How water availabilty affects wheat yield and quality

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Abstract

High yielding, good quality wheat, regardless of its intended end use, requires there be no moisture stress induced by limited water availability. In humid areas of New Zealand, such as Southland, water availability normally does not limit wheat production. In eastern areas, such as Canterbury, moisture stress is common-place and irrigation is necessary to ensure high yields and good quality. In these eastern areas wheat production is further limited by the warm, dry north-westerly (NW) winds. The NW wind through its transfer of heat energy (advection) increases evapo-transpiration by up to 2 mm/day and total seasonal water use by 100 mm with no concomitant increase in yield. Maximum irrigated yields in areas most affected by the NW wind are 6-7 t/ha, while in areas least affected, irrigated yields are up to 10 t/ha. The effect of limited water availability is to reduce potential yield. In the period prior to grain-fill, kernel numbers per hectare are reduced mostly by tiller mortality. During grain-fill, yield and quality are reduced through decreased kernel weight and changed protein contents.

Introduction

A major factor influencing the yield and quality of wheat is the availability of water. The effect of limited water is to subject the crop to moisture stress. In humid regions, e.g., Southland, periods of moisture stress are infrequent. In less humid regions such as Canterbury and Wairarapa, moisture stress is commonplace and irrigation is essential to grow high yielding and quality crops with consistency. Results of irrigation trials in Canterbury show that irrigated yields are always greater than dryland yields, but the size of this increase varies with soil type and dryness of the season, e.g.,

- on light Lismore soils irrigated yields can be 2.1 to 3 t/ha greater than dryland yields in years of below average rainfall (Drewitt and Rickard, 1973; Carter and Stoker, 1985).
- on better Templeton soils, Wilson (1974) found irrigated yields to be 1 to 1.2 t/ha greater than dryland yields.
- on heavier Wakanui soils yield increases through irrigation were less, about 12% or 0.5 t/ha compared with dryland crops (Scott *et al.*, 1973).
- more recently, Baird and Gallagher (1985) quantified the yield increase attributable to irrigation as 12-13 kg/ha/mm of irrigation, or 3% for each 10 mm of irrigation. In a season such as 1990-91 (with about average rainfall), this result suggests yield increases as a result of irrigation would range from 1.6 t/ha on heavier soils (130mm irrigation) up to 2.5 t/ha on lighter soils (with up to 200mm irrigation).

What is often not explicit in these examples is the effect of the environment on yield. Temperature and rainfall (or lack of it), both of which vary considerably across the Canterbury Plains, can have a marked affect on the yield of wheat.

For simplicity two stages of wheat growth and development are used to discuss the effects of moisture stress:

1. Pre grain-fill - during which emergence, leaf and root growth, tillering, jointing, ear emergence, floral initiation, pollination and initial grain growth takes place, and
2. Post grain-fill - during which grain growth from clear milk through to hard ripe grain takes place.

The effect of limited water during either growth period is to reduce the duration of growth and therefore yield. For example, during pre grain-fill the rate of canopy development will be reduced, while during post grain-fill the time to the onset of senescence will be shortened.

Consequence of Limited Water Availability

At no stage can wheat tolerate moisture stress from limited water without productivity being adversely affected. In humid areas, such as Southland, where moisture stress is uncommon, water availability is not a factor in determining wheat yield. However in less humid areas the supply and demand of water (i.e., irrigation) must be carefully balanced to obtain high yields, or yields that are realistic for the prevailing environmental conditions. Improving irrigation management is an important factor in obtaining optimum yields.

Missing a 50 mm irrigation can cost the grower 1.5 t/ha from a potential yield of 10 t/ha, according to the results of Baird and Gallagher (1985). Results from recent rainshelter growth trials by Jamieson (pers. comm.) reveal that subjecting autumn sown wheat to soil moisture deficits greater than the critical deficit will reduce yield by 0.21%/mm of deficit. Figure 1 shows how the critical deficit varies according to soil type, with lighter shallower soils (Lismore, Chertsey) having significantly smaller critical deficits than the deeper heavier soils. Figure 1 also inter-relates effective root depth, soil depth and critical deficit. At young growth stages there is no difference between soil types, i.e., rooting depth is similar. But on the shallower soils root development soon reaches the underlying gravels, water use quickly exhausts the available soil moisture and the critical deficit is reached. On heavier soils, root development continually intercepts moist soil layers and increases the time it takes to reach the critical deficit.

