CHAPTER 2

INTERACTION BETWEEN CULTIVAR AND SOIL FERTILITY ON GRAIN YIELD, YIELD COMPONENTS AND GRAIN NITROGEN CONTENT OF WHEAT

2.1 ABSTRACT

The effect of soil nutrient status on the performance of four wheat cultivars was studied in a long-term field experiment at the University of Pretoria. The objective was to quantify the effect of soil nutrient status on yield, yield components and grain quality characteristics, using a split-plot design in a randomized complete block, replicated four times. The cultivar Carina produced the highest grain yield and grain nitrogen content averaging 6343 kg ha^{-1} (3.58%N) while SST 86, Kariega and Inia did not differ significantly but ranged from 3903 kg ha^{-1} (2.47%N), 4447 kg ha^{-1} (2.49%N) to 4484 kg ha^{-1} (2.58%N) respectively. Increasing soil fertility increased grain yield, grain number, spikelet number, grains per spike, grains per spikelet, grain nitrogen, biomass and harvest index, but depressed mean kernel mass. Significant interactions between cultivar and soil fertility were observed for grain yield, grain number, biomass, harvest index and mean kernel mass. The ability of the cultivar Kariega to produce higher grain yield in the K limiting soil fertility situation deserves detailed investigation. It is concluded that wheat cultivars differ in their potential to utilize limited soil nutrients to produce yield and quality.

Key words: Soil fertility, *Triticum aestivum*, wheat genotypes, yield components.

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2.2 INTRODUCTION

Major objectives in wheat (*Triticum aestivum* L.) cultivar development programmes are increased grain yield, improved grain protein concentration and quality. Improvement of grain yield and protein content through direct selection is difficult because of the well-documented negative association (Pendleton & Dungan, 1960; Terman, Ramig, Dreier & Olson, 1969).

Several authors suggest that improved protein content and higher yield can be obtained from crosses between high-yielding and good quality wheat genotypes (Baligar & Bennet, 1986; Borghi, Corbellini, Cattaneo, Fornasari & Zucchelli, 1986; Perenzin, Pogna & Borghi, 1992), improved soil nutrient concentrations (Laubscher, 1981; McMullan, McVetty & Urquhart, 1988; Randall, Freney, Smith, Moss, Wrigley & Gallaby, 1990) and fertilizer management (Dubetz, 1972; Corino, Boggini, Bonali & Borghi, 1975; Pearson, Rosielle & Boyd, 1981; O'Brien & Ronalds, 1987; Fischer, 1989). Efforts to simultaneously improve grain yield and protein concentration have explored parameters such as total dry matter accumulation and partitioning (Takeda & Frey, 1979), harvest index (Jennings & Shibles, 1968; Donald & Hamblin, 1976), and total nitrogen content (Austin, Ford, Edrich & Blackwell, 1977; Desai & Bathia, 1978; Cox, Qualset & Rains, 1985a).

Grain nitrogen concentration is dependent on grain carbohydrate content (Cox, Qualset & Rains, 1985b; Strong, 1986; McMullan, McVetty & Urquart, 1988), and several studies have demonstrated that genetic variability exists for grain nitrogen content (Johnson, Schmidt & Mattern, -1968; Desai & Bathia, 1978; Cox, Qualset & Rains, 1985b). Therefore, important factors for producing wheat with high yield and protein content when soil moisture and weather conditions are favourable, are genotype and soil fertility.

Fertilization, particularly of nitrogen and phosphorus, is a major input in wheat yield and quality (Fischer, 1979, 1989; Bacon, 1995). Reports on the efficiency of nutrient use, and of wheat genotypes able to produce good yields in less favourable soil nutrient supply conditions, have been published (Arnon, 1974; Fischer, O'Brien & Quail, 1989). Wheat genotypes with the potential to utilize limited soil nutrients may be important to South Africa and other areas with relatively infertile soils.

