CHAPTER 3

THE CONTRIBUTION OF MAIN STEM, TILLERS AND KERNEL POSITION TO GRAIN YIELD AND GRAIN PROTEIN CONTENT OF WHEAT

3.1 ABSTRACT

The relative contribution of main stems and tillers, as well as the contribution of first, second and third kernels in spikelets to grain yield and grain protein content, is seldom quantified. The grain yield of main stems and tillers, and the mass of kernels in the spikelet by floret position, were determined in a long-term fertilization and irrigation experiment at the University of Pretoria. A randomized complete block design in a split-plot arrangement with three replicates was used. Main plots consisted of two different soil fertility levels and sub-plots were assigned to four cultivars. Mean grain yield of main stem (MS), first tiller (T_1) and second tiller (T_2) for the cultivar Kariega was 1.26 g, 0.98 g and 0.53 g respectively; 1.29 g, 0.78 g and 0.40 g for Carina; 1.63 g, 0.69 g and 0.09 g for Inia and 1.71 g, 1.10 g and 0.51 g for SST 86. Within a cultivar, the respective ears (MS, T_1 and T_2) did not differ in mean grain protein content, but significant differences were observed among the cultivars with Kariega averaging 16.2% compared to SST 86 and Inia with 14.5%. Main stems contributed on average 68.6%, first tillers 24.8% and third tillers 4.4% of the mean yield per unit area. Main stems produced on average 44.1 grains, first tillers 28.9 grains and the second tillers 15.3 grains. Main stem kernels were 15% larger than kernels from later-formed tillers. Main stems constituted 51.7% of the total ear number per unit area, first tillers 30.3% and the second tillers 14.4%. Mean kernel mass differed with position in the spikelet. First kernels were on the average 9.3% larger than second kernels, and 26.5% larger than third kernels. Main stems and later-formed tillers did not differ in grain protein content. Under the experimental conditions grain yield was largely contributed to by main stems and first tillers, and especially first and second kernels in the spikelet.

Key words: Grain yield, kernel position, main stem, protein content, tiller.

Publications and conference contributions based on this chapter:

Metho, L.A. and Hammes, P.S., 1997. Contribution of main stem, tillers and kernel position to grain yield and protein content of wheat. ***As a Poster of the First All Africa Crop Science Congress, Pretoria, South Africa.***

Metho, L.A., Hammes, P.S. and Beyers, E.A., 1998. The effect of soil fertility on the contribution of main stem, tillers and kernel position to grain yield and grain protein content of wheat. ***S. Afr. J. Plant Soil, 15, 53-60.***

Metho, L.A., Hammes, P.S. and Beyers, E.A., 1998. The effect of soil fertility on the contribution of main stem, tillers and kernel position to grain yield and protein content of wheat. Presented as a ***Poster*** **during the** ***26th SASCP Congress (January 18-22, 1999) in Stellenbosch, Cape Town, South Africa.***

3.2 INTRODUCTION

Knowledge of the relationship of yield in wheat (*Triticum aestivum* L.) with its components (ears per unit area, kernels per ear and kernel mass) have been of great assistance to plant breeders in making selections, although it is now recognised that selections for components of yield may not necessarily result in yield increases. Many researchers have reported on growth analysis as better selection criteria (Stoskopf, Tanner & Reinbergs, 1963; Voldeng & Simpson, 1967; Donald, 1968; Walton, 1971). Other workers have found associations between morphological characters above the flag leaf and yield of wheat (Watson, 1952; Thorne, 1966; Donald, 1968; Rawson & Hofstra, 1969).

Individual wheat shoots differ in grain yield as well as in protein content and hence, in quality (McNeal & Davis, 1954). This is true even of primary shoots of a single genotype grown in a homogeneous plot (Ledent & Moss, 1979). These differences may be accompanied by variation in flag leaf or peduncle morphological development (Ledent, 1974), and may suggest interrelationships between the phenological and morphological development pattern rather than a single trait approach to yield and quality improvement.

Wheat apex development is central to grain yield as both grain number and kernel mass are components of the ear. Wheat cultivars normally produce kernels varying greatly in size as a result of kernel position on the spike (Briggs, 1991). Kernels from the central spikelets of the rachis are larger than those of the basal or distal spikelets (Kirby & Appleyard, 1981; Whingwiri & Stern, 1982).

Within a spikelet, kernels on the basal florets are larger than those of the distal florets and may be controlled by the time of terminal spikelet formation relative to time of floret initiation (Whingwiri & Stern, 1982). Stockman, Fischer & Brittain (1983) found that there are large differences in the strength and size of sinks among spikelets on the same rachis and among florets in the same spikelet, depending on the sink's position. Hay & Walker (1989) showed that central spikelets have advantages in gaining photoassimilates, while spikelets on the distal region of a rachis are the weaker sinks.

McNeal & Davis (1954) found that the earliest formed and matured kernels contained the highest protein content, suggesting a first come-first serve situation regarding translocation of nitrogen to kernels. McNeal, Berg, Brown & Watson (1966) reported a significant negative relationship between grain protein content and harvest index, suggesting that as grain yield makes up a greater part of top growth, grain protein percentages will be correspondingly lower.

