Cereals for the high rainfall zone of temperate Australia

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Definition and Extent

The high rainfall zone is delineated by the Bureau of Agricultural Economics (4) according to its field officers' assessment of current land use, rather than by rainfall isohyets (Fig. 1). In most of southern and eastern Australia it extends from the coast to the wheat/sheep zone and is characterized by the dominance of beef and sheep production and the near absence of cropping (Table 1). The zone, in fact, corresponds well with the areas in which the growing season as defined by an adjusted ratio of rainfall to evaporation (64) is greater than 9 months (17), while the wheat/sheep zone conforms fairly closely to the areas of 5-9 months growing season (Fig. 2).

Table 1. Average area of farm. enterprises in Australia (ha).*

	Pastoral Zone	Wheat/sheep Zone	High Rainfall Zone
Total farm	76,268	1759	848
Wheat sown	12.2 (0.02%)	200 (11.4%)	5.6 (0.66%)
Crops harvested	14.4 (0.02%)	278 (15.8%)	27.1 (3.2%)

* Source: BAE 1983

History of Wheatgrowing

Until the Blue Mountains were first crossed 25 years after the first European settlement, *wheat* could be grown only in the high rainfall zone and was confined to the coastal strip within 30 miles of Sydney. Grain yields were very low and wheat had to be imported from Tasmania (18).

Because of the large area and small population, Australian agriculture was dominated initially by the high cost of labour. It was not until the stripper was invented in 1843, reducing harvesting costs by 60% (18), that wheat could be produced more cheaply than it could be imported. The high cost of horse- and bullock-drawn transport kept production near ports until the development of railways from 1864 onwards enabled export of Wheat to become economic for the first time (19).

The subsequent movement into drier areas was encouraged by the increasing prevalence of rust in the coastal areas where high rainfall and humidity favoured the *disease. The* move also resulted in improved baking quality and an increased competitive ability of Australian wheat (26).

From 1860 to 1890, the area under wheat in the coastal regions of New South Wales dropped from 30,000 ha to less than 1000 ha, while on the tablelands the area increased from 18,000 to 38,000 ha and further inland from 5000 to 95,000 ha (26). In Victoria during the same period, the wheatgrowing *area* in the coastal regions declined from 43,000 to 8,000 ha, whereas the area doubled from 22,000 to 45,000 ha in the inland counties; an even more dramatic expansion took place in the Northern Divisions of South Australia (26).

The English wheats on which Australian farmers relied until 1890 were not suited to the drier regions where "the late varieties were blasted in the ear and pinched in the grain" (27). Between 1890 and 1930 yields increased due mainly to the introduction of several new earlier-maturing varieties (notably Federation) and improvements in farming practices such as fallowing, fertilizing, cultivation and crop rotation (82). Further mechanization with increasingly powerful machinery has since enabled farmers to take advantage of economies of large-scale production in the wheat/sheep zone, with an *increase* in average farm size from 829 ha in 1960 (3) to 1520 ha in 1978 (5).