Long-term trials are an important way of obtaining information on sustainability of agricultural systems (Nel, Barnard, Steynberg, De Beer & Groeneveld, 1996). This has been demonstrated at

Rothamsted (Johnston & Mattingly, 1976; Jenkinson, 1991), University of Illinois (Mitchell, Westerman, Brown & Peck, 1991), and in Australia and India (Leigh & Johnston, 1994). A long-term fertilization experiment, initiated in 1939 at the University of Pretoria, provided a good opportunity for studying wheat cultivar performance over a wide range of soil fertility.

The objectives of this study were: (i) to quantify the effects of varying soil nutrient regimes on yield, yield components and grain quality characteristics, and (ii) to test the hypothesis that wheat cultivars differ in their potential to produce yield and quality under varying soil fertility situations.

2.3 MATERIALS AND METHODS

Site, Soil and Experimental Design

A long-term fertilization experiment located at Hatfield Farm, University of Pretoria (Lat. 25^{o} 45'S, Long. 28^{o} 16'E, elevation 1372 masl) was utilized for this study. The soil is classified as mesotrophic, luvic dark red brown soil of the Hutton form (Soil Classification Group, 1991) and by the USDA Soil Taxonomy System (Soil Survey Staff, 1990), as loamy, mixed, thermic Rhodic Kaundidalf (Nel, Barnard, Steynberg, De Beer & Groenveld, 1996).

Monthly rainfall, evaporation and mean minimum and maximum temperatures for the 1995 winter season are shown in Figure 2.1 (Appendix Figure 9.A1). Six soil fertility treatment combinations (NPKM NPK PK NP NK & Control) were selected from the long-term fertilization experiment started in 1939.

The long-term 2^5 factorial experiment comprising two levels of nitrogen, phosphorus, potassium, manure and water was laid out according to a randomized complete block design replicated four times. In this experiment spring wheat is rotated with soybean (*Glycine max*. L.) in summer, with the fertilizer applied to the wheat. In our experiment the six selected fertility plots were the main plots and was split to accommodate four local wheat cultivars Inia, Carina, Kariega and SST 86 as the sub-plots. The cultivars were planted in unrandomized strips on the sub-plots. Main plot size was 8.2 m by 6.3 m and the sub-plot size 1.2 m by 6.3 m. Details of treatments are given in Table 2.1.

Soil analysis data is presented in Table 2.2 for the 0-200 mm soil layer for the selected treatments. This reflects the actual site pH and fertility regimes representing the effect of differential fertilization over more than 50 years.

Cultural practices

The wheat was planted on 15 and 16 May 1995 at a 300 mm inter-row spacing. Plant populations ranged from 365 plants m^{-2} for Inia, 284 for Carina, 232 for Kariega and 244 for SST 86 depending on seed size and viability. The seedbed was prepared using a rotovator while planting was done manually. Throughout the growing season water was supplied by overhead sprinkler irrigation amounting to a total of 450 mm. Due to its longer growing period Carina received an additional 120 mm. Standard disease and pest control measures were applied. Harvesting was done by hand and after oven drying at 60 ^{o}C for 48 hr, the samples were threshed with a portable thresher to obtain grain yield.

Data recorded

Plants from 1 m^2 area, as well as an additional sample of 5-plants, were harvested on five occasions from emergence to maturity from each plot. Total above-ground biomass (g m^{-2}), grain yield (g m^{-2}), grain number m^{-2}, spikes m^{-2}, 1000-grain mass, harvest index and final crop height (mm) were determined from the 1 m^2 bulk samples. Number of tillers per plant, spikelets per spike and grains per spike were determined from the additional 5-plant samples. To cause minimum interference with the rotation practice only treatments NPKM, NPK and 'O' Control were retained for determination of grain yield in the case of the late maturing cultivar Carina. Grain nitrogen content and straw nitrogen content at final harvest were determined according to a standard Kjeldhal procedure (AACC, 1983).

Statistical analyses

Data were analysed by analysis of variance using SAS/STAT (SAS Institute Inc. Cary, NC., USA 1989 Copyright). Differences at the $P \leq 0.05$ level of significance are reported. Means were separated using Tukey's range test. Bartlett's test for homogeneity of the variance was performed on main and sub-plot variances. Tests for heterogeneity of variances for all characteristics measured were done and probabilities calculated according to Steel & Torrie (1980).