Wheat producers often harvest late due to late-maturing tillers, as certain wheat cultivars are known for differential ear development, depending on prevailing environmental conditions. In South Africa it is reported that about 0.5 million tons of wheat received at the silos every year is affected by late-maturing tillers (Wheat Board, 1990; 1994).

The effect of late-maturing ears on grain yield and quality has not been quantified, but is reportedly affecting yield and quality in major wheat growing areas of South Africa. The phenomenon of late tillering in small grain cereals have been reported by others (Aspinall, 1961; Kivisaari & Elonen, 1974).

To explore the relationship between wheat yield and quality the objectives of this study were: (i) to quantify the relative contribution of main stems and tillers, as well as the contribution of first, second and third kernels in the spikelets to yield and protein content, and (ii) to test the hypothesis that tillers affect the quality of grain to a greater degree than their contribution to grain yield. Few studies have been specifically focused on individual kernel mass and quality by relative floret positions in the spikelet, and this may contribute towards strategies in selection for yield and improvement of grain protein content.

3.3 MATERIALS AND METHODS

The experimental details, cultural practices, weather (monthly rainfall, evaporation and mean minimum and maximum temperatures) and statistical procedure are presented in Chapter 2. Because of the repeated measurements on the same experimental unit, a within and between-subject factors ANOVA-procedure was performed to analyse the data using the HELMERT option (SAS User's Guide Stat., 1989).

Main plots consisted of two different soil fertility levels and the sub-plots were assigned to four wheat cultivars. This report only deals with two fertility treatments (NPK and NPKM) representing two well-balanced soil nutrient situations producing strong healthy plants with good yields. Due to the tedious nature of the dissections only three replications were included. At maturity two sets of five plants were randomly sampled and separated into main stems and tiller components.

Ears from the main stems and the tillers were threshed separately, dried at 60^0C for 48hrs, and weighed to obtain grain yield. From the second set of five plants kernels were recovered from any five of the central spikelets (7, 9, 11, 13, 15 and 17 or 6, 8, 10, 12, 14 and 16) and grouped separately into first, second and third kernels. Grain protein content, on a 12% moisture basis, was determined by the Wheat Board on ground samples using a near infrared analyser (NIR)/Dumas Method (AACC, 1989).

3.4 RESULTS AND DISCUSSION

This chapter reports on the main effect of genotype and soil fertility on grain yield per ear, number of fertile ears per unit area, grain number per ear, grain protein content and mean kernel mass at specific floret positions on the ear. Grain yield per unit area, yield components, grain nitrogen content and some interactions between cultivars and soil fertility were reported and discussed in Chapter 2.

Fertile ear numbers

Based on the initial plant population, and tiller ratio of the samples, the number of main stems, first tillers and second tillers were calculated. The cultivars differed in number of ears due to differences in plant populations and tillering potential which resulted in differences in number of fertile ears per unit area (Table 3.1).

The cultivar Inia had the highest plant population and thus number of main stems, while SST 86 had the lowest. First tiller occurrence varied, with Inia having the lowest number, while Carina had the largest number of first tillers.

The four wheat cultivars did not differ in number of second tillers produced, although SST 86 had the highest and Inia the lowest. On the average main stems accounted for 51.7% of the total fertile ear number per unit area, first tillers 30.3% and the second tillers 14.4% and lower order tillers 3.6%. Increasing soil fertility from the NPK treatment to the NPKM treatment significantly increased main stems by 15.3%, first tillers by 13.8% and number of second tillers by 54.5%. In general fertile ear number per unit area increased with increasing soil fertility. Morishima, Oka & Chang (1967) and Hsu & Walton (1971) classified wheat varieties as "ear number" or "ear length" types to emphasize the relative importance of ear number as a component of yield. Other researchers Darwinkel, 1978; Nerson, 1980; Gales, 1983; Bulman & Hunt, 1988) have reported genotypic differences in ability of wheat cultivars to produce fertile tillers.

A positive correlation between spike number and grain yield have been reported by Nass (1973). In our study we obtained a positive and significant correlation between fertile spike number and estimated grain yield (Data not shown)

TABLE 3.1 Effect of wheat cultivars and soil fertility on fertile ear number, main stems, first tillers and second tillers per m^2

Treatment		Fertile number of ears per m^2	Main stems (MS) per m^2	First tillers (T_1) per m^2	Second tillers (T_2) per m^2
CULTIVAR	**SST 86**	442(100)	241(57.0)	129(30.5)	107(25.3)
	Inia	532(100)	378(70.9)	100(18.7)	45 (8.4)
	Kariega	568(100)	253(44.6)	216(38.0)	68 (9.8)
	Carina	674(100)	263(39.0)	220(32.7)	100(14.8)
	LSD_T $P_{\leq 0.05}$	120	49.9	55.2	121
FERTILITY	**NPKM**	575(100)	304(115)	177(114)	96(155)
	NPK	523(100)	264(100)	155(100)	62(100)
	LSD_T $P_{\leq 0.05}$	98	37.2	50.9	93.2
MEAN		549	284	166	79
CV%		15.4	11.4	22.5	101

Figures in ( ) refer to MS, T_1, T_2 as percentage of fertile ear number per m^2 averaged over the NPKM and NPK fertilization treatments.

