Chapter 15

# CROP AND PASTURE PLANT SELECTION FOR NEW CULTURAL SYSTEMS

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The history of agricultural development in Australia provides many examples of changing management practices that have provided opportunities for, or even depended on, the genetic development of existing species or the development of new crops and pastures (Oram, 1982). Improvements in agricultural or pastoral productivity have usually depended on the concurrent manipulation of the genotype (breeding) and its environment (agronomy) because the expression of yield is the result of a complex interaction between the two (Figure 15.1). The yield advantage of semi-dwarf wheat genotypes, for example, is realised only under high levels of most agronomic inputs (Figure 15.2).

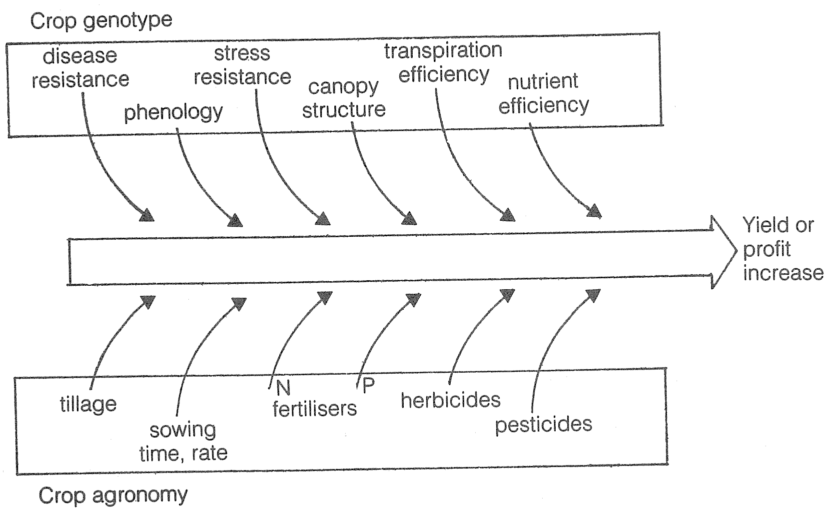


Figure 15.1 The expression of yield as the result of a complex interaction between crop genotype and agronomic management

The substitution of herbicides for cultivation to control weeds, and the impact of this on all areas of crop and pasture management, constitute one of the biggest changes in agronomy in Australia since European settlement. Not only is the crop environment potentially different, but the new crop-establishment technology indirectly influences other areas of agronomy including rotations, pest- and disease-control measures, planting time, fertiliser practices and weed management in pastures prior to cropping. Conservation farming technology also facilitates the spread of cropping to areas that were not cropped previously because of the risk of erosion. This chapter reviews the need for genetic changes to efficiently exploit the new environments created by conservation farming practices. An evaluation is made of the relative agronomic and

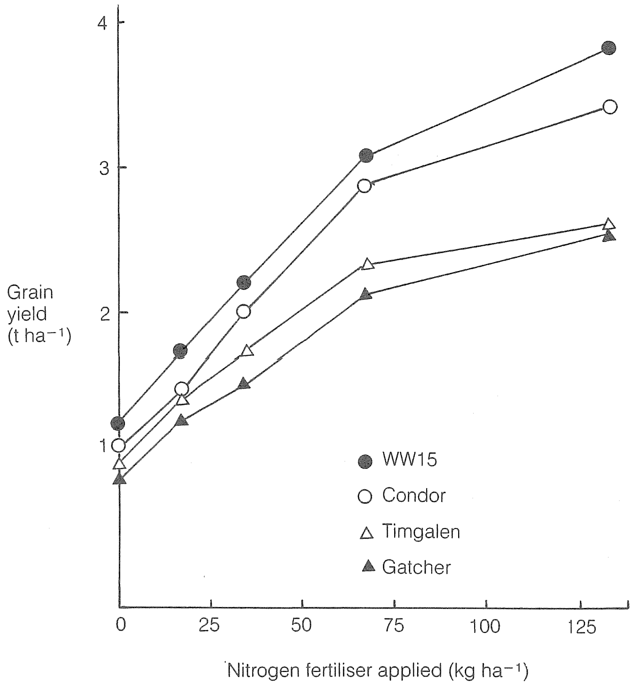


Figure 15.2 The response of semi-dwarf (●, ○) and standard height (▲, △) wheats to nitrogen fertiliser (Syme *et al.*, 1976)

genetic opportunities for solving the problems and for realising any untapped potential associated with new cultural practices.

## EFFECTS ON BREEDING OF CHANGING AGRONOMIC MANAGEMENT

### Interactions between genotype and management

Diverse genotypes respond differently to changes in their environment, some showing superior stability and overall level of performance for characters such as yield. When grown in variable or diverse environments, these broadly adapted genotypes give high average yields, but at an acceptable cost of reduced yields in some specific environments. The approach was elegantly developed by Finlay and Wilkinson (1963) and is illustrated in Figure 15.3. The mean yield of all cultivars at each site and for each season (the site mean yield) provides an evaluation of the environment. The yields of individual cultivars are then regressed against the site mean yield. The slope of the regression (b) for each cultivar is a measure of its yield stability. The average performance of all cultivars is described by the line 'A', in Figure 15.3. Genotype '1' shows above-average stability ($b = 1.0$), with higher than average yield at all sites. Genotype '2' is unstable ($b > 1.0$), being very well adapted to only the highest yielding environments. Genotype '3' is very stable ($b < 1.0$) but poor yielding, showing good adaptation only in the poorest environments. The change in rank between high- and low-yielding sites reflects the interaction between genotype and environment. Any case for breeding plants for new tillage systems will rest ultimately on an interaction of this kind, between genotype and management.

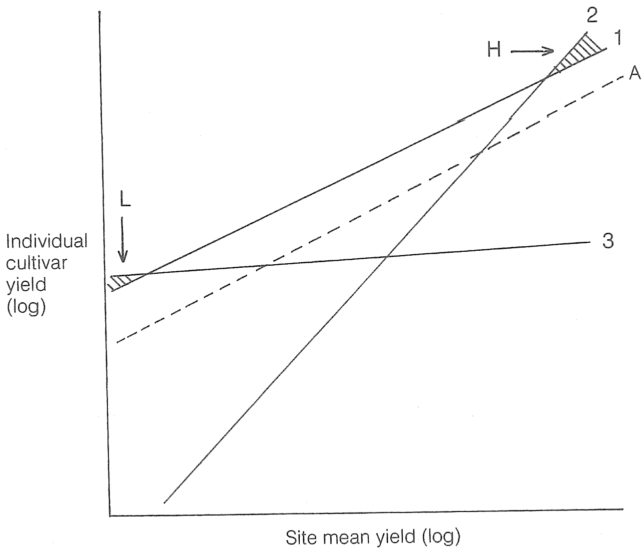


Figure 15.3 Individual cultivar yields regressed against the mean yield of many cultivars, at a range of sites (Finlay and Wilkinson, 1963). Yield stability across diverse environments can be quantified by this analysis: cultivar '1' exhibits average stability with high yield whereas '2' is specifically adapted to high-yielding environments (H) and '3' to low-yielding environments (L); 'A' is the average performance of all genotypes.