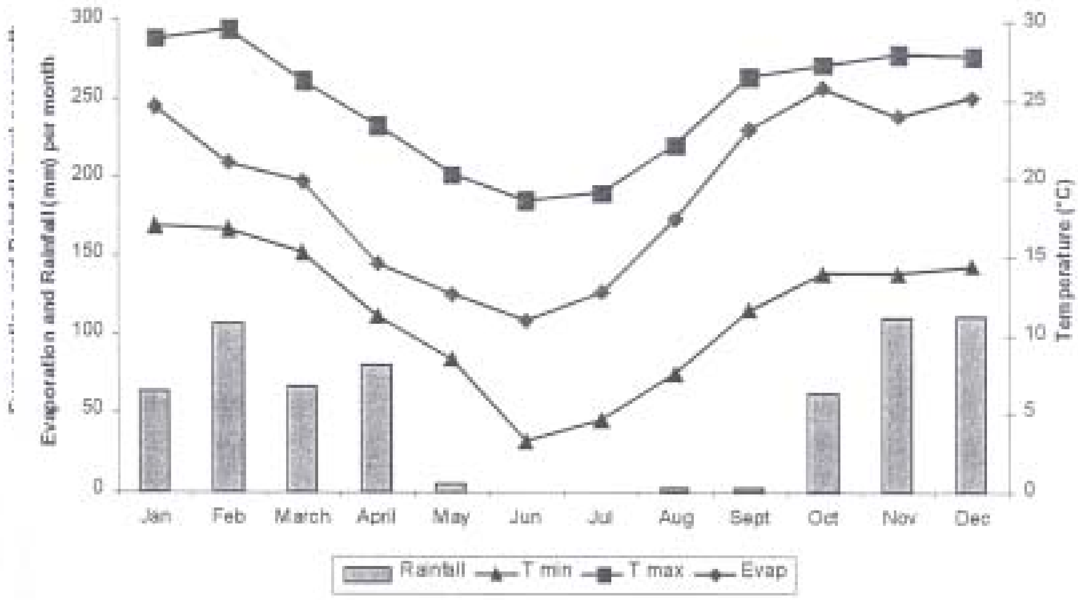

FIGURE 2.1 Metereological data for Hatfield showing mean max and min temperatures, evaporation and rainfall (mm), 1995.

Table 2.1 Details of experiment conducted on four local wheat cultivars grown under irrigation at Hatfield, Experimental Farm, University of Pretoria

Practices 1995	
Crop rotation	Wheat grown during the winter period may to October and soybean (*Glycine Max L. Mervil cv. Usutu* from November to March, except the year prior to 1995 when the plots were fallowed.
Planting date	15 and 16 May (using Planet Junior, planter USA).
Wheat cultivars	Inia – Pureline, semi-dwarf spring type released in 1966 by the Department of Agriculture. Carina – Hybrid, semi-dwarf winter type released in 1989 by Carnia Kariega – Semi-dwarf spring type released in 1993 by the Small Grain Institute. SST 86 – Dwarf spring type released in 1987 by Sensako.
Seeding rate (Based on seed size)	Inia – 100 kg ha^{-1} Carina – 70 kg ha^{-1} Kariega – 100 kg ha^{-1} SST 86 – 150 kg ha^{-1}
Nutrient treatments	N – 100 kg N ha^{-1} (KAN 28%) P – 70 kg P ha^{-1} (Single superphosphate, 8.3%) K – 50 kg K ha^{-1} (Potassium chloride 50%) M – 15 tons ha^{-1} (Farmyard manure) Lime – 180 kg ha^{-1} (Agricultural lime, ($Ca(OH)_2 + MgSO_4$)
Diseases & Pests	No major disease was recorded, however, Loose smut (*Ustilago tritici*) was controlled by removing infected plants. Harvester termites (*Hodotermes sp*) were controlled by parathion (Folimat, WP) at 1,5 kg ha^{-1}. Bird damage limited by using protective netting.
Maturity period	Inia and SST 86 reached physiological maturity on 16 October, Kariega on 23 October and Carina by 16 November.

