Classification of South African Bread Wheat Cultivars According to Hagberg Falling Number Reaction to Fertilizer Treatment

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ABSTRACT

The effect of three fertilizer treatments (suboptimal = 0 N, P, K kg/ha; standard = 20 N, 5 P, 5 K kg/ha; and optimal = 60 N, 15 P, and 15 K kg/ha) on the Hagberg Falling Number (HFN) of 15 South African bread wheats were investigated. No statistical significant effect on the HFN of wheat in general could be seen. A split-plot analysis, however, indicated a cultivar effect for HFN response to fertilizer treatment. This allowed for the grouping of cultivars into four response groups: low, low-to-medium, medium, and high, according to HFN sensitivity to fertilizer treatment. A canonical variate analysis (CVA) was performed on the general performance of each cultivar with regard to three characteristics: yield, protein content, and HFN. This allowed for the refinement of risk groups as created by the split-plot analysis for HFN response. However, HFN measured were never below the 220 sec cut-off mark for grade.

The Hagberg Falling Number (HFN) test was incorporated in the South African wheat grading regulations in June 1998. Before its incorporation, wheat was indirectly evaluated for low HFN through a visual screening test. This test required that a 25-g wheat sample should not contain >2% sprouted wheat because sprouted wheat has large amounts of alpha-amylase activity. Since the incorporation of the HFN test, it became obvious that various factors, other than sprouted wheat, had an influence on the HFN of wheat, as numerous reports of low HFN wheat without visual sprouting were received throughout the summer rainfall wheat producing areas of South Africa. With the release of the Falling Number Report (Anonymous 2001), it was speculated that several cultivars performed poorly regarding HFN due to insufficient nitrogen availability. However, the literature is not clear as to the effect of fertilizer application on HFN in the absence of preharvest sprouting. Tabl and Kiss (1983) and Oskarsen (1989) reported a negative association between nitrogen (N) application and HFN due to increased lodging and therefore elevated grain moisture content (Oskarsen 1989). Hook et al (1989) and Webb and Sylvester-Bradley (1995) reported no visible effect. Gooding et al (1986) and Kettlewell (1999) reported a positive linear association between N application and HFN due to delayed maturity, with such a delay promoting a high HFN. A decrease in alpha-amylase activity due to increased N may also explain high HFN (Pushman and Bingham 1976). Various research studies have indicated the presence of a cultivar effect linked to the HFN response to N application. Both Gooding et al (1986) and Rule (1987) indicated that various N treatments increased the HFN of cultivar Avalon but not cultivar Mission. Biskupski (2000) reported similar results. According to King (1989), N fertilizer will produce grain with higher protein and, as a result, grain with an enhanced capacity to synthesize alpha-amylase.

The aim of this study was to investigate the effect of fertilizer treatment on the HFN of 15 South African bread wheat cultivars to establish a possible relationship between fertilizer application and HFN, as well as to determine the role of cultivar effect on such a possible interaction.

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MATERIALS AND METHODS

Field Trials

The trials were planted over a two-year period (July 2001 and 2002) at the Small Grain Institute (Bethlehem, Eastern Free State) under rainfed conditions in a wheat monoculture. The required analyses were performed beforehand to establish the soil status. Fifteen cultivars were evaluated at three different fertilizer treatments. The trial consisted of three replicates for each treatment. The experiment was arranged as a split-plot design in three randomized blocks with fertilizer treatment as the main plot factor and cultivar as the subplot factor. The three treatments included 0 N, P, K kg/ha (suboptimal); 20 N, 5 P, 5 K kg/ha (standard); and 60 N, 15 P, and 15 K kg/ha (optimal). The suboptimal treatment was considered as the control. The fertilizers were applied as limestone ammonium nitrate (LAN), superphosphate, and potassium chloride. The specific treatment levels were chosen to simulate fertilizer applications by producers in the dryland summer rainfall wheat producing areas. The plot size in all years was 2.4 m x 5 m with a 40 cm interrow spacing. Fertilizer treatments were band placed at planting. Weather data (rainfall, maximum, and minimum temperatures) were recorded within 0.4 km of the trial (Fig. 1).