Because of the variability of soils and climate in Australia, breeders usually select plants with broad adaptation (viz. genotype '1'). The issue now is whether these broadly adapted genotypes will continue to optimise performance across the wider range of environments created by new tillage practices. This is an important issue because it seems likely that a range of practices will be used for many years, even within farms. Moreover, it is often assumed that the environment in the new system is less favourable than in the old (Kronstad *et al.*, 1978).

Reed and Cocks (1982) presented a case for breeding pasture plants for specific management practices but provided no supporting evidence. Scarsbrick (1983) produced similar arguments for crop plants but in both cases it is necessary to know if genotype x management interactions occur, and if the differences between genotypes due to management exceed those due to site or season. These issues have not been resolved but if consistent interactions do occur, then selection of genotypes for specific management (e.g. tillage) systems may be warranted. Alternatively, if management indirectly affects another component of the environment, to which genotypes behave differently (e.g. a disease), then selection for a specific character may be sufficient without the need to select for specific management systems involving many traits, a much more difficult task.

## Unrealised yield potential

When considering the adaptability of genotypes to specific cultural systems it is important to note that equivalent yields in alternative systems in any site/year does not necessarily indicate that the plant genotype used was equally well adapted to the two systems. Equal yields may reflect unrealised yield potential in one of them. For example, residue retention may increase the plant-available water (Chapter 8). Equivalent yield in this case could simply mean that something associated with residues adversely affected the plant, perhaps a residue-related disease (Chapter 13). Yields may also be equal in one set of seasonal conditions but not in another because of, for example, management x seasonal effects on disease.

### Recognising and responding to new opportunities

Another issue that breeders and agronomists must consider is the possibility that new cultural practices will open up opportunities to expand cropping into new areas or to grow new crops in existing areas, both of which may provide opportunities for plant breeding.

### Alternatives to breeding

As an alternative to breeding it may be possible to more easily remove the interaction between genotype and management by making further changes to management. For example, fungicide sprays to control residue-related fungal pathogens (Chapter 13) may be a cost-effective alternative to breeding for resistance to these diseases. The choice between agronomic and genetic solutions to management-related problems clearly requires considerable interdisciplinary research.

A scheme for evaluating the need to modify plants because of changing agronomic management is illustrated in Figure 15.4. These options are considered in detail in the rest of this chapter. First a brief description of new farming systems is necessary, and a summary of the environmental changes that could affect the methods or objectives of plant breeding.

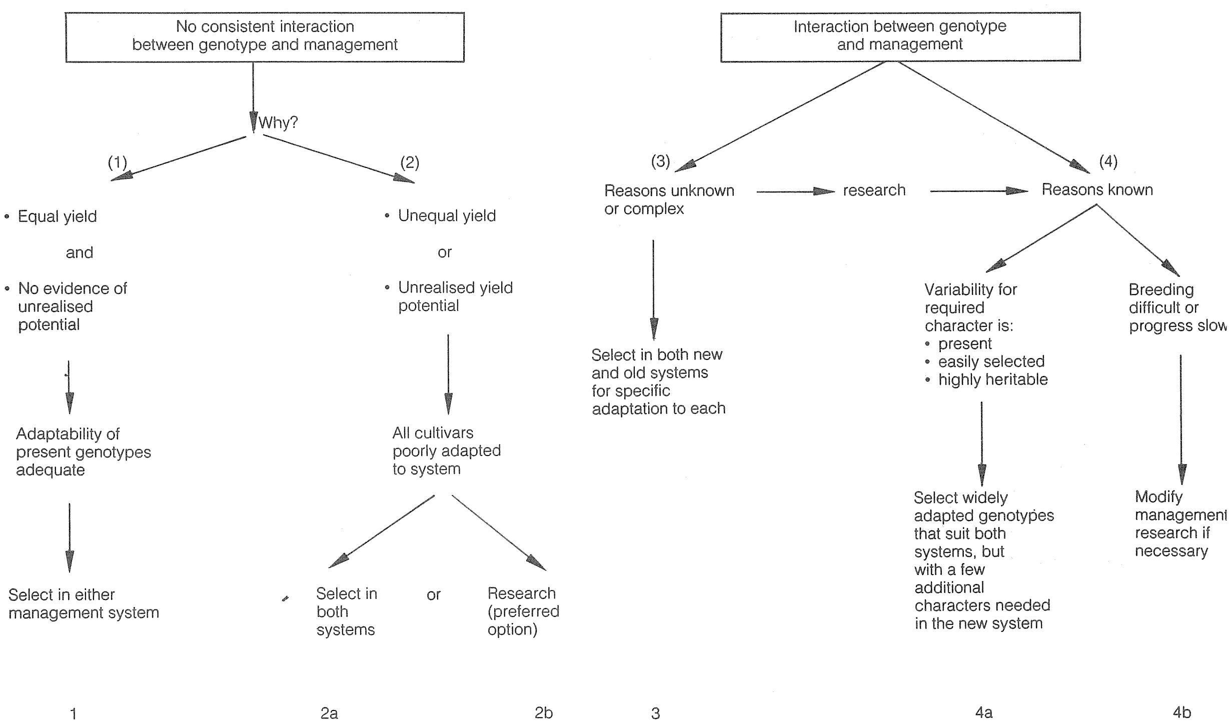


Figure 15.4 A protocol for evaluating the need to modify plants for new management systems

## THE CHANGING ENVIRONMENT DUE TO AGRONOMIC MANAGEMENT

### Description of conservation farming systems

'Direct drilling' has been enthusiastically adopted in Western Australia and much of the higher rainfall wheatbelt of south-eastern Australia, where long fallowing is rarely practised. Pasture or crop residues are grazed to control plant growth in summer and autumn and the remaining crop residues are usually burnt sometime in late summer or autumn. Herbicides are applied shortly before sowing. Some pre-sowing moisture conservation may be foregone, compared with conventional farming methods, because of plant growth in summer and autumn (Chapter 8). The practice of burning crop residues in these areas is under critical review (Chapter 2). Changing crop management affects pastures, mainly through weed management in the pasture phase of rotations (Cornish *et al.*, 1984). Direct drilling of pastures is being used in higher rainfall areas.

In the summer-dominant rainfall areas of northern New South Wales and Queensland, the technique loosely known as 'no till' is being developed (Chapter 3). The aims are to conserve water in a long chemical fallow while controlling erosion by retaining crop residues and reducing soil disturbance to a minimum when sowing. Livestock do not play a significant part in this system.

In addition, there is an area receiving relatively low rainfall, where long fallowing is practised for the first crop after pasture. It includes the lower rainfall areas of central-western New South Wales, the Wimmera and northern Mallee in Victoria and the central-northern region of South Australia. Crops sown into stubbles are sown on short fallows. Development of tillage systems in this region is drawing on both the 'no-till' and 'direct-drill' experience, and is focused on opportunistic chemical fallowing and crop-residue management.

### Broad effects on the environment

The changing cultural practices across much of Australia have several features in common, which in broad terms will determine the environment in which breeders must ultimately work and for which they must select. These include reduced soil disturbance, a growing emphasis on improved methods of crop-residue management and, in the short term at least, greatly increased use of agricultural chemicals. These are leading to changing crop rotations and the spread of cropping to previously uncropped areas.