Grain yield of individual ears

Grain yield of main stems, first tillers and second tillers are shown in Table 3.2. Grain yield of the main stem differed between cultivars, with SST 86 producing the highest yield of 1.71 g and Kariega the lowest (1.26 g). First tiller grain yield did not differ significantly between cultivars and ranged from 0.69 g for Inia to 1.10 g for SST 86. The yield of second tillers was relatively small but differed significantly with that of Kariega being 0.53 g while Inia produced 0.09 g. Yield per square metre was calculated from the number of ears (Table 3.1) and the grain yield of main stems, first tillers and second tillers (Table 3.2). Main stems contributed on average 68.6%, first tillers 24.8% and second tillers 4.4% and the remaining tillers 2.2% of the yield per unit area (Table 3.2).

The estimated grain yield of the cultivars did not differ significantly. Due to the small number of samples (5 plants per treatment) the estimated yield (Table 3.2) differs somewhat from the actual grain yield (Metho, Hammes, De Beer & Groeneveld, 1997). When estimated yields were compared, Inia had the highest and Carina the lowest, while with actual yield Carina produced the highest and SST 86 the lowest. The data show that the main stem (MS) yield was higher and more stable compared to the yield of tillers which varied greatly between the cultivars. Similar results have been reported by Power & Alessi (1978) for spring wheat.

Bulman & Smith (1993) using spring barley (*Hordeum vulgare* L.) reported on the stable nature of main stem ear yield components, and on the relatively small contribution of tillers to grain yield. Gan & Stobbe (1995) reported that main stem grain yield was relatively uniform but tiller yield was highly variable in spring wheat.

Grain yield per ear was highly correlated ($r^2 = 0.85$) to grain yield per unit area. Nass (1973) using stepwise multiple regression analysis concluded that yield per ear and number of ears per plant, and ears per unit area, made the greatest contribution to grain yield. Briggs (1991) reported that while the productivity of wheat cultivars is determined by both the kernel mass and number of grains, approximately 50% of a plant's productivity in total grains and kernel biomass was produced by the first spike (MS), and 80-90% by the first two spikes (MS and T_1). Our data confirm that grain yield of wheat is largely contributed by main stems and first tillers.

In general increasing soil fertility from the NPK treatment to the NPKM treatment tended to increase grain yield of main stems and that of first tillers, but significantly decreased yield of the second tillers (Table 3.2).

TABLE 3.2 Effects of wheat cultivar and soil fertility on grain yield of main stem, first tiller, second tiller and grain yield per m²

Treatment		GRAIN YIELD			Estimated [1] grain yield per m^2	Actual [2] grain yield per m^2
		Main stem (MS) (g)	First tiller (T_1) (g)	Second tiller (T_2) (g)	(g)	(g)
CULTIVAR	SST 86	1.71	1.10	0.51	589	390
	Inia	1.63	0.69	0.09	715	448
	Kariega	1.26	0.98	0.53	564	445
	Carina	1.29	0.78	0.40	541	634
	LSD_T $P \leq 0.05$	0.34	0.52	0.23	195	103
FERTILITY	NPKM	1.59	0.99	0.35	684	493
	NPK	1.35	0.78	0.42	521	465
	LSD_T $P \leq 0.05$	0.39	0.31	0.07	172	139
MEAN		1.47	0.96	0.44	602	479
CV%		17.1	37.6	36.4	20.9	20.0

1. Number of MS, T_1 and T_2 per m^2 x mean grain yield per ear of MS, T_1 and T_2.
2. Metho et al., 1997.

Grain number per ear

Grain number per ear is the product of number of fertile spikelets per ear and grains per spikelet, while grains per unit area is a function of number of grains per ear and ears per unit area. Grain number varied with cultivar, with SST 86 having the largest number of grains per ear, averaging 32.3 grains, and Inia the lowest with 24.5 grains (Table 3.3).

Although not statistically significant, SST 86 had the highest number of grains per ear in the main stems, first tillers and second tillers, while Inia had the lowest numbers. Main stems produced on average 44.1 grains, first tillers 28.9 grains and the second tillers 15.3 grains. On a single plant basis, mean whole plant grain number was 73.4 grains for Inia, 89.5 grains for both Kariega and Carina, and 96.9 grains for SST 86.

Increasing soil fertility from the NPK treatment to the NPKM treatment did not significantly affect grain number per ear or per main stem, but significantly increased grain number of the first tillers by 24%. The number of grains of the second tillers (T_2) was not significantly affected, although increased by 13.3% (see Table 9.A6). In field experiments, several authors (Puckridge & Donald, 1967; Willey & Holliday, 1971; Fischer, Aquilar, Mauver & Rivas, 1976) have reported that increase in grain yield was positively correlated with an increase in grain number.