Table 2.2 Soil analysis (0 – 200 mm) for the six selected fertility treatments for experimental site, 1995

Treatment	PH	Bray 2 P	K	Ca	Mg	Na
	(H_2O)	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}
NPKM	5.8	109	120	865	225	26
NPK	5.4	63	66	553	180	27
PK	6.0	43	92	606	196	25
NP	5.1	37	21	529	199	25
NK	5.2	1.8	81	493	140	26
"O" Control	6.1	1.7	22	541	239	25
LSD_T						
$P_{\leq 0.05}$	0.4	20.6	30.3	49	45	2.4
CV %	3.7	46.5	49.1	23.4	20.1	2.8

Correlation analysis was performed to determine the relationship between grain yield and yield components.

2.4 RESULTS AND DISCUSSION

The main effects of genotype and soil fertility on yield, yield components and grain nitrogen content are summarized in Tables 2.3 and 2.4. Significant cultivar x soil fertility interactions were observed for grain yield, grain number, grain mass, aboveground biomass, crop height and harvest index, and are illustrated in Figures 2.2.

Grain yield

Under the experimental conditions Carina produced the highest yield (6343 kg ha^{-1}) while for SST 86, Kariega and Inia the grain yield ranged from 3903 to 4484 kg ha^{-1}, but did not differ significantly (Table 2.3). These results are not necessarily an indication that Carina is a suitable cultivar for commercial production in the Gauteng Province of South Africa. The extremely long growing period of this cultivar (more than 30 days longer than the other cultivars) is a distinct disadvantage despite its good yield (Appendix Figure 9.A12).

The control plots which received no fertilization or manure since 1939 produced an average yield of 1300 kg ha^{-1}, showing sustainable yield without fertilization. Jenkinson (1991) reported an average yield of 1400 kg ha^{-1} from unfertilized wheat plots at the Rothamsted classical experiments.

Grain yield increased with increasing soil fertility (Table 2.3). The NPKM, NPK and PK treatments did not differ, but yielded more than the NP treatment. The NK and 'O' Control treatments resulted in the lowest yields. Residual nitrogen from the soybean (*Glycine max.*) rotation crop probably explains the good yield obtained from the PK treatment. The NP treatment, which over the years resulted in a K-deficient soil, produced higher grain yield than NK treatment which is associated with low soil P.

The cultivar x soil fertility interaction on grain yield is illustrated in Figure 2.2(A), showing no differences in the performances of the cultivars at the 'O' Control, NK, PK and NPKM treatments. In general the cultivars performed similarly as yield increased with increasing soil fertility. The significant interaction between cultivar and soil fertility was mainly due to Kariega out-yielding SST 86 in the treatment where K was in low supply (NP treatment). This may be an indication of the ability of cultivar Kariega to obtain potassium more efficiently from deeper soil layers, and is an aspect deserving further attention.

These results are consistent with the findings of Carr, Carlson, Jacobsen, Nielsen & Skogley (1991) and Carr, Jacobsen, Carlson & Nielsen (1992) whom reported significant soil x cultivar interactions for grain yield, test weight and grain protein of both spring barley (*Hordeum sp.*) and wheat. Liang, Heyne & Walter (1966) reported that soil variation may explain environmental x cultivar interactions for several cultivars of winter wheat and winter barley. Lee & Spillane (1970) also reported that both cultivar and fertilization management must be considered for optimum crop yield and quality in fields with different soils. However, absence of significant cultivar x soil fertility interactions have also been reported (Strong, 1986).

TABLE 2.3 Effect of cultivar and soil fertility on grain yield, spike number, spikelets per spike, grains per spike, grain number, grain mass and grain nitrogen content