Measurements of plant growth and grain yield provide indirect evidence that cultural practices have a significant effect on the environment, at least for crops. Direct seeding of winter-growing species in either the absence or presence of crop residues frequently leads to reduced early plant growth (e.g. Reeves and Ellington, 1974; Rowell *et al.*, 1977; Fischer *et al.*, 1981; Gates *et al.*, 1981; Hamblin, 1981; Cornish and McNeill, 1982; Ward and Bateman, 1982; Cornish, 1985). These differences generally diminish through the growing season so that differences in total dry matter at harvest are often small. A survey of literature since 1981 (Pratley and Cornish, 1985) shows that the overall yields of winter cereals (mostly wheat (*Triticum aestivum*)) are equal using traditional and conservation farming techniques, the yield of lupins (*Lupinus* spp.) can be increased (Taylor and Lill, 1982), and that the yield of summer crops is also frequently increased. This suggests that genotypes bred under traditional cultural practices are adapted reasonably well to conservation farming, despite differences in the environment.

### Some specific effects on the environment

**Soil physical properties** Where the surface structural stability is improved by conservation farming, infiltration potential is greater, runoff is often reduced, and water storage is potentially increased. Even where total water storage is not increased, surface soil water content is sometimes higher after direct drilling (Hamblin, 1981), especially where crop residues are retained (Chapter 3). Soil temperatures in winter can be a little lower after direct drilling but any effect is small, and variable. Crop residues have a larger effect than tillage on soil temperature (Aston, 1985). Minimum temperatures are usually higher, and the maxima are lower (Chapter 7). Direct drilling is usually associated with increased surface-soil bulk density, increased resistance to a penetrometer (e.g. Hamblin and Tennant, 1979), and increased load-bearing capacity. Although more dense, untilled soils slowly develop an improved macrostructure (Chapter 6).

**Soil chemistry and plant nutrition** Reduced tillage leads to surface accumulation of organic matter and mineral nutrients (Hamblin, 1981). While this may be good for soil structure, surface accumulation of organic matter may accelerate the decline in surface-soil pH, which is primarily associated with clover leys and the use of nitrogenous fertilisers (Cox and Robson, 1980). Mineralisation of nitrogen may be slower with direct drilling (Reeves and Ellington, 1974; Rowell *et al.*, 1977).

**Soil biology and plant pathology** Much remains to be learnt in this general area. Tillage can influence populations of macro-fauna, which may improve soil structure (Chapter 12). Of more immediate concern is the effect of tillage and residue management on diseases. The effects of tillage on take-all (*Gaeumannomyces graminis* var. *tritici*) vary both in Australia (Ellington and Reeves, 1981) and overseas (Rovira, 1981), indicating the likely importance of climate, soil type and farming system for development of the disease. Direct drilling increases the incidence of rhizoctonial bare-patch on light-textured soils (Chapter 14), while stubble retention worsens yellow spot (*Pyrenophora tritici-repentis*) on wheat (Chapter 13). Eyespot lodging (*Pseudocercosporella*) may be reduced by direct drilling (J.E. Pratley, personal communication).

Some cases of poor early crop growth in new tillage systems may be explained by the effects of normally non-pathogenic soil organisms or the toxic residues of some crops (Lovett *et al.*, 1982). There is evidence for increased pest attack associated with reduced soil disturbance (Allen, 1982) while hessian fly (*Mayetiola destructor*) in wheat is a significant future threat to residue retention (Lymbery, 1985).

## EVIDENCE OF INTERACTION BETWEEN GENOTYPE AND MANAGEMENT SYSTEM

The main purpose of this review is to weigh the evidence for interactions between genotype and tillage practice that would provide the basis for a genetic response to changing management. Winter crops, including cereals, grain legumes and oilseeds, have been compared in conventional tillage and under direct drilling at Rutherglen (Ellington and Reeves, 1978), Wagga Wagga (J. Lymbery, personal communication), near Canberra (P. Dann, personal communication) and at Adelaide (Whitely and Dexter, 1982). There were no indications of an interaction between genotype and tillage method, nor any large main effects of tillage on grain yield, except at Adelaide where yields of dry matter were reduced by direct drilling, particularly of the oilseed crops.

Soybeans on the north coast of New South Wales have shown interactions between genotype and sowing method, the direction of the interaction depending on seasonal conditions (Desborough, 1984). Although Desborough (1980) considers that special selection of soybeans may be needed for direct drilling on the north coast, the greatest immediate need seems to be for genotypes with better adaptation to the edaphic and climatic environment of the region, irrespective of tillage practice. Present cultivars have all been bred for inland New South Wales.

Within wheat, interactions between cultivar and sowing method were found in grain yield at Wagga Wagga in 1978 (A. McNeill, unpublished) and 1980 (Cornish and McNeill, 1982), on the Eyre Peninsula, South Australia in 1979 (Catt, 1981), and near Canberra in 1980 (Gates *et al.*, 1981). The results from Wagga Wagga in 1980 illustrate the wide range of genotypic responses to different tillage practices (Figure 15.5). The average yield increase with direct drilling over 36 genotypes was 10%. Some genotypes showed an average increase (Olympic), others greater than average (Gamenya, Dua triticale) and others a substantial decrease (Songlen, Shortim). Some showed no effect (Kite, Timgalen). At first sight this result suggests that genotypes can be selected with specific adaptation to particular tillage practices. But a comparison with the other experiments that included wheat reveals no **consistent** pattern of response among the cultivars.

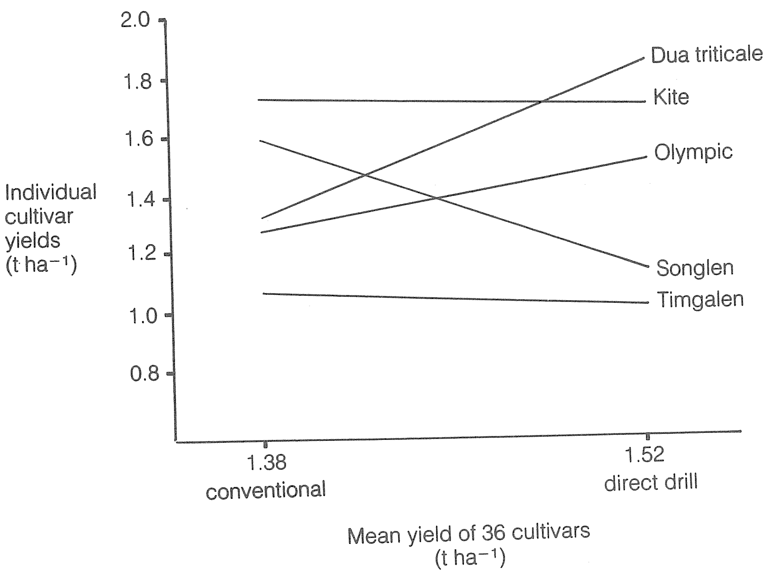


Figure 15.5 Typical interactions between wheat cultivar and tillage method at Wagga Wagga, New South Wales, 1980

## Detailed studies of genotype x management interactions in wheat at Wagga Wagga

Genotype x management interactions were studied in a series of experiments at Wagga Wagga comprising 36 genotypes of winter cereals (mostly wheats) in 1980 and 1981 and seven genotypes of wheat, which were examined in more detail, in 1982 and 1983. The objective was to identify and explain genotype x tillage interactions in wheat. The experiments were located on soils with little or no history of cultivation, to simulate the soil likely to result from continuous reduced tillage, as well as on sites with a history of conventional tillage.

