IMPROVING WHEAT QUALITY BY AGRONOMIC MANAGEMENT

W.R. Scott
Plant Science Department, Lincoln College
Canterbury

ABSTRACT

It is traditionally assumed that large plump grains have a greater hectolitre weight and give higher flour extraction than smaller and/or slightly shrivelled grains. The application of N fertiliser, whilst sometimes increasing grain yield, tends to decrease grain size, but not always to the detriment of flour extraction. The effects of differences in sowing rate and irrigation are more variable.

The potential bread-making quality of wheat grain is probably best indicated by a baking test, which is usually correlated with protein content. As protein content is often estimated by measuring the N content of grain, the N nutrition of the plant can have a marked effect on grain N content. In general, grain N content is increased by high levels of available soil N especially when the supply remains high during grain growth. Bug damage, sprouting and, to a lesser extent irrigation, may reduce the baking score without causing corresponding reductions in grain N content.

Additional Key Words: grain size, nitrogen, sowing rate; irrigation, cultivar

INTRODUCTION

The annual demand for wheat in New Zealand is about 360,000 tonnes with about 300,000 tonnes of this being milling grade wheat for flour production (Elliot, 1981), the bulk of which is used for bread making (Ireland, 1979). For the purpose of this review therefore, quality is defined as those attributes which lead to excellence in either the milling of wheat into flour, or the baking of that flour into bread.

MILLING QUALITY

The aim of flour milling is to produce a maximum amount of crushed endosperm, optimally free of embryo and bran (Simmons and Meredith, 1979). All selections from the Crop Research Division's breeding programme are tested for milling quality at the Wheat Research Institute by a Brabender Quadrumat Junior mill extractionand a flour bridging or Q test (Griffin, 1978). Grain characteristics which consistently lead to a high extraction rate are far from clear (Bayles, 1977). In New Zealand, Griffin (1978) measured kernel weight, dimensions, volume, texture and groove shape for over 40 different wheat lines and correlated these with Brabender milling and Q test results. Within the range shown by normal grains for these characters, no useful associations with milling quality were found at all. Similarly, Simmons and Meredith (1979) found that in grains weighing greater than 35 mg, there was little relationship between Brabender extraction and kernel weight. This result was also found by Sheath and Galletly (1980) although in this case the smallest grains gave the lowest extraction. In England, Bayles *et al.* (1978) found that as the kernel weight of Cappelle-Desprez wheat was increased from 44.6 mg to 49.4 mg flour extraction actually decreased slightly from 74.2% to 73.6%.

Where kernel size is below the range normally expected (say 35 mg) there does appear to be some reduction in flour extraction (Simmons and Meredith, 1979; Griffin, 1978). Perhaps for this reason, it has been suggested that the minimum level of grain size for acceptable milling quality in New Zealand be between 35 mg (Cawley, 1978) and 40 mg (Ireland, 1981). Whatever figure is decided upon it does seem relevant at this stage to review the factors affecting kernel weight, particularly those that reduce it to near or below the threshold level.

CULTIVAR

Wide differences exist in kernel weight among existing cultivars (Table 1). Whereas Hilgendorf and Rongotea both produce large grains, Oroua generally produces small grains. Another point of interest is that the grain size of Rongotea is more variable than other cultivars, an aspect which has also been shown in detailed physiological studies at Lincoln College (Table 2). Although both cultivars reacted similarly to thinning, the range in grain size of Rongotea (26.0 mg) was much greater than in Kopara (12.4), a characteristic which may be detrimental to flour extraction.

NITROGEN

Although increases in individual grain weight from the late application of nitrogen have been recorded (Holmes and Tahir, 1956; Bremner, 1969), the application of nitrogen prior to ear emergence with the aim of increasing yield usually leads to a decrease in kernel weight (e.g. Bayles *et al.,* 1978; Drewitt, 1979a; Scott and Dougherty, 1978). This decrease is presumably due to competition

TABLE 1: Mean kernel weights for N.Z. Wheat Cultivars (Wheat Research Institute Wheat Quality Bulletin No. 3/81.)

