# BREEDING CROPS FOR IRRIGATION

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## ABSTRACT

The question of whether plant breeding programmes should aim to develop separate crop cultivars for irrigated and dryland agriculture is considered. This is not an objective of current programmes in New Zealand, but results of empirical irrigation trials suggest it could be warranted. Most of the breeding effort related to irrigation is devoted to the introduction of resistance to those pests and diseases that are more significant problems under irrigation. Alternatively, breeding for physiological or agronomic characters that might be associated with differential responses to irrigation or, conversely, variable ability to withstand or avoid drought could be useful. Some such characters are briefly considered, but current understanding of the characters is insufficient to justify separate breeding programmes. However, it is suggested that breeding and selection should be conducted under well-watered conditions. In these circumstances plants would best exhibit their genetic potential.

## INTRODUCTION

The use of irrigation in arable agriculture has increased. This development has been accompanied by progressive modification of traditional agronomic practices, leading to a gradual evolution of two distinct crop management systems: irrigated and dryland. However, little effort has been made to breed crop cultivars specifically adapted for either system. The question of whether this is needed is often raised. It was discussed with regard to wheat breeding in New Zealand by McEwan (1959), and is considered further in this paper.

## CURRENT STATUS OF BREEDING PROGRAMMES

In current breeding programmes at Crop Research Division no attempt is made to develop cultivars separately for irrigated and dryland agriculture. Nor is assessment made of the performance of breeding lines with different controlled levels of water supply. It is considered that the cultivars produced are adapted generally to regional agricultural conditions, regardless of whether irrigation is used or not, as they will have been selected over several seasons with different water availability.

In many programmes field plantings of breeding material are not irrigated at all, but in some, irrigation is used to ensure that severe moisture stress does not occur during the growing season. As examples, field pea, potato, and autumn-sown cereal breed lines are not usually irrigated, but spring-sown cereals, lucerne, process peas, and all vegetable crops normally receive supplementary water. In most instances, the criteria for scheduling irrigations are somewhat arbitrary, but are as close as practicable to the recommendations for each particular crop.

When promising lines of some crops approach the stage of release as new cultivars, they are tested with various levels of irrigation, ranging from none to adequate water throughout the growing season, to find whether they are better adapted to either dryland or irrigated conditions. However, the results are very empirical, often inconclusive, and do not explain the differences in response shown by cultivars.

## IS SEPARATE BREEDING WARRANTED?

Evidence from irrigation trials with many crops shows that cultivars perform differently in irrigated and dryland conditions, and respond differently to irrigation. For example, Mr R. Genet of the Potato Section at Crop Research Division grew seven potato cultivars over four seasons with and without irrigation. Several observations can be made from his results (Table 1):

TABLE 1: Mean total yields and irrigation responses of seven potato cultivars from four years of trials.

| | Tuber yield (t/ha) | | Increase in yield with |
|---|---|---|---|
| Cultivar | Irrigated | Not Irrigated | irrigation (%) |
| 503.01* | 59 | 34 | 74 |
| 524.04 | 69 | 51 | 35 |
| 533.01* | 51 | 36 | 42 |
| Ilam Hardy | 61 | 44 | 39 |
| Rua | 55 | 48 | 15 |
| Wha | 67 | 56 | 20 |
| Whitu | 61 | 54 | 13 |

* Results from two years only.

1. Yields without irrigation ranged from 34 to 56 t/ha.
2. Yields with irrigation ranged from 51 to 69 t/ha.
3. Yield responses to irrigation ranged from 13% to 74%.
4. Wha and Whitu appeared to be good cultivars for dryland conditions, but did not respond well to irrigation.

5. 503.01 and 533.01 yielded poorly in dryland conditions, but gave large responses to irrigation and produced high yields.

Sturrock (1978) has also obtained differential responses to both irrigation and shelter in cultivars of dwarf beans grown at Lincoln.

Empirical results and observations such as these are often inconsistent from season to season, not least because of differences in rainfall distribution, and do not reveal the causes of the differences. However, they show that gains could be made by breeding cultivars separately for irrigated and dryland conditions. It would be impractical to use these types of trials routinely on a large scale in breeding programmes, but they are useful when new cultivars approach the point of release for commercial use.

## OBJECTIVES OF BREEDING

Separate development of cultivars for irrigated and dryland conditions would require definition of the objectives for each programme and evaluation of the benefits. Several questions need to be answered. What desirable characteristics should be sought in cultivars to suit them to irrigated or dryland conditions? How much genetic variability for those characteristics is available for exploitation in breeding and selection? Can it be shown that the characteristics are related to superior economic yield?

