Cultural Practices: Focus on Major Barley-Producing Regions

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Chapter 9

Cultural Practices: Focus on Major Barley-Producing Regions

EUROPE

1 John R. Garstang and John H. Spink

EUROPEAN PRODUCTION AND YIELD TRENDS

In the 4-year period from 2002 to 2005, the 27 member States of the European Union (EU) produced 41% of the world barley crop from 25% of the 56.7 Mha under cultivation globally (FAO 2008). The 58.4 million tons of grain from the EU was produced from 13.9 Mha, giving an average yield of 4.2 t/ha. About half of the world's malt
2 production of 18 MT is produced by European maltsters (Euromalt 2008) with the majority of grain used being spring barley of EU origin.

The countries of the EU 27 range from the maritime west, characterized by Ireland and the United Kingdom, to the central continental conditions in Hungary, Romania, and Bulgaria, and from the dry and hot states bordering the Mediterranean to the cool northern Scandinavian states around the Baltic. In the main, barley is grown in the cooler temperate zones where moisture levels are adequate for both autumn and spring planting and are adequate during the early summer months to enable grain to grow and fully mature. Over the last 45 years, yields have increased at an average of about 37 kg/ha per annum (Fig. 9.1.1)

The drop in yields in 1992 was caused by poor weather across much of mainland Europe, the United Kingdom and The Netherlands being the only countries to show an increased yield compared to the previous year. Were it not for the high yield in 2004, there would be little evidence of a year or year increase for a decade. This slower rate of yield increase has also been noted in other cereals from the mid-1990s (Legg 2005).

CROP MANAGEMENT

This section outlines the main cultural practices across Europe that have supported the progressive improvement of yields and relates them to local growing conditions. Unlike other regions of the globe, EU farmers operate within the common agricultural policy in which support payments are linked to compliance with Council Regulation
1782/2003 (European Commission 2003), a so- 3
called cross-compliance. This compliance entails the farmer meeting the management requirements of 18 directives covering, among others, environmental and plant health issues. Additionally, farmers must comply with standards that provide "good agricultural and environmental conditions." These include, among other items, the avoidance of erosion and the preservation of soil organic matter. This legislation impacts on European barley growers, and we will refer to it where it affects the possible options growers may take.

TYPES OF BARLEY GROWN

The 295 barley cultivars granted community plant variety rights with the EU Plant Variety

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Barley: Production, Improvement, and Uses. Edited by Steven E. Ullrich © 2011 Blackwell Publishing Ltd.

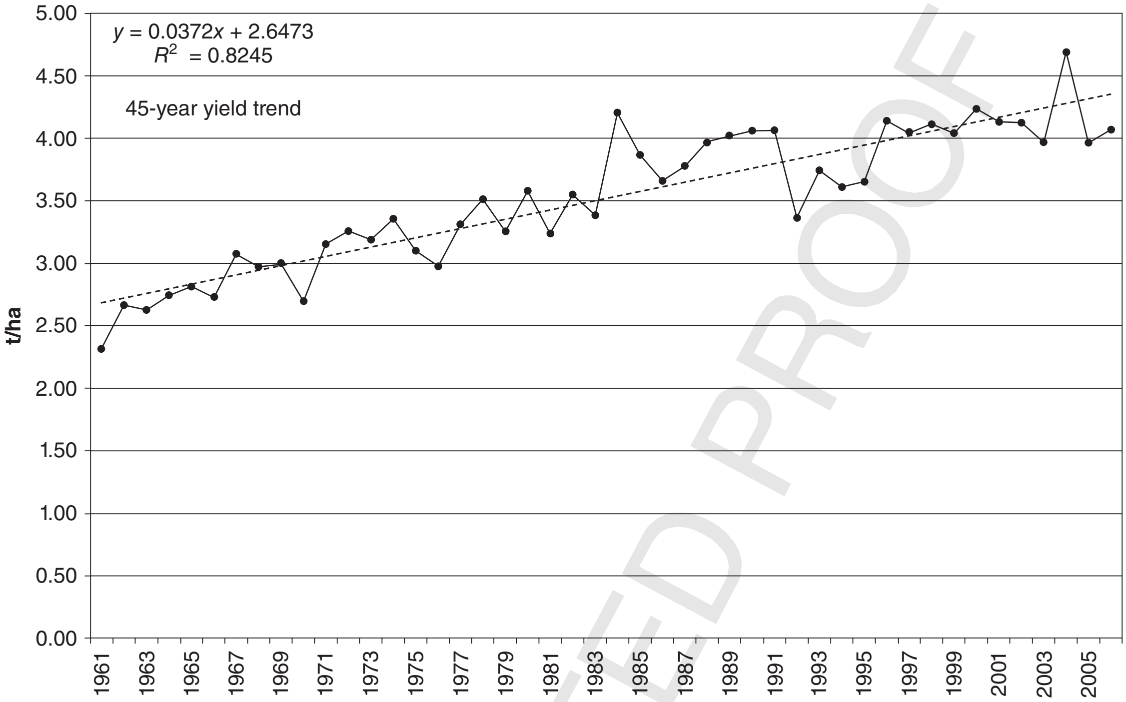

Fig. 9.1.1. EU 27 barley yield, 1961–2006 (ton per hectare, mean of all types). *Source:* FAO (2008).

Office are all classified as *Hordeum vulgare* L. sensu lato (CPVO 2008). This grouping covers all the six- and two-row types of winter and spring cultivars that show value for cultivation and use, while at the same time being distinctly uniform and stable.

Across Europe, the balance of winter and spring barley is determined by the requirements for winter hardiness and early maturity and ripening, where drought would otherwise impact on yield and quality. The effect of location can be seen by comparing production in Ireland and in Spain. Spain, with the largest area of barley in the EU (3:1, spring : winter), grows about 80% of its crop in main arable areas in Aragon and Castilla y Leon in the north and La Mancha to the south of Madrid, harvested in June and July. From 2002 to 2005, the average spring crop yield was 2.58 t/ha. By way of contrast, Ireland (8:1, spring : winter), with its constant supply of moist air from the Atlantic, produced 6.23 t/ha, the highest spring barley yield in the EU (Table 9.1.1). The effect of the different types of climate on yield variability is shown in the coefficients of variation (CV%) for annual yield per hectare. For the years 1996–2006, the CV% for the annual winter and spring barley yields in Ireland and in Spain are 8.64% and 10.48%, and 20.77% and 22.53%, respectively. Crop management practices aim to reduce this variation between years as well as to produce high and profitable yields.

In the warm southern and the mild western areas of Europe, the winter and spring categorization becomes less important. In the absence of harsh winters or with the threat of spring drought curtailing yield, spring barley is often autumn-sown. This increases potential yield but also the period of exposure to pests and disease. While the switch to earlier sowing moves the crop toward some of the management practices normally associated with winter barley, the change does not produce a complete change of phenotype.

The general market perception across Europe favors spring barley for the malting market, although there are some exceptions. In an analysis of supply for the 2006 season, Malteurs de France

Table 9.1.1 Barley area, production, and yield in European countries 2002–2005

	Winter Barley Area ('000 ha)	Spring Barley Area ('000 ha)	Total Area ('000 ha)	% as Spring Barley	Winter Barley Production ('000 t)	Spring Barley Production ('000 t)	Total Barley Production ('000 t)	Winter Barley Yield (t/ha)	Spring Barley Yield (t/ha)	Mean Yield (t/ha)
Germany	1349	644	1993	32	8425	3108	11,533	6.24	4.82	5.79
France	1082	576	1658	35	7109	3436	10,545	6.56	5.98	6.36
Spain	777	2356	3134	75	1965	6073	8038	2.51	2.58	2.57
United Kingdom	452	581	1033	56	2880	3107	5988	6.38	5.33	5.79
Denmark	127	607	734	83	749	3072	3821	5.87	5.07	5.20
Poland	140	908	1048	87	497	2842	3338	3.52	3.13	3.18
Czech Republic	121	387	507	76	490	1607	2097	4.05	4.17	4.13
Finland	0	553	553	100	0	1816	1816	0.00	3.28	3.28
Sweden	6	378	384	100	29	1623	1652	5.35	4.29	4.30
Ireland	20	157	177	89	150	978	1128	7.48	6.23	6.38
Hungary	183	157	340	46	634	481	1115	3.47	3.11	3.28
Romania	266	189	454	41	691	356	1047	2.60	1.90	2.30
Austria	76	123	199	62	391	516	908	5.15	4.22	4.56
Lithuania	8	321	329	98	25	870	895	3.17	2.73	2.72
Bulgaria	281	32	313	10	822	72	894	2.82	2.44	2.85
Slovakia	22	201	224	90	68	721	789	3.12	3.62	3.52
Norway	0	164	164	100	599	0	599	3.69	0.00	3.65
Italy*	0	0	320	—	0	0	1145	0.00	0.00	3.58
The Netherlands	3	49	52	94	19	295	315	6.50	6.00	6.02
Belgium	33	8	41	19	260	45	305	7.82	5.53	7.40
Estonia	0	133	133	100	0	290	291	1.30	2.18	2.18
Latvia	4	133	136	97	8	281	290	2.32	2.11	2.12
Greece	95	0	95	0	207	0	207	2.20	0.00	2.18
Cyprus*	0	0	57	—	0	0	109	0.00	0.00	1.92
Luxembourg	5	5	10	47	31	22	53	6.00	4.92	5.48
Slovenia	6	1	7	14	22	3	25	1.75	1.47	3.45
Portugal	18	0	18	0	21	0	21	1.34	0.00	1.17
Total/means	5075	8663	14,115	62	26,093	31,615	58,962	3.75	3.15	3.90

Source: Eurostat (2008).

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showed Esterel, a six-row winter variety, to be the most popular variety grown in five out of eight regions across central and northern France. Moisture is required for spring barley to mature and ripen with well-filled endosperms giving high yields while avoiding excessive nitrogen content. In the United Kingdom, around 50% of all spring barley production is in Scotland where long, cool days and adequate moisture produce high yields and relatively low nitrogen content.

Spring barley is also grown to avoid loss of the crop over winter. Barley is less tolerant of severe cold than wheat. It also tends to be grown on lighter soils, the top layers of which can lift on freezing, separating the top of the plant from its roots. The most northerly member states around the inner Baltic grow spring barley almost exclusively.

The marked effect of the Gulf Stream is shown by the areas of winter barley grown in Norway and in Denmark, at the same latitudes as the inner Baltic States.

Severe late frosts also present a hazard to winter barley. Once stem extension starts and the young ear is raised 20 cm or more above the ground, late air frosts colder than around −6°C can damage or kill the developing ear. Mild winters associated with climate change can encourage early growth, making late March and April the main period of susceptibility.

In each country, there are also a wide range of agronomic and economic factors that affect the ratio of spring and winter barley. In Denmark, the lower nitrogen requirement of spring barley and its performance on lighter soils make it a better "fit" with the country's environmental legislation and for collocating on dairy farms. The demands of the livestock sector for feed have favored higher-yielding winter barley in Germany and France. The Netherlands, despite an intensive livestock sector, favors spring barley, with 43% of its domestic consumption being used in beer production (Eurostat 2008)—the highest use for brewing in the EU.

In addition to the split of barley into winter and spring types, the winter group can be split into two- and six-row types, and the six-row varieties can now be grouped as conventional and hybrids. Under normal production conditions, six-row barley varieties produce high yields of relatively small grains with low specific weights (Beschreibende Sortenliste 2007). Hybrids appear 4
to be addressing the latter problem, although the grain size does not yet match two-row cultivars (HGCA 2007).

The breakdown of the plantings into malting and feed varieties varies from country to country as markets change. As earlier comments show, six-row winter malting types are popular in parts of France. National variety listings of barley indicate the value of varieties for malting by presenting data showing the malting performance of suitable varieties. The predominance of spring types for malting is clearly shown in the German and U.K. listings. In Germany, out of 37 winter six-row varieties, only 1 has malting data presented, while 10 out of 39 two-row varieties are listed with malting data. In contrast, 41 out of 53 spring varieties are presented with their malting ratings. In the U.K. listings, only 3 winter varieties (all two-row) out of 22 are rated with malting information, while 17 out of 21 spring varieties have hot water extract data presented and 12 are listed as malting varieties. Recent years have seen that wet harvests cause significant malting barley supply problems. Inevitably, market preferences and purchasing standards may change when supply-side problems intervene.

TILLAGE PRACTICES

Previous descriptions of barley tillage techniques (Briggs 1978) highlighted the role of the plough in seedbed preparation. Recent years have seen a move toward minimum cultivation techniques (min-till), which rapidly prepare a surface tilth of only a few centimeters depth and sow the crop often in a single or reduced number of operations 5
(Fig. 9.1.2). 6

Min-till has been widely adopted across Europe as the agricultural industry has responded to low prices by reducing fixed costs through amalgamation of farms with fewer workers resulting in the need to drill more hectares in a fixed drilling window. Surface tillage of the light friable soils

Fig. 9.1.2. Modern drills can go from stubble to drilled crop in a single pass (photo courtesy of Vaderstad Verken AB). For color details, please see color plate section.

on which barley tends to be grown produces a good seed–soil interface with less risk of smearing associated with high clay fraction soils. Also, in dry autumns, avoiding soil inversion conserves soil moisture. Minimum tillage, however, is poor at providing the weed control associated with the burial of seed achieved by ploughing. The implications of this are discussed under weed control later in this section.

Lighter soils have also traditionally been favored for malt production in some areas as the soil nitrogen supply tends to be lower. Changes in brewing technology and market preferences have allowed higher nitrogen grain to be purchased, and the production of malting barley from heavier soils where wheat may be the preferred crop has been shown to be feasible (Garstang and Giltrap 1999). High yield and good malting premia are needed to make malting barley as financially viable as wheat on heavier soils. Selecting the best soils for malting barley production is a compromise between lighter soils with low nitrogen content but with adequate available moisture. The latter is more important in areas where summer drought affects grain quality.

The majority of crops are drilled using a range of machines from simple tined drills to complex combination drills that can put seeds into a range of seedbeds from min-tilled soil to a fully prepared seedbed. Broadcasting of barley is occasionally used for winter barley planting where delays mean a lot of ground must be planted quickly. Broadcast winter barley can produce similar yields and quality to crops drilled in equivalent conditions. Spring barley in northern sites produces satisfactory yield and quality only after ploughing and drilling (Ball 1985).

Studies to optimize the production of barley in the western European conditions of the United Kingdom suggest relatively high seed rates are used with a benchmark spring population of 305 plants/m^2 (HGCA 2006). With only one floret per spikelet, barley is less able to compensate for lower seed rates than wheat, an effect further compounded if spring barley is late drilled. Monitored crops showed 50% emergence after an elapsed thermal time of 150°C days. This period is extended when dry soils slow initial imbibition and the start of germination. The time needed to accumulate 150°C days ranges between 10 days to about 7 weeks depending on the time of year and the location. The net result of varying assumptions about survival rates from planting to the final established population and different 1000 grain weights gives seed rates ranging from about 100 to 250 kg/ha for light seeds (<35 g/1000) with a high survival rate (>90%) and heavy seeds (>49 g/1000) with a low survival rate (60%).

The crop thus reaches the start of the spring period of rapid growth with a sufficient number of healthy plants ready to respond to any applied fertilizer. We will look at this aspect after we have considered weed control measures.

WEEDS AND WEED CONTROL

7 Of the broad-leafed weeds found in Europe, Hanf (1983) reported that 33% of the species could be found throughout Europe. A further 15% could only be found on the mainland roughly to the south of The Netherlands and northern Germany, while a further 23% were restricted to the south of a line drawn approximately from La Rochelle on the west coast of France to Budapest. Another 12% were exclusive to lands to the west of a line from Venice to Friesland, and 6% were confined to the Iberian Peninsula, while the remaining 11% were found in various regions in Eastern Europe and in Italy. The weed flora of Europe is thus diverse, with only one-third of the species being common to the whole continent.

Herbicide use is the main method of weed control in barley across Europe. Removing broad-leafed weeds from cereal presents few problems if weeds are tackled at the seedling stage, while grass weeds are the most difficult target weeds to control. The first selective chemical herbicides were developed to remove broad-leafed weeds from cereals over 60 years ago. Now, active substances like diflufenican and pendimethalin have very broad spectra of annual dicotyledon control in barley, while pendimethalin and other materials also control seedling grasses. In common with many active substances, best control is achieved when used during the preemergence of the weeds 8 or during early postemergence. The use of some materials varies between winter and spring barley. Pendimethalin can be used up to the end of tillering on winter barley but must be used during preemergence of the crop on spring barley. Sulfonylureas are now one of the largest groups of herbicides and work by inhibition of acetolactate synthase (ALS). They control many broad-leafed weeds, and some have been specifically targeted at grass weeds. However, their use in barley is not straightforward as some are suitable only for use on wheat, while some can be used on winter wheat and on spring barley. As with all herbicides, a degree of skill is required by the end user when seeking to optimize their use.

The difficulty with grass weed control is heightened as the portfolio of grass weed herbicides is less well developed for barley than for wheat. For example, in the U.K. 2008 grass weed herbicide market, there are 36 active substances and combinations of substances approved for use on wheat, but only 22 were approved for use on barley. Increases in the distribution of herbicide resistance across most EU countries, and reviews of pesticide safety, point to the need in the future to rely more on the integration of control measures: crop rotation, cultivation techniques, and herbicides, all of which need to contribute to reducing weed presence.

Controlling grass weeds in cereals, which are also grasses, is the main challenge. In European cereals, *Avena fatua* (wild oat) is the most competitive weed on an individual plant basis. It is a widespread weed across Europe with *Avena sterilis* subsp. *ludoviciana* (winter wild oat) becoming 9 more important to the south and on higher land there. *Lolium rigidum* and *multiflorum* (ryegrasses), along with *Phalaris minor* and *paradoxa* (canary grass), are major noncereal grass weeds in southern countries. In the north, particularly on heavier soils with wheat/barley in the rotation, *Alopecurus myosuroides* (blackgrass) is a problem, while in 10 less-intensive arable areas *Poa* spp. (bluegrass) and *Lolium* spp. can become prominent weeds. However, the presence of a mixed rotation with short-rotation forage grass and livestock gives more scope for integrated control measures using grazed pastures and ploughing. Small-seeded grass weeds like *A. myosuroides* and *Poa* spp. can easily exceed 1000 plants/m^2 in severe infestations. At these numbers, yield is reduced; crop lodging increases; and moisture content at harvest can be increased due to extra green material.

The more restricted portfolio of grass weed herbicides available for barley becomes more of a problem where herbicide-resistant weeds are found. To date, herbicide-resistant *A. myosuroides* has been found across northern Europe from the

United Kingdom to Germany and in Spain (Weed 11 Science 2008), while resistant *A. fatua* has been confirmed in France, Belgium, and the United Kingdom. Herbicide-resistant *L. rigidum* has been found in Greece, France, and Spain including resistance to glyphosate in the latter two. Some broad-leafed weeds resistant to ALS inhibitors have also been found in a range of European countries.

Fallow, either as set-aside or for moisture conservation, can allow cultivation or nonselective herbicide to be used for weed control. Ploughing provides the best burial of weed seeds and is the recommended seedbed preparation where herbicide-resistant weeds have become established. In some situations where dormant seeds remain viable in the soil, ploughing can bring to the surface viable seeds shed in previous years. This is more likely to occur where the very high plant populations mentioned above have been allowed to develop. Minimum tillage techniques can provide ideal conditions for grass seed germination, providing a relatively shallow soil cover and good moisture conductivity in undisturbed soil. Repeated use of the technique can build up high populations of grass weeds like *A. mysuroides*.

Stale seedbeds are another commonly used method of weed control. This requires moist soil to promote the germination of weeds for removal by nonselective herbicides or cultivation before drilling the next crop. The relatively early sowing of winter barley compared to wheat can restrict the success of stale seedbeds, particularly following a dry late summer period, which promotes little weed growth. Although seedbed consolidation improves water transfer for the germinating seeds, stale seedbeds need to be produced long enough before drilling to allow weed growth. Weeds resistant to glyphosate as the *L. rigidum* mentioned above may require a switch to other nonselective herbicides like glufosinate-ammonium or inversion ploughing to bury the germinated plants. Where barley follows wheat in the rotation, early germination of tailing corn wheat provides one of the best routes for avoiding wheat volunteers in the following barley crop. Dry soils in late summer and autumn can give poor germination of tailings from the previous crop with a consequent increase in wheat volunteers over winter. In contrast, the drilling of spring barley follows the wetter winter period, so predrilling weed growth is stronger in warm regions. Further north, cooler conditions and early drilling may result in weed growth being delayed by cold weather and developing simultaneously with the spring crop. Late-drilled spring barley produces fewer tillers than an early-sown spring or winter barley, so it competes less well with weeds.

Barley needs to be relatively weed free during establishment and early growth so individual plants can develop in adequate numbers and size. Once crop plant survival is assured, weed competition should then be avoided during the grand period of growth and subsequent grain filling. There is some evidence that in northwestern European growing conditions, winter barley can produce greater responses to herbicides than wheat, which in turn produces greater responses than spring barley (Davies 1997). Time lines of herbicide application are of major importance as are the health and vigor of the crop and thus its ability to compete with the weeds.

Fertility

Efficient nutrient management requires the total nutrient input to be matched to the anticipated total nutrient offtake by the barley crop, taking into account the supply of nutrients already in the soil at the start of the growing season. The legislation and nutrient requirements underpinning this system of nutrient management is well documented (MAFF 2000; De Clercq et al. 2001). In common with the other main cereal crops, nitrogen, phosphate, and potash are the main elements required, with sulfur being required more routinely in parts of Europe where atmospheric deposition rates have fallen and soil supplies are inadequate. The lighter soils stretching from Eastern England and across Holland, Germany, Poland, and the Czech and Slovak Republics are expected to show the greatest changes in sulfur availability as the amount of coal-fired heavy industry diminishes.

The soil nitrogen supply must take into account available nitrogen and variation in the mineralization of soil organic nitrogen supplies during the growing period. High soil nitrogen supply at planting boosts early vegetative growth and the transfer of nitrogen from the stems and leaves to the ear during grain formation, increasing the protein value of feed barley. The same protein increase can also reduce the quality of malting barley if applied fertilizer rates have not been adjusted to take account of soil nitrogen supplies. In southern Europe, the relatively warm soils support higher levels of nitrogen mineralization, which, combined with the effects of drought, can produce grain with relatively high nitrogen content.

Organic fertilizer, whether as slurry or higher dry matter manures, adds to the soil nutrient pool and needs to be considered along with the soil nitrogen supply, with mineralization adding more available nitrogen as the season progresses. Slurry should not be applied in conditions where runoff or leaching occurs (European Commission 2003). Soluble nutrients in the aqueous phase are ready for immediate uptake by the plants, like inorganic fertilizers.