Cultivar	Kernel wt. (mg)	St. Dev.
Kopara	41.1	3.5
Hilgendorf	45.9	3.3
Takahe	43.2	3.2
Karamu	40.0	3.9
Rongotea	46.2	4.6
Oroua	39.9	3.7

TABLE 2: The effect of thinning on kernel weights of grains from florets 1 and 3 of Kopara and Rongotea wheat (Ali Imam, unpublished data).

		Kernel wt. (mg) Unthinned	Thinned
Kopara :	Floret 1	46.6	54.9
	Floret 3	42.5	51.9
Rongotea:	Floret 1	54.7	63.8
	Floret 3	37.8	45.7

S.E. of difference: 0.55

among the increased number of grains for assimilates and N. In 20 trials in South Canterbury and Otago, Greenwood and McLeod (1980) found that N depressed kernel size by an average of 4% regardless of its effect on yield. Very large depressions in kernel size can be produced by N fertiliser causing accelerated water use (Scott *et al.*, 1977) resulting in the production of pinched or shrivelled grain (Ludecke, 1972, 1974; Stephen, 1973), an effect which can be alleviated by the use of irrigation (Table 3).

The data in Table 3 also indicate that on soils of low moisture retention, N fertiliser may reduce kernel weight to below the threshold level.

IRRIGATION AND SOWING TIME

Prolonged water stress throughout grain filling almost invariably reduces kernel weight (Salter and Goode, 1967) presumably by influencing the amount of assimilate reaching the grain (Fisher and Kohn, 1966; Fischer, 1973). Research on soils of low moisture retention at Winchmore has shown that grain size responds well to irrigation and that spring-sown wheat requires more irrigations than winter wheat (Drewitt and Rickard, 1973; Drewitt, 1979a, 1979b, 1980). On soils of higher moisture retention at Lincoln, grain size has been less responsive to irrigation (Wilson, 1974; Doughtery *et al.*, 1975; Scott *et al.*, 1973). In summary, it appears that irrigation is likely to increase grain size to the point where it affects milling quality mainly on soils of low moisture retention and/or with spring sowings, particularly in dry years.

TABLE 3: The interaction of N and irrigation on kernel weight (mg) of Karamu wheat (Drewitt, 1979a).

	No nitrogen	50 kg/ha N at drilling	50 kg/ha N at shoot emergence
No irrigation	36.0	32.5	31.3
Irrigation at nil ASM	45.4	44.8	43.9

S.E. $\bar{x}$ for vertical comparisons: 0.55
S.E. $\bar{x}$ for horizontal comparisons: 0.51

SOWING RATE

In New Zealand variations in sowing rate have produced slight variations in kernel weight but not to the point where they are likely to influence milling quality (Clements *et al.*, 1974; McLeod, 1979; Scott *et al.*, 1973, 1977).

SOURCE LIMITATION

Any factor which leads to a restriction of assimilate to the grain during grain growth is likely to lead to a reduction in kernel weight. The question of water stress has been discussed previously but plant pathogens, insect pests and prolonged cloudy weather may have similar effects.

In an experiment involving artificial crowding of plants after anthesis, Fischer *et al.*, (1977) found that, with a grain population in excess of 20,000/m^2, kernel weight was drastically reduced, sometimes to less than 30 mg. Plump grains were produced only when the source/sink ratio during grain filling was considerably higher than that giving maximum grain yield. A similar situation occurred at Lincoln during the 1979/80 season (Langer, 1980) when Oroua wheat produced in excess of 23,000 grains/m^2 but these grains only weighed 34.2 mg. In New Zealand wheats, the quest by agronomists for higher yield has generally resulted in the production of more grains per unit area. Yield components such as those quoted above should serve as a warning that with existing cultivars the number of grains per unit area can only be pushed to a certain level beyond which kernel weight and plumpness may become limiting for optimum milling quality.