Sampling and Laboratory Analysis

All cultivars were harvested at ≈12% kernel moisture content (early January 2001 and 2002). Cleaned wheat samples were milled with a Hagberg Falling Number hammer mill (0.8 mm) and the protein content was determined with near-infrared reflectance (NIR) (Approved Method 39-10, AACC International 2000) and HFN

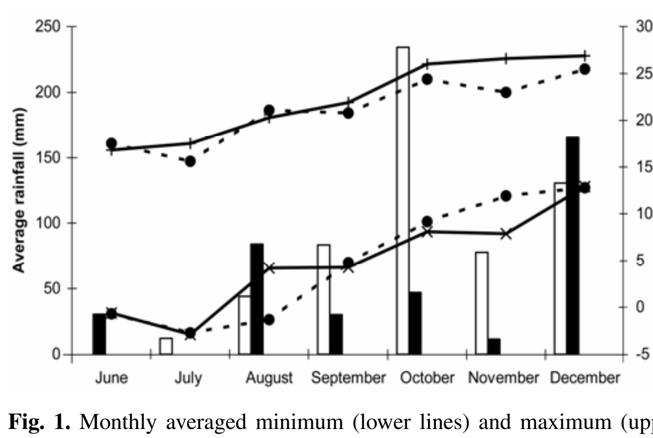

Fig. 1. Monthly averaged minimum (lower lines) and maximum (upper lines) temperatures and rainfall (vertical bars) for the 2001/02 (dashed line/white bars) and 2002/03 (solid line/black bars) seasons (Bethlehem, Eastern Free State).

(Standard Method No. 107/1, ICC 1995) determined within two weeks after harvest. Yield was determined as ton/ha. Individual performance of the cultivars with regard to yield, protein content, and HFN over the two years is indicated in Table I (2001/02) and Table II (2002/03).

Statistical Analysis

A split-plot factorial analysis was used to establish a cultivar effect for yield, protein content, and HFN for each of the two years of evaluation. Once the environmental effect was determined, data were pooled into a two-year analysis to determine cultivar response over seasons that would allow cultivars to be grouped according to HFN response to fertilizer application. Least significant differences (LSD) were used to compare the interaction means for each of the cultivars individually. Cultivar differences that were observed accordingly allowed for the classification of the 15 cultivars into four main groups regarding sensitivity to fertilizer treatment to individual HFN performance. The main grouping of cultivars was made according to HFN performance as established by this analysis. Additionally, a Canonical Variate Analysis (CVA) was used to determine which of the three characteristics (HFN, yield, and protein content) discriminated most between the cultivar and treatment combinations (cultivar-by-treatment). The CVA, also better known as linear discriminant analysis, is used when it is of more interest to show differences between groups such as cultivar-by-treatment combinations than between individuals (Digby and Kempton 1987). The variability in a large number of variables is firstly reduced to a smaller set of variables called canonical variates that are linear combinations of the original measurements and are thus given as vectors of loadings for the original measurements. With this approach, a set of directions is obtained in such a way that the ratio of between group variability to within-group variability in each direction is maximized. In this study, the variates were the three characteristics that were measured (HFN, protein, and yield) for each cultivar and treatment combination (45 cultivar-by-treatment combinations). The scores calculated for each of the canonical variates were then correlated with the original variates to find those that were the most important in discriminating between the

TABLE I
Average Yield, Protein Content, and Hagberg Falling Number for 15 Dryland Cultivars Evaluated at Three Fertilizer Levels for the 2001/02 Season[a,b]