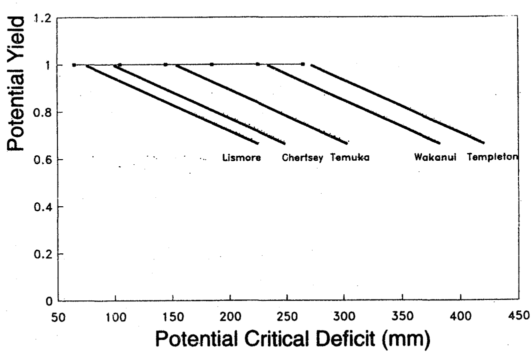

Figure 1. The relationship between critical deficit, potential yield and some common Canterbury soil types. Potential yield is equivalent to 1.0 and decreases by 0.21% per mm once the critical deficit is exceeded.

At ear emergence root depth on light soils is about 0.8 m while on the deeper soils it may be up to 1.5 m. Exceeding the critical deficit is most serious on heavier soils such as Wakanui or Temuka type soils since it is crops on these soils that have yield potentials of 10 t/ha compared to only 6-7 t/ha on lighter soils. For example, exceeding the critical deficit by 20 mm will reduce yield by 0.4 t/ha or $124/ha in a 10 t/ha crop and it will reduce yield by 0.25 t/ha or $74/ha in a 6 t/ha crop (calculated using 1992-93 prices of $295/t of 100 index point wheat).

While crops growing on the better soils have the highest yield potentials and require the least irrigation, they have the most to lose if the critical deficit is exceeded. These findings of Jamieson demonstrate that if the soil profile is at full moisture capacity at emergence, irrigation is unnecessary until the critical deficit is reached. However, to avoid yield reduction it is crucial to begin irrigating before this point. The most common mistakes made by irrigating farmers are:

- beginning too late
- irrigating too infrequently
- applying too much water, and
- stopping too soon.

The effect of these on growth is best discussed by referring to the two growth periods.

Pre grain-fill

Irrigation management during this growth period determines the yield potential of the wheat crop. The first three irrigation mistakes reduce potential yield. Limited water availability reduces both head numbers and kernels per spikelet (Johnson and Kanemasu, 1982; Musick and Porter, 1990). Failure to begin irrigating before moisture stress occurs impacts by reducing vegetative growth; limiting tiller numbers if stress occurs very early, preventing leaf expansion and ultimately death of leaves and/or tillers. Irrigating too infrequently has similar impacts but is less likely to result in tiller death. Moisture stress reduces yield potential in the first instance by reducing the capacity to intercept radiation, slowing photosynthesis and therefore decreasing dry matter production. The death of tillers reduces the number of heads. These growth restrictions limit the number of kernels that will be produced causing an irreversible reduction in yield potential. This mis-management has the greatest effect on yield reduction.

The effect of applying too much water is to over saturate the soil profile. While wheat is not sensitive to waterlogging (Doorenbos and Pruitt, 1977) and growth will not be affected, over-watering results in drainage through the soil profile. This excess water removes nutrients, especially nitrogen, and takes them beyond the root zone of the crop. Excessive irrigation therefore, creates a nutrient shortage or imbalance, reducing dry matter production. This induced nutrient "stress" will directly reduce yield by decreasing kernel numbers. Applying too much water also increases irrigation costs, reducing the crop profit.

Post grain-fill.

The latter three irrigation mistakes in this period reduce both the yield and quality of the grain. Reduced yield and quality may be realised in decreased kernel weights, increased screenings, low protein levels in bread wheat or too much protein in biscuit wheats.

Sound irrigation management in this second growth stage can alleviate the effects of pre grain-fill moisture stress will increase kernel weights, but will not fully compensate for the reductions in kernel numbers (Johnson and Kanemasu, 1982). Failing to irrigate frequently enough will put the crop into moisture stress or compound pre grain-fill moisture stress. Quality is immediately affected by reducing kernel weight and increasing screenings. There is also some evidence (Jamieson, pers. comm.), that kernel abortion can occur. Stopping irrigation to soon will advance senescence, thus shortening the duration of grain-fill, lowering or further lowering kernel weights and/or increasing screenings.