Undoubtedly, many plant and environmental factors contribute to the types of responses shown in Table 1. The problem is to identify the important plant factors and consider them in relation to the three questions. Some possibilities are discussed below.

### 1. Pest and Disease Resistance

Breeding could be used to incorporate genetic resistance to pests and diseases which are more significant problems in irrigated than in dryland conditions. This approach is already used, and an outstanding example of success has been with lucerne. Dunbier *et al.*, (1976) and Dunbier (1977) showed that the traditional cultivar, Wairau, which is susceptible to bacterial wilt (*Corynebacterium insidiosum*), yielded well in dryland situations, where the effect of wilt was not severe. However, with irrigation, wilt infestations became severe and resulted in reduced yields (Table 2). Overseas cultivars with stable genetic resistance to the disease were introduced. Their yields were not reduced in either irrigated or dryland situations; the results for one introduced cultivar, Washoe, are shown in Table 2. However, the introduced cultivars were not ideal for New Zealand conditions, and were used in breeding programmes to produce wilt-resistant, locally-adapted cultivars. The overseas material is also being used to incorporate resistance to other pests and diseases.

This approach is successfully combating problems induced by irrigation of lucerne. However, the new cultivars are equally successful in dryland conditions so, in the strict sense, breeding separately for the two situations is not occurring.

### 2. Plant Attributes

An alternative approach is to breed for physiological or agronomic characteristics which may be associated in the plant with differential responses to irrigation or, conversely, variable ability to withstand or avoid drought. Unfortunately it is not possible to define 'drought resistance' or 'irrigation responsiveness' of plants in the same sense that disease resistance can be defined. Crop physiologists have attempted to achieve this by studying the role of water in the morpholgy and physiology of plants. Moss *et al.* (1974) reviewed this work and listed 34 plant attributes controlling water use which may be amenable to genetic regulation (Table 3). These characters are of little value to breeders until their relative importance can be assessed. Some of the more important ones are:

(a) *Leaf Stomata.* These primarily control the rates of photosynthesis and water use; they regulate the flow of carbon dixoide into leaves and of water vapour out, by opening and closing as the plant water status varies. Several stomatal characteristics vary among genotypes of a species. Differences in the size and density of stomata, which determine the maximum flux of carbon dioxide and water vapour through each unit of leaf area, are highly heritable and, therefore, are amenable to genetic manipulation (Moss *et al.* 1974). Potentially more useful is the variability among cultivars in stomatal sensitivity to water stress. For example, Henzell *et al.* (1975, 1976) observed considerable differences among sorghum genotypes in the patterns of stomatal closure with the onset of water strees. They suggested that stomatal sensitivity may be an important element of genotype variation in resistance to drought, and developed a screening technique which could be used by plant breeders to examine large numbers of genotypes.

TABLE 2: Relative dry-matter yields (% of trial mean) of 'Wairau' and 'Washoe' lucerne cultivars in Canterbury (from Dunbier, 1977)

| Cultivar | % wilt-resistant plants | Winchmore (irrigated) 1972/3 | 1973/4 | 1974/5* | 1975/6* | Lincoln (dryland) 1972/3 | 1973/4 | 1974/5 | 1975/6 |
|---|---|---|---|---|---|---|---|---|---|
| Wairau | 15 | 103 | 95 | 88 | 81 | 110 | 111 | 105 | 115 |
| Washoe | 70 | 91 | 95 | 96 | 115 | 88 | 94 | 104 | 113 |

* By the 1974/5 season bacterial wilt had reduced the number of Wairau plants present.

TABLE 3: Factors controlling water use which may be amenable to genetic regulation (from Moss *et al.*, 1974)

| | |
|---|---|
| *Leaf* | *Roots* |
| orientation | water absorption |
| hairs | water transport |
| reflectance | hairs |
| colour | ability to grow in dry soil |
| leaf area index | aeration (internal) |
| size | penetration |
| duration | size (diameter and length) |
| thickness | branching |
| retention | respiration |
| | reaction to temperature |
| *Stomata* | |
| frequency | *Awns* |
| size | |
| behaviour | *Maturation* |
| | *Photosynthesis* |
| *Shoots and stems* | intensity |
| length | $C_3$ vs $C_4$ pathway |
| crust penetration | |
| | *Respiration* |
| *Fruiting* | photo versus dark |
| duration | |
| relation to transpiration | *Succulence* |
| accretion rate | |
| temperature effects | |

(b) *Photosynthesis rate.* It determines potential productivity, and varies among genotypes of a species in well-watered conditions. It is reduced by water stress, primarily as a result of stomatal closure. However, there is also evidence of reductions which are attributable not to stomatal action, but to increases in the so-called mesophyll resistance to carbon dioxide fixation. This resistance appears to vary among cultivars and may be amenable to genetic regulation (Sullivan and Eastin, 1974; Wallace *et al.*, 1972).