	Yield (t/ha)			Protein Content (%)			Falling Number (sec)		
Cultivar	Suboptimal	Standard	Optimal	Suboptimal	Standard	Optimal	Suboptimal	Standard	Optimal
Betta-DN	2.059a	2.527a	3.133b	8.330a	8.200a	10.567b	282.0a	314.3a	311.7a
Caledon	2.203a	2.420a	3.597b	8.800a	9.100a	11.100b	312.7a	342.3a	343.0a
Elands	2.253a	2.813a	3.382b	7.967a	9.267b	10.000b	365.3a	378.0a	335.3a
Gariep	2.337a	2.300a	3.206b	8.000a	8.700a	10.933b	302.7a	332.7ab	355.0b
Limpopo	2.303a	2.609a	2.867a	8.467a	8.600a	10.067b	300.3a	364.7b	336.7b
PAN 3191	2.520a	2.850a	3.696b	8.433a	8.567a	10.733b	326.0a	323a	355.0a
PAN 3235	2.400a	2.465a	3.505b	8.500a	10.400b	10.367b	289.7a	296.7a	343.7b
PAN 3349	1.789a	2.698b	3.855c	9.067a	8.133a	9.267a	327.0a	338.3a	367.3a
PAN 3364	2.586a	2.918a	3.140b	8.500a	8.733a	9.933b	279.7a	282.3a	311.0a
PAN 3377	2.847a	3.170a	2.979a	9.033ab	8.567b	9.967a	310.0a	325.7ab	352.3b
SST 124	2.013a	2.203a	1.874a	9.467a	9.733a	11.500b	351.0a	344.0a	342.0a
SST 333	1.985a	2.054a	2.811b	10.500a	10.667a	12.000b	346.3ab	340.0a	375.0b
SST 363	1.902a	1.995a	2.056a	8.867a	9.267a	10.667b	333.0a	328.0a	358.3a
SST 399	2.619a	2.743a	3.089a	8.033a	8.300a	9.833b	307.7a	314.3a	350.3b
SST 966	3.001a	3.487a	4.648b	8.100a	8.367a	9.600b	299.0a	299.3a	357.7b
CV (%)		15.4			7.5			6.2	
LSD (0.05)		0.6054			1.1242			33.07	

[a] Suboptimal = 0 N, P, K (kg/ha); standard = 20 N, 5 P, 5 K (kg/ha); optimal = 60 N, 15 P, 15 K (kg/ha).
[b] Individual cultivar values for yield, protein, and Hagberg Falling Number followed by the same letter are not significantly different ($P < 0.05$).

TABLE II
Average Yield, Protein Content, and Hagberg Falling Number for 15 Dryland Cultivars Evaluated at Three Fertilizer Levels for the 2002/03 Season[a,b]

	Yield (t/ha)			Protein Content (%)			Falling Number (sec)		
Cultivar	Suboptimal	Standard	Optimal	Suboptimal	Standard	Optimal	Suboptimal	Standard	Optimal
Betta-DN	1.432a	2.461b	2.115ab	11.867a	11.833a	12.167a	335.7a	344.7a	353.7a
Caledon	2.216a	2.143a	2.269a	10.833a	11.333a	11.733a	330.0a	342.7ab	370.3b
Elands	1.977a	2.315a	2.234a	10.667a	10.600a	11.533a	325.7a	331.0a	337.7a
Gariep	1.930a	2.283a	2.392a	10.667a	10.467a	11.100a	328.3a	346.0a	319.0a
Limpopo	2.360a	1.805a	2.240a	10.867a	11.333a	11.533a	320.3a	316.0a	339.0a
PAN 3191	1.495a	2.263b	2.068ab	11.833a	12.067a	12.833a	264.0a	337.0b	291.7a
PAN 3235	1.853a	1.861a	1.861a	10.500a	12.000b	11.700ab	321.7a	349.0a	331.7a
PAN 3349	2.062a	2.500a	2.836ab	10.733a	10.667a	11.200a	312.3a	329.0a	326.3a
PAN 3364	1.638a	2.562b	2.233ab	12.467a	12.033a	12.600a	296.0a	325.3a	328.7a
PAN 3377	2.291a	2.676ab	3.187b	10.567a	11.500ab	11.967b	291.3a	296.0a	326.3a
SST 124	1.409a	1.797a	1.893a	12.467a	12.467a	12.667a	327.3a	346.0a	346.3a
SST 333	2.401a	2.075a	2.087a	12.600a	12.133a	13.100a	330.3a	337.3a	336.3a
SST 363	1.034a	1.485a	1.978a	11.330a	10.933a	11.433a	302.3a	326.3a	331.3a
SST 399	0.526a	1.190b	0.884ab	12.000a	12.300a	13.467b	318.7a	305.0a	286.3a
SST 966	2.820a	2.474a	2.716a	10.867a	10.733a	11.367a	298.3a	302.7a	322.0a
CV (%)		20.0			6.2			6.6	
LSD (0.05)		0.7123			1.3139			36.93	