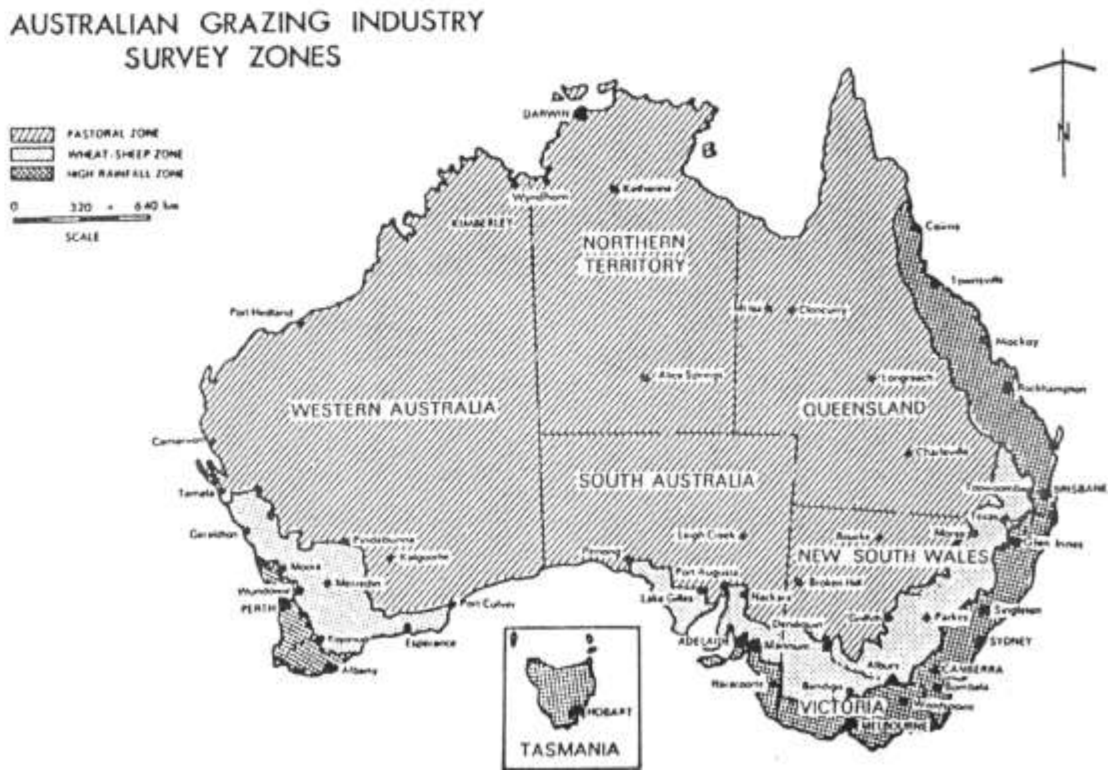

Figure 1. land DSE zones in Australia (B.A.E., 1976)

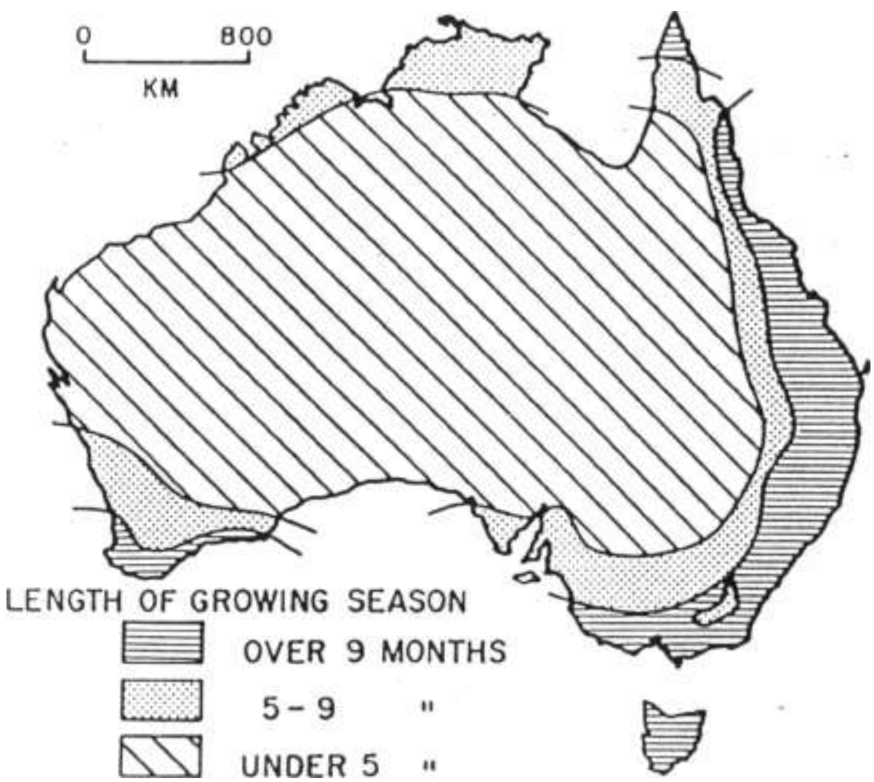

Figure 2. zones of growing season in Australia as determined by moisture and temperature (B.R. Davidson, 1969).

