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The effect of the year of wheat variety release on productivity and stability of performance on two organic and two non-organic farms

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SUMMARY

Nineteen wheat cultivars, released from 1934 to 2000, were grown at two organic and two non-organic sites in each of 3 years (2004–05, 2005–06 and 2006–07). Assessments included grain yield, grain protein concentration, protein yield, disease incidence and green leaf area (GLA). The superiority of each cultivar (the sum of the squares of the differences between its mean in each environment and the mean of the best cultivar there, divided by twice the number of environments; CS) was calculated for yield, grain protein concentration and protein yield, and ranked in each environment. The yield and grain protein concentration CS were more closely correlated with cultivar release date at the non-organic sites than at organic sites. This difference may be attributed to higher yield levels with larger differences among cultivars at the non-organic sites, rather than to improved stability (i.e. similar ranks) across sites. The significant difference in the correlation of protein yield CS and cultivar age between organic and non-organic sites would support evidence that the ability to take up mineral nitrogen (N) compared to soil N has been a component of the selection conditions of more modern cultivars (released after 1989). This is supported by assessment of GLA, where more modern cultivars in the non-organic systems had greater late-season GLA, a trend that was not identified in organic conditions. This effect could explain the poor correlation between age and protein yield CS in organic compared to non-organic conditions where modern cultivars are selected to benefit from later nitrogen (N) availability which includes the spring nitrogen applications tailored to coincide with peak crop demand. Under organic management, N release is largely based on the breakdown of fertility-building crops incorporated (ploughed-in) in the previous autumn. The release of nutrients from these residues is dependent on the soil conditions, which includes temperature and microbial populations, in addition to the potential leaching effect of high winter rainfall in the UK. In organic cereal crops, early resource capture is a major advantage for maximizing the utilization of nutrients from residue breakdown. It is concluded that selection of cultivars under conditions of high agrochemical inputs selects for cultivars that yield well under maximal conditions in terms of nutrient availability and pest, disease and weed control. The selection conditions for breeding have a tendency to select cultivars which perform relatively better in non-organic compared to organic systems.

INTRODUCTION

Over the last half century plant breeding, with a particular emphasis on cereals, has resulted in significant improvements in overall production (Murphy *et al.* 2008). The increases in yield and quality, particularly of wheat, have largely been achieved by changes in agronomic practices and a corresponding selection of cultivars under those conditions (Austin 1999). Such changes include the widespread use of fertilizers, pesticides and growth regulators, which in effect provide more controllable field conditions for the crop (extended nutrient availability and low weed, pest and

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disease pressure). Despite these major advances, there remain shortfalls in the performance of modern cultivars under conditions of greater field heterogeneity (Wolfe *et al.* 2008).

Low input and organic farming systems are dominated by variation in field conditions between years and sites as a consequence of reduced levels of inputs compared to more intensive systems. Major contributors to this variation are the relatively high weed pressures and nutrient release profiles (Wolfe *et al.* 2008). In organic systems, high concentrations of nutrients are rarely available at peak crop demand (MAFF 1988; Pang & Letey 2000). Instead, nutrient release is dependent on the temperature and biological activity of the soil and its interaction with the declining residues from a previous leguminous fertility-building crop and/or farmyard manure. As a consequence, it is not always possible to match nutrient release with crop demand over time.

Most cereal cultivars available to organic farmers in the UK are those that have been selected under conditions of high-input management. These cultivars often do not achieve the yields or protein content, or the consistency under organic conditions that they do in more intensive farming systems. Recent work has identified that cultivars better adapted to organic conditions are those with relatively rapid establishment and resource capture which are able to take advantage of the early nutrient release from fertility building leys (Baresel *et al.* 1998; Addisu *et al.* 2010). In contrast, under conditions of high input, cultivars that exhibit extended nitrogen uptake capacity with less emphasis on ability to compete against weeds are favoured (Foulkes *et al.* 1998; Wolfe *et al.* 2008). In the present paper, farm management using agrochemical inputs, which can be referred to as intensive, high input or conventional will be termed 'non-organic'; this will differentiate the two non-organic sites from the two organic sites.

Nineteen cultivars, released to market from 1934 to 2000, were studied for three seasons at two organic and two non-organic sites to provide insights into the effect of selection on yield, protein concentration and protein yield and stability of these characters, and whether any improvements ascribed to modern breeding are more apparent at organic or non-organic sites.

MATERIALS AND METHODS

Selection of genotypes

Wheat (*Triticum aestivum* L.) genotypes were selected in 2002 and were predominantly cultivars from Western Europe that were either popular themselves, or parents of successful cultivars, at or around their time of release (Table 1). The three exceptions were High Tillering Line (HTL), which is a breeding line, Bezostaya, which is a Russian cultivar dating from 1959 and Thatcher, a high quality, rust resistant variety released from the University of Minnesota in 1934. The selection of cultivars was based on obtaining a high level of genetic diversity, so fewer of the cultivars included were released prior to 1972 than after. The 19 cultivars were comprised of two groups: those selected for high yield potential (Bezostaya, Buchan, Claire, Deben, HTL, Option, Tanker and Wembley), the 'feed' group; and those selected for bread-making potential (Bezostaya, Cadenza, Hereward, Maris Widgeon, Mercia, Monopol, Pastiche, Renan, Renesansa, Soissons, Spark and Thatcher), the 'milling' group. For the purposes of analysis, all cultivars were also included in a third group 'all'. Bezostaya was included in all three groups because it was regarded as both high yielding and high quality. The parent age was taken to be the number of years from the registration date up to 2008, with the exception of HTL which was released as breeding material in 1985.

Site description

The cultivars were sown at two organic sites: Wakelyns Agroforestry, in Suffolk (52°39′N, 1°17′E) and Sheepdrove Organic Farm in Berkshire (51°31′N, 1°30′W); and two non-organic sites: Metfield Hall Farm, continuous wheat, adjacent to Wakelyns in Suffolk (52°41′N, 1°29′E) and Morley Farm, a research farm in Norfolk managed by The Arable Group (52°56′N, 1°10′E). The mean monthly weather variation over the period of early crop growth is given in Table 2 for each site and for Year 1 (2004/05), 2 (2005/06) and 3 (2006/07). Data are omitted where technical errors in the weather stations occurred.

Experiments were carried out in different fields (or areas of field) within the rotation in each year. Wakelyns had a soil type of sandy-loam over clay with clay content in the range 23–26% by volume, pH 7·4–8·0, organic matter in the range of 23–28 g/kg and low indices for P and K. Sheepdrove had a soil type of clay-loam over chalk with clay content of *c.* 40% by volume, pH 7·8, and organic matter in the range of 35–49 g/kg. Metfield had a soil type of sandy-loam over clay with clay content *c.* 16% by volume, pH 7·6–7·9, organic matter *c.* 20 g/kg and Morley had a soil type of sandy loam with a clay content *c.* 21% by volume, pH 7·5–7·7, and organic matter in the range of 17–20 g/kg. The N applications at the two non-organic sites (Metfield and Morley) were from mid-March to early April (*c.* growth stage (GS) 30 (Zadoks *et al.* 1974)) were 156, 129 and 129 kg N/ha at Morley and 83, 172 and 129 kg N/ha at Metfield for trial Years 1, 2 and 3, respectively. The late N applications in May (*c.* GS 39) were 66, 49 and 32·4 kg N/ha at Morley and 106, 64 and 67 kg N/ha