[a] Suboptimal = 0 N, P, K (kg/ha); standard = 20 N, 5 P, 5 K (kg/ha); optimal = 60 N, 15 P, 15 K (kg/ha).
[b] Individual cultivar values for yield, protein, and Hagberg Falling Number followed by the same letter are not significantly different ($P < 0.05$).

groups (cultivar-by-treatment combinations). The plots of canonical variate means for each group indicated the group positions relative to one another (i.e., an indication of the general performance with regard to the characteristics measured) is obtained for each of the cultivar-by-treatment combinations relative to each other. In such a plot, points closer together are similar, and points further apart are dissimilar, with respect to the variates that discriminate between them. The criteria used for describing the optimum classification were the minimum within-group sum of squares method. Data analysis was performed with GenStat for Windows 2003 (7th Ed. R. W. Payne, ed).

RESULTS AND DISCUSSION

Climatic Conditions

The average monthly minimum and maximum temperatures experienced during 2001 and 2002 are indicated in Fig. 1. The 2002/03 season had lower minimum temperatures in October, November, and December but higher maximum temperatures than in 2001/02. The 2001/02 season had higher rainfall (Fig. 1) in comparison to the relatively drier 2002/03 season. Increased rainfall during December 2002, however, increased the risk of preharvest sprouting. Therefore, the 2001/02 season was a cooler moist season, with the 2002 season (for the larger period) being warm and dry.

The individual performance of the cultivars with regard to yield, protein content, and HFN over the two years is indicated in Table I (2001/02) and Table II (2002/03).

Yield

Most of the cultivars produced significantly higher yield with the optimal fertilizer treatment during the 2001/02 season (Table I). The standard treatment also resulted in increased yield with most of the cultivars evaluated but the increases were not significantly higher than those of the suboptimal treatment (control). Limpopo, PAN 3377, SST 124, SST 363, and SST 399 did not show any significant increase in yield as the fertilizer application increased (Table I). During the following season, nine of the 15 cultivars evaluated did not show any response to the fertilizer treatments. This observation may be attributed to climate conditions that were warmer and drier than the previous season, resulting in stressed growing conditions. This is indicated by lower average yield being measured over the 15 cultivars evaluated for the 2002/03 season compared with those of the 2001/02 season (Fig. 2). These findings are similar to those of Smith et al (1990), who indicated that yield response of cultivar Avalon to N varied with site.

Protein Content

Factors affecting the protein in wheat include cultivar, fertility, water, and temperature (Teman et al 1969). The average protein content for the 15 cultivars evaluated was higher for the 2002/03 season compared with the 2001/02 season (Fig. 2). This is consistent with the higher maximum temperatures experienced during the 2002/03 season. According to Corbellini et al (1997), temperature and fertilization contribute to the environmental effects on end-use quality. These authors indicated that temperature effects, particularly high temperatures during grain filling, can significantly elevate protein content while lowering the functionality of protein, ultimately changing the rheological properties of flour. This overall higher protein content measured for the 2002/03 season resulted in few differences being observed between the various fertilizer treatments (Table II). Significant reaction to the various treatments for the 2001/02 season was seen and was most prominent in the optimum treatment (Table I). This is consistent with the general perception that grain protein content increases with the amount of applied nitrogen, whether or not a yield increase resulted (Scleuber and Tucker 1959; Terman et al 1969).

Hagberg Falling Number (HFN)

The HFN for all the cultivars at the various treatments were above the 220-sec cut-off mark for grade for both seasons. The cooler moist conditions during the 2001/02 season resulted in an