Although it is not possible to make exact comparisons because of the ill-defined nature of the geographical boundaries, it is evident from Table 2 that the trend away from the coastal regions and into the more arid parts of the continent has continued to the present day.

Table 2. Total area of wheat harvested 1977-8 (1000 ha)*

	Wheat/Sheep	High Rainfall
New South Wales	3499	26
Victoria	1517	29
South Australia	854	25
Western Australia	3238	4
Queensland	626	5
Tasmania	-	1

* Source: BAE

Soils and Mineral Nutrition

The total area of the high rainfall zone in New South Wales, Victoria, South Australia, Western Australia and Tasmania is approximately 32 Mha. Much of this land must be regarded as unsuitable or unavailable for farming of any kind because of its steep and rugged terrain, the impoverished nature of the soil, or its classification as national parks or reserves. A recent survey found that 20.3 Mha are used for farming and that an average of 31% or about 6 Mha was regarded by the owners as arable (40). This figure is comparable with that arrived at in a broad appraisal of the world potential for food production (10). However, other data (79) suggest that only about 2 Mha might be developed for cropping, while another assessment deemed virtually the whole of the zone to be unsuitable for extensive cultivation, apart from large tracts of country extending from western Victoria into South Australia and smaller areas elsewhere (47).

The wide variation in these estimates results from different interpretations of the term "arable land". The lower values cover only areas considered to be highly suitable for frequent cropping, whereas the higher values also take in land whose slope, low fertility or shallowness Of soil would permit only occasional cultivation (41). Improved cultural practices, such as minimum tillage (62), and the correction of nutritional disorders could substantially increase the *area* that might be generally regarded as arable.

The low fertility of most Australian soils has been attributed (24) to "the low relief and lack of uplift within the continent, the slow and shallow dissection of Tertiary surfaces, the prolonged leaching of ancient profiles and formation of new soils from old', the loss of finer fractions due to wind and water sorting, and the limited development of new surfaces or new materials through glaciation or vulcanism".

Even though only about 16% of soils in the high rainfall zone appear to be fertile (Table 3) according to the soil map of Australia (77), pastures *have* been successfully established on a much greater *area* than this by the use of fertilizers. Profitable crop production in many parts of the zone may depend primarily on correcting inherent deficiencies of phosphorus and nitrogen.

Phosphorus is usually the most important requirement; in 54 N x P factorial experiments carried out in New South Wales over three years, 36 responses to phosphate were obtained, compared with only nine to nitrogen (75). Responses to phosphate are largely independent of weather (69, 75), and even if the crop fails through drought, residual levels can be beneficial. Drilling superphosphate with the seed is the most efficient method of application (43, 74).

Responses to nitrogen are not particularly consistent, and are subject to the weather (68, 69, 80) and to soil factors, particularly nitrogen status as influenced by soil properties and previous management. An extensive series of experiments in South Australia (68) showed the response to be positively related to the May - October rainfall, with little response below 150 mm and large effects at 400 mm. Responses of 20 kg grain for each kg of applied N up to 30 kg N/ha, similar to those obtained in north-west Europe, might therefore be expected in the high rainfall zone in good years. At Canberra, Bremner (unpublished) found with adequate rainfall and phosphate supply that the second crop after pasture and four subsequent crops responded to nitrogenous fertilizer, but only to a level of 34 kg N/ha. Nitrogen fertilizer is subject to leaching during wet weather and may be largely wasted in dry years, but split applications could cater for seasonal conditions and estimated needs, particularly with long-season crops.