Results indicate that grain yield per ear was strongly associated with grain number per ear. The high yield of main stems compared to that of tillers led to a wheat with one culm being identified as crop ideotype by Donald (1968). The advantages of tillers for grain production and for compensation purposes remain debatable due to differences in the grain yield of main stems and tillers. Ledent & Moss (1979) reported a close association between kernel number and shoot or ear yield, while Nass (1973) reported that kernels per ear and kernel weight were associated with yield per ear. Later-formed shoots produced ears that contained fewer grains due to reduced number of fertile spikelets (Darwinkel, 1978). Bulman & Smith (1993) reported that poor grain yield of tillers resulted from the formation of fewer and smaller grains.

TABLE 3.3 Effect of wheat cultivar and soil fertility on mean grain number of main stems, first tillers, second tillers and of whole plant

Treatment		GRAIN NUMBER				
		Main stem (MS)	First tiller (T_1)	Second tiller (T_2)	Mean grain[1] number per ear $\frac{(\Sigma MS + T_1 + T_2)}{3}$	Whole plant grain number (WP)
CULTIVAR	**SST 86**	46.8	31.7	18.5	32.3	96.9
	Inia	40.9	23.0	9.5	24.5	73.4
	Kariega	44.9	31.7	16.9	29.9	89.5
	Carina	43.9	29.3	16.2	29.8	89.5
	LSD_T $P \leq 0.05$	8.44	10.2	9.2	6.1	18.3
FERTILITY	**NPKM**	44.9	32.0	16.2	31.2	93.1
	NPK	43.3	25.8	14.3	27.1	81.6
	LSD_T $P \leq 0.05$	7.1	5.7	5.5	5.6	16.9
MEAN		44.1	28.9	15.3	29.2	87.4
CV%		12.9	22.4	38.3	14.4	14.3

1. Averaged over the NPKM and NPK fertilization treatments.

Kernel mass

The effects of cultivar and soil fertility on kernel mass are shown in Table 3.4. The cultivars differed in mean kernel size of the main stems with Inia having the largest kernels averaging 39.8 mg, while Carina had the smallest kernels at 29.3 mg. Kernels on main stems were on average 15% larger than kernels from the later-formed tillers (T_1 and T_2), probably due to limiting photoassimilate supply in the case of tillers.

Kernels from the first tillers differed with Inia kernels averaging 34.1 mg and Carina 26.8 mg. Kernels from the second tillers did not differ significantly, although they ranged in size from 22.9 mg to 30.6 mg. Hsu & Walton (1971), from a factor analysis for both greenhouse and field trials, reported that 20.9% of the total variation in yield was attributed to 1000 kernel mass. Darwinkel (1978) reported that at higher plant densities there was no relationship between shoot age and grain weight, but when kernels from shoots or ears which emerged first were compared to those that emerged later, it was found that the former had larger and heavier kernels than those from later-formed ears. Kernel mass depends on the availability of plant assimilates during the stage of grain-filling, and this is closely related to the leaf area duration after anthesis (Spiertz, Ten Hag & Kupers, 1971; Thorne, 1974; Annandale, Hammes & Nel, 1987). Puckridge & Donald (1967) and Willey & Holliday (1971) found that very high numbers of grains can only be achieved in dense crops, in which radiant energy for grain-filling will be limited and grain weight will decrease due to less reserve carbohydrate in ear-bearing shoots after anthesis. Briggs (1991) concluded that genotypic variation in kernel mass (or seed size) within wheat cultivars is common and will depend on the levels of environmental stress in a particular growing season as well as on the specific plasticity of individual cultivars. Although not statistically significant, kernel mass tended to increase with increase in soil fertility (Table 3.4). Many workers (Terman, Ramig, Dreier & Olson, 1969; Ledent & Moss, 1979; Bulman & Smith, 1993) have reported that response of kernel mass or grain weight to climatic conditions, nitrogen treatments or soil fertility generally vary. Application of N-fertilizer treatments from 0 to 200 kg N per ha did not affect 1000-grain weight in an experiment conducted by Bulman & Smith (1993).

Wheat yield is generally attributed to three primary components namely number of ears per unit area, number of grains per ear and mean kernel mass. Variations in yield per shoot result from differences in kernel number per ear and kernel mass. Correlations between yield per plant and its primary components (ears per plant, grain number per ear and mean kernel mass) both in green house and field conditions have often been reported (Hsu & Walton, 1970; 1971; Bulman & Hunt, 1988). While acknowledging the contribution of other researchers, considerable effort is still needed to enhance our understanding of how genotypes and soil fertility interact in relation to the role of ears as sinks, and kernel size distribution between individual ears and within the different spikelets.

