is that they served to limit the nitrate flux to drainage. Only 40% of the nitrogen input is from fertilizer while 60% is supplied by deposition and fixation; losses are distributed among all of those sources, not just from fertilizer.

One message in Table 17.7 is that fluxes of more than 160 kg mineral N ha^{-1} are in fact required to produce even average crops. Estimates of leaching losses amount to only a few percent of supply, and lowering them significantly may prove difficult. Possibilities for side effects from this farm are apparent in the average concentration of nitrate in drainage, 0.5 mM, which is only slightly less than the standard set by the US Public Health as the maximum safe level for drinking water (0.7 mM; 10 ppm NO_3-N). That 10 ppm standard is set at about 0.1 of the level at which health problems are sometimes observed and thus is conservative (Lee 1970). A level of 0.5 mM is sufficient for eutrophication of surface waters, however, promoting growth of green algae in lakes and streams; with green algae, streams and lakes in this region are clear in contrast to the cyanobacterial blooms that occur here in low-nitrogen waters.

Our farmers practice a conservative program of fertilization but excessive use of nitrogen fertilizer occurs elsewhere in the Corn Belt. Surveys of maize fields in northeastern Iowa using soil and plant analyses (El-Hout & Blackmer 1990) demonstrated large excesses of mineral nitrogen. Reasons for the excess are not clear. The low cost of nitrogen fertilizer, concerns of farmers about risks of under-fertilization, and their reliance on fertilizer dealers and applicators for advice are cited as factors. Part of the problem also is that farmers have no good means for estimating legume and manure contributions to soil nitrogen and no means for predicting weather and thus crop needs.

Nitrogen fertilizer that is broadcast and incorporated is protected from loss through runoff and volatilization but it is more vulnerable than banded applications to immobilization and denitrification. Blackmer *et al.* (1989) have established 20 ppm NO_3-N in surface soil after emergence in late spring as the CNC_s (Chapter 12) for maize in Iowa. Analyses at that time catch both mineralization that occurred during the fallow and preplant fertilizer. This test would support an alternative practice involving a conservative initial application banded at planting. A second, banded application, adjusted according to the soil test, could be applied later if needed. That approach would provide insurance against both over- and under-fertilization and would be more efficient than the broadcast-incorporation method used on this farm. Side-dressing is more costly than broadcasting, however, in addition it causes traffic damage and surface residues can interfere with the equipment. The alternative of simply using less fertilizer would result in a significant loss of income in favorable years and, with less cover, an increased risk of erosion. Short-season cultivars would allow more drainage, diluting the leachate, but that also would reduce yield and, with a longer fallow, total loss of N and erosion might actually increase.

Herbicides

Contamination of ground and surface waters with herbicides is also a concern. Herbicides have had a dramatic impact on farming, not only through reduced weed competition, but also in reduced tillage. Before herbicides were available, spring tillage on this farm generally involved a sequence of disk, moldboard plow, disk harrow, and tooth harrow. That was followed by two post-emergence cultivations. Conversion of the Corn Belt to conservation tillage was made possible by the appearance of atrazine in the 1970s. Mulch cover is now greater and erosion less than before.

Herbicide systems are not without problems. Atrazine, for example, was too successful. Repeated year after year, tolerant populations of weeds were selected and its effectiveness declined. One reason for atrazine's original success was its resistance to degradation but that and its solubility result in contamination of drainage waters. Similar problems can occur with cyanazine. The solution employed on this farm is to emphasize less persistent materials and to rotate herbicide systems as well as crops. Fortunately, most of the herbicides used here have very low toxicity to mammals although toxicity to fish can be a problem.

Weeds have a strong impact on production in this environment and few practical alternatives exist to our farmers' heavy reliance on high planting densities, rotation, tillage, and incorporated preplant herbicides for weed control. Performance of preplant materials varies with rainfall, temperature, and soil pH but, at present, they represent the most effective and cheapest solution. The heavy residue mulches needed on the steeper slopes for erosion control interfere with both cultivation and topically applied herbicides. Clearly, there is a need for better herbicides that are effective under a wider range of moisture conditions with less risk to the environment.

Farms in transition

Some insights into the difficulty of optimizing farm management emerge in our analysis. A degree of inefficiency is inevitable when farming with uncertain weather and uncertain markets. Not so obvious is the fact that some part of the system is always obsolete or lacking balance with other parts. As the productivity of labor and animals continues to increase, Iowa farms continue in transitions begun 160 y ago. They are seldom optimally structured, in the sense that field areas and types, and species and numbers of livestock, match well with labor supply, equipment, managerial skills, and current markets. Furthermore, skilled farmers are not born but emerge after years of experience: years during which mistakes and inefficiencies occur. Changes in technology and markets call for new skills and adjustments throughout the system and that requires time and capital. A change in the tillage system or a return to swine production, for example, would involve heavy capital expenses for this farm. With present prices and labor productivity, the most practical change may be to increase the scale rather than the intensity of farming. Local experience demonstrates that two active workers can manage crop and beef operations efficiently on 1000 ha farms.

17.12 OUTLOOK

This farm characterizes the extensive nature of most agriculture in North America. Farms throughout the Corn Belt, Great Plains, and the Gulf and Atlantic coastal regions, while emphasizing different crops, are similar in ownership, capital structure, and emphasis on labor efficiency. Matching of crops and methods of production with soil capability and rainfall enables these farmers to maintain extremely low costs in the production of bulk commodities and livestock. The Iowa system appears relatively simple, yet it is quite complex and sophisticated in detail and surprisingly demanding of managerial skills.

Productivity levels are modest. Significant enhancement seems possible through labor intensification in both management and operations. Pasture production, for example, could be significantly enhanced by drainage, renovation, fertilizer, and additional lime. Irrigation, and management of crop nutrition through greater use of soil and plant analyses would increase yield levels and improve yield stability. None of those directions appear to offer benefits in excess of costs and risks, however. Home computers, now coming into use for records of field, herd, and financial affairs, could help in identifying aspects of the enterprise most deserving attention. These farmers present a seeming contradiction with conservatism and caution on one hand and rapid evolution and change on the other. With so many elements in the system, the philosophy is to leave the working parts 'well enough alone'. Not so with weeds, however, which are the most intractable problem to these farms. No present method of control is sufficient or economical and the farmers continue to experiment with new approaches.

Despite its limitations, the nitrogen-cycling model was rewarding of insights to the operation of the system and roles of legumes, livestock, fertilizer, and deposition were brought into perspective. Cattle were revealed to be the major avenue for nitrogen loss. By contrast, the small loss by leaching is a greater off-site issue. A better model, in particular, one that properly predicts temporal variations in microbial activity, is needed for a truly accurate picture of nitrogen cycling. Even without that, the farmers do surprisingly well in nitrogen management through continual observation and adjustment of practices. It would be a useful exercise to see what emerged from a similar analysis for potassium and phosphorus.

17.12 FURTHER READING

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