Applying too much water during this period, while beneficial to biscuit or feed wheats (so long as drainage through the soil is avoided), may be detrimental to bread wheat quality (Musick and Porter, 1990). There is evidence (Eck, 1988; Evans and Wardlaw, 1976) that protein levels can be enhanced by managing an increased, yet non-stress, soil moisture deficit. This enhancement is not exclusive. It requires adequate nitrogen to be available for protein development. While excessive irrigation applications (i.e., no drainage through the profile) should be avoided, higher levels of available soil moisture will prevent excessive protein content in biscuit and pastry wheats (Musick and Porter, 1990) and ensure plump heavy kernels in feed wheats.

While the duration of grain-fill is not long, normally about 40-50 days (Doorenbos and Pruitt, 1977), it does require about 170-200 mm of water. Almost certainly, in the absence of rain at least one irrigation is required to ensure the growth cycle is not shortened and grain quality diminished by limited water. If irrigation is required, care should be taken to apply only what is necessary, particularly if irrigating bread wheat.

Environmental Limits to Wheat Production

Alleviating moisture stress does not always ensure high yields and quality with a geographic area, e.g., Canterbury. Environmental conditions and soil types will differ and interact to influence yield and quality. The environmental factors affecting wheat yield and quality are temperature and rainfall (or lack of it). Crop evapotranspiration (ET) is more affected by solar radiation, than by temperature. However, ET can also be increased by advection, i.e., the transfer of heat energy by warm, dry air and wind. In Canterbury and other eastern areas, advection occurs in association with the north-west (NW) winds. ET inevitably accompanies the photosynthesis process. Wilson and Jamieson (1985), using data from wheat crops grown at Lincoln, demonstrated that increases in yield (dry matter) cannot be achieved without an increase in ET. However, their data, which was corrected for the influence of advection, and that of Howell (1990), show that increasing ET as a result of the addition of advective energy does not result in a concomitant increase in yield.

The effect of environmental conditions, in particular advection, can be clearly illustrated. Table 1 shows the average total water use from 36 wheat crops in different areas of Canterbury. These crops were monitored for irrigation scheduling and so were well watered. While these data are from 1990-91, the total water use varies little between seasons. Areas such as Kirwee (5 crops) and Pendarves (4 crops) are subject to severe NW winds. Climate data for the period October through December shows that Darfield (8 kilometres west of Kirwee) recorded NW winds at 9.00am on 18 days cf. 9 days at Lincoln, and that Darfield had 26 days of force 4-7 (moderate breeze to moderate gale) winds cf. 1 day at Lincoln.

Table 1. Average total seasonal (1 Sept 1990 to 31 Dec 1990) water use of autumn or winter sown wheat in different areas of the Canterbury Plains.

	Water use (mm)	Standard deviation
Irwell	290	41.1
Timaru	321	18.8
Lincoln	330	18.7
Wakanui	345	24.2
Pendarves	395	26.0
Kirwee	403	23.2

From field notes and crop monitoring experience the NW wind at Pendarves is as strong and as frequent as at Kirwee. Crops from the Pendarves (395 mm) and Kirwee (403 mm) areas use substantially more water than crops in Irwell (7 crops, average 290 mm) and Lincoln (6 crops, average 330 mm). The 70-100 mm difference in water use, given rainfall is similar, represents at least two extra irrigations at Kirwee and Pendarves. These two extra irrigations have two important effects on the economics of wheat production in these areas:

1. Irrigation at Kirwee is substantially more expensive than at Irwell. The cost of irrigation when pumping water from a depth of 85-90 m at Kirwee is about $0.36/mm/ha applied, but from shallow wells such as those at Irwell, it is about $0.11/mm/ha applied. Thus, in a typical paddock of 7 ha, the Kirwee or Pendarves grower would have to produce an extra tonne of wheat at todays prices to meet the cost of the two extra irrigations (i.e., $295 for 2 x 50mm irrigations).
2. The two extra irrigations must be managed into an irrigation schedule which is often stretched to its limit. These extra irrigations must often be scheduled at the expense of another crop, missed or applied later than the optimal time. Missing or applying water too late increases the severity of moisture stress and the impact on potential yield.