Once estimates of the nutrient supply from the soils and manures have been made, inorganic fertilizer can be applied to support production of the anticipated crop canopy and grain yield. A barley crop requires about 28 kg N/ha of green area index (GAI), that is, to produce 1 ha of leaf (one side only) per hectare requires 28 kg of nitrogen (HGCA 2006). As a typical crop may approach a GAI of 6, the canopy will require about 168 kg/ha of nitrogen from applied fertilizer and soil sources, and crop offtake will be about 132 kg N/ha in winter barley. Spring barley with a shorter crop growth period and generally lower total biomass will have a maximum nitrogen offtake of 25%–30% less than the winter crop. Over half the nitrogen is taken up by the time the flag leaf is fully emerged (Zadoks GS 39; Zadoks et al. 1974). Both winter and spring malting barley require most of their nitrogen to be applied not much later than the start of the main period of stem extension, Zadoks GS 31. This ensures nitrogen is available for the main period of growth but avoids late surges in supply that can increase grain nitrogen content. In regions where dry weather delays nitrogen uptake, mid-season rains can produce increased late uptake and elevate grain nitrogen content. The pattern of seasonal rainfall means this can happen almost anywhere but is least likely in cool moist production regions (e.g., Ireland, Scotland, The Netherlands, and Scandinavia). Phosphorus application to barley in very low rainfall areas has been shown to improve water use efficiency (WUE) on phosphorus-deficient soils. Nitrogen also gives very significant increases in WUE but also increases absolute water use.

Crop development

Yields of both winter and spring barley in the United Kingdom are the fifth highest in Europe, a performance that could be classified as typical of more intensive national agricultural practices. How the crop grows, develops, and is influenced by inputs is outlined in the Barley Growth Guide (HGCA 2006), which shows that in the United Kingdom, crop yield is sink limited; that is, yield is limited by grain number and potential size rather than the crop's ability to fill the grain . In this section, we look at how this varies across Europe and the impact of management practices. Most of the uncontrolled variation arises from differences in temperature and water supply in the rainfed majority of crops. 12

Once the crop is fully emerged and established, leaf numbers increase. The time taken for each leaf to emerge (phyllochron) is measured in thermal time; a phyllochron averages 108°C days in winter barley in the United Kingdom. Cooler conditions in the north tend to produce fewer leaves (~13), while the warmer conditions in the south can produce around 15 leaves. At a given latitude, late-sown crops accumulate less thermal time and produce fewer leaves, but late-sown crops can compensate by reducing the phyllochron and increasing the rate of leaf emergence. Overall, the net effect is to partially offset the effects of late drilling rather than to remove the effect completely. There is also a significant genetic variation in phyllochron with reports of variation in experiments from 50 to 97°C days (Frank and Bauer 1995).

In spring barley, the phyllchron is about 10% less than the winter crop, and the crop generally produces 8–10 leaves rather than 13–15. Tillering is similarly affected by temperature, but as water and nutrient supply also affect the final outcome, the farmer has more scope for controlling tiller number. Tillering is quite rapid in the autumn. The areas in Europe where winter barley is grown are those where autumn allows adequate growth before winter temperatures curtail growth and where the absolute winter conditions do not produce excessive losses over winter (see also 13 Types of Barley Grown).

Tiller numbers reach a maximum just before the period of rapid stem extension. Early-sown crops have a higher number of potential tillers and can thus be sown at lower seed rates. If this is done, those extra potential tillers must survive so drought and nutrient stress must be avoided during early stem extension when tiller numbers decline naturally. Maximum shoot numbers before the start of stem extension are around 1000–1300 per cubic meter. Once the demands of rapid stem extension and canopy production stress the plant, tillers are lost and numbers fall to between 750 and 800 per cubic meter or to about three per plant if nutrient and water supply is adequate. The final ear numbers are similar in winter and spring barley, but the latter with few tillers per plant needs a slightly higher plant population to compensate.

Tillers increase in height as the season progresses, reaching about half their height by the time of flag leaf emergence (Zadoks GS 39), and the majority of their height by full ear emergence (Zadoks GS 59). Drought-affected crops tend to be shorter, and when such crops reach harvest, the crops may stand little more than 30 cm in height with poorly finished grains and a low stem count. Most severely drought-affected crops occur in countries bordering the Mediterranean.

Crop height is one of the components that affect lodging. The taller the straw, the greater the leverage of wind and the weight of the ear itself. Lodging occurs through either root upheaval or buckling of the stem. Lighter soils with lower clay content give less anchorage. Such soils are widely found across Northern Europe and southern Scandinavia. The lightest sandy land with a tendency to have lower pH is often used to grow rye rather than barley.

Plant growth regulators are applied to barley and other cereals in order to shorten and thicken the stem, thereby reducing the risk of lodging. Two main modes of action are used. The inhibition of gibberellin production reduces apical dominance; if applied when the crop is tillering, it can produce more uniform crops and can increase tiller survival where subsequent growing conditions allow. If applied at the end of tillering and at the start of stem extension (Zadoks GS 30–31), it shortens the lower internodes of the growing stems. This effect is more pronounced in wheat than in barley; nevertheless, gibberellin inhibitor growth regulators are widely used on barley throughout Europe. Ethylene production and its restriction of cell expansion is the basis of the second mode of action used. Compounds producing these effects are typically applied in the latter stages of stem extension, but before the ear has emerged, shortening the upper internodes of the crop. The most effective stem shortening in barley has been achieved by using a sequence of gibberellin inhibitors and ethylene-producing compounds, the most common being chlormequat and 2-chlorothlyphosphonic acid (ethephon), respectively. Mepiquat chloride, another gibberellin inhibitor, is used as a formulated product with both chlormequat and ethephon. More recently introduced gibberellin inhibitors trinexapac-ethyl and prohexadione-calcium offer more flexibility in timing than chlormequat. There is some evidence to suggest that there is a degree of synergism when the two modes of action are used in succession. Late secondary tillering may be accentuated by ethylene-producing compounds if used on drought-stressed crops. This can adversely affect evenness of ripening and malting quality, and late growth regulators need to be withheld if drought stress occurs late in an otherwise normal growing season. Severely drought-stressed crops are unlikely to need additional stem shortening

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Water management

With increasing demands for water from both agricultural and nonagricultural users, water use through irrigation is increasingly directed to higher-value horticulture crops and field crops like maize and sunflowers where the main growth period coincides with increasing summer moisture stress. The majority of barley grown in Europe is largely rainfed and indeed, compared with other cereals, it is well adapted to drier conditions through its WUE. Barley's earlier ripening and harvest also minimize its exposure to much of the hottest weather after the summer solstice. In dry seedbeds in either the autumn or spring, showers can provide sufficient water to trigger germination, but a return of drought conditions can cause considerable seedling loss through desiccation. Additional irrigation is useful in these situations. Over the whole growing season, however, the greatest WUE for grain yield in semiarid dryland winter barley in Spain was achieved from effective rainfall from stem extension to harvest (Moret et al. 2007). Throughout Europe, and not just in the main irrigating countries like France, Spain, and Italy, irrigation during this period often clashes with water use for higher-value crops, so where irrigation is used, it tends to be tactical for the correction of periodic severe water shortage and the prevention of total crop loss or major yield losses. 14 As the values in Table 9.1.1 show, the highest yields are produced in countries with generally adequate rainfall during the principal phases of growth—establishment, stem extension, and grain filling.

HARVEST

As harvest approaches, excessive moisture becomes a nuisance rather than desirable. In common with all cereals, barley grain needs to be at or below 14% moisture content for safe storage. This is a good general figure as the actual value varies with ambient temperature and the specific risk factor. Storage below 4–5°C will avoid in-store heating of grain at 19%–20% moisture, while around 12% moisture is needed if temperatures above 30°C are anticipated. Fortunately, the hotter southern countries are more able to produce drier grain ex-field. Retention of germination is crucial for malting barley production and because of this, drying may be done by the buyer and the cost factored into the sale contract. Grain at about 15% moisture content needs to be stored at less than 15°C if it is to be kept in store. Insect damage to stored barley is temperature rather than moisture dependent, and storage below 15°C is essential. In many areas of Europe, grain harvested in the heat of the day can require grain ventilation with cool night air to get large bulk stores below this threshold. In contrast to other insects, mites need drier grain and lower temperatures to subdue their activity and require grain to be less than 12% moisture or stored at 2°C or less.

In the regions of highest rainfall and high yields, weeds, particularly well-rooted perennial plants, can remain green during harvest. To reduce the risk of excessive wet green material being admixed with dry grain, nonselective herbicides (glyphosate) can be use to desiccate the weeds once the grain has dropped below 30% moisture. Such desiccation in the absence of weeds has been shown to produce lower grain moisture in spring barley harvested in Scottish conditions. Users are not recommended to use this technique on barley intended for seed and to consult their grain merchant before treating any crop grown for malting, distilling, or grown on contract. Green material admixed with grain not only gives an uneven distribution of moisture but also interferes with the even air flow in bulk dried grain. During drying, malting barley above 24% moisture content should not exceed 43 or 49°C when the moisture has dropped below 24%. Green material spread in patches though the bulk of grain makes such moisture assessment and temperature regulation difficult. Such uneven moisture distribution can lead to bands of spoiled grain if drying is inadequate.

TECHNICAL EXPERTISE AND INVESTMENT

Like most continents, Europe is climatically and agriculturally diverse. Barley is produced at varying levels of output in most of the arable areas. Until recently, there has been considerable disparity between some countries and regions in on-farm and infrastructure investment. The resources and techniques discussed in this section, long available to the original 15 EU member states, are now, where economics allow, available to all 27 member states. We should expect some of the lower yields shown in Table 9.1.1 to increase in many member states where climatic and soil factors are not limiting.

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RUSSIAN FEDERATION, UKRAINE, AND KAZAKHSTAN

Mekhlis Suleimenov

BARLEY TYPES PLANTED AND ECOREGIONAL DISTRIBUTION

Barley has been grown in all parts of the Russian Federation, Ukraine, and Kazakhstan (Fig. 9.2.1). 19 Northwestern Asia (NWA) of the former Soviet Union (FSU) includes steppe and forest steppe zones of North Kazakhstan and West Siberia, as well as the eastern part of the South Ural areas of Russia. The NWA area lies between 48° and 56° N latitude and 52° and 110° E longitude. Northeastern Europe (NEE) of FSU includes dry steppes of the Lower Volga, semiarid steppes of the Volga area, North Caucasus, South and Central Ukraine, the Central Chernozem area, the forest steppe zone of Russia and Ukraine, and the non-Chernozem zone of Russia and Ukraine. The NEE area lies between 48° and 55° N latitude and 32° and 52° E longitude.

Kazakhstan and West Siberia

Spring barley in North Kazakhstan and West Siberia occupies on average 10%–15% of area

Fig. 9.2.1. Map of the Commonwealth of Independent States (former Soviet Union).

under small grains. The share of barley is increasing from dry steppe to forest steppe and from lowlands to hilly areas. In areas with shorter growing seasons, the share of barley may go up to 40%–50% of area under small grains.

Until recently, malting barley was not grown in Western Siberia because in the FSU, there were other agroecological regions more suitable for growing malting barley (Sharkov et al. 2003).

Northeast Europe of Russian Federation and Ukraine

In the steppe zone of North Caucasus, Rostov (Sokol and Beltyukov 1988) and Krasnodar (Vasyukov and Kuznetsova 1988), and of Southeast Ukraine, Donetsk (Logvinenko et al. 1998), spring barley is mainly grown as feed grain. The barley area sown is quite often larger than that of winter wheat and maize put together. On average, every third hectare of winter wheat is winterkilled because of low winter temperatures, icy soil cover, and dry soil during sowing. Also, spring barley is the best cover crop in mixture with dry pea for perennial forages.

In the steppes of the Central Chernozem area, Voronezh, barley mostly of malting type occupies 15%–18%, but in some years, with the high rate of winterkilled wheat, its area may go up to 50% of grain area (Gorshkova et al. 1988; Cherkasov et al. 2006).

In Tatarstan, in the forest steppes of Middle Volga, "Kazan" spring barley is the major feed grain, but since 1999, malting barley has also been grown (Blokhin 2006). Barley occupies 26% of the total area under grains.

In the foothill zone of the Krasnodar area, the first winter barley variety Novator was registered in 1992 (Shevtsov and Naidenov 1988). Winter barley has been grown in the steppes of Central Ukraine, at Dnipropetrovsk where annual precipitation is about 500 mm (Saiko 1993). In the forest steppe zone of the Middle Volga, climate change made growing winter barley possible because of very mild winters (Tupitsyn and Valyaikin 2005).

20 In the Upper Volga, non-Chernozem zone, "Ivanovo" barley is grown on soddy-podzolic and gray forest soils for malting and as feed grain occupying a larger area than wheat (Meltsayev and Shramko 2006). In the Orel area on dark gray soils, barley is an important grain crop, but in the transition period after the fall of the Soviet Union, its sown area reduced and yields decreased from 2.68 to 1.01 t/ha (Lopachev et al. 2001).

BARLEY IN CROP ROTATIONS

Kazakhstan and West Siberia

In North Kazakhstan, feed barley is normally grown in a 5-year crop rotation of "summer fallow–wheat–wheat–barley–wheat." Spring wheat sown after barley often gives higher yields than continuous wheat because the seeding dates of barley are 1 week later, which gives possibility for better weed control (Suleimenov 1991). In areas with short growing seasons where barley occupies larger areas, growing continuous barley is possible with no significant difference of yields as compared to sowing after wheat.

In the forest steppe zone of West Siberia, Novosibirsk, the best crops to precede malting barley are winter rye, row crops grown for silage, and buckwheat (Sharkov et al. 2003).

Northeast Europe

In the dry steppe zone of the Lower Volga area, Volgograd, barley is grown in a 3-year crop rotation: "summer fallow–winter wheat–barley" (Belenkov 2006).

Maize grown for silage was found to be the best preceding crop for spring barley in Rostov area (Sokol and Beltyukov 1988). The average barley grain yield grown in 1984–1986 after maize for silage, winter wheat, maize for grain, and sunflower was 4.67, 4.52, 4.43, and 4.30 t/ha, respectively, as compared to 3.94 t/ha on continuous barley. Maize was also found to be the best predecessor for spring barley in the steppes of Southeast Ukraine (Logvinenko et al. 1998).

The best crop to precede spring barley in the northern steppe of Krasnodar area is green manure. On average during 1985–1986, the grain yields of spring barley after green manure, dry F pea, mixture of pea, and oats were 5.36, 4.91, 4.99 t/ha, respectively, as compared with 4.66 t/ha after winter wheat(Vasyukov and Kuznetsova 1988).

In the Central Chernozem zone, Voronezh, barley is placed after maize for silage and grain and after sugar beet (Gorshkova et al. 1988; Gulidova 2001). In Kursk, spring barley sown 5 years continuously improved productivity when it was double cropped with green manure as compared to growing in crop rotation (Kartamyshev et al. 2006)

In the foothills of the Krasnodar area, the most widespread crop to precede winter barley is winter wheat. The grain yield of winter barley sown after winter wheat was 0.3–0.9 t/ha higher as compared with barley sown after row crops (Shevtsov and Naidenov 1988). In the steppe of Central Ukraine, winter barley is grown after food legumes, melons, potatoes, and maize (Tsikov 1981). In the Ulyanovsk forest steppes, it is best to sow winter barley after summer fallow (Tupitsyn and Valyaikin 2005).

In Tatarstan, it is recommended to sow spring malting barley after winter wheat and rye, as well as after row crops, while it is recommended to sow feed grain barley after legumes (Blokhin 2006). In Orel, barley is normally placed after maize. The barley is also used as a cover crop for clover (Lopachev et al. 2001).

SEEDING DATES

Kazakhstan and West Siberia

North Kazakhstan is characterized by a continental climate with hot summers and very cold winters. July is the hottest time of the year combined with highest rainfall.

Studies were conducted during 1986–1989 at the Esil Experiment Station located 400 km west of Astana, on heavy clay loam calcareous dark 21 chestnut soil with 3.2% organic matter (Kaskarbayev 1994). The annual average precipitation is 280 mm. Five seeding dates were tested from May 12 to June 9. Delayed seeding dates allowed better wild oat control, field seedling emergence rate, crop survival rates, plant density, and 1000 kernel weight. Spring barley grain yield increased significantly by sowing at the beginning of June (Table 9.2.1). The same conclusions were made on black soil as well. May 30 was the most adequate seeding date for spring barley Suleimenov (1991). 22

Table 9.2.1 Spring barley grain yield (ton per hectare) as affected by seeding dates in the dry steppes of North Kazakhstan, Esil (data of Z. Kaskarbayev and M. Suleimenov, published in Kaskarbayev 1994)

	Years				
Seeding Date	1986	1987	1988	1989	4-Year Mean
May 12	1.74	1.68	1.20	1.15	1.44
May 19	1.74	2.13	1.51	1.07	1.67
May 26	1.96	2.40	2.02	1.11	1.87
June 2	2.07	2.52	2.08	1.13	1.95
June 9	1.90	2.03	1.35	1.17	1.61
LSD_{05}	0.07	0.19	0.14	0.10	80

In the southern forest steppe of West Siberia, spring barley seeding is best about May 10 (Alimov 1998). In northern forest steppe, malting barley should be sown from the end of April (Sharkov et al. 2003).

Northeast Europe

In NEE, the share of winter and spring precipitation is higher, while summer (July) has less rainfall. The annual average temperature is higher than in Astana: 4.9°C in Saratov and 8.6°C in Rostov. The earliest possible seeding dates of spring barley were found to be most adequate: end of February–March in Southeast Ukraine (Logvinenko et al. 1998) and in the Krasnodar steppe zone (Vasyukov and Kuznetsova 1988), and March until the beginning of April in the Rostov area, in the Central Chernozem area (Gorshkova et al. 1988), and in Tatarstan (Blokhin 2006). In the Rostov area, on average for 1977–1982, delayed sowing by 1 week reduced barley grain yield by 0.29–0.38 t/ha (Sokol and Beltyukov 1988).

In the Krasnodar foothill zone, annual precipitation is about 500–600 mm and winters are relatively mild. Winter barley should develop three to four tillers before winter. It is recommended to sow between September 5 and October 5, and in the drier northern part of the region, from September 10 to 20 (Shevtsov and Naidenov 1988).

The seeding time of winter barley in the Ulyanovsk forest steppe was moved to the end of August until the beginning of September because of climate change. The optimum seeding time is from September 3 to 8 (Tupitsyn and Valyaikin 2005).

SEEDING RATE

North Kazakhstan and West Siberia

In North Kazakhstan, a study on seeding rates of spring barley was conducted during 4 years at the Esil Station in the dry steppe zone (Kaskarbayev 1994) and in the semiarid steppe zone during 1985–1989 at Shortandy, 60 km north of Astana (Kupanova 1988). The grain yield did not differ significantly under seeding rates from 2.5 to 3.5 million seeds per hectare in dry steppe and from 2 to 4 million seeds per hectare in the semiarid steppe. The barley grain yield under lower seeding rates was reduced because of higher weed infestation.

In the southern forest steppe zone, the seeding rates of barley tend to be higher: 5.0–5.5 million seeds per hectare (Alimov 1998). In the northern forest steppe, malting barley is typically sown with heavier rates of 6–6.5 million seeds per hectare (Sharkov et al. 2003).

Northeast Europe

In the dry steppe of the Lower Volga, seeding rates of spring barley are from 3.0 to 3.5 million seeds per hectare (Belenkov 2006).

In the semiarid steppes of the Rostov area, the recommended seeding rates of spring barley for early and delayed sowing are 4 and 5 million seeds per hectare, respectively (Sokol and Beltyukov 1988). In Southeast Ukraine, the recommended seeding rates of spring barley are 4.0–4.5 million seeds per hectare (Logvinenko et al. 1998). In the Krasnodar steppe zone, spring barley grain yields are usually not affected by seeding rates from 2 to 6 million seeds per hectare under favorable weather conditions. But in dry 1983, because of sparse stand, the low seed rate of 2 million seeds reduced grain yield to 2.70 t/ha as compared with 3.57 t/ha with a rate of 6 million seeds per hectare. The same situation was observed when sowing was delayed in 1985(Vasyukov and Kuznetsova 1988).

In the Central Chernozem zone, crop yields are not affected by seeding rates significantly (Gorshkova et al. 1988). Recommended rates are 5–6 million seeds per hectare. The seeding rates increase under unfavorable soil moisture conditions for seed emergence and shortage of fertilizers.

In Tatarstan, the recommended crop density for common varieties is 350–380 plants and for intensive varieties with stronger tillering capacity—300–320 plants/m^2, which is equivalent to 3 million seeds per hectare.

In the Krasnodar foothill area, winter barley grain yields are normally not affected by seeding rates from 3 to 6 million seeds per hectare. However, in the northern part of the area with more severe winters, it is recommended to sow 5–6 million seeds per hectare (Shevtsov and Naidenov 1988).

In Ulyanovsk, the seeding rates of winter barley are in the range of 3–5 million seeds per hectare. Lower rates are used in less risky areas where seed emergence in the field is more reliable (Tupitsyn and Valyaikin 2005).

In the Upper Volga on soddy-podzolic soil, it is recommended to apply seed rates to ensure the establishment of 350–400 plants/m^2 (~4 million seeds per hectare) (Meltsayev and Shramko 2006). In Orel, the recommended seeding rate on dark gray soil is 5 million seeds per hectare. When barley is used as cover crop for forages, its seeding rate is reduced by 1 million seeds per hectare (Lopachev et al. 2001).

SEEDING DEPTH

North Kazakhstan and West Siberia

A North Kazakhstan study of seeding depth was conducted in the semiarid steppe zone at

Table 9.2.2 Spring barley grain yield (ton per hectare) as affected by seeding depth and seed rate in the semiarid steppes of North Kazakhstan, Shortandy (average for 1985–1989) (data of L. Kupanova and M. Suleimenov, published in Kupanova 1988)

	Seed Rate (Million Seeds per Hectare)		
Depth of Seeding (cm)	2	3	4
4	2.46	2.60	2.46
6	2.40	2.49	2.51
8	2.35	2.49	2.53
10	1.67	1.87	2.19
LSD_{05} (t/ha)	Seeding depth—0.18, seed rate—0.17		

Shortandy (Kupanova 1988). On average, over 4 years, the grain yield of barley was not affected by seeding depths of 4–8 cm, but reduced significantly at sowing 10 cm deep especially under low seed rates (Table 9.2.2 here). The field seed emergence rate was higher when seeds were sown 4–6 cm deep (73%–71%).