Table 3: Main Soil Types in the Temperate High Rainfall Zone

Soil type	A Horizon	Transition zone	B Horizon Soil	B Horizon Features	% area
		High fertility soils			
Non-calcic brown soils	loamy	abrupt change	clay	reddish	2
Chernozems	loamy	gradual change	clay	grey-brown	1
Krasnozems	loamy	gradual change	clay	red, permeable	11
Xanthozems	loamy	gradual change	clay	yellow, permeable	2
		Grossly infertile acid soils			
Podzols	sandy	whitish A_2	sandy	porous	8
Yellow earths	sandy		sandy clay	porous yellow	6
Red earths	sandy		sandy clay	porous red	3
Solidized solonetz and solodic	sandy		dense clay	alkali at depth	20
Soloths	sandy	abrupt change	dense clay	acid at depth	12
Lateritic podzols	sandy	ironstone	dense clay	acid at depth	6
Red podzolic	sandy	gradual change	dense clay	acid at depth	4
Lithosols	disintegrating rock		absent		9

Deficiencies of manganese (70), zinc (61), boron (13) copper (67), molybdenum (1), iron (6) and cobalt (63) have been identified in the high rainfall zone. Nevertheless, the mineral status of many of the soils has not been extensively studied (37), and the failure to appreciate the extent of nutritional problems may be a major obstacle to high crop productivity.

While temperate cereals do not in general differ greatly in adaptation to different soil and climatic conditions, they show contrasting responses to soil acidity, which is of increasing concern in the high rainfall zone, following the extensive use of mineral fertilizers (86). Aluminium toxicity is the most serious problem, and although manganese may assume importance in soils of high soluble manganese content or in particular conditions such as waterlogging, varieties selected for aluminium tolerance are likely to be also more tolerant of high soluble manganese levels (28).

Wheat, triticale and rye form an overlapping sequence of increasing aluminium tolerance (57), with a considerable range within each species (66). In wheat, for example, the hexaploids are most tolerant, apparently because of the presence of genome D, with an aluminium-tolerance factor located on chromosome 5D (66). The variation within the hexaploids has been exploited with great success by the Brazilian breeders in particular (72), and some of their varieties feature in current Australian breeding programs. Oats are a little less tolerant than rye. Barley has the least to offer; the performance of aluminium-tolerant varieties on acid soils is much inferior to that of sensitive varieties grown on limed plots (59) or the Brazilian wheats (65). Consequently, although barley is more tolerant of high manganese levels than wheat (65), this advantage can seldom be usefully expressed. At all events, there now exists sufficient genetic material to allow more diverse and productive cropping of acid soils than was possible when the choice was limited to oats or rye.

Water Relations

The main cause of annual and local variations in crop yield in Australia is rainfall (26), in contrast with the situation in Britain, where drought may be expected to affect yield on silt loams in only 15 years out of 100 (32). Potential yield in the wheat belt is linearly related to soil water supply, while actual yields are further reduced by management factors, including diseases and nutrient deficiencies (31). The main contributors to yield are held to be early sowing, a long period of low evaporation, good water supply, especially before synthesis, and high harvest index (30). These conditions are most likely to be met by autumn sowing of long-season varieties on the more fertile soils of the high rainfall zone.

The infertile soils of the zone also present physical problems where sandy topsoils *are* underlain by dense clay (Table 3). Under repeated cycles of wetting and drying, plants can be subjected to periods of both waterlogging and water stress. In the eastern part of the zone, rainfall is up to 10% more variable than the mean for other parts of the world receiving similar amounts (46), and so the frequency of water problems is unusually high. Even though the western districts of Victoria are favoured by tracts of fertile soils and rainfall more reliable than the world mean, their soils also are frequently waterlogged.

Intermittent or continuous waterlogging in the *early* growth stages of cereals can severely reduce root growth and yields of vegetative matter and grain (83). During grain filling, up to 15 days waterlogging may cause little damage, though longer exposures may have severe effects, particularly at higher temperatures (50).