Table 1. *Cultivars with grain characteristics, use, parentage, breeder, country of origin, registration date and pedigree. The category refers to the grouping used in the analyses. Missing data are indicated by '–'*

Cultivar	Category	Winter/Spring	Parentage	Breeder	Country of origin	Registration date	Endosperm (soft/hard)	Grain use
Bezostaya	Both	Winter	(Lutescens 17 × Skorospelka 2)	–	Russia	1959	–	–
Buchan	Feed	Winter	(Beaver × Hussar)	Nickerson	UK	1995	Soft	Feed
Cadenza	Milling	Spring	(Axona × Tonic)	CPB Twyford	UK	1995	Hard	Bread
Claire	Feed	Winter	(Wasp × Flame) COMPOSITE CROSS	Nickerson	UK	1996	Soft	Biscuit
Deben	Feed	Winter	((Hunter × Buster) × Wasp) COMPOSITE CROSS	Nickerson	UK	1998	Soft	Feed
Hereward	Milling	Winter	(Norman 'sib' × Disponent)	PBIC	UK	1990	Hard	Bread
HTL	Feed	Winter	(TL363/30/2 × Talent)	R. Austin/JWS	UK	n/a	n/a	n/a
Maris Widgeon	Milling	Winter	(Holdfast × Cappelle Desprez)	PBIC	UK	1964	Hard	Bread
Mercia	Milling	Winter	((Talent × Virtue) × Flanders)	PBIC	UK	1989	Hard	Bread
Monopol	Milling	Winter	(Pantus × Admiral)	–	Canada	1980	–	–
Option	Feed	Winter	(Rialto 'sib' × Vivant)	PBIC	UK	2000	Hard	Bread
Pastiche	Milling	Winter	(Jena × Norman)	PBIC	UK	1988	Hard	Bread
Renan	Milling	Winter	((Mironov 808 × Maris Huntsman) × (VPM × Moisson) × Courtot)	INRA, France	France	1989	–	–
Renesansa	Milling	Winter	(Jugoslavija × NS55-25)	–	–	1994	–	–
Soissons	Milling	Winter	(Jena × HN35)	Maison Florimund-Desprez Cappelle-en-Pevele	France	1996	Hard	Bread
Spark	Milling	Winter	(Moulin × Tonic)	Nickerson	UK	1991	Hard	Bread
Tanker	Feed	Winter	(Beaver × Zodiac)	Elsoms	UK	1998	Hard	Feed
Thatcher	Milling	Spring	((Marquis × Kanred) × Marquillo)	–	UK	1934	–	–
Wembley	Feed	Spring	((Hobbit × Sona 227) × Sicco)	PBIC	UK	1985	Hard	Bread

Table 2. *Monthly weather data for each experimental site in 2004/05, 2005/06 and 2006/07. Missing data are indicated by '–'*

	Rainfall (mm)				Mean temperature (°C)			
Months	2004/05	2005/06	2006/07	Mean	2004/05	2005/06	2006/07	Mean
Site: Morley								
Sep	–	–	–	–	–	–	–	–
Oct	78	68	–	73·1	10·6	13·4	–	12·00
Nov	56	55	2	37·6	7·1	6·0	9·2	7·44
Dec	40	21	113	58·2	4·7	3·8	5·9	4·80
Jan	48	19	–	33·5	5·4	3·8	6·5	5·26
Feb	61	52	–	56·6	3·4	3·5	5·2	4·04
Mar	45	37	–	41·2	6·2	4·0	6·6	5·61
Apr	37	35	–	35·9	8·6	7·7	10·2	8·82
May	49	66	–	57·6	10·9	11·8	11·3	11·34
Jun	62	22	–	42·3	14·7	15·2	14·4	14·77
Jul	58	37	–	47·4	15·9	19·9	15·3	17·03
Aug	41	153	–	97	15·4	15·7	15·3	15·48
Site: Wakelyns and Metfield								
Sep	–	–	–	–	–	–	–	–
Oct	95	71	–	83·30	11·0	13·6	–	12·32
Nov	49	37	59	48·13	7·4	6·1	8·6	7·36
Dec	33	40	52	41·67	4·9	3·8	6·0	4·94
Jan	37	14	59	36·73	5·6	3·9	6·6	5·35
Feb	42	57	86	61·73	2·0	3·4	5·4	3·61
Mar	42	42	47	43·53	6·2	4·0	6·8	5·67
Apr	41	12	–	26·40	8·7	6·0	–	7·32
May	79	76	–	77·40	11·0	11·5	–	11·29
Jun	50	17	–	33·10	14·9	15·0	–	14·94
Jul	78	10	–	44·10	16·0	19·9	–	17·94
Aug	75	150	–	112·70	15·6	15·6	–	15·56
Site: Sheepdrove								
Sep	–	–	–	–	–	–	–	–
Oct	140	69	113	107·3	9·9	12·3	12·2	11·44
Nov	39	62	316	138·8	7·0	5·4	7·6	6·66
Dec	53	61	60	57·9	4·6	3·8	5·6	4·69
Jan	39	0	97	45·1	5·2	3·4	6·1	4·86
Feb	27	0	86	37·7	3·1	2·4	5·4	3·62
Mar	54	27	56	45·8	5·9	4·0	6·1	5·33
Apr	59	19	1	26·0	8·1	7·6	10·5	8·73
May	48	91	115	84·7	10·4	11·3	11·0	10·89
Jun	38	20	92	50·1	14·6	15·4	14·2	14·74
Jul	50	63	198	103·7	16·0	19·1	14·2	16·41
Aug	47	54	54	53·0	15·7	15·5	14·8	15·35

at Metfield for Years 1, 2 and 3, respectively. The pesticide applications at these sites followed commercial practice. The preceding crop was grass-clover or grass-vetch-clover ley at Wakelyns, grass-clover at Sheepdrove, winter wheat at Metfield and winter oil seed rape at Morley. Plots were drilled in the three successive years: on 6 October 2004, 3–4 October 2005 and 4 October 2006 at Metfield; 25 October 2004, 12 October 2005, 5 October 2006 at Morley; 11 November 2004, 14 October 2005, 17 October 2006 at Sheepdrove; and 13 October 2004, 7 October 2005, and 4 October 2006 at Wakelyns.

Experimental design and conduct

In each experiment, the cultivar plots were randomized in three blocks. Plot size was $20 \times 1{\cdot}45$ m at Sheepdrove and $20 \times 1{\cdot}2$ m at the other three sites. All experiments were established in the autumn of each year and combined at harvest maturity (moisture content <200 g/kg). Seed rate was 170 kg/ha for non-organic sites and 200 kg/ha for organic sites. Calculations were based on an average target plant density of 425 plants/m^2, given a mean thousand-grain weight (TGW) of 40 g in Year 1, and in subsequent years the TGW was calculated for each cultivar. At the organic sites, seed rates were adjusted to take into account an expected mean plant mortality of 0·15.

Assessments

In each year, assessments of powdery mildew (*Blumeria graminis*), yellow rust (*Puccinia striiformis*), brown rust (*Puccinia recondita*), Septoria blotch (*Septoria* spp.), GLA, grain yield (t/ha@150 g moisture/kg) and grain protein concentration (mg/g) were conducted on all plots. Mean GS was determined for relevant assessment using a decimal scale (Zadoks *et al.* 1974).