In the southern forest steppe zone of West Siberia, It is recommended to sow spring barley 5–6 cm deep (Alimov 1998), while in the northern forest steppe zone, malting barley should not be sown deeper than 5 cm (Sharkov et al. 2003).

Northeast Europe

Seeding depth in the steppe of Southeast Ukraine normally is around 6 cm (Logvinenko et al. 1998). In Krasnodar, the seeding depth of winter barley can vary from 2 to 6 cm depending on soil moisture. On average, the best winter survival is obtained when barley is sown 4 cm deep (Shevtsov and Naidenov 1988). Sowing of winter barley in the Middle Volga area on summer fallow is recommended at 5–8 cm (Tupitsyn and Valyaikin 2005).

TILLAGE PRACTICES

North Kazakhstan and West Siberia

According to Akhmetov and Zinchenko (1976), in the semiarid steppe of North Kazakhstan, efficient depth of fall tillage depended on soil moisture. When soil was wet, deep tillage with sweeps at 25–27 cm provided significantly better snowmelt water infiltration in spring. When tillage was done in dry soil conditions, depth of tillage did not play an important role for water accumulation.

In Kostanai Province, recent research shows an advantage of no-till combined with leaving a 30-cm-tall stubble during harvest to trap snow (Dvurechenskiy 2008). This practice improved moisture accumulation in soil by spring barley seeding time by 30 mm, as compared to the traditional 15-cm-tall stubble and fall tillage with blades.

Tillage treatments in the fall for spring barley were studied in the southern forest steppe zone on leached black soils in Kurgan, West Siberia (Isayenko 2006). The factor of weed infestation was decisive in barley grain yield. Yield was highest under moldboard plowing compared to conservation tillage with blades.

Another study on leached black soil in the forest steppe zone in the Novosibirsk area was conducted during 1986–1994 (Alimov 1998). The combination of moldboard plowing with conservation tillage in a rotation was found most efficient for crop yield and energy conservation.

Northeast Europe

In Southeast Ukraine (Logvinenko et al. 1998) and in the Central Chernozem area, (Gorshkova et al. 1988) disking is done two to three times starting soon after harvest of the preceding crop. Main tillage by moldboard plows is done 20–22 cm deep at the end of September until the beginning of October. In the Lipetsk area, barley grain yield on conservation tillage was the same as after plowing but ensured considerable saving of energy (Gulidova 2001). In the Kursk area, green manure grown as double crop with continuous barley increased barley yield significantly when green manure was incorporated by plow or disk harrow (Kartamyshev et al. 2006). In Tatarstan, deep plowing has been replaced by minimum tillage with disks or duck foot cultivators, saving fuel by 20%–50% (Blokhin 2006).

In the Middle Volga area, winter barley is sown on summer fallow. Most important is to have a firm seedbed with tillage no deeper than 5–8 cm prior to sowing (Tupitsyn and Valyaikin 2005). In the steppes of Central Ukraine, early double disking is recommended for seedbed preparation for winter barley sown after maize (Tsikov 1981). However, no-till is being rapidly adopted due to considerable saving of energy and labor (Medvedev 2006).

In the Upper Volga, it is recommended to rotate tillage methods on soddy-podzolic soil. In dry years, minimum tillage is adequate, while in favorable years, moldboard plowing combined with application of adequate rates of fertilizers and pesticides ensured highest grain yields (Meltsayev and Shramko 2006). In Orel, on dark gray soils, deep tillage with moldboard plows can be replaced by minimum tillage when barley follows a row crop with low weed infestation (Lopachev et al. 2001).

WEEDS AND WEED CONTROL

There are three major classes of weeds: rootstock, perennial suckering, and annuals. These weeds are found everywhere and weed control practices are very important components of cropping systems. In the traditional Soviet cropping systems, tillage was the predominant control tactic for rootstock and suckering perennial weeds across all regions. The only widely applied herbicide in the Soviet Union was 2,4-D.

North Kazakhstan and West Siberia

In the southern forest steppe zone of North Kazakhstan, the most widespread weeds are Canada thistle (*Cirsium arvense*), field bindweed
23 (*Convolvulus arvense*), wild oat (*Avena fatua*), tartaric buckwheat (*Fagopyrum tataricum*), green foxtail (*Setaria viridis*), and redroot pigweed (*Amaranthus retroflexus*). The prevailing weeds in the semiarid steppe zone are Canada thistle, field bindweed, wild oat, goosefoot (*Chenopodium album*), redroot pigweed, green foxtail, field pennycress (*Thlaspi arvense*), and shepherd's purse (*Capsella bursa-pastoris*). In the dry steppe zone, the most troublesome weeds are couch grass (*Agropyrum repens*), sedge (*Carex caespitosa*), Canada thistle, field bindweed, gorchack (*Acroptilon picris*), wild lettuce (*Lactuca seriola*), green foxtail, and redroot pigweed (Suleimenov 2006).

Delayed seeding is always considered as one of most powerful means to control some weeds, especially wild oat (Suleimenov 1991). Seeding rates are of importance because weeds compete with crops. It is no doubt that widening of row spacing from 15 cm in a disk drill to 23 cm in a stubble (no-till) drill provides more space for weeds. Another factor is depth of seeding. Under delayed seeding, it is quite common to place seeds deeper than it is necessary for germination and emergence. Sometimes, this works, but delayed and sparse emergence favors weed infestation.

Recently, with wide adoption of no-till farming practices, weed control methods have changed dramatically (Dvurechenskiy 2008). In summer fallow, two sprayings of a glyphosate-type herbicide are recommended: the first in mid-May to control shepherd's purse, field pennycress, wild oat, and thistle, and the second in mid-July to control field bindweed, thistle, lettuce, wild oat, and redroot pigweed.

The most efficient herbicides to control perennial weeds in spring barley are Sekator-turbo (50–75 mL/ha), Musket (40–50 g/ha), and Granstar (12 g/ha) (Dvurechenskiy 2008). To control wild oat and green foxtail in spring barley, Puma Super (0.6–0.9 L/ha) and Bars Super (0.6– 24
0.7 L/ha) are the best herbicides.

Northeast Europe

The most troublesome weeds in the Northern Caucasus and Southern Ukraine are the following: perennial weeds—Canada thistle, field bindweed, sow thistle (*Sonchus arvensis*), and Russian sweet sultan (*Centaurea picris*); rootstock weeds—couch grass; and annuals—redroot pigweed and knotweed (*Poligonum aviculare*) (Suleimenov 2006).

To control suckering weeds, an intensive tillage system after crop harvest is recommended: F double disking followed by deep plowing. After early harvested crops, it is recommended to combine disking with herbicide application. Although intensive tillage is quite common in NEE to control weeds, minimum tillage and no-till technologies are becoming adopted everywhere. Dnipropetrovsk in the Central Ukraine has been an important center for promoting and spreading minimum tillage technologies (Medvedev 2006).

SOIL FERTILITY MANAGEMENT

North Kazakhstan and West Siberia

The dry steppes of North Kazakhstan and West Siberia were developed for grain production in the 1950s. During the first 30–35 years, soils were rich in available nitrogen, and only phosphorus fertilizers were applied. The most widespread method of application was during the summer fallow period, once in 4 years at the rate of 60 kg P/ha (Lichtenberg 1995). The amount of N-NO_3 in the 0- to 100-cm soil layer during 1960–1980s decreased from 433 to 200 kg/ha in summer fallow and from 301 to 125 kg/ha in stubble. Presently, the application of nitrogen fertilizer on stubble fields is recommended based on soil analysis. In 1988, the application of 50 kg N/ha on stubble doubled barley grain yield on black soil (Filonov 2006).

Northeast Europe

The semiarid steppe belt of NEE is located on common black soils. In the Rostov area, spring application of fertilizers before seedbed preparation with duck foot cultivators is most efficient. In a study conducted during 1980–1984, application of 40–60–40 kg/ha of NPK by cultivator in the fall, plow in the fall, and cultivator in spring gave grain yields of 4.08, 4.11, and 4.27 t/ha, respectively, versus 3.41 t/ha in the control with no fertilizer (Sokol and Beltyukov 1988). Higher rates of fertilizers increased grain yield, but the unit of yield per unit of fertilizer return was much lower.

In Southeast Ukraine, barley is able to use very well carry-over manure applied to the previous crop. When the previous crop was maize with 30 t/ha of manure applied, barley grain yield increased by 0.22 t/ha. Fertilizers may also be applied in the fall before deep tillage. The rate of 40–80–40 kg/ha of NPK fertilizer ensured a grain yield gain of 0.87 t/ha and a return of 5.4 kg of grain per 1 kg of fertilizer applied (Logvinenko et al. 1998).

In the steppe of the Krasnodar area in a 2-year study, spring barley sown after a mixture of pea and oat with the most common rate of 60–60–45 kg/ha of NPK yielded 5.72 t/ha versus 4.99 t/ha grain with no fertilizer (Vasyukov and Kuznetsova 1988).

In the Central Chernozem zone, an adequate fertilization rate for malting barley is 60–60–60 kg/ha of NPK (Gorshkova et al. 1988). Further increase of fertilizer rates may increase crop yields but with lower return. In the Kursk area on typical black soil with OM of 5.2%–5.4%, application of the same 60–60–60 NPK rate increased the grain yield of continuous barley by 56.1%, which was equal to barley grown in a crop rotation. When 3- to 5-year continuous barley was double cropped with green manure (rapeseed and clover), barley yield gain was 5.8%–7.4% higher than barley in a crop rotation (Kartamyshev et al. 2006). Double cropping of continuous barley with green manure during 3 years increased soil OM by 0.1%.

Also in the Kursk area on sloped land when barley was sown after sugar beet, the highest yield was obtained from a carry-over effect of 48 t/ha of manure applied for sugar beet; 3.46 t/ha versus 2.42 t/ha for control with no fertilizer (Deriglazova and Boyeva 2006). Combined applications of mineral fertilizers on the background of manure even reduced barley yield.

In the Tatarstan forest steppe, the recommended rates of fertilizers are 60–40–60 kg/ha of NPK. These rates of fertilizers increased protein content from 9.3% to 10.7% in control with no fertilizer up to 13.4%–14.5% (Blokhin 2006). In Penza Province, fertilizer rates recommended are 45–50 kg/ha of NP. The yield increase was 20% as compared to control with no fertilizer averaged over 3 years and four varieties. Split application of nitrogen did not show any advantages (Koshelyayev 2006).

The south part of Krasnodar province is located in a foothill area with rich black soils and relatively high rainfall. The highest grain yields of winter barley (6 t/ha) were obtained with application of fertilizer at rates of 140–250–140 kg/ha of NPK. Nitrogen application was split with 70 kg/ha in the fall and 35 kg/ha both in spring and during the tillering stage (Shevtsov and Naidenov 1988). In the Middle Volga, nitrogen fertilization of winter barley is critical. It is recommended to do side dressing with ammonium nitrate early in the fall up to 40 kg N/ha and at the jointing stage at 60–80 kg N/ha (Tupitsyn and Valyaikin 2005). On dark gray forest soils, mineral fertilizers at the rate of 30 kg N/ha are applied prior to seedbed preparation with duck foot cultivators and 10–15 kg P/ha with seeds (Lopachev et al. 2001). On gray soil with 4.9% OM averaged over 2002–2004, the barley control (no fertilizer applied) grain yield was 1.82 t/ha; with 5 t/ha of straw applied, the yield was 2.19 t/ha; with 33–30–22 kg/ha of NPK, the yield was 2.74 t/ha; and with a combined application of straw and mineral fertilizer, the yield was 3.22 t/ha (Melnik et al. 2006).

COMPLEX OF CULTURAL PRACTICES

North Kazakhstan and West Siberia

In North Kazakhstan semiarid steppe, three levels of cultural practices were continuously applied during 19 years (1988–2006) in a "fallow–wheat–wheat–barley–wheat" rotation: low, common, and high inputs. The three levels included different relative levels of water, plant nutrition, and weed management. Most important was enhancement of water management by improved snow harvest technologies. Over the 19 years, one was wet, three were very dry, nine were dry, and six were favorable. Increasing levels of the combined cultural practices improved barley grain yield dramatically in all types of weather (Table 9.2.3).

Table 9.2.3 Spring barley grain yield (ton per hectare) as affected by three input levels of cultural practices and four different weather conditions in the semiarid steppes of North Kazakhstan, Shortandy (data of K. Akshalov and M. Suleimenov)

	Weather Condition			
Cultural Practice	Very Dry	Dry	Favorable	Wet
Low	0.66	1.43	1.89	1.05
Common	1.19	2.22	2.64	1.18
high	1.85	2.98	3.50	1.94
LSD$_{05}$	0.20	0.25	0.32	0.16

In the wet year, the grain yield was almost doubled from low-input (1.05 t/ha) to high-input practices (1.94 t/ha), although the potential was not realized because of high incidence of diseases. In the three very dry years, the grain yield tripled from the low- to the high-input cultural practices (0.66 t/ha vs. 1.85 t/ha). In the nine dry years, the grain yield more than doubled across management regimes and reached an average 2.98 t/ha for the high-input practice. And in the 6 years with favorable weather conditions, the grain yield was rather high even with low-input cultural practices. Application of the best cultural practices under favorable weather conditions almost doubled barley grain yield, reaching an average level of 3.5 t/ha.

In the southern forest steppe of West Siberia, 5 year (2001–2005) average barley yield gains obtained from fertilizers, herbicides, and fungicides amounted to 60%, 59%, and 7%, respectively. The combined application of the three factors increased grain yield by 109% and reached 3.23 t/ha (Kholmov and Shulyakov 2006).

Northeast Europe

In the Central Chernozem zone, three factors were studied: fertilizer, variety, and seed rate. The average effects of the factors on barley grain yield were fertilizer—37.7%, variety—13.6%, and seed rate—1.5%. For high-yielding cv. Olimpiyets, the share of the same factors was 35.0%, 24.3%, and 4.6%, respectively. It was further concluded that the effect of fertilizers increased in dry years up to 40.9%–43.2%, and that of variety increased up to 33%–34% (Gorshkova et al. 1988).

In the Penza forest steppe, the influence of three factors on barley grain yield was studied: variety, fertilizer, and weather (Koshelyayev 2006). The highest average effect in grain yield was due to fertilizer—25.9%. Variety played an important role in some years, and on average, its effect was 12.6%. Weather's effect on grain yield was, on average, 23.7%. Interaction of weather with fertilizer was also important, affecting 18.9% of barley grain yield.

On dark gray soil, four levels of cultural practices were studied: (i) extensive, with no fertilizer and pesticides; (ii) intensive, with commercial synthetic fertilizers and pesticides plus carry-over effect of 50 t of manure applied to the previous crop; (iii) transitional to organic production, with reduced synthetic chemicals plus carry-over effect of applied manure and 5–6 t of straw to the previous crop and 6–8 t of green manure; and (iv) organic, with no synthetic chemicals but with applications of manure, straw, and green manure. The highest barley grain yields were obtained on intensive and organic transitional cultural practices (3.7 and 4.0 t/ha, respectively) (Lopachev et al. 2001).

SUMMARY

Major components of cultural practices ensuring remarkable yield increases are soil moisture, weed, and soil fertility management. The weakest point of farming practices in the three countries is very low rates of applied fertilizers for wheat and almost no fertilizers for barley. Soil conservation practices including no-till farming have been adopted on a large scale only in Kazakhstan. Weed management needs to be improved a great deal in all regions.

Research data on cultural practices for barley show that in all ecoregions of the Russian Federation, Ukraine, and Kazakhstan, there is great potential for increased grain yields. The expected yields under adequate cultural practices can reach the following, on average: in the steppes of North Kazakhstan and West Siberia—3.0–3.5 t/ha, in the Volga area—3.5–4.0 t/ha, in the North Caucasus and South Ukraine—4.5–5.0 t/ha, in the Central Chernozem area and Central Ukraine—5.0–5.5 t/ha, in the forest steppes of Russia and Ukraine—5.5–6.0 t/ha, and in the foothills of Krasnodar area—6.0–6.5 t/ha for spring barley and 6.5–7.0 t/ha for winter barley.

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NORTH AMERICA

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INTRODUCTION

Most barley (*Hordeum vulgare* L.) in North America is produced in the Canadian Prairie provinces of Alberta, Saskatchewan, and Manitoba and in the northern-tier U.S. states of North Dakota, Montana, Idaho, Washington, and Minnesota. There is limited barley production in Mexico, and essentially, none produced in Belize, Costa Rica, El Salvador, Guatemala, Honduras, and Panama. While barley is produced in most Canadian provinces and in 27 of the U.S. states (Table 9.3.1), our focus here is the cropping systems and cultural practices in the major barley regions of the Canadian and U.S. Northern Great Plains (NGP) and the U.S. Pacific Northwest (PNW). Although winter barley is produced in certain regions of North America with mild climates, winter barley cultivars that can withstand the cold winter temperatures of the NGP and most areas of the PNW have not yet been developed. Spring barley makes up the vast majority of NGP and PNW production and in this chapter, the term "barley" implies spring barley unless otherwise mentioned.

In the 10-year period from 1998 to 2007, barley was produced on an average of 3.92, 1.73, and 0.36 million hectares per year in Canada, the United States, and Mexico, respectively (USDA-NASS 2008) (Fig. 9.3.1A). Production area has remained relatively stable in Canada (Statistics Canada 2008) and in Mexico, but there has been a fivefold decrease in barley hectarage in the United States since its peak in the mid-1980s

Table 9.3.1 Barley production area and average barley grain yield in each province and state in Canada and the United States, respectively, in 2007. Data are from Statistics Canada (2008) and USDA-NASS (2008)

	Production Area (1000 ha)	Average Yield (kg/ha)
Canada		
Alberta	1729	3700
Saskatchewan	1660	3000
Manitoba	380	3900
Quebec	95	4100
Ontario	67	4100
Prince Edward Island	33	3600
British Columbia	20	3600
New Brunswick	13	4300
Nova Scotia	3	3300
	Total: 4000	Average: 3400
United States		
North Dakota	563	3800
Montana	292	3000
Idaho	223	5400
Washington	91	4000
Minnesota	44	3800
Colorado	23	8400
Oregon	21	3200
Wyoming	21	6000
Pennsylvania	17	4900
California	16	4000
Maryland	14	5600
Arizona	13	7700
Virginia	12	4800
South Dakota	12	2700
Wisconsin	9	3800
Utah	9	5200
Delaware	7	5200
Maine	7	4700
North Carolina	6	3600
Kansas	5	3200
Michigan	5	3800
New York	4	3100
All other states	51	3600
	Total: 1465	Average: 4000

(Fig. 9.3.1A). Reasons for the decline in barley hectarage in the United States include (i) conversion of cropland to perennial grasses and shrubs under the federal Conservation Reserve Program; (ii) the difficulty of producing malt-grade barley under rainfed conditions in many years; (iii) the grain price of wheat (*Triticum aestivum* L.), and more recently maize (*Zea mays* L.), generally being higher than that for feed barley; and (iv) soil carryover of some herbicides used for wheat production have plant-back restrictions for barley and other crops for certain time periods.

Average barley grain yields are generally slightly greater in Canada than in the United States, with yields increasing in a near-linear manner in both countries during the past 50 years (Fig. 9.3.1B). Historically, barley grain yields in Mexico have been considerably lower than those in Canada and the United States, but yields in Mexico have increased appreciably in the past 10 years (Fig. 9.3.1B).

Barley is the third most important crop grown in the NGP of Canada after wheat and canola (*Brassica napus* and *Brassica campestris*). In the NGP of the United States, barley is the fourth most important crop after wheat, soybean (*Glycine max* L.), and maize. Malt-grain cultivars make up about 75% of barley hectarage in the NGP, but selection of barley for malt quality is generally only 25%–30% of malt barley production. The remaining land area is devoted to feed-type barley cultivars. In the PNW, most barley produced under rainfed conditions is used for feed and that under irrigation is used for malt. Lesser amounts of barley are also grown for silage for the feedlot industry. In all regions, the majority of barley is produced under rainfed conditions. One exception is in Idaho, where 60% of the state's barley is grown under irrigation (NASS 2008). Malt-grade barley is often difficult to achieve under rainfed conditions due to the vagrancies of climate.

Historically, about 80%–90% of the malt cultivars grown in Canada are two-row types. Malt-grade barley has returned a premium of almost Can$125 per hectare over feed barley prices. The biggest challenge for farmers is production of malt barley cultivars with a careful focus on agronomic practices including crop rotations for disease management, planting dates, planting rates, and fertilizer management to ensure barley grain will meet malt quality standards.

CLIMATE IN RELATION TO BARLEY PRODUCTION

The precipitation patterns in the NGP and PNW are vastly different. The NGP has a continental

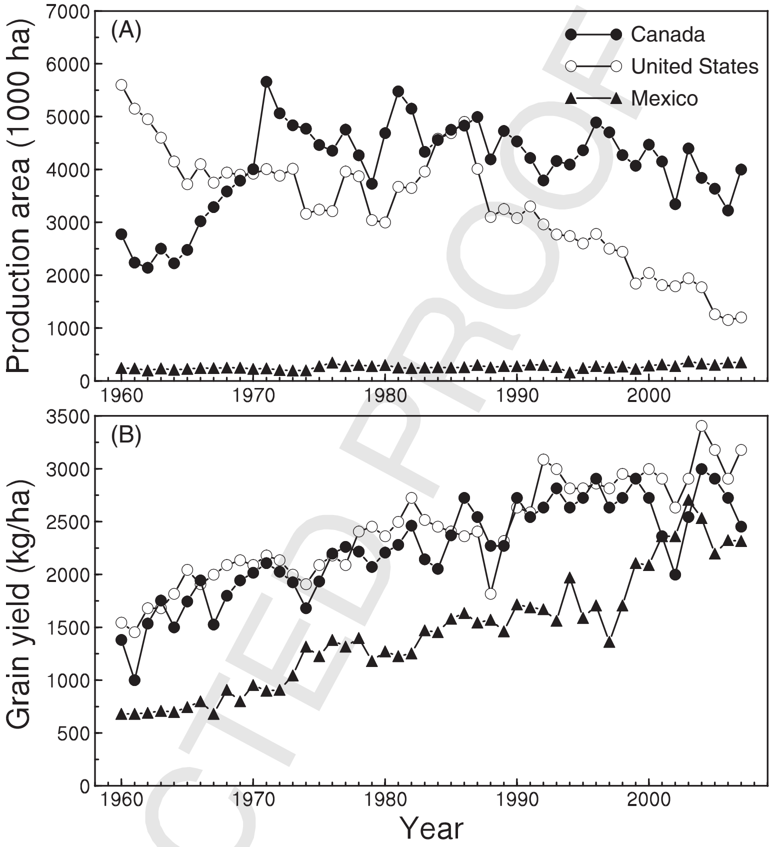

Fig. 9.3.1. Annual production area (A) and average grain yield (B) of barley in Canada, the United States, and Mexico from 1960 to 2007. Data are from the United States Department of Agriculture National Agricultural Statistics Service (USDA-NASS 2008) and Statistics Canada (2008).

climate with long, cold, relatively dry winters and short, warm, and generally wet summers. The annual average precipitation for NGP croplands ranges from 300 to 800 mm (Cochran et al. 2006). The greatest amounts of precipitation occur during the "growing season" months of May, June, and July (Fig. 9.3.2).