Water stress is harmful to cereals at all stages of development. It delays seedling emergence (36), reduces early vegetative growth (14), and if sustained through the boot to the early grain development stage, it reduces seed set (2) and otherwise reduces grain yield (71). These latter, highly critical stages frequently coincide with an escalating water deficit.

Radiation and Temperature

Radiation largely determines the rate of grain growth, while high temperatures reduce its duration (76). It therefore seems that a combination of long growing season, long days and relatively low temperatures during grain filling provides optimum conditions for high yields. Such conditions can be found in England, but Australia cannot offer the long summer days that allow maximum grain development because of its lower latitudes. In the wheatgrowing areas around Cambridge, English wheats flower in early June and grain development begins at an average daily temperature of about 15?C and with 18.3h of daylight (Table 4). Similar temperatures are experienced in Hobart during late November and early *December* and in Wagga during mid- to late September, when daylengths are 2h and 5h shorter respectively than at Cambridge in June.

For grain filling to occur under favourable temperature conditions, daylengths in the Australian wheat belt could well be limiting, yet the onset of hot dry weather usually curtails any extension of the growing season. Hobart, like Cambridge, can expect lower rates of evapotranspiration and less likelihood of severe water stress during grain development than centres in the wheat/sheep zone such as Wagga (Table 4). Only in the cooler parts of the high rainfall zone (Tasmania, southern and eastern Victoria, New South Wales tablelands) are English climatic conditions approached, and it is there that we would expect grain yields to be highest. In fact, barley yields of almost 11 t/ha have been reported near Hobart (55).

Table 4. Climatic data for the month in which mean temperatures approximate those for Cambridge in June.

Place		Temperature (°C)			Daylength	Mean	Mean
	Month	Mean	Max.	Min.	(h)	evapotranspiration* (cm)	rainfall (cm)
Cambridge	June	14.7	20.0	9.4	18.3	6	4
Hobart	Nov-Dec	14.5	19.1	9.8	16.2	6	8
Hamilton	Nov	14.2	20.6	7.9	15.2	8	5
Bombala	Nov	14.0	21.5	6.6	15.1	9	5
Canberra	Oct-Nov	14.8	22.0	7.6	14.4	10	6
Glen Innes	Oct	14.0	21.4	6.6	13.7	10	7
Horsham	Oct	14.2	21.2	7.3	14.0	8	4
Wagga	Sep-Oct	13.9	20.5	7.4	13.3	9	4

*Estimates based on average daily maximum and minimum temperatures (60).

In the colder parts of the zone the unpredictability of frosts presents an additional hazard to wheat production. When the developing ear is raised above the ground by stem elongation, it can be killed by air temperatures of -4 to -6?C (35). Frosts around flowering time can easily pass unnoticed, but can greatly reduce grain set (73) and have devastating effects on yield. However, a frost-damaged crop in the tablelands can be put to profitable use as a hay crop, provided that awnless varieties are grown, that the damage is promptly recognized, and that no time is lost in harvesting.

The common flowering times in various areas reflect what is considered to be a reasonable compromise *between* the risks of frost damage and increasing water stress. Over much of the wheat belt, early October is considered a 'safe' flowering time, while on the adjacent tablelands, the safe time is later and much more variable between locations. In the high rainfall areas of Victoria, where the optimum flowering time is early November (15, 34), only winter and photoperiod - sensitive spring wheats are able to take full advantage of the available growing season (15).

Cereals as Forage Crops

In *cool* regions the growth of pastures virtually ceases in winter, and grazing animals commonly experience feed shortages. The ability to provide substantial amounts of nutritious dry matter before producing a hay or grain crop is therefore an important attribute for prospective cereals. Cereal hay is also valuable as a feed supplement in winter as well as in droughts and may be profitable. Sometimes grazing can be regarded as the more important part of the cropping enterprise, and indeed about 'one-third of the oats acreage in Australia is sown *solely* for green fodder (81). The intensity of grazing will often be governed by the relative values of grain and livestock.