Disease assessments took place between GSs 37–93 (May–August) to capture information on levels of infection prior to leaf senescence. Area of powdery mildew, brown and yellow rust, *Septoria* spp. and GLA (proportion) were assessed on 10 randomly selected flag leaves per plot. Grain moisture content at harvest was determined by conductivity (Protimeter Grainmaster I; GE Protimeter plc, Buckinghamshire) such that yields could be corrected to 150 g/kg moisture content. Grain samples from each plot were assessed for grain protein using the wet chemistry method of Dumas combustion.

Analysis

Cultivar superiority (CS) and residual maximum likelihood (REML) analyses were carried out using Genstat® version 10, 2007 (VSN International Ltd, Hemel Hempstead, UK). The program was adapted by R. Payne (personal communication) for CS analysis from the statistical method of Lin & Binns (1988). For each cultivar, this is the sum of the squares of the differences between its mean in each environment and the mean of the best cultivar there, divided by twice the number of environments. A low CS value indicates a cultivar that has high and stable performance. The CS analysis provides an overall rank of variety performance across sites. The CS analysis of rank is different from an analysis of the mean rank at each individual site (4 sites over 3 years) because there is only one value for each data set (e.g. two organic sites, 3 years). The rank values can be analysed using ANOVA to derive an S.E.D. (and a *P* value) appropriate for comparing overall yield in organic *v.* yield in non-organic systems. The REML variance components analysis used grain yield as the response variate, the fixed model was Constant + system + system × cultivar, and the random model was Experiment + Experiment × block.

RESULTS

The weather conditions during early growth indicated that 2006/07 was a wetter year compared to the other trial years across the four trial sites and Sheepdrove (the most westerly site) generally received higher rainfall overall. The mean yields in 2004/05 and 2005/06 were higher at Metfield compared to Morley. No clear differences are evident for the mean temperature or rainfall, and differences in mean yield may be attributed to other environmental factors. In 2004/05 and 2005/06, the mean yield at Wakelyns exceeded Sheepdrove; Sheepdrove was generally wetter and cooler and may explain a proportion of the difference in cultivar performance between the two organic sites (Table 2).

A REML variance component analysis for yield (Fig. 1) shows there was no clear trend in any of the 3 years of the relative contribution of site to the cultivar yield variability at the two organic sites (Sheepdrove and Wakelyns) or the non-organic sites (Metfield and Morley).

Grain yield was, on average, 44% lower in the organic compared to non-organic systems, with the greatest yields recorded for Morley followed by Metfield, Sheepdrove and Wakelyns. The average yields for Year 1 were 7·60 t/ha, 7·80 t/ha for Year 2 and 6·53 t/ha for Year 3. The highest mean yield recorded was for Deben and the lowest for Bezostaya (Table 3); based on the yield figures alone, Deben or Mercia may be considered the best choice for all systems. Deben and Bezostaya had the highest and the lowest ranks, respectively, in the feed group for yield CS in both organic and non-organic systems, and across all four sites (where 'highest ranking' means the lowest value in the table, and vice versa, as a lower CS value indicates greater stability; Table 4). In the milling group, the highest rank of yield CS was recorded for Mercia in organic and non-organic systems, and across all four sites (Table 5). For the 'all' group, the highest-ranking cultivar for yield was Deben and the lowest was Thatcher (Table 6). There was a tendency for Buchan (registered in 1995), Mercia (1989), Option (2000) and Tanker (1998) to perform relatively better for ranking of yield CS at non-organic compared to organic farms; in contrast, Hereward (released in 1990), HTL (released as breeding material in 1985), Maris Widgeon (registered in 1964), Renan (1989) and Wembley (released in 1985) had relatively better yield CS in organic conditions (Table 6).

The mean protein concentration at the two non-organic farms was 128 mg/g compared to 116 mg/g (corrected to 150 g moisture per kg) at the organic farms. The highest grain protein levels were recorded at Metfield, followed by Morley, Sheepdrove and Wakelyns. The highest mean protein concentration was recorded in Year 2 at 135 mg/g and the least in Year 3 at 109 mg/g (Table 7), which corresponds to the weather data with Year 3 generally being wetter and cooler in May–July compared to Year 2 (Table 2).

Table 3. *Mean yields (t/ha@150 g/kg moisture content) with standard deviation (*s.d.*) of varieties at sites Metfield (Met), Morley (Mor), Sheepdrove (S) and Wakelyns (W) in trial years 2004/05, 2005/06 and 2006/07*

	Mean yield (t/ha@150 g moisture/kg)																	
	2004/05						2005/06						2006/07					
	Met	Mor	S	W	Mean	s.d.	Met	Mor	S	W	Mean	s.d.	Met	Mor	S	W	Mean	s.d.
Bezostaya	9·0	5·6	5·5	5·6	6·44	1·64	7·8	7·3	4·5	5·3	6·20	1·68	7·9	8·5	4·7	1·4	5·64	2·99
Buchan	11·8	9·2	5·8	6·5	8·34	2·57	10·5	10·3	5·7	7·1	8·39	2·24	10·2	10·8	4·9	1·9	6·94	3·89
Cadenza	10·9	7·5	4·4	6·2	7·21	2·52	8·1	8·6	5·1	5·7	6·88	1·73	9·7	9·5	4·8	2·4	6·60	3·26
Claire	11·9	8·9	5·6	7·6	8·49	2·58	10·4	9·9	6·4	8·3	8·77	1·74	10·8	10·6	4·8	3·1	7·30	3·61
Deben	12·6	10·1	5·8	8·0	9·11	2·71	11·9	10·7	6·2	9·3	9·55	2·25	10·8	11·4	5·5	3·7	7·83	3·50
Hereward	11·3	8·8	4·3	7·0	7·85	2·69	8·2	9·0	5·8	6·8	7·47	1·37	9·3	10·2	5·1	3·0	6·87	3·10
HTL	9·7	5·6	5·3	6·4	6·76	1·87	7·8	7·6	4·8	6·1	6·58	1·42	8·7	9·2	4·7	2·8	6·36	2·88
Maris Widgeon	7·4	6·2	6·7	6·6	6·74	0·92	8·1	7·4	5·4	5·6	6·61	1·29	6·9	7·5	4·8	2·3	5·40	2·20
Mercia	12·9	9·5	5·5	6·9	8·72	2·99	11·3	11·6	6·3	7·5	9·18	2·48	11·3	10·4	5·0	2·7	7·34	3·80
Monopol	10·4	7·3	4·2	6·4	7·08	2·80	8·0	8·0	4·5	5·7	6·53	1·63	9·6	9·3	4·8	2·2	6·44	3·25
Option	11·8	8·7	5·7	6·3	8·12	2·56	11·4	11·5	6·3	7·3	9·12	2·47	11·2	10·7	4·7	2·8	7·35	3·85
Pastiche	10·6	7·9	5·4	6·4	7·54	2·06	9·2	9·1	6·2	6·2	7·68	1·64	9·5	10·0	4·4	2·8	6·68	3·33
Renan	10·9	7·8	7·0	6·7	8·10	1·63	9·4	8·4	6·0	7·5	7·81	1·39	8·8	8·4	4·5	2·6	6·05	2·77
Renesansa	8·9	8·5	5·3	5·6	7·09	1·81	9·1	8·9	6·1	3·9	7·00	2·28	8·2	8·3	4·3	1·9	5·67	2·91
Soissons	11·3	9·4	6·7	6·2	8·39	2·26	10·4	10·6	7·4	7·0	8·83	1·86	9·1	10·4	4·8	2·5	6·68	3·36
Spark	11·4	8·6	5·9	6·6	8·16	2·29	9·9	10·1	6·6	6·7	8·33	2·01	10·7	10·7	4·9	2·8	7·25	3·71
Tanker	12·0	10·0	5·2	6·0	8·29	3·01	11·4	11·0	5·4	7·1	8·71	2·77	10·0	10·5	4·4	2·4	6·82	3·65
Thatcher	5·4	4·9	4·3	5·6	5·06	1·19	8·3	8·0	5·3	5·9	6·86	1·38	5·6	7·8	4·1	1·6	4·77	2·36
Wembley	10·8	8·9	5·1	6·3	7·76	2·42	9·9	9·2	7·7	7·4	8·54	1·17	9·4	8·9	4·9	3·3	6·64	2·72
Mean	10·6	8·1	5·5	6·5	7·64		9·5	9·3	5·9	6·7	7·84		9·4	9·6	4·7	2·5	6·56	