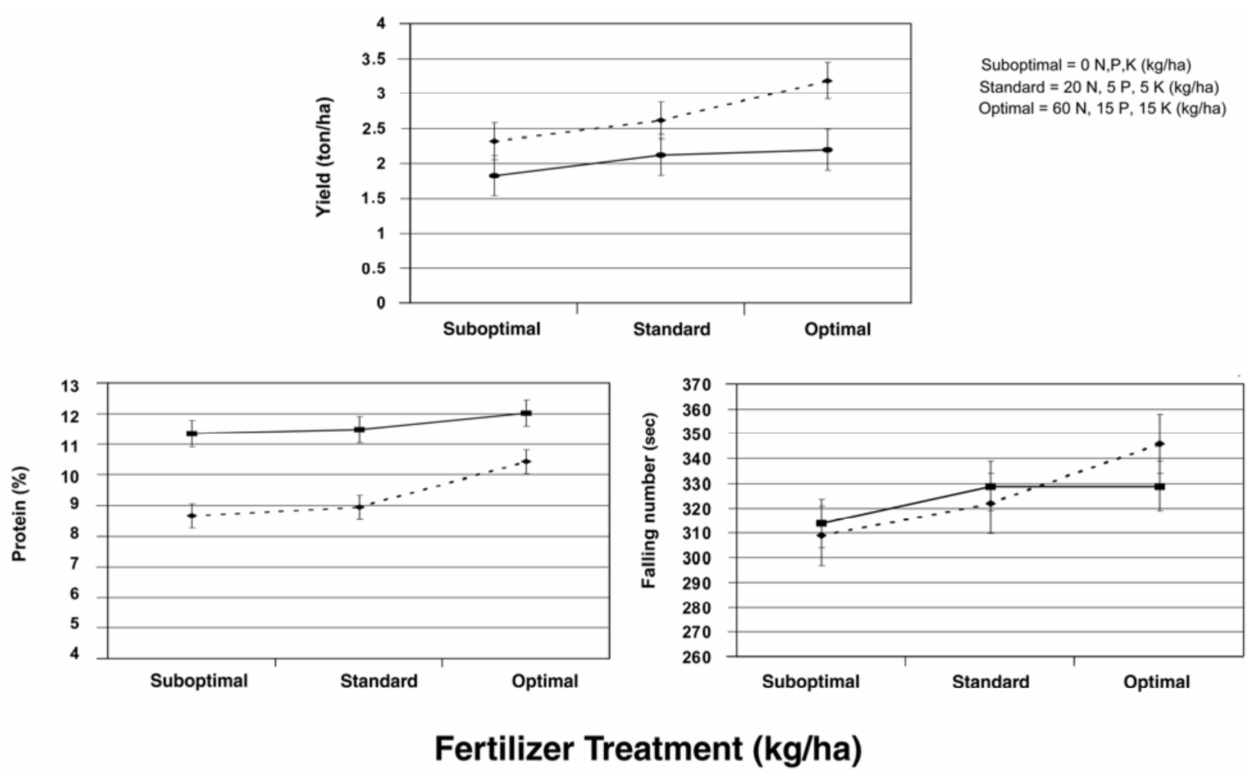

Fig. 2. Average yield, protein, and Hagberg Falling Number response of 15 dryland cultivars to fertilizer level during 2001/02 (dashed line) and 2002/03 (solid line). Standard error of means is indicated.

average increase in HFN for the 15 cultivars evaluated with an increase in fertilizer level (Fig. 2). A similar trend could not be obtained during the warmer 2002/03 season.

During the 2001/02 season, Gariep and PAN 3377 produced significantly better HFN with the optimum fertilizer treatment; the standard treatment did not differ significantly from the control or optimum treatments (Table I). Limpopo gave significantly better HFN for both the standard and optimum treatments compared with the control. PAN 3235, SST 399, and SST 966 all gave significantly higher HFN with the optimum fertilizer treatment. The eight remaining cultivars did not show any response to the fertilizer treatment during the 2001/02 season. During the 2002/03 season, the HFN response was limited to only two cultivars.

With a comparison of interaction means of the pooled data (2001/02 and 2002/03) for each of the cultivars individually with the use of least significant differences (LSD), significant cultivar differences were seen, which allowed for the classification of the 15 cultivars into four main groups regarding sensitivity to fertilizer treatment to individual HFN performance. The four groups identified were high, medium, low-to-medium, and low response (Table III).

As the main objective of this study was to investigate HFN, attention was given to grouping of cultivars according to performance regarding HFN at various fertilizer treatments. The definitions of the four groups are shown in Fig. 3.