BAKING QUALITY

As nitrogen and protein levels are closely linked with baking quality it is not surprising that most reviews have concentrated on these aspects (Wright, 1969; Feyter and Cossens, 1977; Dougherty *et al.*, 1978, 1979; Sheath and Galletly, 1980).

New Zealand is rather unique in that each line of wheat grown is bake tested by the Wheat Research Institute (Meredith, 1970a). Under the old system of the bulk fermentation test (Anon., 1956) the baking score was the combined total of points allotted for loaf volume (maximum 28), texture (14) and flour colour (8). Those lines scoring 30 or more were regarded as suitable for baking, while those attaining less than 30 were used as feed wheats (Cawley, 1967). With the introduction of the mechanical dough development (MDD) process total score has replaced baking score, total score being the sum of loaf volume and crumb texture, the latter being assessed visually from the test bake loaves on a poor to good (0-14) scale. Any wheat with a MDD score of 15 and above is classified as Category A while Category B is milling wheat with a score less than 15. All Karamu wheat is classified as Category B (Elliot, 1981).

Two points are of interest regarding these scoring systems. Firstly, Elliot (1981) has suggested that flour users would prefer to see the minimum baking score and MDD scores raised to 36 and 20 respectively. Secondly, neither system lays down any criteria on milling quality.

When comparing data from different researchers it is noticeable that some relate to N content and some to protein content. In addition, some data are based on whole grain and some on its flour sample only. N contents are readily changed to protein levels by a standard conversion (Kjeldahl N x 5.7). The protein content of whole grain is generally around 1% higher than that of its flour (Bushuk and Wrigley, 1974; McNeal *et al.*, 1971). Finally, N and protein contents are expressed at moisture contents ranging from oven dry to 15%. For the purposes of this review, all N and protein contents have been converted to a 14% moisture basis.

EFFECTS OF N SUPPLY

The amount of N that is orginally deposited within the wheat grain at maturity is a function of the N supply to the grains during their growth and development. This supply may come from direct absorption from the soil during grain filling, redistribution of N accumulated during vegetative growth or some combination of the two (Austin *et al.*, 1977; Daling *et al.*, 1976). Supply of N from the soil can be divided into mineral N derived from past and current mineralisation of organic matter as well as any additions of fertilizer N. Obviously for a given amount of N finally arriving in the grains, the concentration within the grain is inversely related to the number and size of the grains i.e. grain yield.

Not all the N taken up by the crop at maturity is finally deposited in the grain and this proportion, referred to as the Nitrogen Harvest Index, can vary from about 68% to over 90% (Austin *et al.*, 1977; Othman, 1979; Spiertz and Ellen, 1978). To obtain high grain yields an adequate supply of N is needed during vegetative and early reproductive growth to construct a substantial yield framework composed of many grains. However, it is the N supply available during grain filling which determines protein content and hence baking score.

Both Wright (1969) and Malcolm (1977) established that the nature of the preceeding crop had a major influence on baking score. Wheat following pasture or other fertility restoring crops had a higher baking score than when it succeeded depletive crops, particularly cereals. Presumably where high levels of soil organic N are present in the soil, mineralisation is able to supply adequate levels of available N throughout the growth of the crop. However it is not always safe to assume that high levels of organic N always lead to high grain protein levels as high intensity rainfall may cause leaching of N (Feyter, 1974; Feyter *et al.*,1977; Ludecke, 1972, 1974).