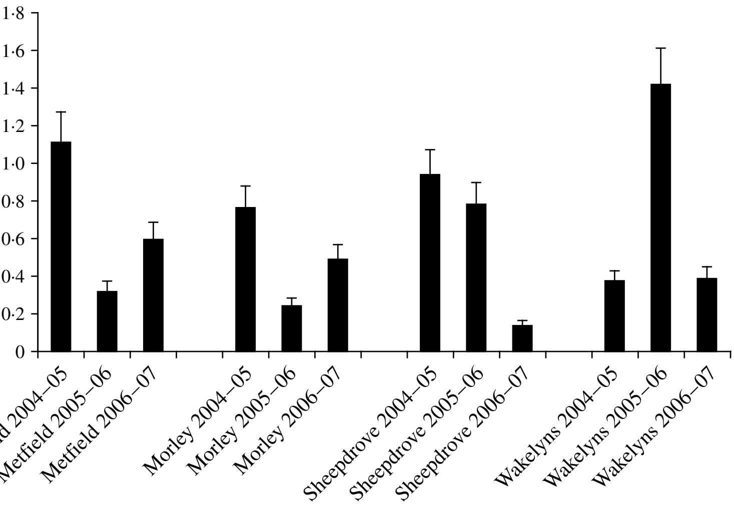

Fig. 1. Variance estimate for yield (t/ha@150 g moisture/kg) for four sites (Metfield, Morley, Sheepdrove and Wakelyns) for 3 years (2004/05, 2005/06 and 2006/07). The error bars indicate the standard error.

Within the milling group, the highest ranking cultivar for protein CS across systems was Thatcher and the lowest Mercia, with cultivars Bezostaya, Cadenza and Renesansa tending to rank higher in organic systems, and Maris Widgeon, Pastiche and Thatcher higher in non-organic systems (Table 5).

Protein yield was 48 % higher under non-organic compared to organic conditions, with the highest mean at Metfield, followed by Morley, Sheepdrove and then Wakelyns. The greatest mean protein yield was recorded in Year 2 and the least in Year 3 (Table 8). Within the milling group, Mercia, Pastiche,

Table 4. *The mean rank of CS in the feed category, for the characters of yield, protein content (mg/g) and protein yield for the two organic, two non-organic sites separately and for all four sites combined*

		Mean rank for yield			Mean rank for protein content			Mean rank for protein yield		
	Age	Organic	Non-organic	All sites	Organic	Non-organic	All sites	Organic	Non-organic	All sites
Bezostaya	49	7·2	7·8	7·5	4·2	3·6	3·9	4·5	5·8	5·2
Buchan	13	4·3	3·5	3·9	2·5	1·7	2·1	4·8	7·0	5·9
Claire	12	2·8	4·2	3·5	7·0	7·3	7·2	1·7	2·8	2·3
Deben	10	1·5	1·5	1·5	5·5	5·8	5·7	5·5	4·0	4·8
HTL	23	6·0	7·0	6·5	5·7	5·8	5·8	4·3	2·5	3·4
Option	8	4·0	3·0	3·5	1·2	1·5	1·3	5·3	7·5	6·4
Tanker	10	6·5	3·2	4·8	6·2	5·3	5·8	3·7	3·8	3·8
Wembley	23	3·7	5·8	4·8	3·8	4·9	4·4	6·2	2·5	4·3

Table 5. *The mean rank of CS in the milling category, for the characters of yield, protein content (mg/g) and protein yield for the two organic, two non-organic separately and for all four sites combined*

		Mean rank for yield			Mean rank for protein content			Mean rank for protein yield		
Cultivar	Age	Organic	Non-organic	All sites	Organic	Non-organic	All sites	Organic	Non-organic	All sites
Bezostaya	49	10·0	10·3	10·2	4·3	6·3	5·3	7·8	10·5	9·2
Cadenza	13	8·2	6·5	7·3	6·5	9·0	7·8	8·3	7·7	8·0
Hereward	18	4·0	5·0	4·5	9·2	9·0	9·1	6·0	6·0	6·0
Maris Widgeon	44	6·2	10·8	8·5	5·6	2·8	4·2	5·0	10·5	7·8
Mercia	19	2·8	1·2	2·0	11·8	11·8	11·8	7·7	2·3	5·0
Monopol	28	8·8	8·0	8·4	6·7	6·5	6·6	8·5	7·7	8·1
Pastiche	20	6·0	5·3	5·7	5·3	3·9	4·6	4·5	3·7	4·1
Renan	19	4·3	6·8	5·6	3·2	3·0	3·1	2·3	5·7	4·0
Renesansa	14	9·7	7·7	8·7	4·3	6·6	5·5	9·2	7·0	8·1
Soissons	12	4·5	3·2	3·8	9·9	9·3	9·6	5·7	3·8	4·8
Spark	17	3·5	2·5	3·0	8·1	8·2	8·1	4·5	2·7	3·6
Thatcher	74	10·0	10·7	10·3	3·2	1·7	2·4	8·5	10·5	9·5

Renesansa, Soissons and Spark ranked higher for protein yield CS at the non-organic compared to the organic sites, and Bezostaya, Maris Widgeon, Renan and Thatcher ranked higher for protein yield CS at the organic sites (Table 5). Across all cultivars, Renan achieved the best mean protein yield CS ranking at organic sites, and Spark at the non-organic sites (Table 5).

Table 9 provides the correlation coefficients between the organic and non-organic cultivar CS ranks. Despite differences in the relative performance of some cultivars between the two systems (as stated above) there is a significant ($P=0{\cdot}01$) positive correlation in cultivar performance for grain protein content across cultivar groups. This trend is also evident in cultivar performance for yield, with the exception of the feed group. However, when the protein yield ranks are assessed for correlations between organic and non-organic systems, no significant trend is evident for any of the cultivar groups.

The correlations between cultivar age and yield CS, grain protein CS and protein yield CS (Table 10) were assessed for the two organic sites, the two non-organic sites, or for all four sites. For the feed group, there was a significant positive correlation between yield CS and age within the organic, non-organic and all sites. For the milling group, there was a positive correlation of yield CS with age in non-organic systems (and across 'all sites'), but not in organic systems. There was a positive correlation between yield CS and age when all the 19 cultivars were assessed at the organic, non-organic and at the four sites (Table 10).