The low response cultivars did not show significant differences over all treatment levels. It therefore appears that fertilizer treatment does not have any effect on HFN. Cultivars included in this group were Gariep, SST 124, SST 333, and SST 399. The second group (low-to-medium response) indicated that the suboptimum and the standard treatments did not differ significantly; the standard and optimum treatments also did not differ significantly. The suboptimum and optimum treatments therefore differed significantly. These cultivars were grouped into the low-to-medium response class, as there appeared to be a very small but gradual improvement of HFN with increased fertilizer treatment. Cultivars in this group included Caledon, Betta-DN, SST 363, PAN 3235, PAN 3349, and PAN 3364.

Medium response cultivars performed significantly better with the standard and optimum treatment than with the suboptimum treatment. These cultivars were grouped, as they should generally perform equally well at the standard and optimum fertilizer treatments regarding HFN, but they may experience a lower than expected HFN should N availability be limited due to leaching or insufficient application at the beginning of the growing season. The cultivars included under this response were PAN 3191 and Limpopo.

The last group (high response) was classed due to its tendency to perform effectively at optimum fertilizer treatment. This group should be seen as a high response group because the optimum performance regarding HFN is linked only to optimum levels of fertilizers. The inaccessibility or insufficiency of N may result in reduced HFN, lower than the potential for HFN for these cultivars (i.e., highest obtainable HFN if sufficient N were available within the seasonal specifications). Cultivars included in this group were SST 966, PAN 3377, and Elands.

The study also indicated that yield, as well as protein content, is influenced by fertilizer treatments. The grouping of sensitive cultivars should therefore not only be restricted to HFN but should also be applied to yield and protein responses. For this purpose, a CVA was performed.

The CVA indicated that the horizontal axis (CVA 1) explained 62.42% of the measured variation. Correlation between the scores (CVA 1 + CVA 2) and the parameters of investigation (yield, protein content, and HFN) indicated that yield had the highest correlation (0.778). This indicates that yield was responsible for the variation between the different points on the horizontal level. On a vertical level (CVA 2), due to the highest correlation (0.863), HFN was responsible for most of the variation observed on the vertical axis and explained 28.98% of the total variation measured. In conclusion, yield and HFN were the main factors distinguishing

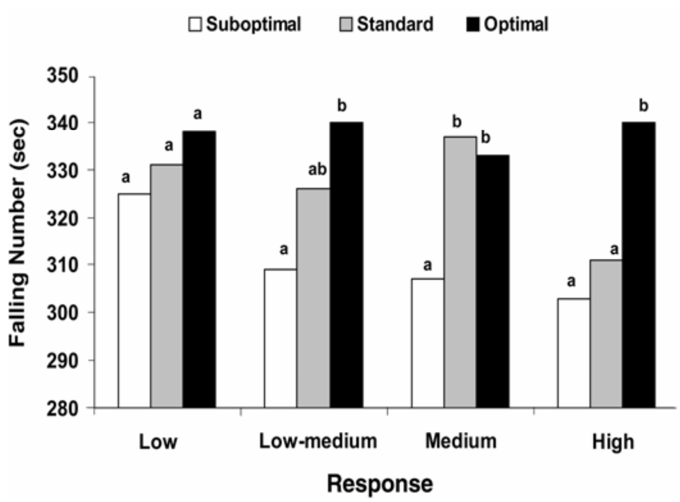

Fig. 3. Cultivar grouping into low, low to medium, medium, and high response groups at different fertilizer treatments according to Hagberg Falling Number (sec) performance (LSD = 23.7 sec).

TABLE III
Classification of 15 Cultivars into Response Groups According to Hagberg Falling Number (HFN) Reaction to Fertilizer Treatment Over Two Seasons[a]

Main HFN Response Groups	Cultivar	Protein Content (%)	Yield (t/ha)
High	SST 966	High	High
	PAN 3377	High	Low-to-Medium
	Elands	Low-to-Medium	Low-to-Medium
Medium	PAN 3191	High	Medium
	Limpopo	Low-to-Medium	Low
Low-to-medium	Caledon	High	High
	Betta-DN	High	Medium
	SST 363	High	Low-to-Medium
	PAN 3235	Medium	High
	PAN 3349	Low	High
	PAN 3364	Low	Medium
Low	Gariep	High	High
	SST 124	High	Low
	SST 333	High	Low
	SST 399	High	Low

[a] Similar classifications for protein content and yield are indicated within the set response groups for HFN.

between the 45 treatment-by-cultivar combinations on the graph and explained 91.4% of the total variation (Fig. 4).