In view of the importance of N supply during grain-filling it is generally agreed that N applied late in crop development is more likely to increase grain N than early applications (Dougherty *et al.*, 1978, 1979; Terman *et al.*,1969; Evans *et al.*, 1975; Othman, 1979). This was graphically demonstrated by Malcolm (1977) in South Canterbury where N applied to Karamu in July produced grain containing 1.45% N and a baking score of 24 while the same amount of N applied in September produced a grain N content of 2.55% and a baking score of 42. The effect of early applications of N on baking quality are more variable but generally give a positive response (Pittman and Tipples, 1978; Bayles *et al.*, 1978; Sheath and Galletly, 1980; Wright, 1969). In 14 trials in North Otago andSouth Canterbury, Greenwood and McLeod (1980) found that the application of 90 kg N/ha increased MDD score from 18.6 to 21.3

On soils containing low levels of organic N, the application of N at early growth stages, whilst giving large increases in grain yield (Scott, 1978) may cause drastic reductions in grain N content (Table 4). It should noted that this depression in grain N levels occurred even when N was applied at 100 kg/ha, a rate which is considered high by New Zealand standards (Greenwood and McLeod, 1980). In this situation the supply of N to the developing grains either from the soil or from redistribution was unable to balance the increased carbohydrate mass stimulated by the N application.

The assumptions made in the above explanations of the differential effects of N fertiliser on grain N content clearly indicate the need for more information on the levels of N available from the soil during all stages of crop development. Without such information, interpretation must involve some guesswork.

TABLE 4: Effect of nitrogen fertiliser on grain N% of Kopara and Karamu wheat grown at Lincoln 1975/76.

	Rate of N applied kg/ha			
	0	25	50	100
Kopara	2.02	2.01	1.92	1.94
Karamu	2.01	1.95	1.87	1.87

S.E. $\bar{x}$ for vertical and horizontal comparisons: 0.02

CULTIVARS

One of the greatest management tools the farmer possesses in controlling baking score is the choice of cultivar. Although grain N content can be altered by environment, some general trends are apparent from Table 5. The premium price paid for Hilgendorft wheat is obviously related to its high MDD score and protein content while the discount on Karamu is related to its lower MDD score. Cross and Haslemore (1979) showed that the lower grain N concentration of the semi drawf Karamu compared with standard height New Zealand cultivars was associated with its smaller vegetative bulk containing less herbage N. The obvious anomalies between MDD score and N % apparent in Table 5 will be discussed by other speakers at this Symposium but they do indicate that both the quantity and quality of protein are important in determining baking score.

TABLE 5: Average MDD Scores and N contents of N.Z. wheat cultivars for the 1981 harvest (Wheat Research Institute Quality Bulletin No. 3/81).

Cultivar	MDD Score	N %
Kopara	18.6	1.75
Hilgendorf	20.1	2.08
Takahe	19.0	1.65
Karamu	15.4	1.65
Rongotea	19.4	1.72
Oroua	22.1	1.77

IRRIGATION

An extensive series of experiments on soils of low moisture retention at Winchmore has shown that grain N % is reduced by irrigation, the reduction becoming greater with increasing frequency of irrigation (Drewitt, 1979a, 1979b, 1980; Drewitt and Rickard, 1971, 1973; Quin and Drewitt, 1979). This reduction is usually associated with improved yield diluting the available N and can sometimes be offset by applying at least 50 kg N/ha at a late stage of growth (booting). The overall effect of irrigation on wheat quality at Winchmore is dramatically shown in Fig. 1, where it can be seen that the large increases in kernel weight caused by irrigation are accompanied by decreases in grain N %.

Although irrigation has little influence on grain size on deeper soils the effects on grain N % and baking score are more variable probably becausc levels of organic matter are often higher and these soils are less prone to leaching. Dalgliesh (1981) examined the effect of irrigation of the quality parameters of Kopara wheat grown at Lincoln on a Wakanui silt loam soil (Table 6). In this experiment, the crop was irrigated just prior to anthesis and again two weeks later. Here irrigation slightly increased grain size, had no effect on grain N %, but decreased the total score, largely due to a reduction in loaf volume. This experiment