A weaker, but negative correlation for grain protein CS was found between the milling, feed and 'all' groups and the age of cultivar. For the milling group,

Table 6. *The mean rank of CS for all varieties trialled, for the characters of yield, protein content (mg/g) and protein yield for the two organic, two non-organic sites separately and for all four sites combined*

		Mean rank for yield			Mean rank for protein content			Mean rank for protein yield		
Cultivar	Age	Organic	Non-organic	All sites	Organic	Non-organic	All sites	Organic	Non-organic	All sites
Bezostaya	49	16·2	17·2	16·7	4·5	6·8	5·6	12·2	17·0	14·6
Buchan	13	9·2	4·8	7·0	14·4	15·7	15·0	12·7	8·2	10·4
Cadenza	13	14·0	12·0	13·0	7·3	10·3	8·8	13·5	12·8	13·2
Claire	12	5·0	5·7	5·3	16·0	15·0	15·5	8·2	8·2	8·2
Deben	10	2·7	2·0	2·3	16·9	18·0	17·5	4·2	6·0	5·1
Hereward	18	7·8	10·5	9·2	11·8	10·3	11·1	9·7	9·7	9·7
HTL	23	11·8	16·0	13·9	8·6	8·0	8·3	9·8	16·2	13·0
Maris Widgeon	44	10·0	17·5	13·8	6·4	2·8	4·6	7·8	17·0	12·4
Mercia	19	5·5	2·8	4·2	17·1	16·8	17·0	11·8	4·2	8·0
Monopol	28	14·5	13·7	14·1	8·0	7·2	7·6	13·8	13·0	13·4
Option	8	8·0	4·2	6·1	14·7	16·0	15·3	11·0	5·3	8·2
Pastiche	20	10·8	11·0	10·9	5·6	4·1	4·8	7·0	6·0	6·5
Renan	19	7·5	12·8	10·2	3·3	3·2	3·3	3·5	9·8	6·7
Renesansa	14	15·8	14·2	15·0	4·8	7·1	5·9	13·2	12·0	12·6
Soissons	12	8·0	7·5	7·8	13·8	11·0	12·4	8·7	6·5	7·6
Spark	17	6·3	6·7	6·5	10·4	9·5	10·0	7·5	4·0	5·8
Tanker	10	13·3	4·0	8·7	11·3	14·1	12·7	13·7	4·7	9·2
Thatcher	74	16·8	17·3	17·1	3·2	1·7	2·4	13·2	17·0	15·1
Wembley	23	6·7	10·2	8·4	11·9	12·6	12·3	8·7	12·5	10·6

Table 7. *Mean protein content (mg/g@150 g/kg moisture content) of trial varieties at sites Metfield (Met), Morley (Mor), Sheepdrove (S) and Wakelyns (W) in trial years 2004/05, 2005/06 and 2006/07*

	Mean protein content (mg/g@150 g moisture/kg)																	
	2004/05						2005/06						2006/07					
	Met	Mor	S	W	Mean	S.D.	Met	Mor	S	W	Mean	S.D.	Met	Mor	S	W	Mean	S.D.
Bezostaya	140	136	138	116	132·5	14·4	129	141	142	141	138·2	6·6	126	127	96	109	114·6	13·8
Buchan	119	116	127	90	112·9	15·2	124	133	128	120	126·3	8·6	116	111	88	106	105·2	11·2
Cadenza	127	122	147	101	124·3	18·6	132	142	137	132	135·4	7·5	120	121	89	111	110·0	13·7
Claire	130	118	129	96	117·9	17·1	128	127	130	120	126·3	6·3	110	107	81	96	98·2	12·4
Deben	115	106	126	94	110·9	17·3	116	134	125	112	121·7	9·7	110	106	83	96	98·6	11·4
Hereward	119	132	138	91	120·1	23·7	137	139	131	133	135·3	5·4	117	120	86	104	106·6	14·0
HTL	142	129	136	103	127·3	16·6	134	142	136	133	136·4	4·3	124	118	95	107	110·7	12·8
Maris Widgeon	148	132	140	105	131·0	17·6	144	153	147	138	145·5	9·0	135	130	96	99	115·1	18·4
Mercia	127	114	131	87	114·7	18·0	123	123	120	122	121·8	4·5	115	111	83	95	100·9	13·4
Monopol	135	126	137	101	124·6	17·3	138	147	147	139	142·7	4·6	122	121	90	101	108·5	14·4
Option	126	117	131	96	116·2	15·5	124	126	120	120	122·7	4·4	112	112	81	105	102·7	13·9
Pastiche	138	136	142	114	132·0	15·8	138	143	138	138	139·4	5·3	133	130	94	110	116·5	18·1
Renan	141	135	147	112	132·9	15·6	140	147	141	139	141·8	4·8	131	134	99	115	119·7	15·3
Renesansa	129	131	138	106	125·8	13·7	136	144	143	146	142·4	5·1	126	129	96	106	114·3	15·3
Soissons	127	120	116	99	115·6	12·1	129	132	124	127	128·0	4·0	125	122	89	100	109·1	15·8
Spark	135	125	149	95	126·0	21·5	138	146	140	127	137·5	9·5	115	115	89	100	104·7	12·3
Tanker	136	115	135	97	120·7	18·4	125	131	141	128	131·3	9·4	115	114	86	103	104·3	12·4
Thatcher	148	133	144	114	134·7	16·2	146	151	155	145	149·0	5·7	144	137	95	109	121·2	21·1
Wembley	123	124	140	87	117·7	22·0	125	137	131	133	131·5	6·3	118	118	86	101	105·8	13·9
Mean	131·9	125·2	136·5	100·5	123·3		131·8	138·9	135·7	131·5	134·5		121·8	120·2	89·7	104·0	108·9	

there was no detectable correlation, indicating that across the ages of the cultivars studied there has not been a significant change in CS for quality. For the feed and the 'all' cultivar groups, there was a reduction in performance ($P = 0{\cdot}05$) in grain protein CS over time (Table 10).

Table 8. *Mean protein yield (t/ha@150 g/kg moisture content) with* S.D. *of trial varieties at sites Metfield (Met), Morley (Mor), Sheepdrove (S) and Wakelyns (W) in trial years 2004/05, 2005/06 and 2006/07*