The PNW has a Mediterranean-like climate where the majority of annual precipitation occurs during the winter (Fig. 9.3.2). Winter temperatures are cool to cold but milder than those of the NGP. The annual average precipitation for PNW dry croplands ranges from 150 mm in South Central Washington to 1000 mm in the Willamette Valley of western Oregon. Crop production is heavily dependent on winter precipitation stored in the soil. High-pressure systems dominate during the summer leading to warm, dry conditions and low relative humidity. This climate is ideal for production of cool-season crops like wheat, barley, and grain legumes.

CROPPING SYSTEMS

Barley is a cool-season crop with early maturity that has a certain tolerance to drought and saline problems. Barley is a good rotational crop throughout the NGP and the PNW and fits well into conservation-till and no-till cropping systems.

No-till dynamic cropping systems are currently used in the major barley producing areas of the NGP (Tanaka et al. 2002). Many of these cropping systems have roots in the crop–fallow systems and evolved over the years to improve precipitation-use efficiency and to conserve natural resources. Barley fits well into dynamic

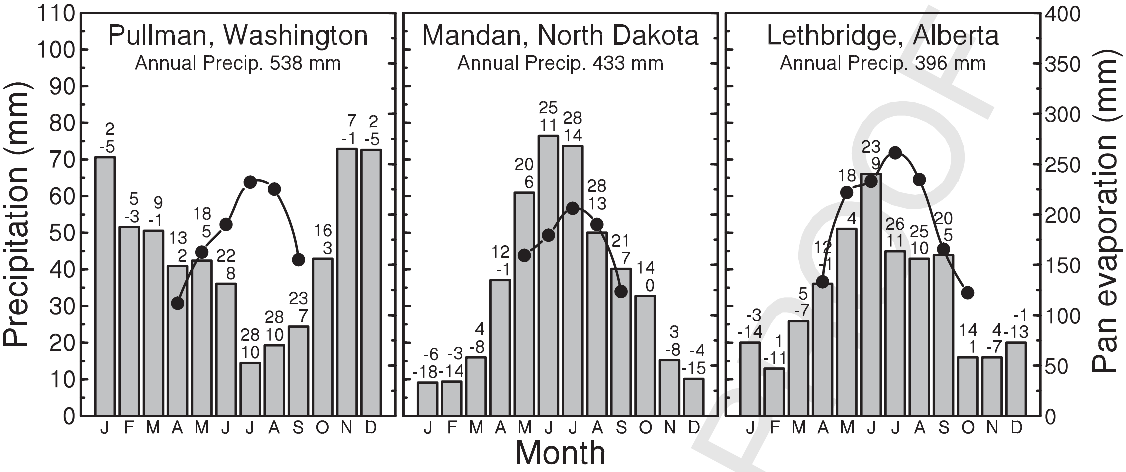

Fig. 9.3.2. Average monthly precipitation (bars) and pan evaporation (dotted line) from three representative barley production areas in North America. Lethbridge, Alberta, and Mandan, North Dakota, are located in the Northern Great Plains of Canada and the United States, respectively. Pullman, Washington, is in the Palouse region of the U.S. Pacific Northwest. The numbers above individual bars are the average monthly maximum and minimum (°C) air temperatures. The data provided are courtesy of Washington State University, Agriculture and Agri-Food Canada, and USDA Agricultural Research Service.

cropping systems (Tanaka et al. 2005). The crop sequence that usually results in the lowest barley grain yield is when barley is planted on its own crop residue. Factors associated with these lower yields were not obvious but may be associated with plant disease (Krupinsky et al. 2006). Some of the best barley crop sequences are when barley is planted on legume residues. Barley planted on spring wheat residue and vice versa improves crop yields and reduces disease pressure (Schillinger and Paulitz 2006) compared to planting barley or wheat on its own residue even though both are cool-season grasses and share many pest problems. In the NGP, crops planted on barley residue tend to yield equal or better than crops planted on spring wheat residue (Krupinsky et al. 2006). For example, deep-rooted and high water-using crops such as sunflower (*Helianthus annuus* L.) and safflower (*Carthamus tinctorius* L.) do better after barley than after spring wheat.

Prior to 1990, barley was grown almost exclusively in tillage-based systems in the NGP with hard red spring wheat as the most common cereal grown followed by barley. Most barley was grown after a 21-month summer fallow period in the drier regions (<400-mm annual precipitation) and was recropped (i.e., no fallow) where annual precipitation was >400 mm. In drier regions, the recropping decision is largely based on the quantity of water stored in the soil over the winter; if the soil wetting front does not extend at least 45 cm deep (in the range of 50–75 mm of available soil water), then NGP farmers will generally leave the land fallow. During the 1990s, due to the development of efficient no-till drills and affordable nonselective herbicides such as glyphosate, there was a gradual shift from tillage-based farming to no-till, where seed and fertilizer are delivered in one pass into the undisturbed standing stubble of the previous crop. In Alberta, the total cropland area under no-till increased from 3% in 1991 to 47% in 2006 (Statistics Canada 2008). In Saskatchewan, 60% of all cropland was in no-till by 2006.

The shift toward no-till has resulted in increased soil and water conservation, which in turn has reduced the amount of land in summer fallow across the NGP with concurrent shift in cropping systems used by farmers. More diverse crop rotations have been adopted that include other cereals, oilseeds, and legumes that have reduced disease pressure and allowed better weed control.

In the PNW, barley is commonly grown in a 3-year winter wheat–spring barley–spring legume rotation in the Palouse region that receives a 450- to 600-mm annual precipitation. Barley is at somewhat of a disadvantage (compared to legume) because it follows winter wheat, a high water user, in the rotation. Palouse farmers prefer to grow winter wheat after a spring legume crop because legumes use less water than barley and results in world-record rainfed winter wheat grain yields that average 6500 kg/ha. Average spring barley yields are 4500 kg/ha. Barley is also popular in the intermediate precipitation (300- to 450-mm annual) region of the Inland PNW where it produces an average 2800 kg/ha grown in a 3-year rotation of winter wheat–spring barley–summer fallow. Barley emerges quickly from the soil and has wide leaves and is therefore more competitive against weeds compared to spring wheat. Relatively little barley (or any spring crop) is produced in the low precipitation (<300-mm annual) region of the PNW where 95% of cropland is in a 2-year winter wheat–summer fallow rotation. However, when 125 mm or more over-winter precipitation is stored in the soil, many farmers will plant recrop spring barley or spring wheat with good results (Schillinger et al. 2007). Spring barley grain and residue yields are equivalent to those of spring wheat (Schillinger 2005), but barley residue decomposes at a faster rate than wheat residue. The rate of straw decomposition involves the interaction of several factors and compounds including the content of hemicellulose, cellulose, lignin, tannins, and nitrogen as well as the carbon : nitrogen ratio (Stubbs et al. 2009).

Barley yields in North America and throughout the world are greatly influenced by water availability. In a study with feed barley at 20 sites in Alberta, McKenzie et al. (2004) reported that the average water-use efficiency was 15 kg grain/ha/mm, similar to the 16 kg grain/ha/mm obtained in Alberta by Hoyt and Rice (1977) and higher than the average 10 kg grain/ha/mm reported by Bole and Pittman (1980). A higher water-use efficiency than observed previously in the NGP can be attributed to improved cultivars and agronomic practices including no-till and residue on the soil surface that conserves soil water, making the water available for transpiration through the plant. The relationship of barley grain yield to water use is affected by potential evapotranspiration and the timing, duration, and intensity of periods of water deficit (Heapy et al. 1976; Baldridge et al. 1985).

Fibrous rooted crops such as barley produce relatively high quantities of belowground biomass. Soil organic matter levels and soil quality can be maintained or even improved by including barley in the crop rotation. Spreading barley residue along the entire width of the combine header at harvest makes planting the next crop easier, reduces immobilization of nutrients during decomposition by microbes, increases the efficiency of herbicides, and reduces diseases.

CULTURAL PRACTICES

Much of the barley in the NGP is harvested by swathing or using preharvest desiccants to hasten drying after the grain reaches physiological maturity (<35% seed moisture); however, on the southern prairies, barley is often direct combined without swathing or use of desiccants. Direct combining is usually best if grain moisture level is <20%. Due to its dry summer climate, all barley is direct combined in the PNW when grain moisture content is <12%.

Barley water use from soil water depletion plus growing season precipitation is slightly greater than that of dry pea (*Pisum sativum* L.). Of 10 crops evaluated for water use in North Dakota, dry pea had the lowest soil water depletion (4.1 cm) followed by barley (4.3 cm) (Merrill et al. 2004). Soil water recharge during the noncrop period greatly influenced the next year's crop. Soil water recharge for barley residue was equal to spring wheat residue (Merrill et al. 2004). Some of the greatest soil water contents at planting in the spring were following dry pea, barley, dry bean (*Phaseolus* spp.), crambe (*Crambe cordifolia*), spring wheat, and soybean.

Planting date

The highest spring barley grain yields in all regions are generally achieved when planted as early as possible in late winter/early spring. In Alberta, McKenzie et al. (2005) found that delaying planting from late April to mid-May reduced grain yield by 20%. This was consistent with other barley planting date studies in North America (Beard 1961; McFadden 1970; Ciha 1983; Lauer and Partridge 1990; Juskiw and Helm 2003). The average yield loss of 20% from first to latest planting in the McKenzie et al. (2005) study was less than observed in Minnesota (35%; Beard 1961) and central 39 Alberta (47%, Juskiw and Helm 2003), likely due to the shorter time period between the first and last planting dates (≈3 weeks) versus the latter-mentioned studies (5–6 weeks). Early-planted barley has a grain yield advantage in all regions because the crop can capitalize on early spring moisture, longer spring days, and cool temperatures before the onset of hot summer temperatures.

Row spacing

Highest grain yields of barley are generally produced from rows spaced 250 mm or less. Low spike density generally occurs with rows spaced >250 mm and, although the plant will compensate with greater kernel number per spike and kernel weight, grain yield is reduced (Schillinger et al. 1999). Spike number per unit area is considered the most important yield component for barley under dryland conditions when severe water stress is not a factor (Arnon 1972). Weed growth tends to be more abundant in rows spaced more than 250 mm apart than in narrower rows.

When barley is swathed, support can be a problem as row width is increased. Drill openers that do not place the seed in distinct rows but rather scatter the seed in 5-, 7-, or 10-cm bands usually have good yield potential, and greater quantities of fertilizers with high salt index can be safely placed with the seed.

Planting rate

Optimum planting rate is influenced by many environmental and economic factors. Assuming that grain yield must increase four times the increase in planting rate to pay for the seed, McKenzie et al. (2005) recommended an optimum stand density of 200 plants/m^2 under rainfed conditions and 250 plants/m^2 under irrigated conditions in Alberta. A planting rate of 400 seeds/m^2 generally results in higher yields versus 200 seeds/m^2 at sites in Alberta and Manitoba. Further, barley is more competitive with weeds at the higher planting rate.

In a 4-year study in eastern Washington, Schillinger (2005) reported no differences in barley grain yield with planting rates of 120, 200, and 280 seeds/m^2. Although spike number per unit area was slightly reduced with low planting rate, the increased number of kernels per spike consistently compensated for reduced plant stand density. Planting rate had no effect on kernel weight or straw production. These results suggest that with precise placement of seed, farmers in the PNW could reduce planting rates by 50% or more from rates commonly used. These results (Schillinger 2005) somewhat contradict those of Lafond (1994), who observed that increased planting rates reduced kernel weight. Overall, the literature suggests that under dry conditions, lower than normal planting rates may actually increase barley yield by reducing plant competition for water, whereas when water is not so limiting, higher planting rates increase crop competitiveness and yield.

FERTILIZER MANAGEMENT

Achieving optimum yields of barley requires careful attention to nutrient requirements in all agroecological, soil, and climatic conditions. A balanced fertilizer program must be developed to achieve high barley yields.

40 Nitrogen (N)

N is by the far the most important nutrient required to ensure optimum barley grain yield and quality and almost universally increases grain yield on soils with low available N. Adequate N promotes vigorous plant growth and a larger leaf area with a deep green color. N in older leaves is redistributed to younger leaves to maintain growth. As a result, the older leaves first show the characteristic lighter green to yellow color followed by withering, indicating N deficiency.

The amount of N fertilizer required depends on the level of soil nitrate-N (NO_3^-), the mineralization potential of the soil, stored soil water, and expected precipitation. These conditions vary greatly across regions. As stored soil water and growing season rainfall increase, so too does the need for N fertilizer. As a general rule, feed barley requires about 38 kg of available N for every 1000 kg of expected grain yield. Franzen and Goos (2007) recommended about 30% less N for feed barley compared to malt barley grown in the NGP.

41 Phosphorus (P)

Native soils of the NGP often had total soil P levels in the range of 1100–1350 kg/ha (McKenzie et al. 2003). However, the portion of usable or plant-available P in native soils is very low; therefore, the majority of soils in the NGP are considered P deficient. Essentially all agricultural soils in the PNW are considered low in available P.

Barley response to applied P fertilizer depends to a large extent on placement and on the quantity of plant-available P already in the soil. The application of P can increase the retention of tillers and can hasten maturity. P levels in some soils have increased over the years as a result of repeated annual P fertilization.

Barley is frequently most responsive to seed-placed P followed by banded P fertilizer (McKenzie and Middleton 1997). Seed-and band-placed fertilizer P allows the roots of barley seedlings easy access to a concentrated quantity of P, whereas mixing P into the soil causes a dilution and in many cases causes P to be fixed in the presence of calcium or iron that reduces P availability. To obtain maximum P fertilizer efficiency, adequate rates of N and other nutrients must also be available to the barley crop. After P fertilizer has been applied for 10–20 years resulting in an increase of residual soil P, a relatively low annual maintenance application of P is generally all that is required to meet crop requirements, that is, replenish soil P that was removed by the previous crop.

Potassium (K)

Barley takes up nearly as much K as nitrogen and therefore has a high K requirement. However, only 20% of the K is removed with the grain with the remainder in the leaves and stems normally returned to the soil. The majority of cropland soils in the NGP and PNW contain adequate K for barley production with extractable soil K levels in the range of 450 to over 1200 kg/ha. There is generally little to no response in barley to K fertilizer when soil test levels are greater than 250 kg/ha. In the few soils that test <250 kg K/ha, or on sandy soils or intensively cropped fields, some K fertilizer may be required.

Sulfur (S) 42

S is the second most deficient nutrient (after nitrogen) in the PNW (Rasmussen and Douglas 1992), whereas S deficiency in barley is less common in the NGP (Cochran et al. 2006). S deficiency is most commonly observed on black and gray wooded soils in the northern regions of the NGP. Barley requires about 1 kg of S for 16 kg of N, and application of 12–20 kg S/ha is common. A 4300 kg/ha barley crop (grain and straw) contains approximately 12–14 kg S/ha, of which 50% is contained in the grain.

In the PNW, sulfur is most commonly applied in combination with N as liquid ammonium thiosulfate or ammonium polysulfide. Granular ammonium sulfate (21-0-0-24) is most commonly used to correct S deficiencies in the NGP. Sulfate-S is water soluble and mobile within the soil; therefore, banding sulfur near the seed at the time of planting is normally the preferred method of application.

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Micronutrients

Research on micronutrients since the 1960s has identified zinc (Zn), copper (Cu), manganese (Mn), and boron (B) as potential deficient micronutrients. Organic (peat) soils were also identified as a primary target for micronutrient deficiencies. Extensive work on the Canadian Prairies identified Cu as the micronutrient most likely to produce significant yield response in barley (Karamanos et al. 1983). Some 1.6 million hectares of cropland in Alberta and Saskatchewan is potentially Cu deficient (Kruger et al. 1985), primarily on the black and gray-black transition soils. Coarse-textured soils are most commonly Cu deficient, and wheat and barley are the two most sensitive crops to Cu deficiency. Copper fertilizer is commonly used in these deficient areas. To date, however, most farmers have applied very little of the other micronutrients for rainfed barley production.

WEEDS, DISEASES, AND INSECTS

Weed control

Many of the pest problems associated with wheat are also common to barley (Ransom 2005), and many of the herbicides used to control weeds in wheat are also registered in barley. Grass weeds that are a problem in barley include wild oat (*Avena fatua*), jointed goatgrass (*Aegilops cylindrica*), yellow foxtail (*Setaria glauca*), green foxtail (*Setaria viridis*), and Italian ryegrass (*Lolium multiflorum*). As a spring-planted crop, barley is effective in controlling downy brome (*Bromus tectorum*), by far the most problematic grass weed in the PNW and in other areas where winter wheat is produced. Downy brome is a winter annual with a growth cycle similar to winter wheat. Rotation to spring barley, spring wheat, legumes, oilseeds, or summer fallow is a prerequisite to control downy brome in the winter wheat-based cropping systems in the PNW (Thorne et al. 2007). Problematic broadleaf weeds include Russian thistle (*Salsosa kali*), common lambsquarter (*Chenopodium album*), horseweed (*Conyza canadensis*), kochia (*Kochia scoparia*), prickly lettuce (*Lactuca serriola*), redroot pigweed (*Amaranthus retroflexus*), mayweed chamomile (*Anthemis cotula*), field bindweed (*Convolvulus arvensis*), wild buckwheat (*Polygonum convolvulus*), and wild mustard (*Sinapis arvensis*).

Postemergence weed control in barley is usually less of a problem than in wheat because emerging barley seedlings tend to have a more vigorous and prostrate early growth habit with wider leaves to compete against weeds. Weeds can cause serious grain yield losses in barley, and their control is essential to attain optimum yield and quality. Reduction in grain yield and quality is generally proportional to the weed biomass in the crop. Weeds present in barley grain can result in major dockage and grade losses. Excessive weed biomass present in silage barley can reduce the quality of the fodder and affect palatability. Malting barley with excessive amounts of certain weeds will not achieve malt grade.

The cost of weed control must be balanced by the expected increase in return to the farmer from an increase in crop production, both in the current year and in future years. Crop competition and herbicides are the primary means of controlling weeds in barley. Most recommended herbicides are relatively cost-efficient and, other than crop competition, are the only widely applicable means of in-crop weed control. Various preventative measures include preplant application of a burndown herbicide such as glyphosate, using certified seed, and thoroughly cleaning combines after harvesting a weed-infested field. Physical control measures are used such as no-till planting to leave weed seeds on the surface where they are less likely to germinate compared to being incorporated into the soil with tillage. Cultural weed control methods include use of crop rotations with forage crops or fall-planted cereals to disrupt the life cycle of existing weeds. Increasing planting rates and planting early are other effective means used to increase crop competition with weeds. Cutting barley for green feed or silage can also be an effective form of weed control.

Some soil residual herbicides used in wheat and in other crops have barley plant-back restrictions ranging from a few months to 2 years.

These include some grass herbicides developed to selectively control downy brome and jointed goatgrass in wheat. In the past 5 years, the soil residual herbicide imazamox has been available for weed control in Clearfield™ wheat (Ball et al. 2003). Clearfield wheat cultivars were developed through mutation breeding for tolerance to imazamox herbicide. Imazamox selectively controls several grass and broadleaf weeds, but, due to its soil persistence, barley should not be planted for 12–18 months (or longer) after its application. Other soil residual herbicides used in wheat that have plant-back restrictions for barley include sulfosulfuron, imazethapyr, and propoxycarbazone. Soil texture, precipitation, soil organic matter, soil microbial activity, and soil pH are factors that influence persistence of herbicides in the soil. Farmers need to be aware of any carry-over problems and cropping restrictions of herbicides that they use.

Diseases

Numerous fungal and viral diseases affect barley. The major barley diseases in the NGP are generally not the same as those in the PNW because of the difference in precipitation pattern (Fig. 9.3.2). Barley diseases of greatest significance in the NGP are common root rot (also known as seedling blight) caused by *Cochliobolus sativus*, net blotch (caused by *Pyrenophora teres*), scald (caused by *Rhynchosporium secalis*), and fusarium head blight or scab (caused by *Fusarium graminearum*). An overview of these diseases is provided by Bailey et al. (2003).

The spores of several root rot fungi are ubiquitous in agricultural soils in both the NGP and PNW where they survive for many years. Common root rot, identified by the extensive brown discoloration of the subcrown internode and crown roots, damages the barley plant by plugging vascular tissue. Common root rot is the only consistently destructive soilborne disease of barley in the NGP. Rotations of several years with nonhost crops such as canola, alfalfa (*Medicago sativa* L.), flax (*Linum usitatissimum* L.), or legumes are necessary to reduce disease incidence.

Net blotch is a common foliar disease in the NGP that can reduce barley yields by 40% depending on the amount of affected tissue in the leaves and spike. The fungus overwinters on crop residue and infections occur in the spring from spores that are spread by rain and wind. Control is by crop rotation, foliar fungicide application, and planting barley cultivars that have some resistance to net blotch.

Scald is a major foliar disease of barley in the wetter regions of the NGP, particularly the black and gray soil regions in Canada. Scald is primarily a foliar disease but is also found on leaf sheaths and glumes. Large water-soaked, grey-green spots become bleached with brown margins as the leaves dry out. Spots often join and kill the entire leaf. The scald fungus overwinters on barley residue and produces spores in the spring. The disease is favored by cool (12–20°C) air temperatures, high humidity, and dense crop canopies where leaves remain wet for prolonged periods.

Scab infections have resulted in rejection of barley for malt and in some instances for feed grain. Crop sequence influences scab infections. The highest scab infections occur with cropping systems where previous crops are wheat, barley, and corn. Fusarium head blight is the most destructive fungal foliar disease of barley in the NGP. The highest severity of this disease occurs predominantly in the United States in North and South Dakota and Minnesota, as well as in Canada in western Manitoba and eastern Saskatchewan, with minimal levels in Alberta. Fusarium head blight has caused major economic losses due to reduced access to malt and feed markets.