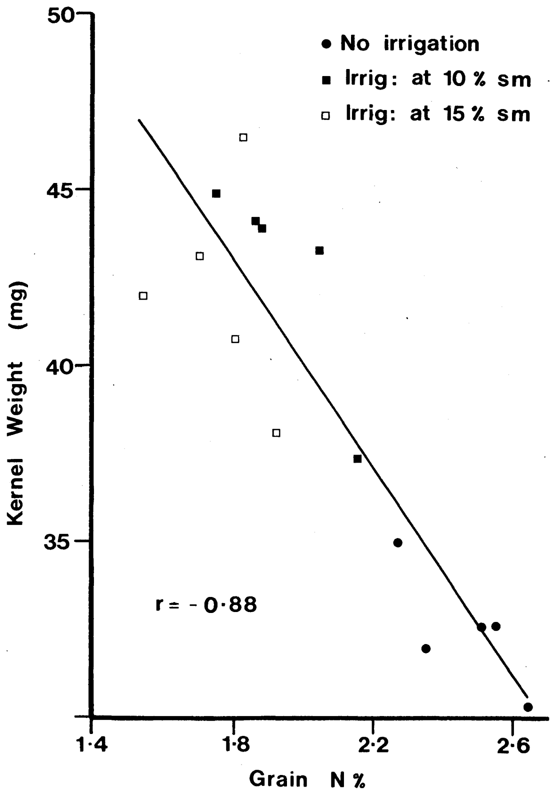

Figure 1: The relationship between kernel weight and grain N% (after Drewitt, 1979b).

therefore provides another example of an agronomic treatment that has changed baking score without changing grain N %. Presumably irrigation altered protein quality although it is tempting to suggest that irrigation reduced protein N without affecting total N. However, this seems unlikely as Wu and McDonald (1976) found that in wheat grain, the proportion of N found as protein and non-protein N was not significantly influenced by N fetiliser, cultivar, location of growth or crop year.

PROTEIN QUALITY

In New Zealand, protein quality is very important where sprout damage (Meredith, 1967) and bug damage Meredith (1970b) occur. In these cases protein quality is hardly changed but quality is drastically lowered rendering the flour useless for bread making.

Sprout damage is most likely to occur when wet or humid weather occurs at harvest time. Timely harvesting, perhaps in conjunction with the use of grain driers can go some way towards reducing sprout damage. A more permanent solution lies in the growing of sprout resistant

TABLE 6: Effect of irrigation on quality parameters of Kopara wheat (Dalgliesh, 1981).

	Kernel wt. (mg)	Flour protein %	Loaf Volume	Crumb texture	Total score
Not irrigated	38.4	10.15	12.79	7.17	19.96
	N.S.	N.S.	**	N.S.	**
Irrigated	38.1	10.23	11.58	7.13	18.81

cultivars which generally have lax ears and red grains (Lancaster and Wright, 1970; McEwan, 1959). As bug damage is more likely to occur in dry seasons (Meredith, 1970b), irrigation probably reduces the incidence of this problem.

In a recent investigation by the Ministry of Agriculture and Fisheries a positive correlation was found between MDD bake scores and grain sulphur (S) content (J.A. Douglas, pers. comm.). Whether there is a causal relationship between S - containing proteins and baking score remains to be seen but it does raise some interesting possibilities. On cropping soils the supply of S to the wheat crop comes from past and current mineralisation of S from soil O.M. (Swift, 1977) as well as any additions of fertiliser S. Where ammonium sulphate is used as a N source there is no guarantee that the S in the fertiliser ends up in the grain because sulphur is readily leached from some cropping soils (A.S. Black, pers. comm.). Once sulphur has been taken up by the plant it is not clear to what extent breakdown and redistribution of organic sulphur compounds can provide S for the requirements of younger plant parts (Bouma, 1975).

Perhaps Drewitt's (1980) assertion that the adverse effects of irrigation on baking score are less severe under high natural fertility than in crops relying on supplementary N is related to the fact that sulphur is being mineralised along with N on the fertile soils to maintain an adequate S supply to the developing grains. Further research on this aspect of protein quality is clearly warranted.