The value of cereal crops for grazing as compared with undisturbed pasture remains debatable. The costs and labour involved in the management of the crop have to be taken into account, and the pasture production lost during seedbed preparation and crop establishment must be more than counterbalanced by the superior growth of the crop during the colder months. Unless the crop can be grazed, the feed shortage will be exacerbated, and it has been shown that wool production and liveweight decline with increasing proportion of the total area under crop (12). Nevertheless, on many farms a worthwhile area of crop could be grown without seriously restricting the amount of pasture available. Cereals in the leafy stage are of high digestibility (38), but defoliation normally reduces subsequent grain yields, particularly if continued past the early joint stage (25). Pugging of the soil surface by animals in wet or muddy conditions can result in damage to soil structure and feed wastage (85).

Results from the numerous field trials are conflicting, and objective assessments are difficult because of the differences in soil and seasonal conditions, in crop and animal types and management, and in the effects on whole farm production. The decision whether or not to grow crops for grazing involves many considerations, depending on particular circumstances (85). It has been suggested that since grazing forage crops has little effect on wool production and lambing performance, but can greatly increase liveweight gains, forage crops could be used to produce prime meat for the premium winter market (16).

For best results, early (February/March) sowings are essential. In Australia, only oats have been grown to any extent for grazing and cereal hay, mainly because of their high dry matter production (78) and generally good regrowth after defoliation, although it has been suggested that the use of wheat and barley might give a better seasonal spread of production (48).

Our (unpublished) results suggest that spring wheats having no long day or vernalization requirements may be capable of producing large amounts of forage at low temperatures, since they are soonest to reach the reproductive stage, when most rapid growth appears to take place. However, grazing will destroy the developing ears in such early-developing varieties, which cannot then be expected to produce grain.

Most Australian wheats are designed for sowing in May or June. They show little response to vernalization or photoperiod (22), and if they are sown early, their rapid reproductive development and stem elongation result in the more advanced ears being liable to removal by grazing, while the later ones are exposed to frost damage. Other Australian varieties which have been more recently developed are late-maturing by virtue of a vernalization requirement. They are sown in mid-April, which is too late to allow grazing, and are therefore better regarded as specialized grain varieties.

The Tasmanian winter wheat, Isis, is the only Australian variety suitable for early sowing and grazing, and is capable of producing substantially more dry matter and grain than the spring wheat Condor when both are sown to flower at the same time (34). Yet Isis is long-strawed and very susceptible to stripe rust, and it has a yield potential which appears to be much lower than that of modern English wheats (21).

It appears that long-season English wheats have the capacity to provide both winter grazing and high grain yields following early sowing (21), and should prove valuable in Australian breeding programs.

Winter and Spring Wheats

Winter wheats have long been neglected in Australia for a variety of reasons, but mainly because of problems associated with early autumn sowings. The possible advantages of early-maturing winter wheats, including increased yields and drought resistance through a longer growing season, greater cold resistance, less risk of heading during winter, better recovery after grazing, more effective weed control and higher N uptake before the winter rains, were expounded as far back as 1937 (51). Their use has also been advocated as a means of simplifying farm management and increasing the versatility and reliability of crops (53), since they may be expected to reach anthesis within a narrow range of calendar dates, irrespective of sowing time or seasonal conditions.

Although our initial results (21) indicated no difference in stability in flowering times between winter and spring genotypes, subsequent (unpublished) work with a wider range of material has demonstrated that winter types do generally have a narrower range of flowering dates from different sowing times. For that reason, winter types may become preferred throughout the zone. Suitable varieties may emerge from breeding programs in the wheat/sheep zone.

Harvesting

Summer rains, which are common in many parts of the zone, ***lead*** to high moisture contents in grain and straw, uneven drying, and harvest difficulties due to green weeds (7). They can also delay harvesting and cause grains to sprout in the ear (23), and most deterioration occurs when prolonged wetting is accompanied by high temperatures (56). The generally higher dormancy of red wheats is strictly associated with the red pericarp (23), and hence cannot be used in the breeding of milling wheats, which must be white-grained to conform with current Australian standards. Strong winds can also cause losses of grain (7).