In the PNW, fungi that infect roots, crowns, and stems are the primary pathogens affecting barley production. Rhizoctonia bare patch disease caused by *Rhizoctonia solani* AG8 is an important fungal disease of barley, wheat, and other crops in no-till fields. The disease results in patches of killed or stunted plants several meters in diameter. Rhizoctonia bare patch is unique to no-till fields; it is not a problem when tillage disrupts the fungal hyphal networks in the soil surface. At present, there are few management strategies for rhizoctonia bare patch (other than tillage), but breeding efforts are underway to introduce genetic resistance into barley and wheat cultivars. A comprehensive overview of soilborne cereal pathogens in the PNW is found in Paulitz et al. (2002).

Insects

Insects are occasionally a concern in barley production but are usually not a major problem. The insect pests of greatest concern are wireworm (*Agriotes lineatus*) and cutworm (order Lepidoptera). In drier years, grasshoppers (order Orthoptera) are occasionally of significant concern. Insects that are normally of minor problem include aphids (order Hemiptera) and barley thrips (order Thysanoptera). In recent years, a new insect pest, the cereal leaf beetle (*Oulema melanopus*), has been identified but is considered only a minor problem in both the NGP and PNW where parasitic insects have been introduced for its control (Glogoza 2002).

FUTURE OUTLOOK

The future for barley may be very promising given the current global status of cereal grains. One shift that could occur is the greater use of winter barley, both feed and malting types, as more cold-hardy cultivars are developed. When not killed by cold, winter barley cultivars have demonstrated considerably higher grain yield potential than spring barley. Although winter barley cultivars so far developed do not have good low-temperature tolerance (Fowler 2008), there is potential for genetic improvement for this trait (Thomashow 2001). Development of cold-hardy winter barley cultivars would likely lead to a rapid expansion of barley hectarage in regions where winter wheat is typically grown.

Since 2007, barley grain price has been on par with that of wheat where before it decidedly lagged behind that of wheat in U.S. markets. Barley production in Canada is expected to remain stable and, overall, it is felt that farmers will continue to show interest in barley, a crop with many desirable agronomic characteristics that also provides valuable crop rotation benefits. To more consistently achieve malt-grade quality, farmers need to continue to fine-tune fertilizer applications in line with available soil water and climatic considerations and to practice effective crop rotations for disease control.

On a broader scale, barley may play a significant role for biofuel production and human nutrition and health. For example, 20% of U.S. corn grain is currently used for ethanol production. Barley is an effective addition to a healthy diet to lower cholesterol and glycemic index due to high grain soluble fiber content. Scientists are only beginning to understand the importance of barley for human nutrition and health maintenance. 43

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WEST ASIA AND NORTH AND EAST AFRICA

Salvatore Ceccarelli and Stefania Grando 47

INTRODUCTION

North Africa and West Asia countries (Fig. 9.4.1) are not only among the oldest areas where barley was cultivated but are also the areas where agronomic science developed during the Roman Empire, particularly through the *De Re Rustica* ("On Agriculture"), the 12-volume treaty written by Lucius Iunius Moderatus Columella. Columella introduced agronomic practices unknown at the time, the most famous of which being fallow.

Contrary to breeding, barley agronomy is relatively less variable among countries of West Asia and North Africa. This is probably the consequence of the fact that (i) barley is predominantly

Fig. 9.4.1. North Africa (Morocco, Algeria, Tunisia, Libya, and Egypt) and West Asia (Jordan, Lebanon, Israel, Turkey, Syria, Iraq, Iran, Saudi Arabia, and Yemen). *Source:* ICARDA GIS Unit.

grown in marginal areas, where, for example, there are fewer options for rotations, and is predominantly used as animal feed both as grain and as straw; and that (ii) barley is grown in winter (autumn planting and late spring-early summer harvesting) following a dry summer.

One of the major differences in the barley-based farming systems between West Asia and North Africa, particularly in the rainfed areas, is the almost complete disappearance of the fallow in West Asia, while a barley–fallow rotation is still common in North Africa, particularly in Algeria.

In East Africa, mainly Ethiopia and Eritrea (Fig. 9.4.2), barley is grown twice a year. The main cropping season, known locally as *meher*, relies on June-September rainfall, while the minor cropping season, known as *belg*, is during the short rainy season, March–April. Because of the increasing frequency of droughts, the belg has virtually disappeared in most of Eritrea and in the northern part of Ethiopia (Tigray). Barley is the most suitable crop for belg season production, and it accounts for about 30% and 28%, respectively, of the total major cereal areas and total cereal production 48 during this season (Table 1). Ethiopia grows over 50,000 ha of malt barley in the Arsi and Bale highlands.

FERTILIZER USE

Being a typical crop of marginal environments with low yield potential and high risk of crop failures, barley has been always and traditionally allocated low amounts of fertilizers, despite the 49 demonstration by ICARDA of the effect of fertilizers, both nitrogen and particularly phosphate, in improving water-use efficiency (Cooper et al. 1987). In the semiarid areas, farmers are particularly reluctant to use phosphate because its maximum benefit is when applied before or at planting when farmers do not have any indication on how the cropping season will be. The high probability of either a low yield or of a crop failure explains the risk-adverse strategy of keeping investments at a minimum. This applies only to a limited extent to nitrogen. As this fertilizer can be top dressed at the end of tillering, it is common in wet years to see farmers hand spreading nitrogen, usually urea or ammonium nitrate, to barley fields.

In high rainfall areas or under irrigation (such as Iran, Iraq, or Turkey), barley is regularly fertilized as expected yields are much higher and the risk of crop failures is remote. Therefore, in these areas, it is common for farmers to apply fertilizer regularly even though in doses lower than for wheat.

In Ethiopia and Eritrea, nutrient depletion and land degradation are commonly recognized as two of the main yield factors in barley production. However, because of the type of land tenure, the land is owned by the government and farmers cannot sell their land and have no incentives to use improved agronomic practices. However, in some potential barley growing regions of Ethiopia, farmers apply (mainly on malt barley) 60–60 kg/ha urea and diammonium phosphate (DAP). The rate of urea applications can vary based on the preceding rotation crop where less urea is applied if the ~~ration~~ crop is legume.

ROTATIONS

In West Asia and North Africa, barley is grown under a number of rotations, which mostly depends on rainfall pattern. In the past, the dominant rotation was barley–fallow, which several studies have shown as the best rotation in dry areas. However, with the exception of several areas in North Africa, the barley–fallow rotation has been almost completely replaced by continuous barley. This is mainly due to two reasons. The first is the increase in the human population with a consequent increase in the demand of animal products, such as meat, milk, and its derivates, and the increase in a number of small ruminants. This has created a continuously increasing demand of animal feed, and as mentioned earlier, barley is considered to be the ideal and most dependable animal feed in the majority of North Africa and West Asia countries. The second is the failure of forage and pasture research to find

Fig. 9.4.2. (a) Ethiopia and (Continued)

suitable and adapted legumes to be used as animal feed, which, like barley, can grow during the cold months of the Mediterranean winter, and to withstand the drought in the later stages of crop growth.

Besides continuous barley (no rotation), the most common rotations found in North Africa and West Asia are with lentil, cumin (particularly common in Syria, but depending on the market price of cumin), and, much less common, vetch.

(b)

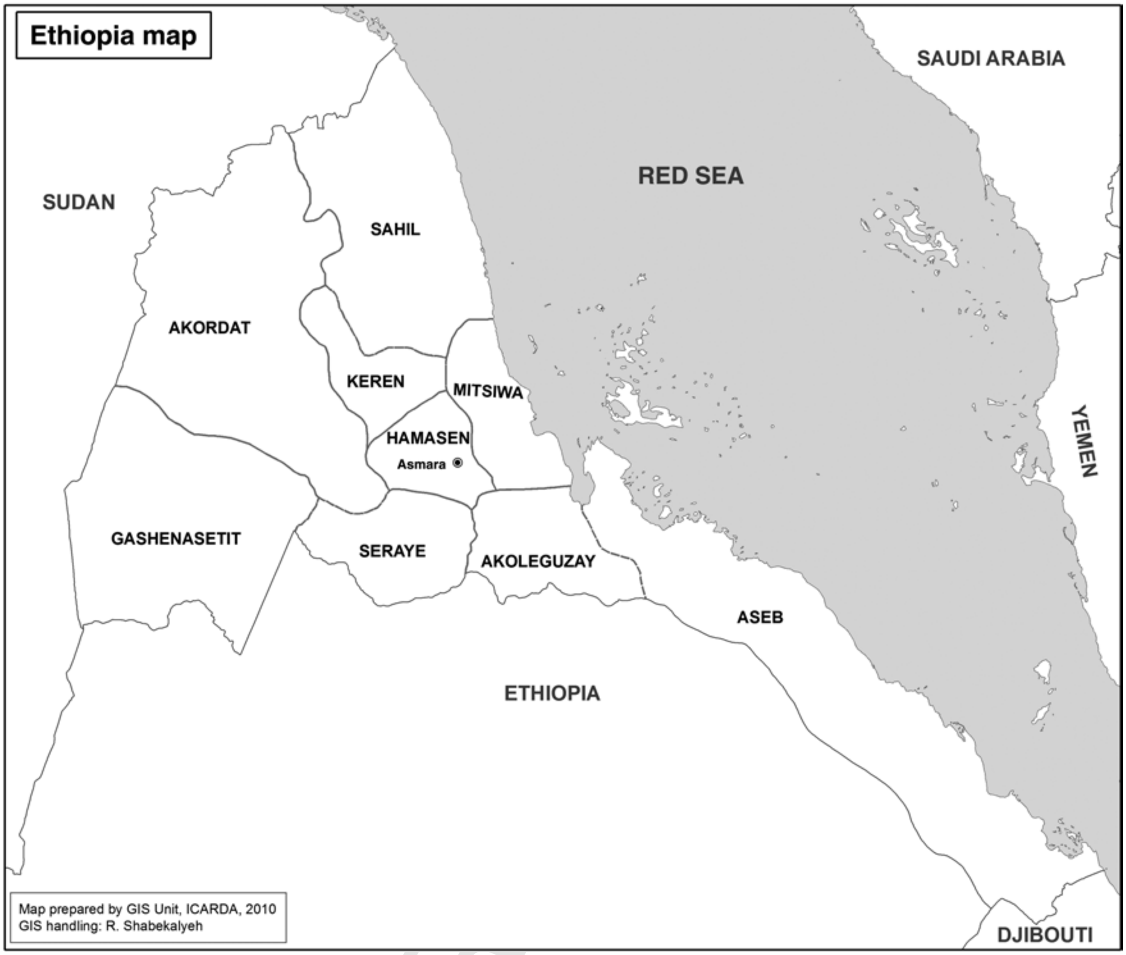

Fig. 9.4.2. (b) Eritrea and their administrative regions. *Source:* ICARDA GIS Unit.

Occasionally, in the wetter areas, it is possible to find barley following wheat or chickpea, but this is considered to be one of the worst rotations.

In the highlands of East Africa, farmers have practiced the barely–fallow cropping system, but this is now disappearing due to population and livestock pressure, as seen elsewhere. In the mid-altitude areas, farmers rotate barley with faba bean, field pea, and oil crops, mainly brassica and linseed as well as wheat.

TILLAGE

Because of its importance as animal feed, in the majority of years, and in most of the barley areas, barley stubble is grazed during summer months until the soil is left barren. Therefore, in the areas with continuous barley, soil tillage consists usually of a disk plough, often delayed until later in the autumn.

Even when a rotation is used, in most of the rainfed areas, tillage is more often done after the first rains and after the emergence of weeds and volunteers in order to insure a reasonably clean seed bed.

Preliminary experiments conducted recently at ICARDA's main research station with conservation tillage have shown its advantage in a number of crops.

In some countries, notably Algeria, some progressive farmers have an interest in experimenting with conservation tillage.

In the highlands of north and northwest Shewa where water logging is a major problem during the meher season, farmers use a soil preparation system locally known as *guie* (soil burning). This involves three to five plowings of fields that have been left fallow for at least 5 years. The practice is very tedious. Early maturing farmers' varieties, Demoye and Magie, are used in this system. Grain yield is higher in the first year (about 2.0 t/ha) but dramatically declines in subsequent years. Other cultural practices are similar to the late barley production system (Yirga et al. 1998a). In some parts of Bale, farmers, on average, plow their land five times
50 ~~(Bekele et al. 2004)~~.

SOWING

In most of North Africa and West Asia countries, and in most of the areas where barley is grown, sowing is done in autumn using spring or facultative types usually on a dry soil profile, following a summer with no rainfall and high temperatures.

The rainfed agriculture of these areas is therefore different from other rainfed and dry areas of the world because at the moment of sowing, farmers cannot count on any amount of stored moisture. As will be seen, this explains a number of farmers' choices in terms of agronomic practices.

In North Africa and West Asia, there has been a dramatic shift in the last 30–50 years from hand broadcasting to mechanical sowing with either imported or locally made drills (Turkey is one of the major producers of drills as well as other agricultural machinery).

Hand broadcasting, as it is still practiced, in mountainous areas and by poor farmers, is done after opening furrows with a disk plough and is followed by splitting the furrows with the same disk plough to cover the seed. The resulting arrangement of the plants in the field would be irregular as would be the seed depth. The lack of control of seed depth had its own advantages, particularly in conditions with an irregular and unpredictable opening of the rainy season. In the case of an early rain in the autumn (a false start of the rainy season) followed by a long period of drought, if seeds are at different depths, only a fraction of them will be reached by the wet front. These will eventually germinate and then dry out for lack of moisture. However, most of the seed will remain in the soil ready to germinate at the real start of the rainy season. In this situation, only a fraction of the sown seed will actually constitute the crop, and this might be a reason why in a number of dry areas, particularly of West Asia, farmers are using high seed rates (as high as 250 kg/ha); however, in other dry areas of the region, such as Jordan, farmers never use more than 100 kg/ha of seed.

In most of the highlands of Ethiopia and Eritrea, the crop is cultivated in two seasons per year. The main cropping season, locally known as meher, uses the June–September rains with harvest in December–January. The March–April rains provide moisture for a second season, locally called belg, with the crop harvested in June–August. In some regions, such as Gojam in Ethiopia, barley is also produced from September to January, locally known as Bega, under residual moisture. During the belg season, barley is the most widely grown cereal. It covers about 40% of the area and gives 46% of the total cereal production (Central Statistical Authority 1992).

SEEDING RATES

In Ethiopia and Eritrea, barley is planted by broadcasting and the optimum seeding rate is 100–125 kg/ha for broadcast sowing and 85–100 kg/ha for drill sowing. The seeding rate for malt barley is 100 kg/ha in Ethiopia.

In the Near East, the issue of seeding rate is one of the main arguments among farmers, and within a given country, it varies from as little as 60 to 100 kg/ha to as much as 250 kg/ha. Research at ICARDA has shown those seeding rates above 70 kg/ha to have no effect on yield; nevertheless, those farmers who are accustomed to use high seeding rates are very reluctant to change. This is probably a relic of the past when, as mentioned before, the lack of control of seed depth and poor seed quality justified higher seeding rates.

PLANTING DATES

While in most of the countries in North Africa and the Near East planting time for barley is between late October and mid-December and largely depends on the date of the first rain, planting date is much more variable in Ethiopia and to some an extent in Eritrea, where the date of planting determines different production systems as follows.

Late-barley production system

This is the most dominant system important in the high-altitude areas of both Ethiopia and Eritrea and is practiced during the main rainy season (June–October). Two variants of this system (Genbote and Sene gebs) are known based on the planting dates. In South Gonder, North Welo, and northwest Shewa, Genbote is planted in May and Sene gebs is planted between mid-June to early July. Sene gebs is the most common system in Eritrea. Different farmers' varieties are grown in the two subsystems (Yirga et al. 1998a,b). These varieties require 5–6 months to mature. Grain yields for this system vary from 0.6 to 2.0 t/ha (Yirga et al. 1998a).

Early-barley production system

This is also a main rainy season system and is important both in the mid- and high altitudes of Gojam and Gonder (Northwest Ethiopia) and in some parts of Shewa. Early farmers' varieties such as Semereta in Shewa and Gojam, Belga in North Gonder, and Tebele in South Gonder require 3.5–4.0 months to mature. The varieties are planted from mid-May to June and are harvested between early September and early October. Important early barley varieties are Aruso in Arsi and Bale and Saesa in Tigray (Negusse 1998). In Welo, farmers' varieties such 51
as Ehilzer and Tebele, two-row types, are important for early growing areas (Yallew et al. 1998). 52
The yield of early barley in a normal year varies from 0.7 to 1.5 t/ha (Yirga et al. 1998a).

Belg barley production system

This system is practiced in North and Northwest Shewa, North Welo, Bale, and a few areas in Arsi. Belg barley is planted in February and/or early March and is harvested in early July. Early maturing farmers' varieties that require 3–4 months to mature are usually cultivated. In this system, farmers do not apply fertilizer. Moisture stress and Russian wheat aphid (*Diuraphis noxius*) are the major threats to barley in this system. The yield of belg barley in a normal year varies from 0.8 to 1.2 t/ha (Yirga et al. 1998a).

Residual moisture barley production system

This system is important in some parts of Gojam, North and South Gonder, and West Shewa. Early maturing farmers' varieties, Belga in North Gonder and Semereta in Gojam, are important in this system. Planting is done between September and October, immediately after harvest of the main season barley crop. The seed of the main season barley is sown again in the same field or in any other field where the main season crop has failed. Fertilizer is not generally applied in this system. Harvesting is done from December to February. Grain yield from this system is generally low, less than 1.0 t/ha (Yirga et al. 1998a), and it is mainly used as seed for the next season.

WEED CONTROL

In the case of weed control, as in many of other agronomic practices, there is a considerable difference between barley grown in wetter areas and the same crop grown in dry areas.

In wet areas, wild oat is one of the most common weeds. Because expected yields are higher, chemical weed control is often practiced particularly when heavy weed infestations occur using any available and cheap herbicide. In North Africa and for broadleaf weeds, the herbicide 2,4D has been frequently used.

In dry areas, one of the most common weeds is the wild brassica. In these areas where expected yields are lower and the demand for animal feed is high, a weed, particularly if highly palatable by small ruminants like the wild brassica, ceases to be a weed and it is rather considered an additional source of feed. Therefore, in those countries where labor is still cheap, or is available within the family, most of the weed control is done by hand.

In Ethiopia, research conducted on station showed that a single hand weeding (25 days after planting or 20 days after emergence) is optimum for barley. Results of recent studies indicated that diclofopmethyl, at a rate of 1.5 L/ha, is the most preferred herbicide if the grass weed population consists of *Avena fatua* and *Phalaris paradoxa* (EARO 2000). Broadleaf weeds are still well controlled with 2,4D herbicide at a rate of 1 L/ha.

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AUSTRALIA

Blakely H. Paynter and Neil A. Fettell

The paper of Sparrow and Doolette (1975) provides a good historical view of barley production in Australia between 1860 and 1975. There are sections on the history and development of the Australian barley crop, agronomy, and breeding. This chapter focuses essentially on the environment in which barley is currently grown but reflects on some of the changes that have occurred in the last 30 years or since the Sparrow and 53 Doolette (1975) paper.

CROPPING ENVIRONMENT FOR BARLEY IN AUSTRALIA

Barley (*Hordeum vulgare* L.) is grown in all regions of Australia except the Northern Territory. This includes summer-dominant rainfall zones in northern New South Wales and Queensland and winter-dominant rainfall zones in South Australia and Western Australia. The semiarid cropping zone also includes a transitional zone where rainfall is distributed about equally between summer and winter in parts of Victoria and southern New South Wales (Foster 2000; McKenzie et al. 2004). More than 80% of Australia has an annual rainfall of less than 600 mm, with most barley planting

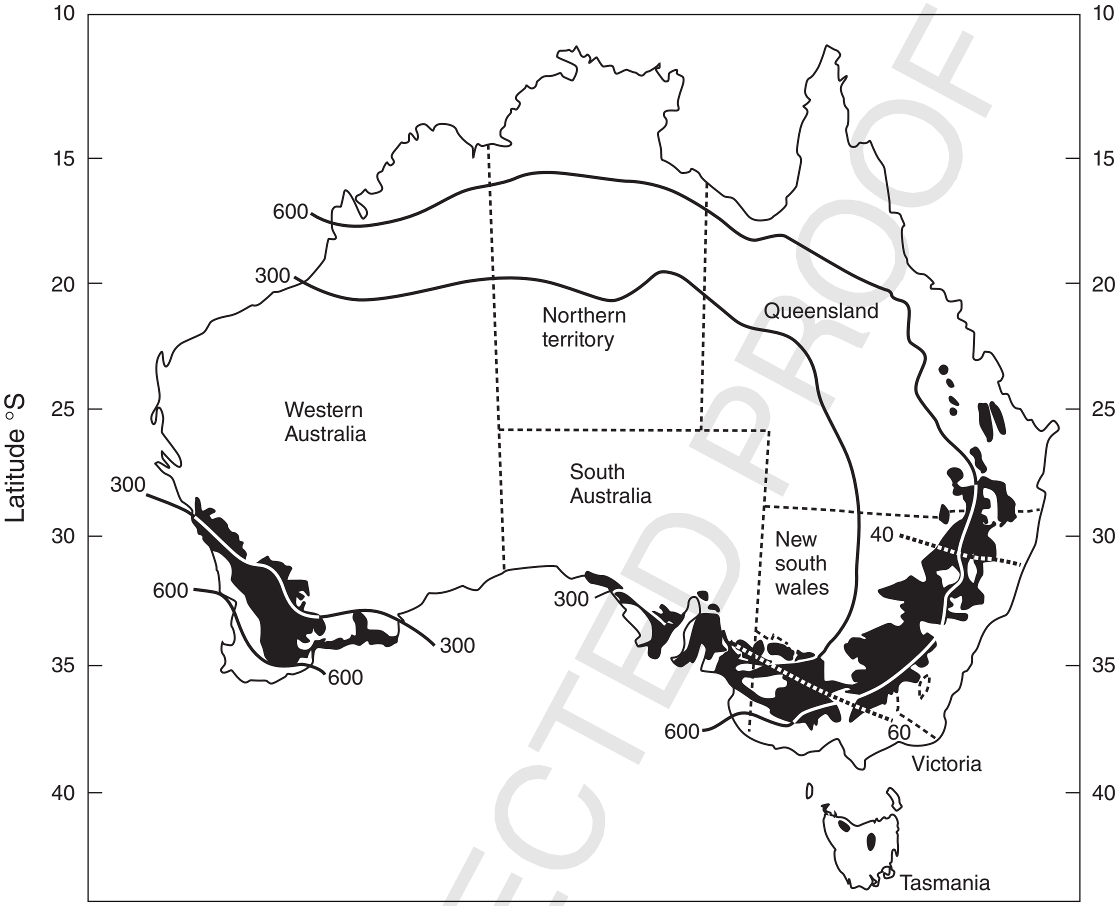

Fig. 9.5.1. Map showing the main cereal cropping areas of Australia (shaded) and annual rainfall isohyets in millimeters (solid lines). Agricultural land to the left and south of the 60% dotted line receives more than 60% of annual rainfall in the winter months. Agricultural land to the north of the 40% dotted line is the summer-dominant rainfall zone. Agricultural land between the 40% and 60% dotted line is the transitional rainfall zone. Adapted from Foster (2000) by W.K. Anderson and J.F. Angus (unpublished data).

occurring between the 300- and 600-mm annual rainfall isohyets (Fig. 9.5.1).