(c) *Root systems.* The nature of root systems differs among cultivars of many crops (Blum *et al.*, 1977a, 1977b; Hurd, 1974; Taylor and Klepper 1978). Rooting patterns in soil profiles are hereditary characters, and extensive root systems are advantageous to dryland plants, especially if they are produced early in growth. The geometry of each root is also variable and important because it affects the resistance to water influx (Taylor and Klepper, 1978).

(d) *Awns.* In cereal crops, the presence or absence of awns is an heritable characteristic. Awns increase the surface area of the ear, increasing photosynthesis and transpiration, but also modify the radiation balance of a crop canopy so that less water is transpired (Ferguson, 1974).

(e) *Leaf wax.* The quantity of epicuticular wax on plant leaves is variable and genetically controlled (Blum, 1975). It affects the transpiration rate in two ways: by affecting water vapour diffusion through the cuticle and by modifying the radiation balance through alteration of leaf reflectance.

These examples are not exhaustive, but they illustrate potentially important adaptive features. Despite the recognition of their probable importance, they are largely ignored in current breeding programmes. There are two main reasons for this. Firstly, most of the characters are not easily measured, an important requirement where large numbers of genotypes need to be screened. Secondly, modifications of the characteristics have not resulted in improved yields, despite the fact that individually they are apparently important. It does seem unlikely that any individual attribute would render a plant 'drought resistant' or 'irrigation responsive'; it is probable that many factors are involved.

These problems make it difficult to select combinations of attributes for breeding programmes. Consequently, improvement in plant response to drought by deliberate selection has been rare (Boyer and McPherson, 1975). Clearly, there is a need for continued research by crop physiologists to explore further the causes of variability of water relations of plants, and to devise rapid screening techniques for important characters.

### 3. Empirical Approaches

Cultivars suitable for irrigated or dryland conditions can be identified without knowledge of the underlying physiological causes of variation. This type of approach is used in breeding programmes at the International Rice Research Institute in the Philippines (O'Toole *et al.*, 1978). All breeding material is routinely screened under severe drought conditions in controlled environments at the seedling stage. The surviving lines are assumed to have drought-resistant properties, and are used to breed cultivars for dry regions. Good results from this procedure, which was also suggested by Boyer and McPherson (1975), have been reported.

Another simple approach is to select cultivars for early maturity. The growth period is shortened so potential yields are reduced, but the risk of encountering late-season droughts which commonly occur in dryland conditions is also reduced. For irrigated conditions late maturing cultivars can advantageously make use of a longer growing period without the risk of drought damage, and accumulate more dry-matter.

With crops such as peas, determinate cultivars should be selected for irrigated conditions to avoid prolonged flowering and maturity periods. Indeterminate cultivars, which flower over longer periods, are more suitable for dryland conditions; the risk of the whole flowering period encountering drought is thereby reduced.

## CONCLUSIONS

There is evidence of potential to improve cultivar performance under both irrigated and dryland conditions. However, present knowledge of the genetic variability concerning the water relations of plants is insufficient to define clearly the breeding requirements of cultivars for both situations.

There are obvious benefits from breeding for greater resistance to pests and diseases which tend to be more severe problems under irrigation. In addition, it would be useful to grow and select breeding material in well-watered conditions. In these circumstances, plants should best exhibit their genetic potential. It should also be easier to recognise undesirable agronomic and morphological characteristics, and lines susceptible to pests and diseases. Some of the resulting cultivars would not be well adapted to dryland conditions, but they could be identified before release by either using the technique of screening seedlings under drought conditions or evaluating responses in field trials with and without irrigation.

This approach seems preferable to breeding and selecting in dryland conditions, and then hopefully identifying cultivars suitable for irrigated conditions; the opportunity to select lines with genetic potential to produce high yields in favourable conditions is obviously diminished.

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