The additional harvesting step of windrowing may be worthwhile, in view of the advantages of evening out crop drying, reducing grain moisture to acceptable levels, and extending the harvest period ***(7);*** however, germination losses can be substantial if rain falls while the crop is still lying in the windrows (23).

Perhaps the most serious deterrent to cropping relatively small areas is the heavy requirement for investment in machinery which is only required for a short period each year. A solution to this problem may involve logistics of organization on a district rather than an individual farm basis.

Pests and diseases

Any return of wheatgrowing to the high rainfall zone would be accompanied by the threat of diseases which earlier encouraged the shift to drier areas. Both leaf and stem rusts can cause large reductions in yield (42), although wheat breeding in Australia has long been dominated by selection for resistance to rust (29). Stripe rust is a newer threat which is particularly relevant to the zone, since its effects are worst at high humidities and temperatures between 10 ***and*** 150C (84), and the strong resistance to the disease which is maintained in modern English wheats (58) may ***be*** useful.

High rainfall early in the season encourages yellow spot, and later favours the incidence of black point in grain (45). Other important diseases likely to be accentuated by high rainfall include eyespot (44) and speckled leaf blotch (9).

Early-sown crops emerging in autumn are likely to ***be*** a prime target for attacks by flights of aphids which spread barley yellow dwarf virus (49). This disease may present the biggest problem to farmers and breeders in the near future because it affects all cereals, and the presence of so many perennial grass hosts may make the high rainfall zone a less favourable environment for cereals.

Cereals may also be attacked by a number of pests including nematodes, red legged earth mites, cut worms, army worms and aphids (39).

Choice of cereals

Wheat is superior to other winter cereals in some agronomic respects, as well as in feeding value and in price advantage because of its use for human food, and has consequently received greatest attention in this review. Despite the dearth of wheat varieties suitable for dual-purpose use in this country, ample genetic resources are available, particularly in the United Kingdom. Although Australian varieties must be white-grained if intended for milling, red grains could provide a useful colour mark for feed wheats, and confer greater resistance to sprouting.

Oats already have an established place in farming in the zone, being well adapted to the wetter areas, and able to survive sowing into a dry or otherwise unsatisfactory seedbed. They are suitable for winter grazing, and the grain can be readily fed to stock with complete safety. However, grain is liable to be lost by shedding. If other cereals gain widespread acceptance, oats could assume greater importance as a break crop, especially to reduce the threat of take-all. Barley, because of its sensitivity to soil acidity and its comparative lack of genetic sources of tolerance, is likely to be

unsuitable for many parts of the zone, and it is prey to a number of leaf pathogens associated with wet localities and seasons. It also lacks the flexibility required for a dual-purpose crop; for example, varieties currently available here develop too rapidly to be used for grazing, and in the event of a failure in grain production, it is quite unsuitable for haymaking because it is heavily awned. Nor does the crop weather well during and after ripening, being apt to lodge and shatter. Barley can however be used for short-season grain production; for example, where the sowing of wheat has *been* so long delayed by rain or drought that reasonable grain yields cannot be expected. In *many* varieties pollination occurs in the boot, giving greater protection from frosts at flowering, and these may be better suited than wheat to the more extreme climatic regions of the high rainfall zone. High quality malting grain for a limited market could also be produced in the colder areas.

All cereals yield best on fertile, well-drained foams, but rye is noted for outyielding the other cereals on infertile, sandy and acid soils, and alone can be expected to succeed on coarse sands (52). Rye and triticale, the wheat x rye hybrid, could well *become* important crops on the poorer sandy soils of the zone.

The triticales present a particularly exciting prospect, being highly tolerant of acidity (54) and yet very high yielding as a result of intensive breeding efforts at CIMMYT and elsewhere.