The most obvious effect of direct drilling was to substantially reduce vegetative growth in all genotypes (Table 15.1). The magnitude of the reduction varied with the site and year. It led to a change in the balance between pre- and post-anthesis water use. The effect of this on crop water status is shown in Table 15.2. These effects on crop water relations now appear to be quite common (Chapter 8) and parallel the well-known effects of other agronomic practices on the pattern of growth and water use.

**Table 15.1 Reduction in crop dry matter at anthesis (*$DM_a$*) due to direct drilling on sites with different histories at Wagga Wagga, NSW (P.S. Cornish, unpublished data)**

| Year | Immediate site history | Reduction in $DM_a$ (%) |
|---|---|---|
| 1980 | Pasture | 29 |
| | Wheat (3 years, cultivated)[a] | 5 |
| 1981 | Wheat (4 years, cultivated)[a] | 20 |
| | Pasture | 19 |
| 1982 | Wheat (2 years)[a, b] | 14 |
| 1983 | Wheat (3 years)[b] | 5 |

[a] Residues burnt before sowing experiment.
[b] Direct drilling and conventional cultivation on plots with same tillage treatment in preceding years.

**Table 15.2 Effects of tillage on plant water status of wheat at Wagga Wagga, NSW (P.S. Cornish, unpublished data)**

| *Relative leaf water content*—1980 | | | | | Week 19[a] (after sowing) | | |
|---|---|---|---|---|---|---|---|
| Conventional | | | | | 70.4 | | |
| Direct drill | | | | | 78.9 | | |
| *Leaf water potential* (-bars)—1981 | | | Week 17½ | 18[a] | 19 | 19¼ | 20 |
| Conventional | | | 20.0 | 20.8 | 25.6 | 36.5 | 45.0 |
| Direct drill | | | 17.7 | 19.2 | 22.5 | 30.8 | 39.3 |
| *Leaf water potential* (-bars)—1982 Week | 7 | 9 | 12 | 15 | 18 | 19[a] | 21 |
| Conventional | 14.9 | 12.6 | 15.5 | 14.7 | 22.1 | 28.6 | 38.5 |
| Direct drill | 15.6 | 13.3 | 16.4 | 14.1 | 19.9 | 24.5 | 34.4 |

[a] Anthesis.

Agronomists aim to optimise the balance between pre- and post-anthesis growth and water use so that the yield potential set by anthesis can be realised with the post-anthesis water supply (Fischer, 1979). Each season will have an optimal dry matter at anthesis ($DM_a$). Yield is maximised when the combination of genotype and management results in the optimal $\hat{D}M_a$ for the season. The direct drilled crops at Wagga Wagga were closer on average to this optimum than conventional crops in 1980 and 1981. Both seasons experienced adequate rainfall for growth in winter but well below average rainfall in spring. The greater amount of water available to direct drilled crops in spring led to small yield increases in most cultivars. This was not the case in 1982, when direct drilled crops failed to use all of the water available to them. In 1983, water did not limit plant growth significantly at any time: there was only a small effect on dry matter at anthesis, and no significant effect of tillage on yield.

Significant interactions for grain yield between genotype and tillage method occurred only in 1980 and 1981. Some of the interactions in 1980 are shown in Figure 15.5. These interactions were apparently related to the effect of tillage on the $DM_a$ of each cultivar, relative to optimal $DM_a$ for the season. This is illustrated in Figure 15.6; the greatest yield increases were in cultivars in which vegetative growth under conventional cultivation greatly exceeded the apparent optimum for the season, whereas yield decreases occurred in a few cultivars where direct drilling resulted in a yield potential that was apparently too low to efficiently use the available water (Songlen). These interactions will obviously depend on seasonal conditions, which determine the optimal levels of pre-anthesis growth and water use. It is clear that both the main effect of tillage on yield, and genotype x tillage interactions, will vary from season to season and with other aspects of management which can influence crop growth and water use. This appears to explain the lack of **consistent** interaction mentioned earlier.

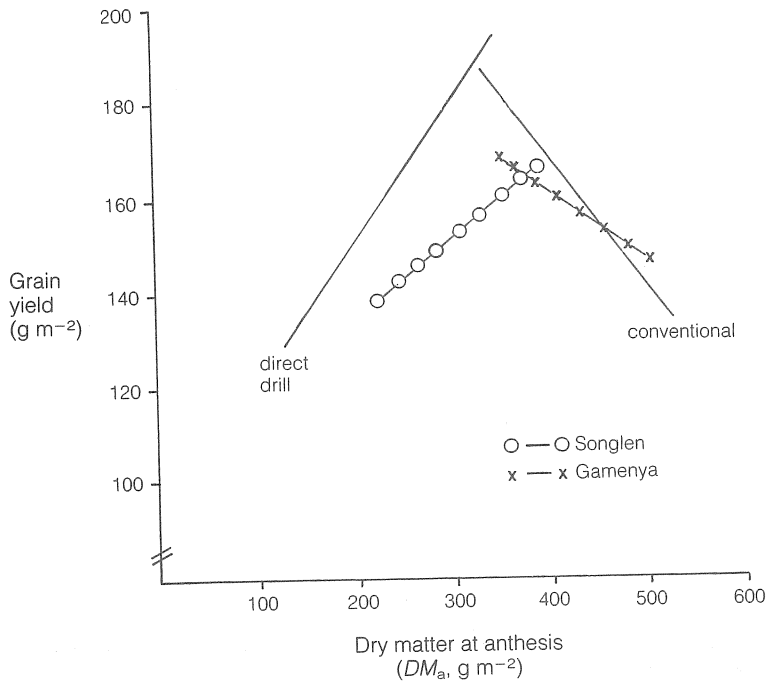


Figure 15.6 The relationship between grain yield and crop dry matter at anthesis (1980 at Wagga Wagga, New South Wales) for 36 genotypes under direct drilling (DD) or conventional cultivation (CC).
Direct drill: $y = 86 + 0.31x$ ($r^2 = 0.78$)
Conventional: $y = 269 - 0.25x$ ($r^2 = 0.25$)
The two regressions imply an optimum dry matter at anthesis of about 340 g $m^{-2}$ for 1980. Songlen (o) was close to the optimum in CC and therefore suffered a yield reduction in DD. Gamenya (x) produced excessive dry matter in CC, and increased yield in DD because of reduced terminal water stress.

Of importance to breeders is the finding that variation in yield due to cultural treatment was less than that due to climate (Table 15.3). Moreover, the work at Wagga Wagga suggested a good correlation between yields in the two systems in 1982 and 1983, and a lower but still significant correlation in 1980 and 1981 (Figure 15.7); that is, cultivars that performed well in one system did so in the other as well.

**Table 15.3 Effect of crop-establishment method, site history and season on grain yield (t ha$^{-1}$) of wheat; data are means of 7 to 36 cultivars (P.S. Cornish, unpublished data)**

| Treatment | Grain yield (t ha$^{-1}$) | | | | | |
|---|---|---|---|---|---|---|
| | 1980 | | 1981 | | 1982 | 1983 |
| | Crop[a] | Pasture[a] | Crop[a] | Pasture[a] | Crop[a] | Crop[a] |
| Direct drill | 1.57 | 1.52 | 2.50 | 2.29 | 1.19 | 5.38 |
| Conventional | 1.43[b] | 1.38[b] | 2.31[b] | 2.23 | 1.30[b] | 5.35 |

[a] Previous site history—residues burnt where previously crop.
[b] Tillage difference significant ($P < 0.05$).