Treatment	Grain yield ($kg\ ha^{-1}$)	Spikes (m^{-2})	Spikelets per spike	Grains per spike	Grain number (m^{-2})	1000 Grain mass (g)	Grain N content (%)
Cultivar [1]							
SST 86	3 903	349	16.9	29.3	11 650	36.2	2.47
Inia	4 484	403	16.7	27.6	12 342	36.9	2.53
Kariega	4 447	454	18.2	29.9	14 821	33.4	2.49
Carina	6 343	508	20.1	42.8	23 956	27.4	3.58
LSD_T							
$P \leq 0.05$	1 031	100	2.0	10.5	3 587	2.1	0.98
Fertility [2]							
NPKM	6 163	511	19.6	38.0	19 266	33.9	2.78
NPK	5 590	477	19.2	35.2	16 629	35.1	2.58
PK	4 896	394	18.9	31.8	12 424	39.5	2.16
NP	3 332	475	17.6	24.8	11 903	27.8	2.31
NK	1 300	260	14.7	13.7	3 523	36.6	2.39
'O' Control	1 081	219	13.0	13.6	2 918	37.4	2.13
LSD_T							
$P \leq 0.05$	1 480	168	1.9	11.9	3 880	3.9	0.30
CV %	18.3	21.5	9.7	21.7	16.6	5.8	5.4

(1) Cultivar data based on treatments NPKM, NPK and 'O' only.
(2) Fertility data excludes Carina.

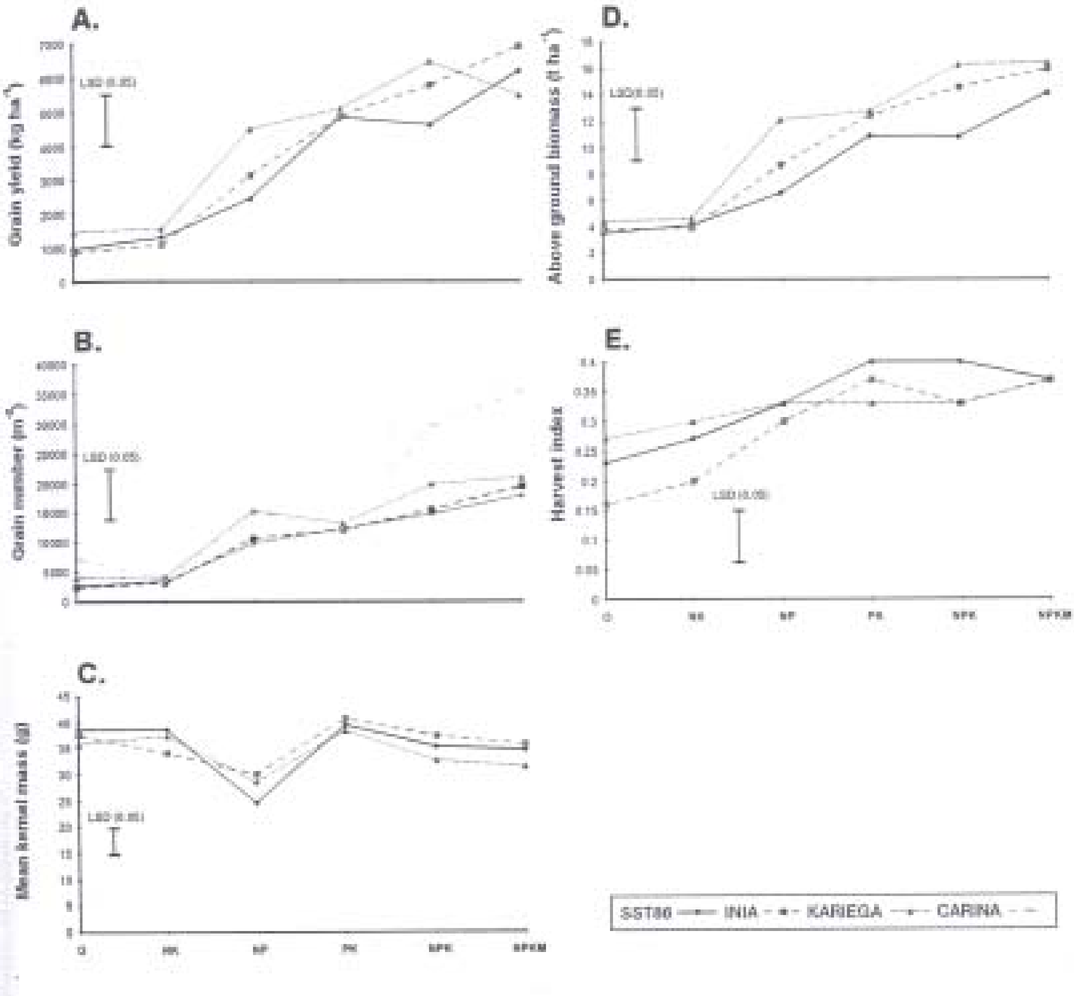

FIGURE 2.2 Interaction between cultivar and soil fertility on grain yield (A), grain number (B), mean grain mass (C), biomass (D) and harvest index (E).