The results show that wheat cultivars differ in grain yield potential of individual ears. Main stem yield was relatively high and stable compared to the yield of later-formed tillers which varied greatly between the cultivars. Similar results have been reported by among others Power & Alessi (1978). Gan & Stobbe (1995), working with spring wheats, reported that main stem grain yields were relatively uniform but tiller grain yields were highly variable. Tillers contributed poorly due to fewer grains and smaller kernel mass. The results show that kernel size depends on position of ear, whether main stem or from later-formed tillers. Our data confirms those reported by Levi & Anderson (1950) and Briggs (1991) who found differences in kernel mass in different positions in the spike and spikelet. The data indicate that, under the experimental conditions, grain yield of wheat is largely contributed by main stems and first tillers, and especially first and second kernels in the spikelet.

Grain protein content per ear

The protein content of the ears varied as shown in Table 3.5. Main stems differed with Kariega having 16.2% protein and SST 86 having 14.5%. The first tillers did not differ in grain protein content and varied from 14.7% to 15.6%. In the case of second tillers the cultivars differed in grain protein content with Kariega having 16.2% protein, while Inia contained 14.5%.

Levi & Anderson (1950) and McNeal & Davis (1954) reported small, and not significant differences in protein percentage between the main stems, tillers and composites. The relatively high protein values (14.2-16.2%) obtained in my study is typical for very small samples of grain, according to Randall (Personal communication, 1997). The treatments NPK and NPKM did not differ in grain protein content, except in second tillers where grain protein content in the NPKM treatment significantly increased. Large differences in grain protein was observed in other fertility treatments of this experiment, indicating grain protein increased with improved soil fertility status (Appendix Table 9.A7.). Schlehuber & Tucker (1959), Johnson, Schmidt, Mattern & Haunold (1963), Laubscher (1981) and Fischer (1989) have reported improved grain protein content and higher grain yield of wheat with improved soil fertility. The same authors reported that the major factors affecting grain protein are climate, soil fertility and genotype. The benefits of applying nitrogen fertilizer to increase both yield and grain protein levels in wheat have been reported by many research workers (McNeal & Davis, 1954; Finney, Meyer, Smith & Fryer, 1957; Seth, Herbert & Middleton, 1960; Alkier, Raczs & Soper, 1972; Strong, 1982; Randall, Freney, Smith, Moss, Wrigley & Galbally, 1990). Inverse relationships between protein content of wheat grains and yield level have also been reported (Malloch & Newton, 1934; Terman, Ramig, Dreier & Olson, 1969).

Kernel mass and grain protein content in floret positions 1, 2 and 3 in the spikelet

Differences between cultivars in kernel mass and grain protein content for the different kernel positions in the spikelet are shown in Tables 3.6 and 3.7. In floret position 1 the cultivar SST 86 had the largest kernel mass averaging 42.4 mg, while Kariega kernels were the smallest at 37.8 mg. Kernels in floret position 2 differed with Inia having the largest kernels at 39.5 mg, and Kariega the smallest averaging 34.0 mg. In floret position 3, Inia produced the largest kernels averaging 35.9 mg, while Carina had the smallest averaging 21.5 mg. Floret position affected kernel size the least in cultivar Inia, where kernels from floret 3 were 14.3% smaller than those from floret 1. The cultivar Carina showed the largest variation in kernel size, as third kernels were 46% smaller than first kernels (Table 3.6). The 1st and 2nd kernels did not differ in mass, but kernels in 3rd position in the spikelet were significantly smaller compared to the 1st and 2nd kernels in all cultivars. Kernels from central spike positions were significantly larger than kernels from the basal and distal end of the spike (data not shown). These results are based on the data collected on the well-formed central spikelets, as distal or basal spikelets varied greatly in number of grains produced and in kernel size.

TABLE 3.4 Effect of wheat cultivars and soil fertility, on mean kernel mass of main stem, first tiller and second tiller

Treatment		MEAN KERNEL MASS		
		Main stem (MS) mg	First tiller (T_1) mg	Second tiller (T_2) mg
CULTIVAR	**SST 86**	36.4 (100)	30.3 (83.2	30.6 (84.1)
	Inia	39.8 (100)	34.1 (85.7)	30.4 (76.1)
	Kariega	31.1 (100)	29.9 (91.5)	28.9 (92.9)
	Carina	29.3 (100)	26.8 (91.5)	22.9 (78.2)
	LSD_T			
	$P \leq 0.05$	5.8	6.9	11.4
FERTILITY	**NPKM**	35.7 (110)	30.3 (103)	29.5 (108)
	NPK	32.6 (100)	28.6 (100)	28.2 (100)
	LSD_T			
	$P \leq 0.05$	7.6	3.6	7.9
MEAN		34.2	29.5	28.8
CV%		12.9	14.1	23.6

Figures in ( ) are expressed as percentages relative to kernel mass of MS.