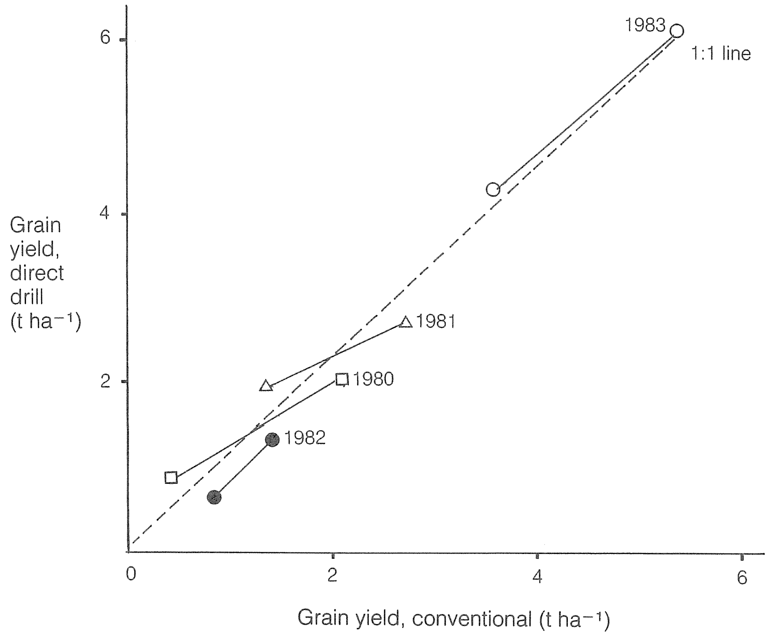


Figure 15.7 The relationship between grain yield under direct drilling and conventional cultivation for a range of genotypes over 4 years.
The yield advantage of direct drilling was greatest in low-yielding genotypes, in 1980 and 1981 when good winter rain preceded a dry spring.
The data indicate equivalent yields in the two tillage systems over a wide range of seasonal conditions, and that high-yielding genotypes are equally well adapted to either system.
1980: $y = 0.62 + 0.63x$ ($r^2 = 0.49$, $n = 36$)
1981: $y = 0.98 + 0.58x$ ($r^2 = 0.35$, $n = 36$)
1982: $y = -0.1 + 0.96x$ ($r^2 = 0.79$, $n = 7$)
1983: $y = 0.67 + 0.88x$ ($r^2 = 0.87$, $n = 7$)

As direct drilling influences grain yield primarily through the effect on early growth and patterns of water use, it might be useful if **consistent** interactions for early growth occurred between tillage and genotype. Results at Wagga showed that cultivars do vary in vigour and that interactions are common. However, the interactions have not been consistent. Studies of reduced early growth in direct drilled crops provide no consistent explanation for the effect (Cornish, 1985), suggesting that several mechanisms could be involved, varying in importance from year to year and possibly affecting genotypes differently. If this is the case then selection for increased early vigour is unlikely to be completely successful. For the present, agronomic means of increasing early crop growth (sowing rate/time, fertilisers) should be explored for those well-watered situations in which yield is most likely to be increased by greater pre-anthesis growth. These include irrigated crops and the high rainfall wheatbelt.

### Generalisations arising from the Wagga Wagga research and overseas experience

The relative importance of the factors that control crop production under both 'conservation farming' and conventional tillage obviously vary from site to site and year to year. The importance of various factors controlling the **difference** in production between alternative systems must also vary. Consequently, the prospect of identifying consistent and useful genotype x tillage interactions is remote for either yield or early growth. Cultivars of wheat with narrow adaptation to specific cultural systems are unlikely to be developed. This conclusion has also been reached in the United Kingdom for direct drilled cereals (J. Blackman, personal communication) although it is not based on exhaustive experimentation. Primitive and wild wheats remain to be evaluated.

The foregoing conclusion is strictly valid only for modern wheat, although the absence of consistent genotype x tillage interactions with other crops suggests it applies to them also. The conclusion also applies strictly to **direct drilled** crops, where crop residues are not retained. There are no Australian data with which to test its applicability to crops direct sown into residues. In the United States, however, there is limited evidence for genotype x tillage interactions with spring wheat sown into residues, but not with barley (Ciha, 1982a; 1982b). There was no indication of how consistent the interactions were. In much more extensive experiments with winter wheat in the Pacific north-west of the United States, R. Allan (personal communication) found very few consistent patterns of performance of genotypes in response to tillage practice. He concluded that it would not be realistic to attempt to develop a model of the perfect no-till wheat plant; that is, to attempt to follow path 3 in Figure 15.4.

R. Boyd (personal communication) suggests, however, that it would be worthwhile in a research project to make a cross and mass select the $F_2$ for uniformity of height and phenology, then split the $F_3$ for continued propagation under alternative tillage practices. The resultant populations could be compared after 4-5 years either in bulk or with several hundred randomly selected lines from each. Alternatively, a group of morphologically distinguishable cultivars could be mixed and planted in each of two alternative systems for a sequence of years to observe any changes due to natural selection.

It must be concluded from the present data that breeders should continue to select for wide adaptability using appropriate statistical techniques (Brennan and Byth, 1979). It is likely that cultivars developed under one management regime will be reasonably well suited to another. The choice of regime does not appear to be very important (path 1 in Figure 15.4).

This does not mean, however, that some new selection criteria, or greater emphasis on some existing criteria, will not be needed. Cultivars that in all other respects suit a range of management systems may also require specific characters to suit a specific management system, while not affecting their general adaptability (path 4 in Figure 15.4). Resistance to a management-related disease is a good example of this. These possibilities are considered in the next section, together with the alternative agronomic solutions (path 4b in Figure 15.4).

## PROBLEMS AND UNREALISED POTENTIAL - GENETIC AND OTHER SOLUTIONS

### Problems with germination and emergence

There have been many calls for cultivars with improved 'seedling vigour' to overcome apparent problems of poor establishment in direct-sown crops (Scarsbrick, 1983; Byth *et al.*, 1980; Wood and Fukai, 1982). With direct drilling (i.e. crop residues burnt) a high degree of managerial skill is required to ensure sowing at a uniform, correct depth in a seedbed free of clods, which may reduce emergence. Failure to achieve this has certainly led to failures in crop establishment in commercial practice (Cornish, 1983). Less serious reductions in emergence or even delayed emergence could account for the reduced early growth of direct drilled crops. However, the limited data available suggest that the reduced growth is largely a post-emergence phenomenon (Table 15.4), even when percentage emergence is reduced (Whitely and Dexter, 1982; Cornish, 1985). In the no-till system, the presence of crop residues introduces an additional range of potential problems, both mechanical (seed placement) and biological (lowered seedbed temperatures, stubble phytotoxicity). Reduced emergence in the absence of specialised sowing machinery has been reported (Felton *et al.*, 1980).

**Table 15.4 Reduction in wheat crop dry matter over time in response to direct drilling at Wagga Wagga, NSW (mean of 36 cv in 1980, 1981 and 7 cv in 1982 and 1983, P.S. Cornish, unpublished data)**

| Weeks from sowing (approx.) | Reduction in dry matter % | | | |
|---|---|---|---|---|
| | 1980 | 1981 | 1982 | 1983 |
| 4 | – | – | – | 4 |
| 7 | 17 | – | 11 | 19 |
| 11 | 37 | 33 | 43 | 24 |
| 14 | – | – | 35 | – |
| 18 | 29[a] | 20[a] | – | 10 |
| 19 | – | – | 14[a] | 5[a] |

[a] Date of anthesis.