Yield components

In general Carina produced significantly more spikes per unit area, more spikelets per spike and more grains per spike than SST 86. Number of spikes per unit area, spikelets per spike and grains per spike determine grain number per m^2. Regardless of cultivar differences in tillering and final spike number, our data are consistent with many reports which have demonstrated the need for higher spike densities to produce higher yields (Scott, Dougherty & Langer, 1975; Hampton, McCloy & McMillan, 1981). Bullman & Hunt (1986) found that grain yield of wheat was linearly related to spike number.

Studies by Darwinkel (1978; 1983) and Nerson (1980) have shown that although grain number per spike and kernel mass can compensate somewhat for deficient spike populations, they cannot adequately make up lost yield potential. When spike densities are low (as in '0' Control and NK treatments), grain number per spike and kernel mass cannot compensate sufficiently for the low number of spikes to make up for lost yields (Nerson, 1980).

Generally, increased soil fertility increased number of spikes per m^2, spikelets per spike, grains per spike and hence grains per m^2. The NP, PK, NPK and NPKM treatments did not differ in spikes per m^2 and spikelets per spike, with the '0' and NK treatments significantly lower. Treatments NPK and NPKM produced the highest number of kernels per spike, with '0' (control), NK and NP treatments lowest. The PK treatment was intermediate in grains per spike (Table 2.3).

The interaction between cultivar x soil fertility was not significant for spikes per m^2, spikelets per spike and grains per spike. However, cultivar x soil fertility was significant for grain number per m^2, due to Carina producing more grains than SST 86, Inia and Kariega in the NPK and NPKM treatments (see Figure 2.2).

Kernel mass varied with cultivar, though not statistically different, with Carina producing the smallest kernels, as can be seen from the 1000 grain mass in Table 2.3. Kariega produced intermediate kernels, while SST 86 and Inia had larger kernels. At higher soil fertility (NPKM treatment) smaller kernels were produced, probably because of poor grain-filling in response to competition due to the large sink-size. The PK treatment resulted in the largest mean kernel mass and the NP treatment had the smallest kernels (Table 2.3). The interaction between cultivar and soil fertility was significant for kernel mass due to the fact that on plots low in P (NK treatment) SST 86 produced larger kernels than Inia, while on K-deficient plots (NP treatment) the cultivar Inia had larger kernels than SST 86 (Figure 2.2). Although the NK and 'O'. Control treatments had relatively large kernels, these plots produced the lowest yields, due to low grain number per unit area.

Our data indicate that the magnitude of compensation between yield components was relatively small, a decrease in number of spikes per m^2 was not adequately compensated for by either grains per spike or kernel mass. Each yield component varied independently of the others and hence, the findings are in agreement with those reported by Gallagher & Biscoe (1978) and Hay & Walker (1989).

While no single yield component was predominant in determining yield, number of grains per unit area was positively correlated ($r = 0.95$) with yield. Evans (1987) reported that components of yield are interdependent to a greater or lesser degree, and that greater number of spikes per unit area is counteracted by a smaller number of grains per spike.

Grain nitrogen

The cultivars differed in grain nitrogen content with Carina having the highest percentage (Table 2.3; Appendix Table 9.A2). SST 86, Inia and Kariega did not differ in grain nitrogen content.

Generally grain nitrogen increased with increasing soil fertility, with the NPK and NPKM treatments significantly higher than the PK and Control treatments. The interaction between cultivar x soil fertility for grain nitrogen was not significant. Benzian & Lane (1981) reported a consistent linear relationship between grain nitrogen concentration and grain yield of wheat to increasing fertilizer N. Many authors have reported fertilization strategies in which split N application between planting and flowering increased grain nitrogen content (Finney, Meyer, Smith & Fryer, 1957; Langer & Liew, 1973; Strong, 1981). Strong (1986) reported no significant interaction between N and growth application stage in wheat.