In most areas of Australia, barley is produced in a dryland farming system and relies on stored soil moisture and/or in-crop rainfall. Small areas of irrigated barley are also grown in New South Wales and Queensland. The growing season for barley is winter and spring (May–October), and rainfall for this period ranges from 170 to 550 mm. Year to year variability is extremely high in most regions, with coefficients of variability of nearly 20%. This results in highly variable winter crop yields (Singh and Byerlee 1990).

Westerly air streams dominate the climate of southern Australia (Hobbs 1988; Foster 2000). The position of the subtropical band of high pressure in the Indian and Southern Oceans is responsible for much of the rain-generating disturbances. High rainfall-generating systems often occur when the westerlies combine with moist air from the tropics. The climate of eastern Australia is more complex where rainfall from the westerlies is supplemented by summer rainfall from moist air masses from the Pacific Ocean (Foster 2000). Cyclic warming and cooling of ocean temperatures in the central and eastern Pacific have a large bearing on the likelihood of summer rainfall patterns in eastern Australia. This effect is known as the El Niño Southern Oscillation (ENSO). The ENSO state is determined by measuring differences in sea level pressure at Darwin and Tahiti and is reported as the Southern Oscillation Index (SOI). El Niño years (ocean warming, negative SOI) usually mean a lower likelihood of rainfall. La Niña years (ocean cooling, positive SOI) are usually associated with average to above-average rainfall. The more negative the SOI, the further south down the east coast of Australia the drought extends.

The ENSO effect is important but less significant in Western Australia. Rainfall patterns in Western Australia are more related to a dipole pattern of sea surface temperatures in the Indian Ocean, an effect known as the Indian Ocean Dipole (IOD). A positive IOD corresponds with above-average sea surface temperatures in the western Indian Ocean region, a cooling of waters in the eastern Indian Ocean, and a greater likelihood of lower rainfall in southern Australia. A negative IOD brings the opposite conditions and increases the chances of average to above-average rainfall.

Rapid advances are being made in the understanding of the ENSO and IOD systems, with a number of climate models predicting the ENSO state and giving a rainfall outlook for the season (Fairbanks 2006). Some of the models used in Australia include the operational models of the
54 Bureau of Meteorology (http://www.bom.gov.au) and the Queensland Department of Natural Resources and Water (http://www.longpaddock.qld.gov.au) and the experimental models from the International Research Institute for Climate and Society (http://www.portal.iri.columbia.edu), European Centre for Medium-Range Weather Forecasts, Experimental Centre for Climate Prediction (http://www.ecmwf.int), and the Department of Agriculture and Food Western Australia (http://www.agric.wa.gov.au) experimental ENSO Sequence System. While the reliability and timing of seasonal predictions is not yet sufficient for farmers to make major management decisions based on these growing season outlooks, the predictive skill of the various models is improving. For example, the Department of Agriculture and Food Western Australia experimental ENSO Sequence System successfully picked 13 of 16 ENSO states for the period 1988–2003 (Tennant and Fairbanks 2004; Fairbanks 2006).

The agroclimatic regions in which barley is grown are described as being Mediterranean in Western Australia, South Australia, and northwestern Victoria and temperate in Tasmania, southern Victoria, New South Wales, and southeastern Queensland (Stokes and Howden 2008).

BARLEY PRODUCTION—AREA AND TONS

Wheat (*Triticum aestivum* L.) is the most important annual crop in Australia followed by barley (Fig. 9.5.2). The decision to grow more or less barley relative to wheat is often related to differences in their relative product prices. There are often small increases in barley production following a year of high barley price and, conversely, small decreases in production following a year of low relative price.

Despite these fluctuations in relative product price, the area sown to barley has mirrored the continued rise in area sown to wheat since the 1940s (Fig. 9.5.2). Before the 1960s, the total area sown to barley in Australia was less than 1 million hectares. It has since quadrupled to 4 million hectares over the last 40 years (Table 9.5.1). Subject to variations in seasonal conditions, annual barley production now averages over 7 million tons. The largest barley crop grown in Australia was in 2003/2004. In that year, over 10 million tons of barley was grown on 4.5 million hectares.

By state, the largest barley-producing areas in Australia are South Australia and Western Australia followed by Victoria and New South Wales (Table 9.5.1, Fig. 9.5.3). These four states account for 97% of Australia's barley production, with South Australia and Western Australia accounting for nearly 30% each. Smaller areas of barley production occur in Queensland and Tasmania. This is a significant change from 1906

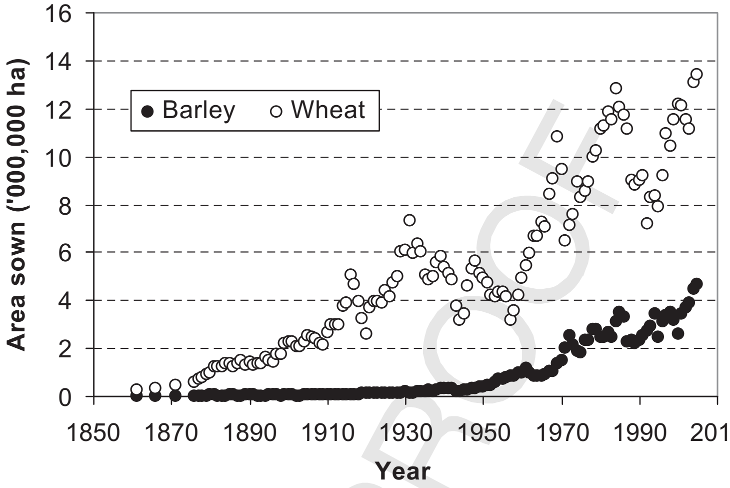

Fig. 9.5.2. Production ('000,000 ha) of wheat and barley in Australia since 1861. *Source:* Australian Bureau of Statistics (ABS 2006).

Table 9.5.1 Production by state and for Australia averaged over 5-year periods from 1906 to 2005 for (a) barley area sown ('000 ha), (b) average barley grain yield (ton per hectare), and (c) wheat area (hectare) sown for every 1 ha of barley sown 81

Period	Qld	NSW	Vic	Tas	SA	WA	Aust
(a) Area sown ('000 ha)							
1906–1910	3	4	23	2	14	2	50
1911–1915	3	5	26	3	24	3	63
1916–1920	2	3	34	2	46	4	91
1921–1925	3	2	34	2	76	4	121
1926–1930	2	3	36	2	103	6	152
1931–1935	3	4	36	3	116	8	169
1936–1940	4	6	60	3	168	22	262
1941–1945	4	8	55	2	151	26	247
1946–1950	8	9	70	3	235	27	351
1951–1955	22	9	105	3	378	56	572
1956–1960	78	32	133	4	494	140	880
1961–1965	77	86	90	7	494	164	916
1966–1970	154	163	131	10	498	215	1172
1971–1975	125	345	261	12	699	637	2079
1976–1980	216	460	364	11	967	525	2544
1981–1985	225	508	357	12	1050	691	2843
1986–1990	212	449	352	9	947	512	2481
1991–1995	164	515	536	13	993	608	2828
1996–2000	155	615	597	12	962	810	3152
2001–2005	113	778	793	8	1176	1160	4030
(b) Grain yield (t/ha)							
1906–1910	0.84	0.81	1.18	1.33	0.97	0.68	1.05
1911–1915	0.79	0.80	1.13	1.41	0.81	0.63	0.96
1916–1920	0.96	0.74	1.20	1.10	0.97	0.64	1.04
1921–1925	1.05	0.98	1.37	1.36	1.03	0.67	1.12
1926–1930	0.96	0.85	1.14	1.32	0.93	0.63	0.97
1931–1935	1.04	0.97	1.11	1.29	1.00	0.61	1.01
1936–1940	0.87	0.97	0.96	1.55	1.00	0.69	0.97
1941–1945	1.08	0.66	0.71	1.43	0.92	0.67	0.85
1946–1950	1.24	0.86	1.04	1.43	1.09	0.66	1.05
1951–1955	1.41	0.96	1.12	1.66	1.28	0.72	1.19
1956–1960	1.46	1.16	1.16	1.80	1.16	0.79	1.13
1961–1965	1.44	1.39	1.17	1.70	1.22	0.82	1.18
1966–1970	1.52	1.22	1.09	2.01	1.04	0.88	1.11
1971–1975	1.46	1.10	1.17	2.07	1.21	1.06	1.16
1976–1980	1.82	1.34	1.22	1.87	1.14	1.23	1.27
1981–1985	1.85	1.27	1.32	2.05	1.28	1.17	1.30
1986–1990	1.91	1.58	1.53	2.50	1.55	1.34	1.54
1991–1995	1.28	1.66	1.68	2.57	1.74	1.64	1.67
1996–2000	1.81	2.02	1.85	2.53	1.93	1.84	1.90
2001–2005	1.55	1.74	1.86	3.06	1.91	1.83	1.84

F

Table 9.5.1 *Continued*

Period	Qld	NSW	Vic	Tas	SA	WA	Aust
(c) Wheat area (ha) sown for every 1 ha of barley							
1906–1910	12	159	35	6	49	51	48
1911–1915	16	211	37	5	37	142	52
1916–1920	20	485	32	4	21	156	43
1921–1925	19	607	30	4	13	160	33
1926–1930	31	562	36	4	12	189	34
1931–1935	36	471	38	3	13	170	36
1936–1940	35	290	18	2	7	53	20
1941–1945	31	165	17	1	5	32	16
1946–1950	23	192	18	1	4	39	15
1951–1955	11	142	9	1	2	22	8
1956–1960	3	36	6	1	1	9	5
1961–1965	5	23	14	1	2	11	7
1966–1970	4	19	10	1	3	13	8
1971–1975	4	7	4	<1	2	4	4
1976–1980	3	7	3	<1	1	7	4
1981–1985	4	7	4	<1	1	7	4
1986–1990	4	6	3	<1	2	7	4
1991–1995	4	3	1	<1	1	6	3
1996–2000	6	5	2	<1	2	5	3
2001–2005	6	5	2	1	2	4	3

Source: ABS (2006).

to 1910 when Victoria represented 50% of the area sown to barley in Australia, South Australia 30%, and Western Australia only 4% (Table 9.5.1). South Australia has been the dominant barley-producing state since 1914, but this changed in 2001/2002. Since the 2001/2002 season, Western Australia has matched South Australia in area sown to barley. It is expected that these two states will continue to dominate production over the coming seasons.

The dominant areas of production in Western Australia include the Central Wheatbelt and the South Coast (Fig. 9.5.3). The major areas of production in South Australia are the Yorke Peninsula, southern Eyre Peninsula, and Murray Mallee, while in Victoria, these are the Mallee and the northern Wimmera. In New South Wales, barley production is concentrated along the western slopes and, to a lesser extent, the plains of the Dividing Range. In Queensland, the crop is largely grown on the Darling Downs and Goondiwindi border districts. There are growth areas into the western downs and central Queensland to supply the growing demand from intensive livestock industries.

Tasmania is the highest-yielding barley region in Australia with average grain yields of 3.0 t/ha over the period 2001–2005 (Table 9.5.1). Across the four major barley-growing regions of South Australia, Western Australia, Victoria, and New South Wales, the average grain yield of barley over the same period ranged between 1.7 and 2.0 t/ha.

The average rate of yield increase over the last 40 years has been just over 20 kg/ha/yr in the four main barley cropping areas in mainland Australia (Table 9.5.1). This has been associated with the release of over 40 new cultivars (Poulsen and Lance 2010) and has improved cultivar-specific management techniques (i.e., Paynter 1996; Paynter et al. 1999a,b; Smith and Paynter 2005; Russell et al. 2008a,b, 2009). This increase in yield is despite reductions in total annual rainfall across Australia during that period (Foster 2000; CSIRO 2007; Stokes and Howden 2008). Anderson et al. (2005) showed that over the period from 1985 to 2005, research to improve crop management contributed about two-thirds of the increased yield of Australian wheat crops, while genetic improvement contributed about

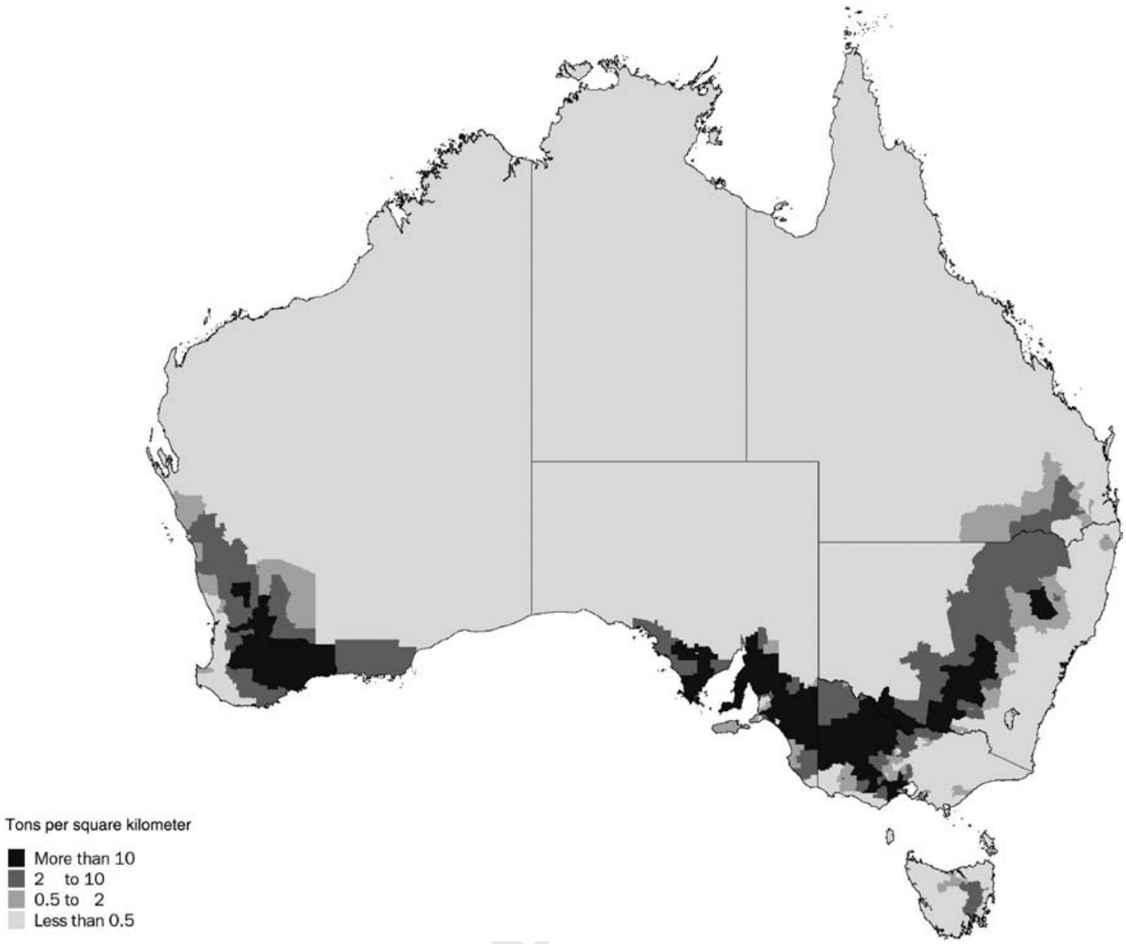

Fig. 9.5.3. Production density (ton per square kilometer) of barley in Australia for the growing season of 2005/2006. *Source:* ABS (2008).

one-third. A similar relationship would be expected in barley.

The Australian barley market is largely export focused, although the proportion of grain exported varies by state. Over the period from 2001 to 2005, exports of barley averaged 5.1 million tons. Of this average, 2.7 million tons were sold into feed barley markets; 1.8 million tons were exported to malting markets as grain; and another 0.6 million tons were exported as 55 malt. In that same period, an average of 1.3 million tons was used by the domestic stock feed industry and another 0.2 million tons by the domestic brewing industry. The use of barley by the domestic feed industry is likely to be an underestimate given on-farm use and local sales.

The Western Australian and South Australian barley industries are very much export focused with over 95% of production shipped as grain or malt to international markets. The main brewing markets for this grain and malt are China, Southeast Asia, Japan, South Africa, and South America. Grain exported as feed is sent to Japan, Taiwan, and a number of Middle Eastern countries such as Saudi Arabia. F

In Victoria, New South Wales, and Queensland, there is a much smaller export focus and a larger domestic focus. Between 20% and 30% of total feed barley production in those three states is used by the domestic feed industry. The main end users are dairy in Victoria, beef in New South Wales, and both beef and pigs in Queensland. There is also a growing demand from the Australian brewing industry for malting barley to be grown in New South Wales and Queensland to cope with rising population demand.

TYPES OF BARLEY GROWN

The area sown to barley in Australia is dominated by cultivars with a two-row head, a white aleurone, and a hull. Dual-purpose grazing, forage, and hulless barley cultivars, including some with a six-row head, are grown, but usually only on small areas each year. There is a growing demand in the higher rainfall areas of New South Wales and Queensland for barley cultivars for use as a grazing, hay, and/or silage crop. The adoption of dual-purpose grazing and forage barleys outside that area is limited. The future growth of the hulless industry is dependent on the growth of the food barley market and demand from the nonruminant feed barley market.

Six-row barley cultivars for grain production were recommended for sowing in Western Australia right up until the 1980s (Shier and Reeves 1957; Fisher 1982). During the early 1980s, Beecher occupied 12% of the barley area in Western Australia, but it is now sown on only 0.1% or less than 2000 ha. Six-row grain cultivars have historically been more commonly grown in Western Australia than in eastern Australia (Sparrow and Doolette 1975). The two most common six-row cultivars grown in Western Australia were Atlas and Beecher. Beecher was recommended for sowing on the saline soils of the Eastern Wheatbelt (Fisher 1982) and has since been replaced by two-row cultivars such as Mundah (released in 1995). Six-row cultivars like Beecher are no longer accepted at receival due to their blue aleurone.

To meet the demand for premium malting quality barley, large areas of the Australian barley crop are sown to cultivars suitable for use in the brewing industry. In Western Australia, around 80% of the barley area is sown to cultivars with a malt rather than a feed classification (Table 9.5.2). Since 1985, this ratio of malt to feed cultivars has been fairly stable in Western Australia and has ranged between 75% and 90%. In South Australia, malting barley cultivars occupy about 60% of the barley acreage, in Queensland around

Table 9.5.2 Percentage (%) of the Western Australian barley area sown to different malting barley cultivars[a] and those with a feed classification averaged over a 3-year period since 1982

Cultivar	1982–1984[b]	1985–1987	1988–1990	1991–1993	1994–1996	1997–1999	2000–2002	2003–2005	2006–2008
Baudin							0.0	11.7	23.2
Clipper	25.4	5.3	0.8	0.9	0.0				
Dampier	11.3	0.9	0.2	0.0					
Franklin			0.0	0.5	6.2	3.7	0.1	0.0	0.0
Gairdner					0.0	4.6	18.2	26.4	21.2
Hamelin							0.0	3.9	10.5
Schooner	0.0	0.8	0.3	0.0	0.0	4.0	6.3	3.7	0.8
Stirling	22.2	69.2	82.8	78.5	72.8	66.1	61.3	35.0	15.8
Vlamingh								0.0	3.6
Other malt	0.0	0.0	0.0	0.0	0.4	2.5	3.0	1.5	1.0
Feed	41.1	23.6	16.1	20.1	20.7	19.1	11.1	17.8	23.9

Source: Cooperative Bulk Handling Pty Ltd, Perth, Western Australia.

[a] Other malt cultivars includes the area sown to Unicorn, Harrington, Buloke, and Flagship. Clipper, Dampier, Unicorn, and Harrington are, however, no longer segregated as malt cultivars in Western Australia.

[b] Data period 1982–1984 has no data for 1982.

50%, and in Victoria and New South Wales around 70%.

The decision whether to grow barley for malting or for feed depends on five main factors:

1. premium paid for cultivars that are segregated as malting,
2. relative yields of malting and feed-grade barley cultivars,
3. differences in input costs due to their agronomy and disease constraints,
4. likelihood that grain of a malting cultivar will meet the malt barley receival specifications, and
5. location of receival segregations for malt barley cultivars.

The selection for higher grain yield and improved malting quality using European semidwarf germplasm by Australian barley breeders has seen the proportion of the barley area sown to cultivars with a semidwarf habit increase (Poulsen and Lance 2010).

This effect has been most obvious in Western Australia where semidwarf cultivars occupied only 10% (~68,000 ha) of the barley area in the early 1980s. Between 2006 and 2008, they occupied just under 50% (~500,000 ha). This change has occurred with the adoption of malting barley cv. Franklin (released in 1989) followed by Gairdner (released in 1997) and then Baudin (released in 2002) (Table 9.5.2). These cultivars have a higher grain yield potential than Stirling (released in 1980), the most common cultivar grown in Western Australia over the last 20 years. Their likelihood of achieving malt barley specifications, however, is lower (Paynter et al. 2004, 2008a; Paynter 2005a,b).

Gairdner is also widely grown in eastern Australia. It is estimated that Gairdner occupies some 10% of the malting barley area in South Australia, 30% in Victoria and southern New South Wales, and nearly 40% in northern New South Wales and Queensland. The dominant malting cultivars in South Australia, Victoria, and southern New South Wales during the last decade have been the tall cultivars, Schooner (released in 1983) and Sloop (released in 1997). They were also grown in northern New South Wales and Queensland in conjunction with Grimmett (released in 1982). The longevity of Schooner as a malting cultivar is a result of its higher likelihood of meeting malt specifications, particularly in drier environments (Fettell 2007). However, semidwarf feed barleys such as Skiff, Kaputar, Tantangara, Mackay, and Grout (released in 1988, 1993, 1998, 2001, and 2005, respectively) have performed well in eastern Australia. The adoption of Baudin in this region has been limited by its susceptibility to leaf disease, in particular barley leaf rust (caused by *Puccinia hordei*).