Together with these observations of poor emergence in direct-sown crops, it also appears that wheat establishment generally could be suffering from high sowing speeds and the use of wide sowing equipment with little or no ground-following ability. The variable sowing depth that results is potentially disastrous for emergence of semi-dwarf wheats with short coleoptiles (e.g. Allan *et al.*, 1962; Sunderman, 1964; Whan, 1976). The problem is made worse with early sowings when high temperature and low surface soil moisture can further reduce coleoptile length (Allan *et al.*, 1962; Gul and Allan, 1976b). Some seed dressings can also delay or reduce emergence under adverse conditions (Cornish, 1986). In short, residue retention and sowing into uncultivated soil have probably exacerbated a problem that already exists with semi-dwarf wheats and possibly with other crops also. The issue here is whether to breed for improved germination and emergence or whether an agronomic approach would be better, such as better sowing machinery or simply increased sowing rates. The answer lies in defining the cause of the problem.

### Reasons for reduced germination and emergence

There have been no comprehensive attempts in Australia to quantify and explain the effects of cultural practices on these processes so the following discussion is somewhat speculative.

**Physical factors** Collis-George and Lloyd (1979) tried to provide both a theoretical and practical framework to examine the physical effects of soil on germination and emergence. Their procedures are very time-consuming and do not lend themselves to a dynamic assessment of germination and emergence. Using these procedures, Lloyd (1981) found no difference between the seedbed of direct drilled and conventionally sown crops sown by A.A. McNeill at Cowra, New South Wales. She concluded that low soil water was the factor most likely to affect emergence, but this was not affected by tillage. However, McNeill (personal communication) reports that rain intervened between these measurements and emergence, culminating in a substantially lower population after direct drilling, for unknown reasons. The static measurements of Collis-George and Lloyd (1979) must have very limited utility. Dexter (1976; 1978), Hewitt and Dexter (1984) and Whitely and Dexter (1984) have also developed procedures for quantifying soil structure and responses to it, but they are time-consuming and so far inaccessible to most agronomists and plant breeders. While these workers have shown that soil physical factors can explain cases of poor emergence in new cultural systems, it is not possible to be explicit about the causes in most situations. Without this information no guide can be given to breeders with respect to selection criteria.

In New Zealand, Baker and colleagues at Palmerston North have intensively studied the soil physical requirements for germination and emergence in the context of design of sowing implements for direct sowing of crops and pastures (Baker and Badger, 1977). The clear message from their work is that implements can be designed to greatly improve plant establishment once the factors limiting germination and emergence are known. Some work of this kind has started in Australia but more is needed.

The reduced maximum temperature under crop residues (Chapter 7) can be an advantage for summer-grown crops (Lovett *et al.*, 1982) and will presumably aid establishment of winter crops if water is limiting. In the United States, however, it is regarded as one of the main problems with sowing winter species into crop residues (Kronstad *et al.*, 1978; R. Allan, personal communication) and this appears to be the case in Australia (Aston, 1985). It may be possible to overcome this problem by developing sowing implements that confine residues to the inter-row area. Alternatively, selection for improved emergence and early growth at low temperatures has been successful with maize (Hardacre and Eagles, 1980) and sunflower (Downes, 1985) and may also be successful with other crops. In the meantime residues can be burnt just before sowing in many areas of southern Australia with minimal risk to the soil (Chapter 2).

**Chemical factors reducing emergence** The main concerns here are the presence of phytotoxic chemicals in undecomposed residues or chemicals produced during decompositon (Kronstad *et al.*, 1978; Lovett *et al.*, 1982). Problems associated with phytotoxins can probably be overcome by sowing into standing residues, but this may not be compatible with water and soil conservation objectives, or with the farming system if grazing is necessary.

Plant species vary in the toxins produced, and in the response to the toxins produced by other species (Lovett *et al.*, 1982). Therefore there seems to be scope to solve phytotoxin problems in the short term by crop rotations and, in the longer term, by plant breeding.

### Likely responses to selection for improved establishment

The field environment is complex and highly variable. Unless a small number of factors associated with cultural practices consistently reduce germination or emergence it is unlikely that plant selection will greatly improve establishment.

In the studies with a range of winter cereals at Wagga Wagga, described earlier, there was no interaction between genotype and tillage method although final establishment percentage and seedling growth rates were often reduced by direct drilling. In a total of 14 experiments there were no cases of emergence failure with direct drilling, and population was reduced on average by 12%. Such small but fairly consistent differences should be overcome by increasing sowing rate, a conclusion also reached by McNeill (1978) based on 28 site/years of data. In northern New South Wales, Felton *et al.* (1980) sowed eight cultivars of wheat and one each of barley and triticale directly into wheat residue and into a conventionally cultivated seedbed. They found no effect on establishment, nor any interaction between genotype and tillage practice. These few results indicating no interaction between genotype and tillage do not encourage a field selection programme to improve establishment. However, the conditions of these experiments may not have been as adverse for establishment as would occur in commercial practice.

Wheat breeders in the Pacific north-west of the United States have selected for improved establishment for over 20 years, since the limitations of semi-dwarf cultivars first became apparent. However, improved emergence capacity is still listed as a major requirement in breeding programmes (Allan, 1982). Although progress has apparently been made with field performance (Gul and Allan, 1976b) it has been slowed by the complexity of the field environment. This has also led to poor correlations between glasshouse or laboratory screening procedures and field performance (Gul and Allan, 1976b).

Allan and his associates have examined many physiological, morphological and agronomic traits in relation to establishment (e.g. Allan *et al.*, 1965; Gul and Allan, 1976a; 1976b). Of all the factors studied, coleoptile length is the one factor that is easily measured in glasshouse tests and also consistently related to emergence rate and final establishment in the field. Coleoptile length in grasses is presumably comparable to hypocotyl length of dicotyledonous species with epigeal germination, in relation to emergence. If breeders are to concentrate more on selection for improved establishment in new tillage systems then these traits are clearly the place to start, taking into account possible differences between seedbed conditions and climate between Australia and the United States.

### Germination and emergence - conclusions

Agronomic solutions can be envisaged for most of the problems associated with direct sowing. Better sowing equipment is urgently required. Plant selection is not favoured, mainly because selection criteria have not been defined, except possibly for coleoptile length in cereals.

## Problems and unrealised potential resulting from the high strength of untilled soil

### Reduced root growth

Because reduced cultivation frequently increases the bulk density and strength of soil there has been considerable speculation that root extension would be impeded and that this could explain the reduced early growth of direct-sown crops (e.g. Ellington and Reeves, 1978; Fischer, 1980).

Root extension is undoubtedly reduced in some situations (Hamblin and Tennant, 1979; Whitely and Dexter, 1982; Cornish, 1985). Although some circumstantial evidence in each of these studies links the reduced root extension with reduced shoot growth there is no conclusive evidence that impeded root extension is responsible in general for the poorer shoot growth of direct-sown crops. While Whitely and Dexter (1982) reported a relationship between shoot growth and the volume of disturbed soil, McNeill and Cornish (unpublished) at Wagga Wagga found no such relationship.