Overseas varieties

The introduction of high yielding semidwarf Mexican wheats has encouraged wheatgrowing in *many* parts of the world where it had previously been unprofitable. It led, for instance, to a tenfold increase in wheat acreage in Arizona from 1966 to 1975 (33), and rapidly brought several third world countries towards self sufficiency (8). A.T. Pugsley introduced some of this material into Australia in the early 1960s, but the requirement to comply with local standards delayed its release to farmers until 1973. The semidwarfs have extended wheatgrowing further into drier marginal areas and irrigation districts.

A revolution in wheat breeding has also been taking place in England. Farm yields have been increasing spectacularly and *have* eclipsed the record yields of Mexican derivatives. These long-season wheats offer the best prospects of wheatgrowing in the cool parts of our high rainfall zone. Significantly, the 11 t/ha barley crop in Tasmania (55) was achieved with a European variety that outyielded the local alternative by about 50%.

We have been examining a large number of wheats from all over the world, classifying them according to their vernalization and photoperiod responses (22), and assessing the field performance of a selection of these over different environments (21). The new generation of English wheats, though impressive in both forage and grain yields, are late maturing by Australian standards, even when sown at the beginning of March, due to their long day requirement. Some crosses with Pitic have shown improvement in this respect, but much remains to be done in terms of combining high yields with a suitable phenology similar to that of Isis.

Potential of the High Rainfall Zone

The boundary between the wheat/sheep and high rainfall zones, as approximated by the length of the growing season (Fig. 2), is consistent with the view (11) that areas with May-October rainfall greater than 38 cm are better suited to pastures than to wheatgrowing. While it is not unusual for wheat to be produced in 5-9 months growing seasons, as in Texas and Oklahoma, for instance, where average yields have been similar to those in Australia (18), wheat is also grown in regions with longer growing seasons, such as other parts of the United States and much of Europe, including England, where the average farm yield of wheat has now reached 7.5t/ha (J.A. Blackman pers.comm).

Farming in the high rainfall zone is, and will remain, predominantly pastoral. However, the possibility of successfully growing cereal crops on a considerably larger proportion of the farm than at present offers opportunities for diversification and broadening of the economic base as well as lifting animal production. Livestock farming combines well with wheatgrowing, since animals return nitrogen and organic matter to the soil without removing significant amounts of minerals (11), and a cash crop can often be readily fitted into a program of pasture establishment or renewal. This could be especially valuable in years of recovery from drought when stock numbers are low, prices for restocking high, and land consequently under-utilized; in such a situation, an area of crop could provide much-needed additional income.

Market forces rather than the difficulties of the physical environment dictate the nature of farm enterprises. It has been pointed out (20) that the average farm size in an area of 3 Mha adjacent to Sydney is about 1/4 of that in the surrounding areas, but that the value of farm products is correspondingly higher. With little change in the physical environment, the nature of farm products alters to satisfy the markets available. The high yields and profitability of English wheats depend upon high inputs that are foreign to farming practices in our wheat/sheep zone. Higher levels of fertilizer application and crop protection measures may be unavoidable in the high rainfall zone, given the greater likelihood of pests and diseases and nutritional deficiencies, but would be justified if they resulted in substantially greater productivity. If economic incentives were sufficient, more intensive farming practices such as irrigation, drainage, and frost avoidance measures could be employed to counter environmental problems.

For appreciable changes to take place in the geography of crop production, the introduction of new varieties must often be accompanied by the development of appropriate agronomic practices. Although the expansion of wheatgrowing into inland areas began before 1890, increased yields became possible only by the search by Farrer and others for early-maturing, sparse tillering varieties adapted to dry soils and high evaporation rates (27), while the employment of new harvesting technology became practicable only with varieties that stripped easily and crops that dried out in the ear. Today, the existence of rust-resistant varieties and effective fungicides has largely removed the original reason for the abandonment of cereal growing in the high rainfall zone. It must now be demonstrated that varieties with superior yields and commercial acceptability can be successfully and profitably grown in these environments before a significant return to cropping can be expected.

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