	Mean protein yield (t/ha@150 g moisture/kg)																	
	2004/05						2005/06						2006/07					
	Met	Mor	S	W	Mean	S.D.	Met	Mor	S	W	Mean	S.D.	Met	Mor	S	W	Mean	S.D.
Bezostaya	1·1	0·7	0·7	0·6	0·73	0·23	0·9	0·9	0·5	0·6	0·72	0·18	0·9	0·9	0·4	0·1	0·57	0·35
Buchan	1·2	0·9	0·6	0·5	0·81	0·29	1·1	1·2	0·6	0·7	0·90	0·25	1·0	1·0	0·4	0·2	0·64	0·40
Cadenza	1·2	0·8	0·5	0·5	0·76	0·28	0·9	1·0	0·6	0·6	0·79	0·21	1·0	1·0	0·4	0·2	0·64	0·36
Claire	1·3	0·9	0·6	0·6	0·86	0·33	1·1	1·1	0·7	0·9	0·94	0·19	1·0	1·0	0·3	0·3	0·64	0·37
Deben	1·2	0·9	0·6	0·6	0·83	0·30	1·2	1·2	0·7	0·9	0·99	0·24	1·0	1·0	0·4	0·3	0·68	0·35
Hereward	1·1	1·0	0·5	0·5	0·79	0·32	1·0	1·1	0·7	0·8	0·86	0·18	0·9	1·0	0·4	0·3	0·65	0·35
HTL	1·2	0·6	0·6	0·6	0·74	0·27	0·9	0·9	0·6	0·7	0·76	0·17	0·9	0·9	0·4	0·3	0·62	0·32
Maris Widgeon	0·9	0·7	0·8	0·6	0·75	0·16	1·0	1·0	0·7	0·7	0·82	0·17	0·8	0·8	0·4	0·2	0·55	0·28
Mercia	1·4	0·9	0·6	0·5	0·86	0·36	1·2	1·2	0·6	0·8	0·95	0·27	1·1	1·0	0·4	0·2	0·66	0·40
Monopol	1·2	0·8	0·5	0·6	0·78	0·34	0·9	1·0	0·6	0·7	0·79	0·20	1·0	1·0	0·4	0·2	0·62	0·37
Option	1·3	0·9	0·7	0·5	0·84	0·31	1·2	1·2	0·6	0·8	0·95	0·28	1·1	1·0	0·3	0·3	0·67	0·40
Pastiche	1·2	0·9	0·7	0·6	0·85	0·28	1·1	1·1	0·7	0·7	0·91	0·20	1·1	1·1	0·4	0·3	0·70	0·42
Renan	1·3	0·9	0·9	0·6	0·89	0·24	1·1	1·1	0·7	0·9	0·94	0·17	1·0	1·0	0·4	0·3	0·64	0·34
Renesansa	1·0	1·0	0·6	0·5	0·73	0·22	1·1	1·1	0·7	0·5	0·84	0·27	0·9	0·9	0·4	0·2	0·58	0·35
Soissons	1·2	1·0	0·7	0·5	0·84	0·29	1·1	1·2	0·8	0·8	0·96	0·22	1·0	1·1	0·4	0·2	0·65	0·39
Spark	1·3	0·9	0·8	0·5	0·88	0·30	1·2	1·3	0·8	0·7	0·98	0·26	1·0	1·1	0·4	0·2	0·67	0·39
Tanker	1·4	1·0	0·6	0·5	0·86	0·38	1·2	1·2	0·6	0·8	0·96	0·28	1·0	1·0	0·3	0·2	0·63	0·38
Thatcher	0·7	0·5	0·5	0·6	0·57	0·12	1·0	1·0	0·7	0·7	0·87	0·17	0·7	0·9	0·3	0·2	0·52	0·31
Wembley	1·1	0·9	0·6	0·5	0·75	0·28	1·1	1·1	0·9	0·8	0·95	0·12	0·9	0·9	0·4	0·3	0·62	0·31
Mean	1·17	0·84	0·63	0·55	0·79		1·06	1·09	0·67	0·73	0·89		0·96	0·97	0·36	0·22	0·63	

Table 9. *Correlations of CS ranking in organic and non-organic systems*

	Group					
Character	All	*P*	Feed	*P*	Milling	*P*
Yield	0·6943	<0·01	0·6415	ns	0·765	<0·01
Protein content	0·9299	<0·01	0·9517	<0·01	0·8896	<0·01
Protein yield	0·2486	ns	0·0812	ns	0·4027	ns
D.F.	17		6		9	

ns = not significant.

Table 10. *Correlation coefficients for cultivar age with CS for yield (t/ha@150 g moisture/kg), protein content (mg/g@150 g moisture/kg) and protein yield (t/ha) at all four sites (Metfield, Morley, Sheepdrove and Wakelyns), and at the two organic sites (Sheepdrove and Wakelyns) and at the two non-organic sites (Metfield and Morley) considered separately*

	Cultivar category					
Character	All	*P*	Feed	*P*	Milling	*P*
All sites						
Yield	0·881	<0·01	0·906	<0·01	0·906	<0·01
Protein	−0·601	<0·01	−0·741	<0·05	−0·508	ns
Protein yield	0·859	<0·01	0·907	<0·01	0·863	<0·01
Organic						
Yield	0·527	<0·05	0·825	<0·01	0·438	ns
Protein	−0·563	<0·05	−0·750	<0·05	−0·462	ns
Protein yield	0·254	ns	0·716	<0·05	0·163	ns
Non-organic						
Yield	0·916	<0·01	0·897	<0·01	0·927	<0·01
Protein	−0·610	<0·01	−0·712	<0·05	−0·529	ns
Protein yield	0·918	<0·01	0·912	<0·01	0·929	<0·01
D.F.	17		6		9	

ns = not significant.

The analysis of yield and grain protein concentration does not take into account the total protein yield for each cultivar. The positive correlation at all sites, and at the non-organic sites between cultivar age and protein yield CS indicates that there has been a significant increase in protein yield performance over the time period during which the cultivars were released (Table 10). This demonstrates that the significant negative correlation between age and grain protein CS is likely to be attributed to: (i) a dilution effect within the crop – more grain but of lower protein content; and (ii) breeding selection in favour of yield characteristics. The assessment of protein yield highlights that for the cultivars studied, yield increased with time, the protein concentration has either decreased or stayed the same, and that the protein yield improvement is simply a result of

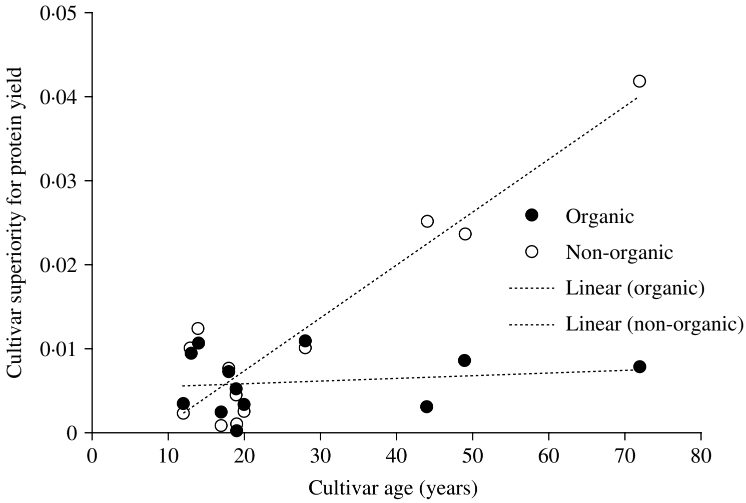

Fig. 2. Plot of cultivar protein yield superiority against cultivar age for non-organic trial sites, Morley and Metfield Hall (open circles) and organic trial sites (Sheepdrove Organic farm and Wakelyns Agroforestry) (closed circles) for 12 milling cultivars. A low value for superiority indicates a higher level of performance (stability of performance and total protein yield). Correlation coefficient for non-organic sites = 0·929 (P = 0·01), correlation coefficient for organic sites = 0·163.

the relative changes in yield and protein concentration.

The positive correlations between protein yield CS and cultivar age are weaker across the three cultivar groups in organic systems compared to non-organic. For the milling and 'all' cultivar group, there was no detectable correlation at the organic sites (Table 10, Fig. 2).

Analysis of CS ranks for yield, protein content and protein yield between organic and non-organic systems highlights cultivars that rank differently between systems (Table 11). The more modern cultivars, registered after 1989 (age 19) had a tendency to rank higher in non-organic systems, with Option and Buchan having a higher rank for yield, and Option, Tanker, Buchan, Spark and Mercia having a higher rank for protein yield. Cultivars registered before 1989 tended to rank higher in organic systems. Renan, HTL and Maris Widgeon had a higher rank for yield, and Renan, HTL, Wembley, Maris Widgeon and Thatcher had a higher rank for protein yield. Maris Widgeon, which ranked higher in non-organic systems, was the only cultivar to show a rank difference for protein content. Renan and Mercia were both registered in 1989 with Renan tending to perform better under organic conditions and Mercia under non-organic conditions.