TABLE 3.5 Effect of wheat cultivars and soil fertility on mean grain protein content of main stem, first tiller and second tiller

Treatment		MEAN PROTEIN CONTENT (%)		
		Main stem (MS)	First tiller (T_1)	Second tiller (T_2)
CULTIVAR	**SST 86**	14.5	15.3	15.8
	Inia	14.5	14.7	14.5
	Kariega	16.2	15.6	16.2
	Carina	15.7	14.9	14.9
	LSD_T			
	$P_{\leq 0.05}$	1.82	1.58	0.98
FERTILITY	**NPKM**	15.2	15.6	16.2
	NPK	15.2	14.7	14.5
	LSD_T			
	$P_{\leq 0.05}$	1.05	1.22	0.15
MEAN		15.2	15.1	15.3
CV%		7.6	6.9	3.9

TABLE 3.6 Mean mass of kernels in floret positions 1, 2 and 3 in the spikelet of four South African wheat cultivars

Treatment		MEAN KERNEL MASS		
		Floret position 1 (mg)	Floret position 2 (mg)	Floret position 3 (mg)
CULTIVAR	**SST 86**	42.4 (100)	38.7 (91.3)	32.7 (77.1)
	Inia	41.9 (100)	39.5 (94.3)	35.9 (87.7)
	Kariega	37.8 (100)	34.0 (89.9)	28.3 (74.9)
	Carina	39.8 (100)	35.6 (89.4)	21.5 (54.6)
	LSD_T			
	$P_{\leq 0.05}$	3.93	4.26	5.64
FERTILITY	**NPKM**	41.7 (106)	37.6 (104)	27.3 (85.6)
	NPK	39.3 (100)	36.3 (100)	31.9 (100)
	LSD_T			
	$P_{\leq 0.05}$	4.02	3.74	3.54
MEAN		40.5	36.9	29.6
CV%		6.9	7.8	11.8

TABLE 3.7 Mean protein content of grains in floret positions 1, 2 and 3 in the spikelet of four South African wheat cultivars

Treatment		MEAN PROTEIN CONTENT (%)		
		Grains in floret position 1	Grains in floret position 2	Grains in floret position 3
CULTIVAR	**SST 86**	15.4	15.4	14.2
	Inia	14.8	14.8	14.1
	Kariega	16.4	16.0	14.3
	Carina	15.8	15.5	14.7
	LSD_T			
	$P_{\leq 0.05}$	1.01	1.33	1.19
FERTILITY	**NPKM**	15.9	15.9	14.5
	NPK	15.2	41.9	14.1
	LSD_T			
	$P_{\leq 0.05}$	0.74	1.44	0.64
MEAN		15.6	15.4	14.3
CV%		4.2	5.9	5.3

Wheat normally produces kernels varying greatly in size as a result of kernel position on the spike (Briggs, 1991). Gan & Stobbe (1995) reported that kernels from the central spikelets of the rachis are larger than those of the basal or distal spikelets, and within a spikelet, kernels on the basal florets are larger than those of the distal florets. Briggs (1991) concluded that smaller kernels result partly from floret position effects and partly from kernel mass reduction for later-formed tillers. Grain protein content for kernels from floret position 1 varied between cultivars with Kariega having 16.4% protein, and Inia 14.8% (Table 3.7).

Grain protein content did not differ between cultivars in floret positions 2 and 3. In floret position 2 grain protein ranged from 14.8% to 16.0%, while for floret position 3 protein content varied from 14.1% to 14.7%. When grain protein content of kernels in floret position 3 was compared with those in floret position 1, Inia showed the least variation in protein content while Kariega varied most (Tabel 3.7; Appendix Table 9.A8). The data confirms those reported by Levi & Anderson (1950) and McNeal & Davis (1954) who found that earliest formed and matured kernels contained the highest protein content, suggesting a "first come-first serve" situation as regards translocation of nitrogen from plant tissues to kernels. More recently Jenner, Ugalde & Aspinall (1991) reported that under adequate growing conditions, both rate and duration of starch deposition during grain filling are determined mainly by factors that operate within or close to the grain itself. The rate and duration of protein deposition are determined by factors of supply external to the grain. The same authors suggested that grain yield and grain protein percentage should be selected as independent traits in cultivar improvements.

Increasing soil fertility from the NPK treatment to the NPKM treatment resulted in slight increases in grain protein content of kernels. Elevated grain protein have resulted from crosses of cultivated wheat and wheat-related species, in addition to application of N-fertilizer and breeding for cultivars efficient in N uptake and translocation (Fischer, 1989).

3.5 CONCLUSIONS

The effect of soil fertility on the relative contribution of main stems and fertile tillers were quantified. In general main stems (MS) contributed 69%, first tillers (T_1) 25%, second tillers (T_2) 4% and the remaining tillers 2% of the mean yield per unit area, depending on cultivar and growing situation. On the average, main stems accounted for 52% of the total fertile ear number

per unit area, first tillers 30% and the second tillers 14%, and lower order tillers 4%. Relative kernel mass and protein content generally declined in the spikelet from the
1st to the 3rd floret position.

Tiller contribution to yield was low compared to that of main stems. The protein content of main stems and tillers did not differ, thus disproving the initial hypothesis that tillers may affect grain quality.

The relative contribution of main stems and tillers, as well as the relative contribution of first, second and third kernels in spikelets to grain yield and protein content, are seldom quantified. The data presented are rarely available, because the process is often tedious and time consuming, but valuable to crop modellers and users, and may be utilized in agronomic management strategies and crop modelling in different environments for optimum yield and quality.