The recent approval of four new malting barley cultivars with a nondwarf habit—Buloke (released in 2006), Commander (released in 2008), Flagship (released in 2005), and Vlamingh (released in 2006)—is expected to see this increase in planting of cultivars with a semidwarf habit abated. A significant phasing out of Grimmett, Schooner, and Stirling (the backbone cultivars of the Australian barley industry since the early 1980s) will also occur.

Buloke and Flagship are expected to complement Baudin in the high-extract, high-diastase markets of China, Japan, South Africa, and South America. Commander and Vlamingh are better suited to markets where lower levels of starch adjuncts are used in the brewing process.

The adoption of new malting barley cultivars has been assisted through agronomic research trials and the subsequent release of cultivar-specific management packages. These guidelines describe details on how, when, and where to grow the cultivar. They include information on disease management, nutrition, seeding rates, dates of seeding, suitable soil types, herbicide tolerance, relative grain yield, and quality as well as details of the cultivars' main agronomic characteristics.

In Western Australia, for example, management guidelines have been released for the following malt barley cultivars: Harrington (Paynter 1996), Gairdner (Paynter et al. 1999a), Hamelin (Smith and Paynter 2005), Baudin (Russell et al. 2008a), Vlamingh (Russell et al. 2008b), and Buloke (Russell et al. 2009).

PLACE OF BARLEY IN THE FARMING SYSTEM

While product price drives the decision to grow barley or wheat, there are a number of reasons for growing barley that often override the product price differences. These include differences in tolerance to leaf disease, root disease, and waterlogging. In addition, barley offers growers advantages in integrated weed management (barley is more competitive against weeds and there are different herbicide options) and harvest management (barley is generally ready to harvest earlier than wheat). For example, Cousens (1996) and Walker et al. (2001) showed that barley gave greater weed suppression than wheat, and as a consequence, a lower herbicide rate was required for effective grass weed control.

In rotations with a double-cereal phase, barley is often a better choice as the second cereal for managing leaf diseases and for reducing input costs for fungicides, as well as for providing different weed management options. One of the reasons for this is that the leaf pathogens that attack wheat usually do not affect the productivity of barley (Mathre 1997). For example, wheat powdery mildew (caused by *Blumeria graminis* f. sp. *tritici*) and barley powdery mildew (*B. graminis* f. sp. *hordei*) are similar, but wheat powdery mildew does not infect barley. While *Septoria nodorum* (*Phaeosphaeria nodorum*) and *Septoria tritici* (*Mycosphaerella graminicola*) may infect barley, they do not usually cause any yield loss in Australia. Similarly, yellow spot (*Pyrenophera tritici-repensis*) rarely develops in barley.

Waterlogging is common on the duplex soils present in southern Australia (Moore 1998; McKenzie et al. 2004). Paddocks prone to waterlog are best not sown to barley unless there is a dry seasonal outlook. Barley has a lower tolerance of waterlogging than wheat under both saline and nonsaline conditions. Barley is very sensitive to waterlogging between germination and emergence, and when it is elongating before heading (Belford and Thomson 1981; Stepniewski and Labuda 1989a,b). The depth to the perched water table and the duration when it is within 30 cm of the surface and when it occurs in the life cycle of the plant influence the degree of yield loss likely in barley exposed to waterlogged conditions. High grain yields can still be achieved provided that the waterlogging does not persist for more than a few weeks.

The importance of barley in the farming system relative to wheat changes with state. Some of this is related to differences in soil type and fertility, domestic market demand, and the presence of other root pathogens such as nematodes. In South Australia and Victoria, there was 1 ha of barley sown to every 2 ha of wheat in the period 2001–2005 (Table 9.5.1). In Western Australia, New South Wales, and Queensland, wheat was more dominant, with only 1 ha of barley sown to every 4, 5, and 6 ha of wheat sown in that same period, respectively. In Tasmania, there was only a small area of both barley and wheat with barley being more widely sown.

Over the last 40 years, there has been a shift in the importance of barley in the farming system relative to wheat in New South Wales, Victoria, and Western Australia. In those three states, there has been an increase in area sown of barley relative to wheat compared to South Australia where there has been little or no change. Strong barley product price and higher-yielding cultivars along with research to support improved agronomic management are some of the reasons for the renewed interest in barley in Australia over the last 5 years.

While barley is grown in a wheat-dominated farming system, it is rotated with other crops. In southern Australia, other crops in the rotation include oats (for grain and hay) (*Avena sativa*), canola (*Brassica napus*), narrow-leafed lupins (*Lupinus angustifolius*), field peas (*Pisum sativum*), annual pasture legumes (predominantly *Medicago* spp., *Ornithopus* spp., and *Trifolium* spp.), and lucerne (*Medicago sativa*) depending on rainfall zone and soil type. In the northeast, sorghum (*Sorghum bicolor*) and chickpeas (*Cicer arietinum*) are also important rotation crops.

Common rotations in Western Australia are sequences of barley as the second cereal after pulse crops like lupins or field peas or as a first cereal after canola. In eastern Australia, barley commonly follows wheat and, to a lesser extent, canola. Wheat and canola are usually grown following pulse crops or legume pastures to better utilize the higher soil nitrogen supply.

In all regions, growers are moving away from fixed rotations and are increasingly making decisions on when to sow barley based on the current and expected price of barley versus other commodities, the risk of not meeting target quality specification due to the seasonal outlook, input costs, paddock nutrient status, the likely cost of inputs, root disease risk, weed seed banks, and herbicide resistance issues. Malting barley is best sown in a rotation following a nonlegume such as wheat or canola or oats to assist with the management of nitrogen inputs in targeting a 10.5% protein crop (Paynter 1995; Paynter and Young 1996; Smith and Paynter 2005).

Genetically modified (GM) crops are still in their infancy in the Australian cereal farming system, although GM cotton is grown in the cotton-growing areas of New South Wales and Queensland. From 2008, the planting of GM canola has been allowed in Victoria and New South Wales and from 2009 in Western Australia. The area sown to GM canola is expected to increase significantly in subsequent years as growers and governments embrace the technology. In the other states, there are government moratoriums that currently prevent the commercial production of GM crops like canola, lupins, barley, and wheat. It is expected that these bans on GM crops in cereal-based farming systems will be gradually lifted by 2013. This is dependent on governments and the consumer developing a better understanding of the benefits and risks from growing these crops as well the development of strategies to manage the risks. In some states, the governments are also being cautious so as to not cause damage to Australia's international market share.

SOIL TYPES ON WHICH BARLEY IS GROWN

Soil types vary significantly across paddocks and between states in Australia (Leeper 1964; Moore 1998; Bolland 2000; Schoknecht 2002; McKenzie et al. 2004). Many of the soils in Western Australia, South Australia, Victoria, and parts of southern New South Wales contain a high proportion of kaolinite clays that have a low exchangeable cation capacity and low pH buffering capacity. Being highly weathered, they also have a low capacity to hold water and generally have low fertility. In northern New South Wales and Queensland, the soils contain more illite and montmorillonite clays that have greater exchange capacity, hold more water, and have inherently higher soil fertility. The soil type present in each region impacts on the relative performance of wheat versus barley and the capacity of growers to grow malting quality barley.

In southwestern Western Australia, there are 21 main soil groups that are grouped into nine broad categories (Moore 1998; Schoknecht 2002). The three dominant soils by area are duplex soils (texture contrast within top 80 cm), deep sandy soils (sand to at least 80 cm), and gravelly soils (dominated by ironstone gravel). Duplex soils with sandy surfaces and clay subsoils are also common in drier areas of southern Australia. Many have large amounts of calcareous material throughout the profile and are highly alkaline, particularly at depth, often with high levels of boron and salinity. More favorable soils, comprising neutral to acid surface loam over moderately alkaline clay subsoils, occur widely in the more temperate parts of this region. Finally, there are large areas of cracking clay soils used for cropping in the northern New South Wales, Queensland, and lesser areas in central Victoria.

The low clay content of sandy surfaced soils means that they have a low capacity to retain macronutrients such as nitrogen, sulfur, and potassium (Bolland 2000; Foster 2000; McKenzie et al. 2004). Those nutrients are readily leached and need to be regularly applied. The presence of iron oxides in many Australian soils leads to the fixation of applied phosphorus, which means that fertilizers containing phosphorus need to be regularly applied.

Barley can be grown on a wide range of soils found in Australia, although its yield is often restricted when sown on soils with a soil pH ($CaCl_2$) below 4.5 due to aluminum toxicity

(Dolling et al. 1991a,b, 2001) or above 7.5 due to boron toxicity (Cartwright et al. 1984; Riley and Robson 1994; Riley et al. 1994).

Soil acidity is a problem on many soils, either occurring naturally or induced by agricultural practices. Agricultural production increases hydrogen ions in solution through the application of nitrogenous fertilizer, the sowing of annual legume pastures, and the removal of plant material (hay, grain) (Helyar and Porter 1989; Dolling et al. 2001; Bolland et al. 2004). Australian soils are sensitive to increases in hydrogen ions due to their low buffering capacity. Most farming systems rely on applying lime to the soil at a rate of 100–200 kg/ha/year to maintain acceptable pH levels (Dolling et al. 2001). Australia-wide, some 12.4 million hectares of agricultural land is acidic at the surface ($pH \leq 4.8$, 0–25 cm), of which 3.8 million hectares is also acidic in the subsoil ($pH \leq 4.8$, 30–40 cm) (Dolling et al. 2001). Acidic soils with a $pH \leq 4.8$ are found predominantly in New South Wales and Victoria, with smaller areas in Western Australia and Tasmania.

The solution to improving barley productivity on acidic soils is to apply lime, although this is difficult and expensive if the soil is acidic at depth (Bolland et al. 2004). The application of 1–2 t/ha of lime can lift soil pH by 0.3–0.7 pH units (Dolling et al. 1991a,b, 2001). Subsequent increases in grain yield and productivity are due to improvements in rooting depth associated with the reduction in aluminum toxicity (Reid et al. 1971; Foy 1988). While breeding is not the solution, improved germplasm can minimize the problem and can assist in paying for the costs of a liming program. Improved germplasm can also improve yield and quality stability as soil pH (and aluminum toxicity) is not constant across paddocks and many paddocks have areas with marginal acidity. The first Australian cultivar with improved acid tolerance (Brindabella) was released in 1993 (Read and Oram 1995). More recently, the barley breeding program at the Department of Agriculture and Food Western Australia has identified a molecular marker for a gene that confers tolerance to aluminum called *Alt* (C. Li, pers. comm.). Elite germplasm containing the *Alt* gene are up to 20% higher yielding in small plot trials on highly acidic soils (Table 9.5.3). Not applying lime, even with the use of more tolerant germplasm, will eventually result in subsurface acidification, which is more difficult to fix than surface acidification (Dolling et al. 2001).

A number of the soils with clay at the surface or at depth have alkaline subsoils. On these soils, soil pH ($CaCl_2$) can be above 7.5 and boron toxicity may be a problem (Cartwright et al. 1986; Riley 1988; Rengasamy 2002). Soils with an alkaline subsoil ($pH \geq 7.0$, 30–40 cm) occupy 74 million hectares of agricultural land (Dolling et al. 2001). These soils are located predominantly in South Australia and Victoria and in the eastern and southeastern areas of Western Australia. Unlike acidic soils, it is not possible to ameliorate

Table 9.5.3 Grain yield (% of their parent) of backcross lines (BC_4) of either Baudin or Hamelin relative to their parental line (Baudin or Hamelin expressed as ton per hectare) when sown at three sites in Western Australia with acidic subsoils in 2006 and 2007

	2006			2007			
Cultivar	Boscabel	Kalannie	HoltRock	Chittinup	Kalannie	Newdegate	Overall
Baudin (t/ha)	1.43	0.39	1.08	2.55	0.15	1.23	1.14
WABAR2473 (%)	139	116	124	102	147	133	121
WABAR2476 (%)	122	115	137	99	163	144	120
WABAR2478 (%)	139	133	136	86	157	134	114
Hamelin (t/ha)	1.92	0.32	1.16	2.82	0.17	1.37	1.30
WABAR2480 (%)	97	110	122	117	179	134	122
WABAR2481 (%)	99	139	127	122	142	130	111
WABAR2482 (%)	106	134	124	122	167	135	122

Source: Chengdao Li.

soils with alkaline subsoils. Breeding is therefore the only solution to improving the tolerance of barley to soils prone to boron toxicity. Genetic resistance to boron toxicity exists, and the recent identification of the *Bot1* gene (Sutton et al. 2007), which works by preventing the entry and accumulation of boron in the plant, will allow commercial cultivars to be developed with tolerance to boron. Through conventional breeding, a number of cultivars have been developed with improved adaptation to boron toxic soils. Some of these cultivars also show little or no leaf symptoms due to the accumulation of boron in their leaf material. To date, however, the absence or presence of leaf symptoms has not always been associated with enhanced yield performance (Riley and Robson 1994; Riley et al. 1994; Bolland 2000; J. Eglinton, pers. comm.). Riley et al. (1994) observed that susceptible cultivars are able to compensate to some degree for the loss of photosynthetically active leaf areas due to boron lesions by increasing their leaf area on primary tillers. Yield loss caused by boron toxicity is greatest in lower rainfall years where susceptible cultivars are unable to extract moisture from the toxic subsoil. In wetter years, the impact of reduced rooting depth is less noticeable and a susceptible cultivar can yield similarly to more tolerant cultivars.

Aside from the issues of aluminum or boron toxicity, the selection of soil type can have a critical impact on the success of barley grown for the malting barley industry. As soil type varies (along with water-holding capacity) across a paddock, so too does the probability of a cultivar meeting malting barley receival specifications. Table 9.5.4 shows examples of how cultivars may differ in their grain plumpness or screening level when grown in a paddock with contrasting soil types over two dates of seeding. The primary reason for the difference in screening response is related to differences in grain shape and not differences in their average grain weight response. Baudin, Gairdner, and Vlamingh have a similar time to

Table 9.5.4 Screenings (% < 2.5 mm) of five malting barley cultivars when sown at three sites (growing season rainfall from May to October in brackets) over two dates of seeding in the 2002 season for two different soil types in the same paddock

Soil Group[a]	Loamy Earth		Sandy Duplex	
Location	Calingiri	(235 mm)		
Date sown	May 22, 2002	June 11, 2002	May 22, 2002	June 11, 2002
Baudin	27	23	7	10
Gairdner	30	37	20	16
Hamelin	10	23	9	7
Stirling	6	11	2	4
Vlamingh	12	13	3	6
Location	Brookton	(277 mm)		
Date sown	June 5, 2002	June 27, 2002	June 5, 2002	June 27, 2002
Baudin	13	13	16	25
Gairdner	12	30	18	36
Hamelin	8	17	20	18
Stirling	5	15	9	20
Vlamingh	4	7	12	13
Location	Katanning	(263 mm)		
Date sown	May 16, 2002	June 11, 2002	May 16, 2002	June 11, 2002
Baudin	39	49	18	18
Gairdner	43	48	27	23
Hamelin	17	30	12	11
Stirling	11	30	5	12
Vlamingh	20	27	15	9

Source: Paynter et al. (2008a).

[a] Soil type was assessed according to Schoknecht (2002).

flower, but Vlamingh has plumper grain than Baudin, which in turn is plumper than Gairdner. Therefore, it is important for Australian growers to match their paddocks (and soil types) with the cultivars they are growing.

DATE OF SEEDING

In Australia, winter temperatures are relatively mild (mean July temperatures between 7 and 15°C) and cold damage to vegetative barley is rare. Therefore, spring-type barleys are sown in autumn (May–June) with the aim of flowering in early spring (mid-August to late September). Harvest occurs between October and December. The optimum flowering date is complicated by the conflicting need to avoid frost damage around ear emergence and flowering and to complete grain filling before the high temperatures and frequent dry periods of late spring (Shackley 2000). Cultivars with a high photoperiod response are favored in most areas of Western Australia and in the medium and lower rainfall areas of South Australia, Victoria, and New South Wales (Young and Elliott 1994; Flood et al. 2000; Paynter et al. 2001; Paynter 2005b) as they have a shorter vegetative period when sown late.

Based on simulations using historical rainfall records, the median sowing date for cereals in South Australia ranges between May 15 and 30, a week earlier than currently practiced (Yunusa et al. 2004). In another simulation study by Sadras 57 et al. (2002), the median sowing date for wheat was May 24 for the Mallee regions of South Australia, Victoria, and New South Wales. Simulations done in Western Australia have the median sowing date around May 23 (Abrecht and Balston 1996; Abrecht 2007).

Studies with wheat suggest that current sowing dates have moved forward some 3 weeks compared to the early 1980s. This shift has been more pronounced in Western Australia and Queensland (Stephens and Lyons 1998). Barley has also followed this same trend with the introduction of desiccant herbicides and minimum tillage seeding (direct drilling or no-tillage). In southern Australia, seeding was often delayed in the 1960s and 1970s until July in higher rainfall areas to prevent the development of rank crops (Sparrow and Doolette 1975). The release of later-maturity cultivars in conjunction with improved tillage practices has also allowed earlier sowing in these high-rainfall, generally longer seasoned environments.

Barley and wheat often need to be sown at a similar time on Australian farms, particularly in years when sowing rains are late. Delayed sowing has long been recognized as deleterious for both yield and likelihood of producing high-quality grain, with yield reductions as high as 30% (800 kg/ha) for a 3- to 4-week delay (Ridge and Mock 1975; Paynter and Hills 2007; Paynter et al. 2008a,b). In Western Australia, the yield loss due to delayed sowing was estimated to be just less than 20 kg/ha/day (calculated from Paynter and Hills 2007 and Paynter et al. 2008b).

In the 1980s, the usual practice was to sow barley later than wheat. This has largely changed in recent years with research showing the benefits of early sowing to the yield and quality of barley. Barley is now more commonly sown before wheat in Western Australia, although in eastern Australia, it largely depends on what cultivar is sown. Longer seasoned barley cultivars like Gairdner would be sown before main season wheats in eastern Australia, but the earlier-maturing cultivars like Schooner would usually be sown after wheat.

The most significant benefit of earlier sowing is an increase in the chance of grain meeting malt barley receival specifications (Paynter 1995, 2005a,b; Paynter et al. 2008a). This is mainly due to an increase in grain plumpness and a reduction in screenings. It may also be associated with the delivery of grain with a protein level between 9.5% and 12.5%. Delayed sowing often increases grain protein and may result in grain not meeting the current protein specification for malting barley. However, improved grain plumpness with earlier sowing is not a universal response (Table 9.5.4). In three comparisons (averaged across 10 cultivars) in eastern Australia, Fettell et al. (1999) found that kernel weight was greater with delayed sowing, a result of a higher rate of grain filling. Sowing time effects on grain set and hence source–sink ratios are a likely cause of these differing responses, and there are strong across-season interactions due to rainfall distribution.

PLANT POPULATION AND SEED RATE

Target plant populations of up to 100 plants/m^2 were commonly recommended for barley before the 1990s (Sparrow and Doolette 1975; Young 1995; Paynter 1996). Recent research has shown that the optimum seeding rate can be increased to produce higher yield without major detrimental impacts on grain quality. The latest cultivar-specific management guidelines reflect this change in target plant population.

Current target plant populations are the same for malting and feed barley cultivars and vary around Australia:

- Western Australia—120–150 plants/m^2 (Paynter et al. 1999a,b, Smith and Paynter 2005; Russell et al. 2008a,b, 2009) 58
- South Australia and Victoria—120–140 plants/m^2 in rainfall zones below 350 mm, 140–160 plants/m^2 for annual rainfall between 350 and 450 mm, and 160–180 plants/m^2 above 450 mm.
- Southern New South Wales—80–130 plants/m^2, with the lower density used in drier areas (Fettell 2008; McRae et al. 2008).
- Queensland and northern New South Wales—100–120 plants/m^2 (McIntyre 2008).

At an average seed weight of 40–45 mg and assuming 80% establishment, 120 plants/m^2 is equivalent to a seeding rate of 60–70 kg/ha. In South Australia, this is nearly double the recommended seeding rates of the late 1960s and early 1970s (Sparrow and Doolette 1975).

In Western Australia, the yield benefit of 300 kg/ha has been achieved by lifting the target plant population from 100 to 150 plants/m^2 (Paynter and Hills 2009; B. Paynter, unpublished data). In northern New South Wales, Doyle and Kingston (1992) concluded that a sowing rate of 60 kg/ha was optimal for yield or equivalent to about 130 plants/m^2 for the cultivars they used. In southern Australia, Fettell et al. (1999) reported higher yields at populations of 160 compared to 80 plants/m^2, and in New South Wales, an optimum of about 120 plants/m^2 is suggested (Fettell 2007). Higher plant densities invariably result in lower kernel weights (Doyle and Kingston 1992; Young 1995) and often reduced grain plumpness, although the effect may be reduced in cultivars with inherently large grain size and under favorable conditions (Fettell et al. 1999; Paynter et al. 1999b, 2008a; Fettell 2007).

Other benefits of sowing barley at a higher target plant population include improved competitiveness with weeds, decreased impact of mid-season waterlogging and improved plant establishment where insects or soil moisture may be an issue (Young 1995; Paynter and Hills 2009; B. Paynter, unpublished data).

NUTRITION WITH A FOCUS ON NITROGEN

Due to the low inherent fertility of many Australian soils (particularly in Western Australia), application of nutrients is required to optimize production either on an annual basis for nutrients like nitrogen and phosphorus or every 3–5 years for micronutrients like copper and zinc (Bolland 2000).

For malting barley production, nitrogen is one of the more important nutrients. A focus on premium quality malting barley has seen the malting and brewing industry target grain protein levels in delivered barley. As a consequence, both upper and lower limits for protein exist on delivery. In Western Australia, the problem for many barley growers is delivery of grain with low protein, whereas in Queensland and in New South Wales, excessive protein is a major reason for downgrading. In seasons or environments with low in-crop rainfall during spring, high grain protein is an issue for most growers. In many environments, the nitrogen rate for maximum yields may cause grain protein concentrations to exceed the malting specification, particularly in cultivars with inherently higher protein concentrations (Fathi et al. 1997).

The four key factors influencing the management of grain protein include soil type, rotation (legume vs. nonlegume), fertilizer application, and yield potential (cultivar, seasonal outlook, stored soil moisture, and date of seeding).

Application strategies for nitrogen have changed over the last 20 years in Australia. This is to meet industry demand as well as to cope with increasing nitrogen input costs and the difference in grain plumpness of newer malt barley cultivars.