The cultivars were assessed for disease incidence, which included rust, powdery mildew, and *Septoria* spp., of which the last was the most prevalent. The incidence of *Septoria* spp. was assessed in mid-July (Table 12). There was a negative correlation between yield, grain protein content and protein yield with *Septoria* spp. incidence for the three cultivar groupings. However, the trend was only significant at the organic sites, and the 'all' group for yield and protein yield (Table 13). Although *Septoria* spp. presumably had a causal negative influence on yield this was not correlated with cultivar age.

Assessments of GLA indicated that for the cultivars studied, there was no significant correlation between GLA and yield, grain protein content or protein yield for the three cultivar groups (Table 14). However, when GLA was regressed against cultivar age, there was a significant positive trend at non-organic sites for the 'all' group and for the feed group. This trend was repeated for the four sites together, but was not detectable at the organic sites (Table 15).

DISCUSSION

The 44 % mean yield reduction under organic conditions is consistent with other data comparing yields between organic and non-organic systems (e.g. Przystalski *et al.* 2008).

However, some cultivars performed relatively better in organic compared to non-organic systems for the different characters of yield and protein. Further analysis of these results using rank correlations identified a significant positive relationship for cultivar yield and grain protein content of the cultivars across both systems, but no significant trend was evident for protein yield. Hence, for the trial cultivars used, the ranking of cultivars in non-organic systems is an indicator of performance relating to

Table 11. *Rank CS for varieties between organic and non-organic systems for yield, protein content and protein yield. The 19 cultivars were comprised of two groups: those selected for high yield potential (the 'feed' group) and those selected for bread-making potential (the 'milling' group)*

			Yield		Protein content		Protein yield	
Cultivar	Age	Group	Organic	Non-organic	Organic	Non-organic	Organic	Non-organic
Option	8	Feed	8·0	4·2	14·7	16·0	11·0	5·3
Deben	10	Feed	2·7	2·0	16·9	18·0	4·2	6·0
Tanker	10	Feed	13·3	4·0	11·3	14·1	13·7	4·7
Claire	12	Feed	5·0	5·7	16·0	15·0	8·2	8·2
Soissons	12	Milling	8·0	7·5	13·8	11·0	8·7	6·5
Buchan	13	Feed	9·2	4·8	14·4	15·7	12·7	8·2
Cadenza	13	Milling	14·0	12·0	7·3	10·3	13·5	12·8
Renesansa	14	Milling	15·8	14·2	4·8	7·1	13·2	12·0
Spark	17	Milling	6·3	6·7	10·4	9·5	7·5	4·0
Hereward	18	Milling	7·8	10·5	11·8	10·3	9·7	9·7
Mercia	19	Milling	5·5	2·8	17·1	16·8	11·8	4·2
Renan	19	Milling	7·5	12·8	3·3	3·2	3·5	9·8
Pastiche	20	Milling	10·8	11·0	5·6	4·1	7·0	6·0
HTL	23	Feed	11·8	16·0	8·6	8·0	9·8	16·2
Wembley	23	Feed	6·7	10·2	11·9	12·6	8·7	12·5
Monopol	28	Milling	14·5	13·7	8·0	7·2	13·8	13·0
Maris Widgeon	44	Milling	10·0	17·5	6·4	2·8	7·8	17·0
Bezostaya	49	Milling	16·2	17·2	4·5	6·8	12·2	17·0
Thatcher	72	Milling	16·8	17·3	3·2	1·7	13·2	17·0

grain protein content and yield in organic systems. Caution must be used in interpreting these results because the same weather and soil type at Wakelyns and Metfield are likely to have affected the potential for positive correlations. Wakelyns and Sheepdrove, on the other hand, exhibit considerable physical differences as well as different organic management systems.

There were some cultivars that ranked differently in organic compared to non-organic conditions. For the cultivars assessed, those that were registered before 1989 had a tendency to perform relatively better under organic conditions and post-1989 to rank higher in non-organic conditions.

Results recorded by Murphy *et al.* (2007) from the trialling of 35 wheat genotypes in paired organic and non-organic systems in the USA revealed that in contrast to the present results, the genotypes that yielded well in non-organic systems ranked differently in organic systems. However, they did also identify a small number of broadly adapted genotypes which performed well across both systems. Since the selection criteria for cultivars were based on their recorded success, rather than the selections of genotypes in the F2 populations by Murphy *et al.* (2007), it can be suggested that the cultivars trialled in the present study can be classified generally as the more 'broadly adapted genotypes'.

Across farming systems, the most successful cultivars incorporate an increased ability to recover a greater level of mineral fertilizer or nitrogen within the soil profile and/or to produce more dry matter for a given level of nitrogen (Foulkes *et al.* 1998). Protein yield, which is the product of grain yield and grain protein content, defines the total tonnage of protein within the crop per hectare. Protein yield is therefore a valuable method of highlighting the ability of a cultivar to take up nitrogen and convert it to grain protein. From the current data, there was no correlation between the rank of cultivar protein yield between organic and non-organic systems. Based on the findings of Foulkes *et al.* (1998), the difference may be due to the relative ability of cultivars to exploit soil nitrogen compared to mineral nitrogen fertilizer.

Further analysis, correlating CS and age, has provided insights into the effect of breeding from 1934 to 2000. The CS analysis developed by Lin & Binns (1988) was used successfully to quantify the relative stability of cultivar performance in terms of yield, grain protein content and protein yield. The current results are consistent with the fact that there have been major increases in CS of yield over time for cultivars selected for the higher inputs of the non-organic systems. Overall, greater improvements in performance stability were identified in the more modern cultivars when grown in non-organic compared to organic systems. CS integrates absolute and relative performance for any chosen character. Yield differences among cultivars were greater under non-organic than organic conditions, suggesting that

Table 12. *Mean incidence of* Septoria *spp.* (*proportional area of flag leaf*). *The dates of the assessments for Metfield* (*Met*), *Morley* (*Mor*), *Sheepdrove* (*S*) *and Wakelyns* (*W*) *were 12, 15, 14 and 13 July in year 1* (*2004/05*)*; 5 July, 7 July, 19 June and 5 July in year 2* (*2005/06*)*; and 2 July, 5 July, 18 June and 3 July in year 3* (*2006/07*)