3.6 REFERENCES

ALKIER, A.C., RACZS, G.J. & SOPER, R.J., 1972. Effects of soil - applied nitrogen and soil nitrate - nitrogen level on the protein content of Neepawa wheat. *Can. J. Plant Sci.* 52, 301-309.

ANNANDALE, J.G., HAMMES, P.S. & NEL, P.C., 1984. Effect of soil fertility on the vegetative growth, yield and water use of wheat (*Triticum aestivum* L.). *S. Afr. J. Plant Soil.* 1, 96-97.

AMERICAN ASSOCIATION OF CEREAL CHEMISTS, 1989. Approved methods of the AACC 8th edn (1989 update currently in use), AACC St Paul, Minnesota.

ASPINALL, D., 1961. The control of tillering in the barley plant. I. The pattern of tillering and its relation to nutrient supply. *Aust. J. Biol. Sci.* 14, 493-505.

BRIGGS, K.G., 1991. Spatial variation in seed size and seed set on spikes of some Canadian wheat cultivars. *Can. J. Plant Sci.* 72, 247-249.

BULMAN, P. & HUNT, L.A., 1988. Relationships among tillering, spike number and grain yield in winter wheat (*Triticum aestivum* L.) in Ontario. *Can. J. Plant Sci.* 68, 583-596.

BULMAN, P. & SMITH, D.L., 1993. Yield and yield components response of spring barley to fertilizer nitrogen. *Agron. J.* 85, 226-231.

DARWINKEL, A., 1978. Patterns of tillering and grain production of winter wheat at a range of plant densities. *Neth. J. Agric. Sci.* 26, 383-389.

DONALD, C.M., 1968. The breeding of crop ideotypes. *Euphytica.* 17, 385-403.

FINNEY, K.F., MEYER, J.W., SMITH, F.W. & FRYER, H.C., 1957. Effect of foliar spraying of Pawnee wheat with urea solutions on yield, protein content and protein quality. *Agron. J.* 49, 341-347.

FISCHER, R.A., AQUILAR, I., MAURER, R. & RIVAS, S., 1976. Density and row spacing effects on irrigated short wheats at low latitude. *J. Agric. Sci.* 87, 137-47.

FISCHER, R.A., 1989. Development in Wheat Agronomy. Wheat and Wheat Improvement. Second Edition, American Society of Agronomy, Inc. Pub., Madison, Wisconsin USA. pp. 249-269.

GALES, K., 1983. Yield variation of wheat and barley in Britain in relation to crop growth and soil conditions - a review. *J. Sci. Food Agric.* 34, 1085-1104.

GAN, Y. & STOBBE, E.H., 1995. Effect of variations in seed size and planting depth on emergence, infertile plants, and grain yield of spring wheat. *Can. J. Plant Sci.* 75, 565-570.

HAY, R.K.M. & WALKER, A.J., 1989. An introduction to the physiology of crop yield. Longman Scientific and Technical, Harlow, England.

HSU, P. & WALTON, P.D., 1970. The inheritance of morphological and agronomic characters in spring wheat. *Euphytica.* 19, 53-60.

HSU, P. & WALTON, P.D., 1971. Relationships between yield and its components and structures above the flag leaf node in spring wheat. *Crop Sci.* 11, 190-193.

JENNER, C.J., UGALDE, T.D. & ASPINALL, D., 1991. The physiology of starch and protein deposition in the endosperm of wheat. *Aust. Plant Physiol.* 18, 211-226.

JOHNSON, V.A., SCHMIDT, J.W., MATTERN, P.J. & HAUNOLD, A., 1963. Agronomic and quality characteristics of high protein F_2 - derived families from a soft red winter - hard red winter wheat cross. *Crop Sci.* 3, 7-10.

KIRBY, E.J.M. & APPLEYARD, M., 1981. Cereal development guide, 2nd ed. Arable unit National Agricultural Centre, Stoneleigh.

KIVISAARI, S. & ELONEN, P., 1974. Irrigation as a method of preventing detrimental late tillering of barley. *J. Sci. Agric. Soc. (Finland).* 46, 194-207.

LAUBSCHER, E.W., 1981. Nitrogen application, protein content and quality of wheat. Paper presented on award of the FSSA Silver Medal, 1981. *Fertilizer Society of South Africa Journal.* 2, 41-47.

LEDENT, J.F., 1974. Contribution a l'etude des relations entre l'epi et les parties sommitales de la plante chez le froment d'hiver (*Triticum aestivum* L.). *Rev. Agric.* 27, 1407-1420.

LEDENT, J.F. & MOSS, D.N., 1979. Relation of morphological characters and shoot yield in wheat. *Crop Sci.* 19, 445-451.

LEVI, I. & ANDERSON, J.A., 1950. Variations in protein contents of plants, heads, spikelets and individual kernels of wheat. *Can. J. Res. F.* 28, 71-81.

MALLOCH, J.G. & NEWTON, R., 1934. The relation between yield and protein content of wheat. *Can. J. Res.* 10, 774-779.