With the use of the CVA, the initial classification according to HFN through split-plot ANOVA could be extended to yield as well as protein response. Table IV represents the final classification of the cultivars. As the data obtained from the CVA gave a combined reaction of yield, protein, and HFN to fertilizer treatment, the initial grouping was altered. As this specific study was centered on the HFN response of various cultivar-to-fertilizer treatments, four main response groups (high, medium, low-to-medium, low response) were maintained. The combined performance of each cultivar is indicated with the use of the canonical variate means used to plot the different cultivars on the CVA graph (Fig. 4). By adding the *x*- and *y*-axis coordinates for each cultivar, a potential response value is obtained (Table IV). The more negative the value, the poorer the performance of the cultivar for the combined factors. The closer the value is to zero, the more average a response was obtained. The more positive the value, the higher the performance of the cultivar for all three factors. A good example is T1: Elands in the bottom-left quadrant and T3: SST 333 in the top-right quadrant of Fig. 4. T1: Elands represents the performance of Elands at the suboptimum level (treatment 1) and indicates that the cultivar is situated further from the 0:0 point of all the cultivars in the lower than average yield and HFN quadrant. T3: SST 333 represents SST 333 at the optimum fertilizer treatment (treatment 3). This cultivar is also situated further from the 0:0 point but in the quadrant for higher than average yield and HFN. According to Table IV, Elands (suboptimum fertilizer treatment) indicated a performance potential of –2.1425, the lowest potential of all the cultivars, with SST 333 (optimum) the highest potential (2.581). According to Fig. 4, these two cultivars represent the lowest and highest potential cultivars, which is reflected in the potential value assigned to each in Table IV.

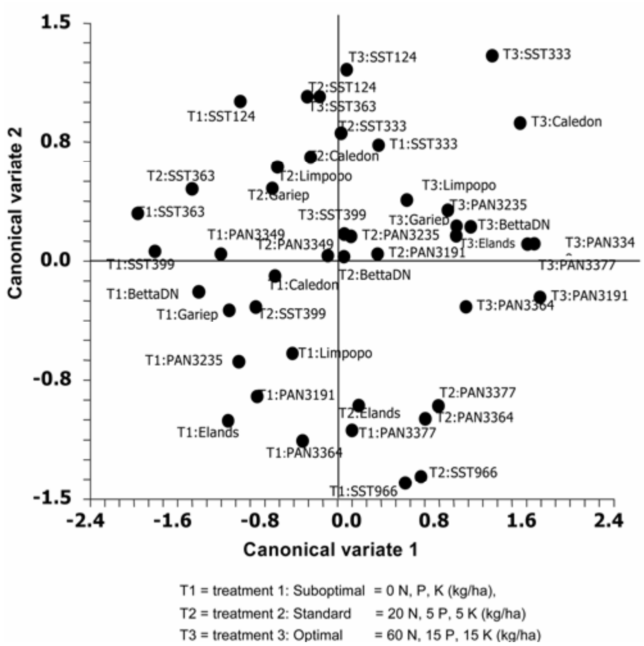

Fig. 4. Canonical variate analysis (CVA) of the Hagberg Falling Number response of 15 South African wheat cultivars to various fertilizer applications over two seasons of evaluation.

These results should be seen as a guideline for the cultivation of these cultivars. It is general practice to fertilize to obtain high yields with good protein content. Should fertilizer application be insufficient, the high response cultivars (i.e., Elands, PAN 3377, and SST 966) will not be able to obtain optimum HFN for the season. These findings are also important should leaching of nitrogen due to heavy rain be a problem in certain areas.