CONCLUSIONS

One of the purposes of this Symposium was to discuss the direction that future research on wheat quality should take. This review suggests that there are at least two aspects:

1. Information is required to define more precisely those physical characteristics of grain that influence milling quality and how these characteristics can be influenced by agronomic treatments.
2. More quantitative data are required to show how protein content and/or baking score can be influenced by agronomic treatments. To give some understanding of the principles involved, this information should be obtained in conjunction with data on levels of available soil N and perhaps sulphur.

REFERENCES

Anon. 1956. Notes from Wheat Research Institute. *N.Z. Wheat Review 6:* 66-71.

Austin, R.B., Ford, M.A., Edrich, J.A., Blackwell, R.D. 1977. The nitrogen economy of winter wheat. *Journal of Agricultural Science, Cambridge 88:* 159-167.

Bayles, R.A. 1977. Poorly filled grain in the cereal crop. II. The relationship of poor grain filling to processing quality. *Journal of the National Institute of Agricultural Botany 14:* 241-249.

Bayles, R.A., Evers, A.D., Thorne, G.N. 1978. The relationship of grain shrivelling to the milling and baking quality of three winter wheat cultivars grown with different rates of nitrogen fertilizer. *Journal of Agricultural Science, Cambridge 90:* 445-446.

Bouma, D. 1975. The uptake and translocation of sulphur in plants. *In* "Sulphur in Australasian Agriculture" Ed. K.D. McLachlan, Sydney University Press. pp. 79-86.

Bremner, P.M. 1969. Growth and yield of three varieties of wheat with particular reference to the influence of unproductive tillers. *Journal of Agricultural Science, Cambridge 72:* 281-287.

Bushuk, W., Wrigley, C.W. 1974. Proteins composition, structure and function. *In.* "Wheat; production and utilisation". Ed. G.E. Inglett. The Ari Publishing Company, Westport, Connecticut, U.S.A. pp. 119-145.

Cawley, R.W. 1967. Wheat testing service. *N.Z. Wheat Review 10:* 29-35.

Cawley, R.W. 1978. Payment for wheat by quality. *DSIR Cereal News 5:* 1-2.

Clements, R.J., Cross, R.J., Sanders, P. 1974. Effect of sowing rate on the growth and yield of standard and semidwarf wheat cultivars. *N.Z. Journal of Experimental Agriculture 2:* 139-144.

Cross, R.J., Haslemore, R.M. 1979. Nitrogen uptake and redistribution in Karamu and other spring wheats. *N.Z. Journal of Agricultural Research 22:* 547-552.

Dalgliesh, W.S. 1981. A study of yield, quality and subsoil water uptake of wheat (*Triticum aestivum* L.) cv. Kopara. M. Agr. Sc Thesis, Lincoln College.

Daling, M.J., Boland, G., Wilson, J.H. 1976. Relation between acid proteinase activity and redistribution of nitrogen during grain development in wheat. *Australian Journal of Plant Physiology 3:* 721-730.

Dougherty, C.T., Love, B.G., Mountier, N.S. 1978. Response surfaces of semidrawf wheat for seeding rate, and levels and times of application of nitrogen fertiliser. *N.Z. Journal of Agricultural Research 21:* 655-663.

Dougherty, C.T., Love, B.G., Mountier, N.S. 1979. Response surfaces of 'Kopara' wheat for seeding rate, and levels and times of application of nitrogen fertiliser. *N.Z. Journal of Agricultural Research 22:* 47-54.

Dougherty, C.T., Scott, W.R., Langer, R.H.M. 1975. Effects of sowing rate, irrigation and nitrogen on the components of yield of spring-sown semidwarf and standard New Zealand wheats. *N.Z. Journal of Agricultural Research 18:* 197-207.

Drewitt, E.G. 1979a. Effect of previous cropping on irrigation and nitrogen responses in spring-sown karamu wheat. *N.Z. Journal of Experimental Agriculture 7:* 71-78.