METHO, L.A., HAMMES, P.S., DE BEER, J.M. & GROENEVELD, H.T., 1997. Interaction between cultivar and soil fertility on grain yield, yield components and grain nitrogen content of wheat. *S. Afr. J. Plant Soil.* 14, 158-164.

McNEAL, F.H. & DAVIS, D.J., 1954. Effect of nitrogen fertilisation on yield, culm number and protein content of certain spring wheat varieties. *Agron. J.* 46, 375-378.

McNEAL, F.H., BERG, M.A., BROWN, P.L. & WATSON, C.A., 1966. Nitrogen and dry matter in five spring wheat varieties at successive stages of development. *Agron. J.* 58, 605-608.

MORISHIMA, H., OKA, H.I. & CHANG, T.T., 1967. Analysis of genetic variation in plant type of rice. I. Estimation of indices showing genetic plant type and their correlation with yield capacity in segregating population. *Japan J. Breed.* 17, 73-84.

NASS, H.G., 1973. Determination of characters for yield selection in spring wheat. *Can. J. Plant Sci.* 53, 755-762.

NERSON, H., 1980. Effects of population density and number of ears on wheat yield and its components. *Field Crops Research.* 3, 225-234.

POWER, J.F. & ALESSI, J., 1978. Tiller development and yield of standard and semi-dwarf spring wheat varieties as affected by nitrogen fertilizer. *J. Agric. Sci. Camb.* 90, 97-108.

PUCKRIDGE, D.W. & DONALD, C.M., 1967. Competition among wheat plants sown at a wide range densities. *Aust. J. Agric. Res.* 18, 193-211.

RANDALL, P.J., FRENEY, J.R., SMITH, C.J., MOSS, H.J., WRIGLEY, C.W. & GALLABY, I.E., 1990. Effect of additions of nitrogen and sulfur to irrigated wheat at heading grain yield, composition and milling and baking quality. *Aust. J. Exper. Agric.* 30, 95-101.

RAWSON, H.M. & HOFSTRA, G., 1969. Translocation and remobilization of ^{14}C assimilate at different stages by each leaf of wheat plant. *Aust. J. Biol. Sci.* 22, 321-331.

SAS INSTITUTE, 1989. SAS/STAT user's guide. 5th Edition. SAS Inst., CARY NC., pp. 122-123.

SCHLEHUBER, A.M. & TUCKER, B.B., 1959. Factors affecting the protein content of wheat. *Cereal Sci. Today.* 4, 240-242.

SETH, J., HERBERT,T.T. & MIDDLETON, Q.K., 1960. Nitrogen utilization in high and low protein wheat varieties. *Agron. J.* 52, 207-209.

SPIERTZ, J.H.J., TEN HAG, B.A. & KUPERS, L.J.P., 1971. Relation between green area duration and grain yield in some varieties of spring wheat. *Neth. J. Agric. Sci.* 19, 211-222.

STOCKMAN, Y.M., FISCHER, R.A. & BRITTAIN, E.G., 1983. Assimilate supply and floret development within the spike of wheat (*Triticum aestivum* L.). *Aust. J. Plant Physiol.* 10, 585-594.

STOSKOPF, N.C., TANNER, T.W. & REINBERGS, E., 1963. Attacking the yield barrier. *Can. Dep. of Agr. Cereal News.* 8, 8-12.

STRONG, W.M., 1982. Effect of application of nitrogen on the yield and protein content of wheat. *Aust. J. Exp. Agric. Anim. Husb.* 22, 54-61.

TERMAN, G.L., RAMIG, R.E., DREIER, A.F. & OLSON, R.A., 1969. Yield – protein relationships in wheat grains, as affected by nitrogen and water. *Agron. J.* 61, 755-759.

THORNE, G.N., 1966. Physiological aspects of grain yield in cereals. In. F. L. Milthon, J.D. Ivins (Eds), The Growth of Cereals and Grasses. *Butterworth,* London, *England.* pp. 88-105.

THORNE, G.N., 1974. The physiology of grain yield of wheat and barley. *Rothamsted Exp Stn. Rep.* Part 2, pp. 5-25.

VOLDENG, H.D. & SIMPSON, G.M., 1967. The relationship between photosynthetic area and grain yield per plant in wheat. *Can. J. Plant Sci.* 47, 359-365.

WALTON, P.D., 1971. The use of factor analysis in determining characters for yield selection in wheat. *Euphytica.* 21, 416-421.

WATSON, D.J., 1952. The physiological basis of variation in yield. *Adv. Agron.* 4, 101-145.

WHEAT BOARD, Wheat Board Crop Quality Reports, 1990/1994. Wheat Board, Technical Services, P.O. Box 908, Pretoria, South Africa.

WHINGWIRI, E.E. & STERN, W.R., 1982. Floret survival in wheat: significance of the time of floret initiation relative to terminal spikelet formation. *J. Agric. Sci. Camb.* 98, 257-68.

WILLEY, R.W. & HOLLIDAY, R., 1971. Plant population, shading and thinning studies in wheat. *J. Agric. Sci. Camb.* 77, 453-461.