Plants grown under ideal conditions have more roots than they need for nutrient and water uptake. The experiments of Russell and Goss (1974) are a classic example of how root growth can be mechanically reduced without affecting shoot growth, provided adequate water and nutrients are available. It is possible, however, that hormone synthesis in roots can be influenced by mechanical impedance and so affect shoot growth (Peterson *et al.*, 1984). Before trying to select for increased root growth we need to have clear evidence that reductions in root extension occur widely to **the extent that root function and hence shoot growth are impaired.**

Because soil structure improves with continuous reduced tillage, many people have assumed that root growth would also improve and that early crop growth would be better after several years of direct sowing. However, there is no reliable evidence that this occurs. Reductions in early shoot growth still occur consistently at the Rutherglen Research Institute where direct drilling has been practised continuously for many years (Ellington and Reeves, 1981). Long-term tillage trials of A. McNeill (personal communication) comprising 28 site/years of experimentation confirm the persistence of early growth effects, even after seven years of continuous direct drilling in which measurable improvements in structure occurred. Direct drilling on soils with contrasting cropping history and therefore current structural status has also consistently given reduced growth (Table 15.1). It appears that the reduced shoot growth is not closely related to soil structural status nor, possibly, to root extension.

Should it be proven that impeded root extension commonly reduces the productivity of direct-sown crops or pastures then some solution will clearly be necessary. Whitely and Dexter (1982) indicate that differences between species occur in the adaptability of root systems to direct sowing, although their data also indicate that changes in sowing equipment may be a simpler solution. In their experiments, a narrow slit cut to 120 mm depth gave the same root growth and total plant dry matter as full seedbed cultivation to the same depth. Both treatments were much better than sowing into a shallow (30 mm) vee-shaped groove or a 5 x 30 mm hole. A slit cut below sowing depth to encourage root growth is one design feature of sowing equipment being developed by J. Baker in New Zealand (Figure 5.3).

## Pasture ecology

Seed production and the re-establishment of annual legume pasture species may be reduced by deleting tillage for the crops sown in a rotation. High soil strength can reduce burr burial in subterranean clover, help stock to eat seed over summer, and restrict root entry to the soil and seedling root growth, all of which have been implicated in the decline in productivity of annual legume pastures (Carter *et al.*, 1982). Taylor (1980) has shown that cultivation can reduce pasture re-establishment after a short period of cropping, but increase re-establishment compared with no-tillage after a longer cropping phase. The effect of seed burial by tillage was to slow the rate of hard-seed breakdown, an advantage in extended cropping phases. Effects like these may have a major impact on selection of pasture plants in conjunction with new cultural practices for crops.

## Plant nutrition

Effects of high soil strength on root growth and plant nutrition may explain some of the differences in early growth caused by direct drilling. With nitrogen, occasional increases in fertiliser N requirement have been reported for direct drilled crops (Gates *et al.*, 1981) but more generally the responses have been either inconsistent (Tennant, 1981) or suggest no increase in fertiliser requirement (Reeves and Ellington, 1974; Rowell *et al.*, 1977). Any responses probably reflect mineralisation/immobilisation of N, rather than root-extension effects. Responses to phosphorus have not been documented as well as nitrogen but Cornish (1981) and Gates *et al.* (1981) have reported an increased requirement for P-fertiliser in direct drilled crops. There is little doubt that the surface accumulation of P with direct drilling can place it out of the reach of the seminal roots of cereals (Figure 15.8). High soil strength can also reduce root extension and phosphorus uptake (Cornish, 1984), while strength and structure can interact to determine where roots grow in soil and how well they function in nutrient uptake (Dexter, 1978). If impeded root growth is proven to seriously reduce nutrient uptake under field conditions, then the work of Dexter and his associates at the Waite Institute could, in time, guide breeding or agronomic studies to improve root growth and/or function. Dexter (1978), Whitely and Dexter (1984), and Taylor and Ratliff (1969) cite genotypic differences in relevant root parameters, but they will be difficult to select for. Root systems also have a great capacity for compensatory growth (Crossett *et al.*, 1975) so that phenotypic differences under one set of controlled conditions may not be reflected in the field.

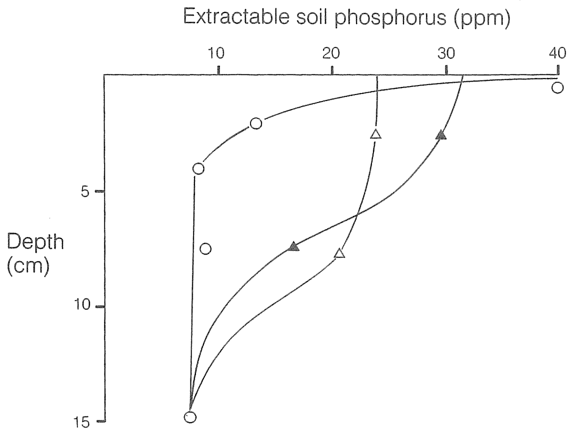


Figure 15.8 The distribution of available phosphorus in soil under pasture (○) and under crops after direct drilling (▲) or conventional cultivation (△)

## Plant water relations

Establishing crops and pastures could be more susceptible to drying of the soil surface if seedling root growth is impeded by the higher strength of soil after direct sowing. High soil strength leading to shallow rooting partly explains the widespread failure to establish perennial grass species by aerial sowing (Cornish, 1979). N. Fettell (personal communication), working in the low-rainfall wheatbelt at Condobolin, New South Wales, and Whitely and Dexter (1982) at Adelaide provide examples of this for crops. At Wagga Wagga, however, during three almost rain-free months after sowing in 1982, there was little difference in the leaf water potential of conventionally sown and direct drilled wheat crops (Table 15.2) despite an average 43% reduction in crop dry matter 13 weeks after sowing (Table 15.4). Similarly, Hamblin and Tennant (1979) reported reduced shoot growth after direct drilling under conditions when water was most unlikely to be limiting. Rather than reduced water uptake affecting plant growth, it is probably more generally true that reduced shoot growth influences water uptake (Chapter 8).

The fact that new tillage practices can consistently reduce early growth (of winter crops) and water use without necessarily reducing grain yield indicates the need to review cereal crop water relations, irrespective of tillage practices. Such a review could well have a major impact on plant breeding, for example by defining phenological strategies to improve water-use efficiency in particular regions (Fischer, 1979).

### Sowing opportunities

Uncultivated soils are more trafficable in wet weather, but more difficult to sow in dry conditions. On balance, planting time should be more flexible than with conventional tillage, possibly enabling regular planting near the time calculated to maximise water-use efficiency.

Fischer (1980) suggested the possible need for quicker maturing wheat varieties to accommodate delayed sowing with direct drilling. Conversely, early sowing may sometimes be needed to overcome problems of reduced early growth (Hamblin, 1981). These effects need evaluation on a regional basis.

In the Mediterranean-like climate of southern Australia, sowing of crops has been traditionally delayed by the need to prepare seedbeds after the season 'breaks'. Direct sowing allows earlier sowing with potential yield benefits. Early sowing will require new cultivars, either longer-season types or winter wheats with a flexible planting time. Early sowing will also increase the risk of diseases such as *Septoria tritici* blotch (speckled leaf blotch) in wheat and will therefore increase the need for disease resistance.