One of the key drivers impacting on the most cost-effective use of nitrogen is cultivar. While nitrogen is needed to meet grain yield and grain protein targets, it may also push Australian barley growers out of malting because of high screenings. Nitrogen application generally decreases average grain weight, and this may result in an increase in screenings depending on the grain shape of the cultivar. Malting barley cultivars with a narrow grain shape (i.e., Baudin, Buloke, Flagship, and Gairdner) are more sensitive to nitrogen application than cultivars with a broader grain shape (i.e., Hamelin, Stirling, Schooner, and Vlamingh) (Paynter 2005c,d; Fettell 2007; Hills and Paynter 2008; Paynter et al. 2008a; B. Paynter, unpublished data). It is in seasons where moisture conditions during grain filling are marginal that the impact of grain shape is most noticeable. Grain shape can be the difference between grain meeting the receival standard or being downgraded.

Traditionally, most nitrogen has been applied up front at seeding or as a two-stage application with some starter nitrogen at seeding and a follow-up application at 4–6 weeks after seeding. The availability of liquid nitrogen has meant that nitrogen application can now be spread over a greater part of the growing season. With the introduction of higher-yielding malting cultivars, the timing of nitrogen has been examined more closely. The aim has been to find ways of minimizing the impact of nitrogen application on screenings without compromising grain yield or grain protein.

The practice of canopy management—limiting crop nitrogen early to limit tillering—and applying nitrogen as late as stem elongation, flag emergence, or even flowering is designed to yield fewer but fatter grains (Poole 2005). The theory is that it reduces the risk of high screenings from too much nitrogen applied before stem elongation. The advantage of this method is a better assessment of the yield potential of the barley crop. This is because it allows the grower to take seasonal forecasts for spring rainfall into account as well as to review current disease pressure and growing conditions. Until the reliability of seasonal forecasting tools improve, it is still not possible to determine the best time to apply nitrogen to optimize grain protein and minimize screenings. Research by Paynter (2005d), Poole (2005), and Hills and Paynter (2008) has demonstrated that the concept of canopy management in barley is sound. Delayed application, however, is less effective in the summer-dominant rainfall areas where there is less in-crop rainfall to wash fertilizer into the root zone (Doyle and Shapland 1991; Kingston et al. 2001).

Australian barley growers are using a number of decision support tools to help determine nitrogen requirements for a given rotation, soil type, and expected grain yield. These include Select Your Nitrogen and Yield Prophet®.

Select Your Nitrogen (SYN) was developed by the Department of Agriculture and Food Western Australia and is a spreadsheet-based decision support tool for quantifying nitrogen availability and crop response. SYN is a weekly time-step, simulation model designed to give the user a quantitative feel for how different components of the farming system impact on available nitrogen, grain yield, and grain quality, as well as the dollar returns. The main purpose of SYN is not to recommend a fertilizer rate; rather, it is to show the consequences of any possible nitrogen management strategy in any cropping situation.

Yield Prophet (http://www.yieldprophet.com.au) was developed by the Birchip Cropping Group in collaboration with the CSIRO. Yield 59 Prophet is a web interface for the crop production model APSIM (http://www.apsim.info) developed by the CSIRO. It simulates crop growth based on paddock-specific inputs of soil type, pre-sowing soil water and nitrogen, rainfall, irrigation, and nitrogen fertilizer applications and climate data. Like SYN, Yield Prophet is a risk management tool for dryland farming systems in Australia, with an emphasis on decision support for nitrogen fertilizer inputs.

A rule of thumb that is applicable to the production of malting barley in southern Australia is that paddocks, rotations, and rates of applied nitrogen, which typically produce wheat between 7% and 10% protein, suit the production of malting barley (Paynter and Young 1996). Areas where high protein wheat is grown—either due to soil type, low rainfall, or rotation—are not likely to be suitable for malting barley production.

In Victoria, there is a rule of thumb based on testing for deep soil nitrogen (0–60 cm) (McLellan et al. 2001). Paddocks where soil mineral nitrogen is greater than 100 kg N/ha at seeding are less likely to be suitable for malting barley production. Similar rules of thumb based on deep soil nitrogen (0–90 cm) exist for New South Wales where Kingston et al. (2001) suggest that deep soil nitrogen should not exceed 120 kg N/ha for successful malting barley production.

In northern New South Wales and Queensland, a rule of thumb used for nitrogen application is not to apply more than 40% of the nitrogen needed to grow prime hard wheat (McIntyre 2008). For malting barley, this equates to 0.5 kg of nitrogen at sowing for every millimeter of available soil moisture between 0- and 120-cm depth (Dalal et al. 1997). Thus, if there is 150 mm of available soil moisture, the crop will require 60 kg N/ha to produce a 10.5% protein barley crop.

PEST MANAGEMENT

Root diseases such as take-all (*Gaeumannomyces graminis* var. *tritici*) and rhizoctonia (*Rhizoctonia solani* Kühn AG-8) are present in most Australian farming systems, while crown rot (*Fusarium pseudograminearum*)is a major disease in northern New South Wales and Queensland. Take-all and crown rot can be managed by rotation (MacNish and Nicholas 1987; MacNish 1995; Wallwork 1996; Macleod et al. 2008) and rhizoctonia by tillage (MacNish 1985, 1995; Jarvis and Brennan 1986; Wallwork 1996; Macleod et al. 2008). Both barley and wheat are similarly sensitive to rhizoctonia, but barley tolerates take-all better than wheat. MacNish (1995) demonstrated that for every 1% increase in take-all severity on wheat roots, barley yields relative to wheat increase by 1%. Barley can therefore be sown instead of wheat in rotations where low levels of take-all exist. In rotations where take-all is severe, oats, pulse crops, or annual pasture legumes are often sown. Fungicides applied either to the seed or in the planting furrow (carried on fertilizer) can also assist in suppressing take-all and foliar diseases.

Nematodes are also present in most Australian farming systems. The most common nematodes found are cereal cyst nematode (*Heterodera avenae*) and root lesion nematode (*Pratylenchus* spp.). Cereal cyst nematode is found in Victoria, South Australia, and Western Australia and, to a limited extent, in New South Wales (Vanstone et al. 2008). Since barley cultivars are tolerant to cereal cyst nematode, yield loss in barley is limited even when infection does occur. Barley cultivars, however, vary in their resistance to cereal cyst nematode. A resistant cultivar retards nematode development, leading to fewer cysts on the roots and lower nematode levels in the soil for subsequent cropping seasons. Cultivars such as Barque, Capstan, Commander, Doolup, Flagship, Hindmarsh, Keel, Maritime, and Yarra are resistant to cereal cyst nematode. So, where cereal cyst nematode is a problem, growers are advised to include nonlegume crops in their rotation and to sow a resistant cultivar. Where high levels of cereal cyst nematode are present, a break of at least 2 years will be required to reduce nematode levels below those that are yield limiting.

Several species of root lesion nematode are known to occur in cropping soils of southern Australia (Riley and Kelly 2002; Thompson et al. 2008; Vanstone et al. 2008). 60 61 *Pratylenchus neglectus* is the most widely distributed species occurring in most cropping environments of Queensland, New South Wales, Victoria, South Australia, and Western Australia. 62 *Pratylenchus thornei* is also relatively common. There have also been isolated reports of other species, including *Pratylenchus penetrans*, *Pratylenchus brachyurus*, *Pyrenophora* 63 *teres*, *Pratylenchus zeae*, and *Pratylenchus crenatus* (Riley and Kelly 2002; Vanstone et al. 2003, 2005). *P. teres* is not known to occur outside of Western Australia (Vanstone 2008). It is not possible to eradicate nematodes in dryland cropping systems, but their populations can be managed. Resistant barley cultivars can be used to reduce the nematode population over one or more seasons. The nematode population can quickly increase again when a susceptible crop or cultivar is sown. Barley cultivars and other crops may differ in their capacity to host *P. thornei* and *P. neglectus*. This means that where a mixed population occurs, a crop or cultivar may increase the population of one species and may reduce the population of the other. The rotation chosen and the cultivar sown, therefore, need to be tailored to match the nematode species present.

Barley cultivars differ in their resistance to the different species of root lesion nematodes. Some barley cultivars such as Barque and Flagship are resistant to both *P. neglectus* and *P. thornei*. Capstan, Doolup, Maritime, and Gairdner are resistant to only *P. neglectus*, while Hindmarsh, Keel, Schooner, SloopSA, and SloopVic are resistant to only *P. thornei*.

The favored rotational crops for malting barley are canola and wheat. These two species are generally susceptible to root lesion nematode and, as such, this rotational sequence is not ideal for root lesion nematode management. Where mixed populations of the nematode are present, field pea, narrow-leafed lupin, and rye (*Secale cereale*) could make good break crops as they are resistant to both species (Vanstone et al. 2008). In rotations where *P. neglectus* is present, faba bean (*Vicia faba*), lentil (*Lens culinaris*), and triticale (*Triticosecale*) are also good options. Oats are a useful rotational crop where *P. thornei* is present. It should be noted, however, that individual cultivars within a rotational species can still vary in their reactions to root lesion nematode. The crops that reduce nematode numbers may not suit rotational sequences for growing malting barley. For example, the increased nitrogen status would have to be taken into account following field pea, lupin, lentil, and faba bean. Triticale is usually grown on acidic soils that are not suited to the production of barley, due to barley's sensitivity to low soil pH and aluminum toxicity.

There is a significant variation in the major leaf diseases that affect barley production in the different barley-growing areas of Australia (Table 9.5.5). These differences are largely related to differences in environmental (rainfall patterns and temperature profiles) and cultural practices. Cultivars also differ in their leaf disease resistance profile from the different pathotypes of each disease in each environment. A cultivar may be rated as moderately resistant to a disease in one environment but susceptible in another environment.

Depending on the disease, there are a number of cultural (i.e., rotation, tillage, fungicides, date of seeding, and clean seed) and genetic (resistance) strategies that can be used to reduce both incidence and severity (Table 9.5.6).

Stubbleborne leaf diseases such as scald and net blotch are best managed by not sowing barley into previous season (6-month-old) barley stubble and sowing resistant cultivars. Even 18-month-old barley stubble can still cause net blotch infection (Jayasena and Loughman 2001). In the case of net blotch, growers are also advised to not sow susceptible cultivars on the downwind side of infected stubble. In addition, as both scald and the net form of net blotch can be transmitted via seed, harvesting seed from an uninfected paddock will reduce the likelihood of early infection. Should seed from an infected crop be used, then dressing the seed with a registered fungicide will be required.

The control of leaf disease in barley has been made easier with an increase in the range of registered active ingredients and a reduction in the cost of some fungicides. Less than 10 years ago, growers were reluctant to spray foliar fungicides on their barley crops as there was no perceived economic benefit. As productivity has increased during this time and the relative cost of the fungicide has reduced, there is now a much greater use of fungicides. Best practice disease management now includes the application of a fungicide

Table 9.5.5 Rating[a] of barley leaf disease importance in each state (region) of Australia should disease-susceptible cultivars be grown

	State (Region) of Australia						
Disease (Causal Organism)	WA	SA	Vic	NSW–S	NSW-N	Qld	Tas
Scald (*Rhynchosporium secalis*)	Medium	Medium	High	High	Low	Very low	High
Net-form net blotch (*Pyrenophora teres* f. *teres*)	High	High	High	High	High	High	Low
Spot-form net blotch (*Pyrenophora teres* f. *maculata*)	Medium	Medium	Medium	Medium	High	High	Low
Powdery mildew (*Erysiphe graminis* f. sp. *hordei*)	High	Medium	Medium	Medium	Medium	Medium	Medium
Leaf rust (*Puccinia hordei)*	High	High	High	Medium	Medium	Medium	Medium
Stem rust (*Puccinia graminis*)	Nil	Very low	Very low	Low	Low	Low	Very low
Barley grass stripe rust (*Puccinia striiformis* f. sp. unknown)	Nil	Low	Lon	Low	Very low	Very low	Very low
Spot blotch (*Bipolaris sorokiniana*)	Nil	Nil	Nil	Nil	Low	Low	Low
Wirrega blotch (*Drechslera wirreganensis*)	Low	Very low	Very low	Nil	Very low	Nil	Nil

Source: Greg Platz, Hugh Wallwork, Mark McLean, Meixue Zhou, and Sanjiv Gupta. 83

[a] Rating of disease importance: high: potential to cause moderate to heavy losses in susceptible varieties; medium: potential to cause low to moderate losses in susceptible varieties; low: unlikely to cause significant losses; very low: occasionally detected, of no commercial significance; nil: not detected.

Table 9.5.6 Effectiveness of management and cultural practices on barley leaf disease control, where 1 = very effective, 2 = moderately effective, 3 = not effective, and – = not known or no product registered for control

	Cultivar Resistance	Crop Rotation	Green Bridge Destruction	Stubble Destruction	Disease-Free Seed	Chemical—Seed	Chemical—Foliar
Scald	2	1	3	1	2	2	1
Net-form net blotch	1	2	3	1	2	2	2
Spot-form net blotch	2	2	3	1	2	3	2
Powdery mildew	1	3	3	3	3	2	1
Leaf rust	1	3	1	3	3	2	1
Stem rust	2	3	2	3	3	2	1
Barley grass stripe rust	1	3	2	3	3	2	1
Spot blotch	2	2	3	2	2	2	—
Wirrega blotch	2	2	3	2	—	—	—

Source: Greg Platz and Kith Jayasena. 84

to the seed or the fertilizer and a follow-up foliar spray at either stem elongation and/or flag leaf emergence and, in some cases, even during heading.

In terms of product range, eight different fungicide products are now registered for foliar application on barley (subject to label registration) in Western Australia, for example. These include triadimefon, propiconazole, propiconazole+cyproconazole, azoxystrobin+cyproconazole, tebuconazole, flutriafol, and epoxiconazole. In addition, there are eight fungicide products that can be applied to the seed to control loose smut (*Ustilago tritici*) and covered smut (*Ustilago segetum* var. *hordei*). The registered seed dressing fungicide products include carboxin, carboxin+thiram, difenoconazole+metalaxyl-M, fluquinconazole, flutriafol, tebuconazole, triadimenol, and triticonazole. Some of these products also have activity against the seedborne net form of net blotch (carboxin+thiram and difenoconazole+metalaxyl-M) or the foliar diseases scald and powdery mildew (fluquinconazole, flutriafol, triadimenol, and triticonazole). Two fungicide products are registered for application to fertilizer, with flutriafol active against scald and powdery mildew and triadimefon active against powdery mildew. Fungicide products registered for barley for each state and for each disease can be found on the Australian Pesticides and Veterinary Medicines Web site (http://www.apvma.gov.au).

Damage from field insects is not generally a major factor for barley crops in Australia, although significant damage can occur if conditions favoring the buildup of insect populations occur. Seasonal factors, rotations, paddock management, and date of planting will influence the risk of loss from particular insects. The main insect pests of barley during the seedling stage include webworm (*Hednota* spp.), cutworm (*Agrotis* spp.), desiantha weevil (*Desiantha diversipes*), red-legged earth mite (*Halotydeus destructor*), and lucerne flea (*Sminthurus viridis*). Growers can reduce the risk of loss from seedling insect pests by appropriate paddock management. Factors that influence the level of damage include rotation, grass weed control in previous crop, soil type, date of seeding, and length of fallow before seeding (Grimm 1995). During tillering, the main insect pests are aphids. Corn aphid (*Rhopalosiphum maidis*) and wheat/oat aphid (*Rhopalosiphum padi*) can cause yield losses of up to 2 t/ha in crops averaging over 5 t/ha. Rice root aphid (*Rhopalosiphum rufiabdominalis*) and grain aphid (*Sitobion miscanthi*) are also found and may be important as virus vectors. Aphids, while seasonal, are becoming more important as our yield potential increases. Aphids affect barley by direct feeding and/or by transmitting the barley yellow dwarf virus. The use of insecticides on the seed (i.e., imidacloprid) or a foliar spray when 50% of tillers have at least 10–15 aphids per tiller can reduce the impact of aphids on barley production. Some cultivars have good resistance to barley yellow dwarf virus, such as Baudin and Gairdner, but are still susceptible to the feeding damage caused by the aphid. During flowering and grain ripening, the main insect pests of barley include aphids, armyworm (*Mythimna convecta*, *Mythimna loreyimima*, *Persectania ewingii*, and *Persectania dyscrita*), and the Australian plague locust (*Chortoicetes terminifera*). Native parasites can exercise good control of armyworm and spraying is not normally required every year. Spraying is usually undertaken when locusts are in plague proportions, and the locust plagues in Western Australia are rarely as severe as those in the eastern States. Outbreaks of locusts are very seasonal and usually occur when in seasons following strong periods of rainfall in inland Australia (nonagricultural).

Australia has a significant advantage over many barley-growing regions in the world in that it is free of a number of exotic insects and diseases. Biosecurity protocols therefore exist for the movement of barley (and other plant material) into Australia, between states, and from farm to farm. Shea et al. (2003), for example, describes the process of practical on-farm biosecurity. A number of exotic threats have been identified as being potential threats to the Australia barley industry. One of the main purposes of Australia's strict quarantine and biosecurity is therefore to protect Australia's favorable pest and disease status and enhances Australia's access to international markets.

Most of the highest category threats identified for barley are associated with grain contamination and market access, although a number of them can cause significant yield loss as well. Changes in farming practices or even climate change may increase or decrease the likelihood or incidence of a particular threat occurring in Australia. For example, the trend toward summer cropping with maize (*Zea mays*), French millet (*Panicum miliaceum*), Japanese millet (*Echinochloa esculenta*), or sorghum, the adoption of no-tillage, the lack of resistant barley varieties, and prolonged wet weather during flowering increase the risk of the *Fusarium* spp. complex developing. These fungi can produce toxins that can contaminate affected grain and render it unsuitable for marketing and consumption.

The main exotic threats that are present in different states in Australia include the *Fusarium* spp. complex, European snails (*Helix pisana*), and corynetoxin contamination. A range of exotic threats including Khapra beetle (*Trogoderma granarium*), Russian wheat aphid (*Diuraphis noxia*), wheat stem sawfly (*Cephus cinctus*), European wheat stem sawfly (*Cephus pygmeus*), barley stripe rust (*Puccinia striiformis* f. sp. *hordei*), and barley stem gall midge (*Mayetiola hordei*), however, are not currently present in Australia, and we aim to keep Australia free from those threats.

TILLAGE

Until the 1970s, cultivation was a necessary part of Australian farming systems. The introduction of new herbicide options such as the nonselective, nonresidual knockdown herbicide Spray Seed® and the selective, residual herbicide trifluralin, along with the increasing use of tined seeders, saw the beginning of the direct drill or minimum tillage revolution (Reithmuller 2000). It was not until the early 1990s, however, did the use of narrow tined tungsten carbide points lead to one-pass seeding with minimum disturbance otherwise known as no-tillage. This system allowed farmers to sow earlier on less rainfall, and with engineering improvements to seeders such as disturbance below the seed, there has been a rapid adoption of no-tillage. Recent changes to the no-tillage system include greater retention of straw (stubble) and the sowing of crops on wider rows (i.e., widening from 18 to 22–36 cm).

In 2004, an estimated 72% of Australian farmers direct drilled their crop (Hodges and Goesch 2006), up from 26% in southeastern Australia and 58% in Western Australia in 1998 (Knopke et al. 2000). In 2008, it is estimated that nearly 70% of South Australian farmers and 88% of Western Australian farmers would be using no-tillage principles to sow their crop (D'Emden and Llewellyn 2006).

The study of D'Emden and Llewellyn (2006) suggests that the predominant reason for adopting no-tillage in Australia was soil conservation rather than weed control. Most growers believed that while weed emergence would be lower under no-tillage, there would be an increase in reliance on herbicides. No-tillage systems, however, increase the need for herbicides due to the reduction in cultural weed control. In order for no-tillage systems to be successful, growers have had to adopt integrated weed management systems, especially with the increase in resistance in annual ryegrass (*Lolium rigidum* Gaud.) to postemergent, selective herbicides and the risk of developing resistance to glyphosate (Llewellyn and Powles 2001; Neve et al. 2003). Some of the integrated weed management techniques adopted include manuring (green or brown), double-knock techniques, presowing and rotating between paraquat and glyphosate, presowing to minimize weed competition, and weed seed set (Walsh and Powles 2007).

On many soils with surface layers texturing from sandy to loamy sand (common in Western Australia), machinery traffic can cause compaction of the soil layer 10–20 cm below the surface (Hamza and Anderson 2003). This is because these soils have a particle size that, when moist, can be compacted. Barley roots can often penetrate this compacted layer, but they do not go all the way through resulting in less grain yield and higher screenings. As most no-tillage operations do not penetrate this layer, deep ripping of the soil to 40 cm can improve productivity (yield and grain quality) by increasing rooting depth and, in some situations, by reducing the incidence of rhizoctonia bare patch (Ellington 1986; Jarvis and Brennan 1986; Reithmuller 2000). The impact of deep ripping can often be seen in subsequent seasons. In some situations (particularly where the soil has a clay texture), the use of gypsum can maintain the effect for longer or can improve the

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effect of deep ripping (Hamza and Anderson 2003). Deep ripping is therefore a recommended practice for barley growers when cropping compaction-susceptible soils. In eastern Australia, where wheel track compaction on clay soils can also restrict water movement and root growth, controlled traffic systems in which all tractor and harvester wheels are restricted to permanent tracks are increasing in use.

One of the consequences of this swing to no-tillage and retention of straw has been an increase in the risk of stubbleborne diseases like the net form of net blotch (*P. teres* f. *teres*) and, in northeastern Australia, common root rot (*Bipolaris sorokiniana*). To reduce this risk, Australian barley growers are advised to ensure that there is at least a 2-year break between barley crops in the same paddock as well as to avoid sowing susceptible cultivars on the downwind side of infected stubble.

No-tillage systems can also lead to more rhizoctonia bare patch problems (MacNish 1985; Macleod et al. 2008). With no-tillage, plants can become affected by the pathogen soon after germination. Treating the seed with a seed dressing containing the active ingredients difenoconazole and metalaxyl-M can suppress root infection from both rhizoctonia and pythium root rot (*Pythium* spp.). In problem areas, growers are advised to sow oats in preference to wheat or barley. Soil disturbance to at least 10 cm remains as the only effective method of reducing damage caused by the patch-forming strains of *R. solani*. Cultivation does not destroy the fungus but reduces its impact on barley.

The widespread adoption of no-till farming systems in the last 20 years, along with the associated increase in row spacing, has also probably played a role in reducing losses from cereal cyst nematode (Vanstone et al. 2008).

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