Drewitt, E.G. 1979b. Relationships between grain yield, grain N% and grain weight in irrigated and non-irrigated late winter and spring-sown karamu wheat. *N.Z. Journal of Experimental Agriculture 7:* 169-173.

Drewitt, E.G. 1980. Maximum wheat production under irrigation. *Proceedings Lincoln Farmers Conference 29.*

Drewitt, E.G., Rickard, D.S. 1973. The effect of irrigation on the yield components and nitrogen uptake of three wheat cultivars. *Proceedings Agronomy Society of N.Z. 3*:73-80.

Elliot, A.G. 1981. The market for wheat in New Zealand. Wheat Quality Seminar 4/5 June.

Evans, L.T., Wardlaw, I.F., Fischer, R.A. 1975. Wheat. *In* "Crop Physiology, Some Case Histories". Ed. L.T. Evans, Cambridge University Press, London pp. 101-149.

Feyter, C. 1974. Wheat production in South Otago. *N.Z. Journal of Agriculture 128(2):* 21-23.

Feyter, C., Cossens, G.G. 1977. Effects of rates and methods of nitrogen application on grain yields and yield components of spring-sown wheats in South Otago, New Zealand. *N.Z. Journal of Experimental Agriculture 5:* 371-376.

Feyter, C., Cossens, G.G., Risk, W.H. 1977. Effects of rainfall on nitrogen responses of spring-sown wheats. *N.Z. Journal of Experimental Agriculture 5:* 161-165.

Fischer, R.A. 1973. The effect of water stress at various stages of development on yield processes in wheat. UNESCO, 1973. Plant response to climatic factors. Proceedings of the Uppsala Symposium 1970. (Ecology & Conservation 5): 233-241.

Fischer, R.A., Aguilar, I., Laing, D.R. 1977. Post anthesis sink size in a high-yielding dwarf wheat: yield response to grain number. *Australian Journal of Agricultural Research 28:* 165-175.

Fischer, R.A., Kohn, G.D. 1966. The relationship of grain yield to vegetative and post flowering leaf area in the wheat crop under conditions of limited soil moisture. *Australian Journal of Agricultural Research 17:* 281-295.

Greenwood, P.B., McLeod, C.C. 1980. The use of nitrogen fertilisers on dryland wheat. *Proceedings Lincoln College Farmers' Conference 29:* 182-195.

Griffin, W.B. 1978. Selection for milling quality. *DSIR Cereal News 5:* 3-4.

Holmes, J.C., Tahir, W.M. 1956. The effect of some factors on growth, development and yield of winter wheat. *Journal of Agricultural Science, Cambridge 48:* 115-123.

Ireland, J.K. 1979. Utilisation of wheat in New Zealand. *N.Z. Wheat Review 14:* 25-31.

Ireland, J.K. 1981. Summary of view of the New Zealand Flour Millers' Association. Wheat Quality Seminar 4/5 June.

Lancaster, I.M., Wright, G.M. 1970. Testing for field resistance to sprouting. *N.Z. Wheat Review 11:* 75-79.

Langer, R.H.M. 1980. Components of wheat yield. *Proceedings Lincoln College Farmers' Conference 29: 134-141.*

Ludecke, T.E. 1972. Nitrogen fertilisers for wheat in Canterbury. *Proceedings of the Lincoln College Farmers' Conference 22:* 85-91.

Lukecke, T.E. 1974. Prediction of grain yield responses to nitrogen fertilisers. *Proceedings Agronomy Society of N.Z. 4:* 27-29.

Malcolm, J.P. 1977. Use of nitrogen with wheat. *N.Z. Fertiliser Journal 49:* 14-15.

Meredith, P. 1967. Sprouted wheat and quality of bread. *N.Z. Journal of Agriculture 115(6):* 22-23.

Meredith, P. 1970a. The baking quality of New Zealand wheats. *N.Z. Wheat Review 11:* 20-28.