## Problems with pests and diseases

The only clear examples of increased disease with new cultural systems are cases of rhizoctonial bare patch, a problem that may be solved by limited soil disturbance, and yellow spot in wheat. Breeding is already underway in Queensland for yellow-spot resistance (Chapter 13). Field experience in south-eastern Australia in 1984 showed that mice in plague proportions can do serious damage to direct drilled wheat. Even greater damage was sustained in the presence of crop residues. This might not be a long-term problem. If it is, however, observations of selective attack on some cultivars (N. Fettell, personal communication) could be relevant.

In relation to pests and diseases, Phillips' remarks at the 2nd Agronomy Conference (1982) bear serious thought '... yields rarely reflect the increased risks ... both in Australia or other countries'.

## Problems (and potential) with increased herbicide use

Screening for crop tolerance to herbicides (and other agricultural chemicals) will become more important in relation to toxic residues and to the safety of selective herbicides. Screening and selection in tissue culture for increased tolerance to broad-spectrum herbicides may be possible (Scowcroft *et al.*, 1982). New uses for existing chemicals may be possible with improved plant tolerance. For example, resistance to atrazine could make chemical fallowing for wheat feasible in situations where toxic residues are now a problem.

Long-term use of chemicals and reduced tillage could change the weed spectrum beneficially (Pratley and McNeill, 1982; Taylor and Lill, 1982). In other cases, herbicide-tolerant genotypes could be favoured. For this and other reasons there have been claims that increased competitive ability would be desirable in crop cultivars for new tillage systems (Hutchings, 1977; Gates *et al.*, 1981) but it is more likely that successful weed control will come from an integrated approach to weed management combining chemicals, grazing management, crop rotations and perhaps strategic cultivation (Pratley and Cornish, 1985).

Pastures will also be affected by increased herbicide use. On the one hand, weed suppression in pastures could lead to more productive pastures, although the primary aim of attacking weeds in pastures is to reduce the cost of their control in the subsequent crop. On the other hand, the use of herbicides to reduce seed-set by weeds in pastures could also reduce seed production by the improved pasture species (Carter *et al.*, 1982).

## OPPORTUNITIES FOR NEW CROPS AND PASTURES AND WIDER USE OF OLD CROPS

### Changing crop rotations

Crop rotations will continue to play an important role in controlling weeds, pests, diseases and soil N levels in new tillage systems. But the capacity to continuously crop many soils without risk of serious structural degradation, combined with economic pressure to crop more intensively, could lead to changes in rotations. More intensive cropping in some regions is certain, raising questions for breeders concerning crop sanitation and particularly sources of nitrogen for non-leguminous crops. Satisfactory grain legumes will be more important than ever. Lupins are the most promising crop for much of southern Australia, but yields will need to improve (at least in New South Wales) if farmers are not to opt for cereals and fertiliser-N. Other likely requirements for lupins include the ability to fix N at higher soil N levels and shorter-season types to allow greater flexibility in planting time. Evaluation of other grain legumes should be stepped up to at least cover *Vicia faba* (faba beans), semi-leafless *Pisum arvense* (field peas) (Berry, 1985) and *Cicer arietinum* (chickpeas) to provide legumes that are adapted to a wide range of soil types and regions.

Legume-based pastures will continue to be important across southern Australia although their place will fluctuate, depending on economics. Longer cropping phases in rotations will increase the need for hardseededness (or resowing) of legumes.

In the higher-rainfall areas of north-eastern Australia, double cropping and opportunity cropping are possibilities. Full exploitation of the potential to double crop in this area may need some changes in crop phenology.

### Changing boundaries to cropping

A major drawback to the development of cropping in otherwise suitable areas in northern Australia has been the risk of soil erosion (Wood and Fukai, 1982). The development of conservation farming practices for these areas allows for a vast expansion of cropping. Wood and Fukai (1982) indicate where plant breeding may be required to solve the problems that could arise (Table 15.5).

**Table 15.5 Major requirements for plant breeding in Northern Australia (Wood and Fukai, 1982)**

- Phenological manipulation
- Improved establishment (in poor seedbeds, and at high temperatures)
- Salt tolerance (small, but increasing)
- Nutrient-use efficiency
- Drought resistance (need to define traits first)
- Pest and disease resistance

New tillage systems have already allowed cropping to expand on the north coast of New South Wales, including the introduction of wheat-soybean double cropping (Desborough, 1981). The risk of erosion in this area is high, hence conservation farming methods were a prerequisite for success. Crop yields have been good, although the cultivars grown were selected for the much drier inland areas of New South Wales. The north coast now boasts about half the soybean area in New South Wales (P. Desborough, personal communication) so it is clear that attention from breeders will be required.

Direct drilling will also facilitate the spread of cereal cropping from traditional areas into the adjacent higher-rainfall areas of New South Wales and Victoria by reducing the risk of soil erosion and improving the trafficability of soil in wet weather. Cropping in this area will face problems of waterlogging, soil acidity, and pests and diseases (especially speckled leaf blotch and barley yellow dwarf virus). The first requirement, however, will be to provide varieties with an appropriate phenology. These will probably be winter wheats or photoperiod-sensitive spring wheats (Davidson *et al.*, 1982; Crofts *et al.*, 1984) and winter rapeseed and late lupins as break crops. Problems of aluminium and manganese toxicity associated with acid soils are receiving attention from breeders and agronomists at Wagga Wagga (J. Fisher and B. Scott, personal communication). Tolerance of high manganese and aluminium in soils could also be necessary eventually in traditional cropping areas if the present decline in soil pH continues.

## CONCLUSIONS

The factors that determine productivity in one management system differ from those in another in complex ways, which are as yet poorly understood. For this reason, considerable interdisciplinary research will be necessary before clear direction can be given to breeders on the need for breeding and the traits concerned. Those traits that are already clearly important include resistance to the diseases yellow spot and rhizoctonial bare patch in wheat, and phenological adaptation, mainly to enable cereal cropping in higher-rainfall areas. Minimal cultivation may control *Rhizoctonia.* Other traits that are probably important include tolerance of the phytotoxic products of stubble breakdown, better growth of winter crops at the reduced temperatures found under crop residues, greater root growth in strong soils, increased early crop growth in environments with high yield potential, improved plant establishment and greater tolerance to herbicides. Poor emergence, reduced root extension and poor early crop growth are often cited as problems requiring a genetic solution, but the present indications are that improvements in the design of sowing equipment and attention to sowing rates and plant nutrition offer better alternatives.

The capacity to crop more intensively without damage to the soil will increase the demand for crop alternatives to wheat, especially legumes. Intensified cropping and increased herbicide use will also bear on the establishment, re-establishment and productivity of annual legume-based pastures. The subject is under-researched compared with crops. New opportunities for cropping are developing, with soybean and wheat cultivars for double cropping on the north coast of New South Wales representing an immediate need, and winter cereals for the high-rainfall zone of southern Australia also being important.

With respect to traditional crops, it is clear that new tillage practices affect the environment, but the present evidence does not indicate a need to breed genotypes specifically adapted to particular practices. Rather, broad adaptation to the range of practices is favoured, although it may be necessary to select for some new traits that are necessary in one system but not a disadvantage elsewhere (e.g. resistance to yellow spot). It appears that traditional approaches to breeding will result in adequate adaptation to cover the range of environments created by tillage. The choice of tillage practice during evaluation does not appear to be very important, except where specific traits have been identified, such as management-related diseases.

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