Daily water uses are significantly higher in areas affected most by advection, since total water use is higher in areas and duration of growth is similar in all areas. Figure 2 compares the daily water use of two Domino crops (with the same planting date) at Kirwee and Lincoln. Daily water use for most of the growing time is at least 1 mm/day greater at Kirwee. However, at booting (late October) and soft dough (early December) it is 2 mm/day or more greater. The effect of consistently higher daily water use is to deplete available soil moisture more rapidly. This more rapid depletion is compounded by the shallow light soils with small available moisture in areas such as Kirwee. To ensure water availability does not limit growth, irrigation is required sooner and more frequently at Kirwee compared to Lincoln where the soils are deeper, heavier and have more available moisture.

Capillary rise, the upward movement through the soil of water from a water table or wetter soil layers, is an important influence on water use. The height of capillary rise is greater in fine-textured than in coarse-textured soils. Thus on the heavier, deeper soils such as at Irwell or Wakanui, capillary rise could provide a significant amount of moisture to the root zone from deeper moister layers. However, on the shallower, coarser-textured soils underlaid by gravels with very low moisture contents, capillary rise is negligible. Here the capillary capacity is limited and is further restricted by the absence of moisture retentive sub-soils. In Canterbury, the latter soils are in areas most affected by the NW wind, while the heavier soils are least affected by the NW wind. The absence of capillary "assistance" in areas such as Kirwee or Pendarves, simply adds to the demands on the irrigation system.

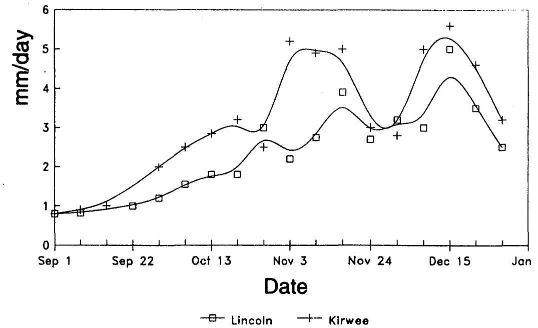

Figure 2. Comparison of daily water use of Domino wheat grown at Lincoln and Kirwee. Both crops have the same planting date and were grown by the same farmer.

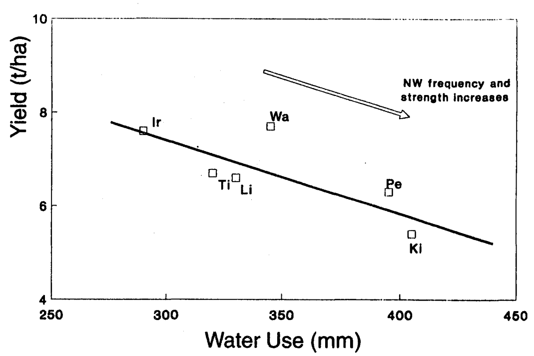

Figure 3. The relationship between yield, total seasonal water use, and increasing frequency and strength of the north-westerly wind in different areas of the Canterbury Plains. Ir = Irwell, Ti = Timaru, Li = Lincoln, Wa = Wakanui, Pe = Pendarves and Ki = Kirwee.

The higher water use in areas affected by the NW wind does not lead to increased yields. The opposite is true. Areas most affected by the NW wind have the lowest yields. Figure 3 illustrates the pattern of water use and yield across the Canterbury Plains for the 1990-91 season. Clearly, where the NW wind is more frequent and stronger, water use is large (e.g., Kirwee and Pendarves about 400 mm) and yields are lowest, (about 5.5 to 6.3 t/ha). As the influence of the NW wind declines, such as at Wakanui and Irwell, so water use decreases and yields are greater (7.6 t/ha).

While yields vary from season to season, water use does not. In 1991-92, Kirwee water use was about 385 mm and yields were 7 t/ha; Irwell water use was about 255 mm and yields 10 t/ha; Timaru water use was about 305 mm and yields 7.4 t/ha. The trend in Figure 3 for 1990-91 is consistent with this pattern in 1991-92, although the yields were very different.

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