The reason for the increase in HFN with optimum fertilizer treatment observed in the response group is unknown. Both Jönsson (1966) and Kettlewell (1999) reported that increased N application resulted in increased HFN due to decreased alpha-amylase activity in glasshouse as well as field trials. Kettlewell (1999) further speculates that prematurity alpha-amylase (PMAA) is responsible for the increase in HFN by N in the absence of sprouting. PMAA can arise in certain cultivars (Flintham and Gale 1988) and is speculated to be simulated when grains dry slowly during ripening (Gale et al 1983). Pushman and Bingham (1976) found that N application resulted in decreased alpha-amylase in some of the cultivars evaluated and no effect in the others, which could explain the cultivar effect indicated in the current study. Retained pericarp alpha-amylase activity (RPAA) refers to the type of enzymes located in the pericarp of immature grains and which activity declines greatly by harvest (Olered and Jönsson 1970). RPAA is capable of reducing the HFN of cultivars that contain unripe grains at harvest (Lunn et al 1997). According to Kettlewell (1999), crops that tend to suffer from such RPAA when a second, later population of tillers develop, the effect of N

TABLE IV
Classification of 15 Dryland Cultivars for Hagberg Falling Number (HFN), Yield, and Protein Response to Fertilizer Treatments Calculated from Canonical Variate Analysis (CVA)[a,b,c]

HFN Classification	Cultivar	Suboptimal		Standard		Optimal	
		Potential	Rank	Potential	Rank	Potential	Rank
High response	Elands	–2.1425	15	–0.8481	13	1.1144	11
	PAN 3377	–1.0675	5	–0.1193	8	1.7151	5
	SST 966	–0.9095	4	–0.7277	12	2.1294	3
Medium response	PAN 3191	–1.7236	13	0.2799	3	1.4960	6
	Limpopo	–1.1289	6	–0.0900	7	0.8858	12
Medium-to-low response	PAN 3235	–1.6723	12	0.1467	5	1.1982	8
	SST 363	–1.6652	11	–1.0110	14	0.6160	14
	Betta–DN	–1.5970	10	–0.0465	6	1.1803	9
	PAN 3364	–1.5848	9	–0.3221	11	0.7582	13
	PAN 3349	–1.1581	7	–0.1867	9	1.7770	4
	Caledon	–0.7993	3	0.2760	4	2.4132	2
Low response	SST 399	–1.7459	14	–1.1684	15	0.0998	15
	Gariep	–1.4338	8	–0.2732	10	1.3051	7
	SST 124	–0.0175	2	0.6269	2	1.1578	10
	SST 333	0.9755	1	0.7065	1	2.5810	1

[a] Classification according to HFN response to fertilizer treatment spit plot analysis.
[b] Suboptimal = 0 N, P, K (kg/ha); standard = 20 N, 5 P, 5 K (kg/ha); optimal = 60 N, 15 P, 15 K (kg/ha).
[c] HFN is the main factor; combined HFN, yield, and protein performance are subfactors. Rank indicates position of cultivars with regard to all three factors.

on the HFN may be of commercial significance as the effect may result in the HFN being lowered to unacceptable levels.

Clare et al (1990) concluded that as the response of HFN to N was similar to the response of yield, crops would unlikely suffer reduced HFN due to the fact that crops are generally fertilized for yield. This is confirmed by the current study. What makes the classification of cultivars into response groups necessary in the South African wheat industry are the varying climatic conditions experienced over the whole of the wheat-producing area.

Cultivars that remain constant with regard to HFN, irrespective of the fertilizer treatment, may be ideal for areas with limited N availability.

CONCLUSIONS

An investigation into the effect of fertilizer treatment indicated that fertilizer had, in general, no statistically significant effect on the wheat HFN. However, cultivar differences did allow for the individual effect of fertilizer on the HFN of these cultivars to be identified. This allowed for the grouping of cultivars into four response groups: low, low-to-medium, medium, and high. Classification was refined with the use of CVA (HFN, yield, and protein). HFN measured were never <220-sec cut-off mark for grade.

The results indicated that crops are unlikely to suffer reduced HFN (<220 sec) due to insufficient plant nutrition. In addition, the risk of reduced HFN is minimized by the fact that the current level of fertilization followed by most commercial farmers is aimed at high yield and protein content. It was established that certain cultivars tend to respond more to changes in N treatment than others. Changes in the amount of N, for whatever reason, may therefore have a detrimental effect on these cultivars.

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