These results are in agreement with our findings showing grain yield and grain nitrogen content varied with cultivar and only improved in balanced soil fertility treatments (NPK and NPKM treatments) but were reduced in less favourable soil fertility situations (PK, NP, NK and '0'(Control) treatments). Benzian & Lane (1979) found that grain yield, nitrogen concentration of the grain and nitrogen yield varied widely from site to site and from year to year. The proportion of total amount of nitrogen present in the grains, the nitrogen harvest index, centres around 0.78 – 0.82 under optimum conditions (Spiertz & De Vos, 1983) and was comparable with our findings (Appendix Table 9.A9).

Biomass, harvest index and crop height

The cultivars differed in biomass production, harvest index and final crop height (Table 2.4). Carina produced the largest biomass, highest harvest index and was the tallest, while SST 86 had the lowest biomass and was the shortest. Carina, SST 86 and Kariega did not differ in harvest index while Inia had the lowest (Table 2.4).

In general biomass, harvest index and crop height increased with increasing soil fertility (Table 2.4). The NPK and NPKM treatments did not differ but produced the largest biomass. The PK and NP treatments were intermediate, while the NK and 'O' (Control) treatments were the lowest. Treatments PK, NPK and NPKM had the highest harvest index and tallest crop height, while NP, NK and 'O' Control treatments had significantly lower harvest indices and shorter crop heights (Table 2.4; Appendix Table 9.A4).

The cultivar x soil fertility interaction was significant for biomass and harvest index, as illustrated in Figure 2.2. Yield increases have been attributed to genotypic improvement of dry matter distribution as has been found by a comparison of old and modern wheat and barley varieties (Austin, Bingham, Blackwell, Evans, Ford, Morgan & Taylor, 1980). High N dressings resulted in increased biomass yield at anthesis and in enhanced N contents of the vegetative parts of the crop and grain yield (Spiertz & De Vos, 1983). Further increase of the amount of N associated with high soil fertility may result in adverse effects such as lodging.

TABLE 2.4 Effect of cultivar and soil fertility on biomass, harvest index and crop height at final harvest

Treatment		Biomass (t ha^{-1})	Harvest index	Crop height (mm)
Cultivar [(1)]				
	SST 86	9.3	0.33	708
	Inia	11.4	0.29	943
	Kariega	12.3	0.32	900
	Carina	15.6	0.36	1 018
	LSD_T			
	$P_{\leq 0.05}$	1.5	0.01	64
Fertility [(2)]				
	NPKM	15.5	0.37	950
	NPK	13.8	0.36	919
	PK	12.0	0.37	886
	NP	9.1	0.32	736
	NK	4.2	0.26	692
	'O' Control	3.9	0.22	682
LSD_T				
$P_{\leq 0.05}$		3.3	0.11	75.6
CV %		16.0	16.2	6.0

Significant at the $P \leq 0.05$ level.

[(1)] Cultivar data based on treatments NPKM, NPK and O only.

[(2)] Fertility data excludes Carina.

2.5 CONCLUSIONS

Wheat cultivars are often recommended for relatively large geographic areas encompassing a range of varying soil fertility situations. Edaphic variation in chemical or physical properties can result in large differences in grain yield and grain nitrogen content and hence, grain quality. Research has also indicated that relative performance of wheat cultivars may change across contrasting soils in a field (Ciha, 1984; Carr *et al*., 1992).

Our data, from a long-term fertilization trial which has been maintained under differential fertilization for more than fifty years, indicate that differences in grain yield and quality occurred mainly in plots low in K. The cultivars generally reacted similarly across the range of soil fertility regimes, however, significant cultivar x soil fertility interactions were observed for grain yield, grain number, mean kernel mass, biomass and harvest index, showing differential cultivar performance.

These results show that breeding and cultivar evaluation should continue placing more emphasis on soil fertility in order to understand how cultivars react to less favourable soil fertility situations to produce yield and quality.

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