Meredith, P. 1970b. "Bug" damage in wheat. *N.Z. Wheat Review 11:* 49-53.

McEwan, J.M. 1959. Sprouting in New Zealand wheat varieties. *N.Z. Wheat Review 7:* 61-4.

McLeod, C.C. 1979. Rates of seeding for winter and spring wheat. *N.Z. Wheat Review 14:* 93-95.

McNeal, F.H., Berg, M.A., Brown, P.L., McGuire, C.F. 1971. Productivity and quality response of five spring wheat genotypes, *T. aestivum* L. to nitrogen fertiliser. *Agronomy Journal 63:* 908-910.

Othman, M. 1979. Response surfaces of growth and yield of wheat. Ph.D. Thesis, Lincoln College.

Pittman, U.J., Tipples, K.H. 1978. Survival, yield, protein content, and baking quality of hard red winter wheats grown under various fertiliser practices in southern Alberta. *Canadian Journal of Plant Science 58:* 1049-1060.

Quin, B.F., Drewitt, E.G. 1979. The growth, nitrogen uptake and yield of spring-sown wheat on Lismore silt loam. *Proceedings Agronomy Society of N.Z. 9:* 133-138.

Salter, P.J., Goode, J.E. 1967. Crop responses to water at different stages of growth. Commonwealth Bureau of Horticulture and Plantation Crops, East Malling, Maidstone, Kent (Research Review 2).

Scott, W.R. 1978. Development and yield of 'Kopara' and 'Karamu' wheat under different rates of nitrogen. *N.Z. Journal of Agricultural Research 21:* 436-466.

Scott, W.R., Dougherty, C.T., Langer, R.H.M. 1977. Development and yield components of high-yielding wheat crops. *N.Z. Journal of Agricultural Research 20:* 205-212.

Scott, W.R., Dougherty, C.T., Langer, R.H.M., Meijer, G. 1973. Wheat yield as affected by sowing rate, irrigation, and time of white clover introduction. *N.Z. Journal of Experimental Agriculture 1:* 369-376.

Sheath, G.W., Galletly, W.S. 1980. Effects of sowing time and nitrogen on the grain yield and quality of four wheat cultivars grown in North Otago. *N.Z. Journal of Experimental Agriculture 8:* 235-241.

Simmons, L., Meredith, P. 1979. Width, weight, endosperm, and bran of the wheat grain as determinants of flour milling yield in normal and shrivelled wheats. *N.Z. Journal of Science 22:* 1-10.

Spiertz, J.H.J., Ellen, J. 1978. Effects of nitrogen on crop development and grain growth of winter wheat in relation to assimilation and utilization of assimilates and nutrients. *Netherlands Journal of Agricultural Science 26:* 210-231.

Stephen, R.C. 1973. Wheat yield responses to applied fertiliser in mid and north Canterbury. *N.Z. Wheat Review 12:* 48-49.

Swift, R.S. 1977. Mineralisation of nitrogen and sulphur from soil organic matter: a comparison of pasture and arable soils. International Symposium on Soil Organic Matter Studies, Brunswick, Germany. Vol. 1: I.A.E.A. Vienna. pp. 275-281.

Terman, G.L., Ramig, R.E., Dreier, A.F., Olson, R.A. 1969. Yield-protein relationships of wheat grain as affected by nitrogen and water. *Agronomy Journal 61:* 755-759.

Wilson, D.R. 1974. Comparative responses to irrigation of five wheat cultivars. *Proceedings Agronomy Society of N.Z. 4:* 34-37.

Wright, G.M. 1969. Effect of nitrogenous fertilizer on wheat yield and baking quality. *N.Z. Journal of Agricultural Research 12:* 727-746.

Wu, K.Y., McDonald, C.E. 1976. Effect of nitrogen fertilizer on nitrogen fractions of wheat and flour. *Cereal Chemistry 53:* 242-249.