			Mean Septoria (proportion of flag leaf)						Mean Septoria (proportion of flag leaf)		
Site	Cultivar	Age	Year 1	Year 2	Year 3	Site	Cultivar	Age	Year 1	Year 2	Year 3
Met	Bezostaya	49	0·11	0·06	0·12	S	Monopol	28	0·14	0·01	0·09
Mor	Bezostaya	49	0·04	0·02	0·10	W	Monopol	28	0·16	0·07	0·49
W	Bezostaya	49	0·19	0·08	0·12	Met	Option	8	0·00	0·04	0·07
S	Bezostaya	49	0·30	0·15	0·43	Mor	Option	8	0·12	0·01	0·05
Met	Buchan	13	0·00	0·02	0·08	W	Option	8	0·20	0·08	0·14
Mor	Buchan	13	0·05	0·02	0·10	S	Option	8	0·30	0·07	0·69
W	Buchan	13	0·10	0·03	0·07	Met	Pastiche	20	0·00	0·02	0·09
S	Buchan	13	0·16	0·03	0·37	Mor	Pastiche	20	0·04	0·01	0·07
Met	Cadenza	13	0·00	0·02	0·06	W	Pastiche	20	0·16	0·01	0·03
Mor	Cadenza	13	0·08	0·00	0·06	S	Pastiche	20	0·21	0·02	0·43
W	Cadenza	13	0·10	0·02	0·08	Met	Renan	19	0·00	0·02	0·12
S	Cadenza	13	0·24	0·05	0·38	Mor	Renan	19	0·07	0·08	0·22
Met	Claire	12	0·00	0·01	0·06	W	Renan	19	0·21	0·02	6·2
Mor	Claire	12	0·08	0·01	0·08	S	Renan	19	0·29	0·06	0·23
W	Claire	12	0·11	0·02	0·08	Met	Renesansa	14	0·00	0·01	0·15
S	Claire	12	0·13	0·02	0·37	Mor	Renesansa	14	0·06	0·11	0·25
Met	Deben	10	0·00	0·01	0·08	W	Renesansa	14	0·12	0·10	0·14
Mor	Deben	10	0·06	0·01	0·06	S	Renesansa	90	0·34	0·17	0·45
W	Deben	10	0·09	0·02	0·09	Met	Soissons	12	0·00	0·02	0·15
S	Deben	10	0·19	0·01	0·45	Mor	Soissons	12	0·13	0·04	0·13
Met	Hereward	18	0·00	0·01	0·07	W	Soissons	12	0·13	0·02	0·11
Mor	Hereward	18	0·04	0·01	0·03	S	Soissons	12	0·17	0·07	0·52
W	Hereward	18	0·01	0·02	0·05	Met	Spark	17	0·00	0·01	0·06
S	Hereward	18	0·20	0·02	0·22	Mor	Spark	17	0·03	0·00	0·04
Met	HTL	23	0·00	0·01	0·09	W	Spark	17	0·06	0·01	0·04
Mor	HTL	23	0·07	0·01	0·03	S	Spark	17	0·10	0·00	0·16
W	HTL	23	0·11	0·01	0·06	Met	Tanker	10	0·00	0·02	0·08
S	HTL	23	0·14	0·02	0·32	Mor	Tanker	10	0·07	0·00	0·07
Met	Maris Widgeon	44	0·00	0·02	0·14	W	Tanker	10	0·21	0·13	0·09
Mor	Maris Widgeon	44	0·08	0·01	0·10	S	Tanker	10	0·28	0·05	0·50
W	Maris Widgeon	44	0·10	0·02	0·04	Met	Thatcher	72	0·00	0·01	0·12
S	Maris Widgeon	44	0·11	0·03	0·52	Mor	Thatcher	72	0·02	0·10	0·12
Met	Mercia	19	0·00	0·02	0·08	W	Thatcher	72	0·08	0·02	0·06
Mor	Mercia	19	0·02	0·01	0·05	S	Thatcher	72	0·15	0·06	0·62
W	Mercia	19	0·10	0·04	0·15	Met	Wembley	23	0·00	0·04	0·20
S	Mercia	19	0·36	0·20	0·68	Mor	Wembley	23	0·09	0·03	0·13
Met	Monopol	28	0·01	0·03	0·06	W	Wembley	23	0·10	0·03	0·06
Mor	Monopol	28	0·03	0·00	0·06	S	Wembley	23	0·23	0·04	0·65

such differences played a greater role in determining CS values under non-organic than under organic conditions. The greater improvements in the CS analysis in the non-organic systems may have been more to do with the effect of yield increases than stability which is supported by an absence of clear differences in variance estimates across sites. The stability trends were less evident under organic management, which supports the finding of Calderini & Slafer (1999) that the recent improvements in yield potential of cultivars are likely to be at the expense of yield stability. Moreover, the more modern cultivars are less able to maintain high performance in the more heterogeneous conditions of organic farms. These conditions generally include greater weed competition as well as reduced mineral nitrogen availability.

The protein yield CS of cultivars across the three groups was higher in the more modern (released after 1989) cultivars in the non-organic systems compared to those grown under organic conditions (for the milling cultivars, or all cultivars). This difference may be attributed largely to the more modern cultivars having a better ability to take up mineral nitrogen,

Table 13. *Correlation coefficients for mean GLA (proportional flag leaf green) against yield (t/ha@150 g moisture/kg), protein content (concentration (g/g)@150 g moisture/kg) and protein yield (t/ha) at all four sites (Metfield, Morley, Sheepdrove and Wakelyns) combined, and at the two organic sites (Sheepdrove and Wakelyns) and at the two non-organic sites (Metfield and Morley) separately for all years*

	Correlation coefficients for mean *Septoria* spp. incidence (proportion of flag leaf area)					
Character	All	*P*	Feed	*P*	Milling	*P*
All sites						
Yield	−0·473	<0·05	−0·487	ns	−0·502	ns
Protein content	−0·232	ns	−0·236	ns	−0·302	ns
Protein yield	−0·462	<0·05	−0·482	ns	−0·507	ns
Organic						
Yield	−0·612	<0·01	−0·622	ns	−0·615	<0·05
Protein content	−0·221	ns	−0·167	ns	−0·229	ns
Protein yield	−0·566	<0·05	−0·569	ns	−0·556	ns
Non-organic						
Yield	−0·154	ns	−0·011	ns	−0·086	ns
Protein content	0·105	ns	−0·130	ns	−0·158	ns
Protein yield	−0·112	ns	−0·068	ns	−0·176	ns
D.F.	17		6		9	

Table 14. *Correlation coefficients for mean* Septoria *spp. incidence (proportion of flag leaf area) against yield (t/ha@150 g moisture/kg), protein content (mg/g@150 g moisture/kg) and protein yield (t/ha) at all four sites (Metfield, Morley, Sheepdrove and Wakelyns) combined, and at the two organic sites (Sheepdrove and Wakelyns) and at the two non-organic sites (Metfield and Morley) separately for all years within the quality and yield group and all varieties*

	Correlation coefficients for mean GLA (proportion of flag leaf green)		
Character	All	Feed	Milling
All sites			
Yield	0·407	0·481	0·352
Protein content	0·266	0·239	0·285
Protein yield	0·436	0·492	0·391
Organic			
Yield	0·392	0·451	0·332
Protein content	0·277	0·232	0·295
Protein yield	0·445	0·478	0·399
Non-organic			
Yield	0·365	0·466	0·326
Protein content	0·016	−0·03	0·078
Protein yield	0·405	0·469	0·400
D.F.	17	6	9

Table 15. *Linear regression results (F values listed) for* Septoria *spp. incidence (proportion of flag leaf area) and GLA (proportion of flag leaf green) against cultivar age at all four sites (Metfield, Morley, Sheepdrove and Wakelyns) combined, and at the two organic sites (Sheepdrove and Wakelyns) and at the two non-organic sites (Metfield and Morley) separately for all years within the milling and feed group and all varieties*

	Linear regression of character against cultivar age (*F* probability)		
	Cultivar group		
Character	All	Feed	Milling
All sites			
Septoria	0·589	0·387	0·541
GLA	0·001	0·002	0·017
Organic			
Septoria	0·999	0·565	0·618
GLA	0·084	0·285	0·083
Non-organic			
Septoria	0·128	0·163	0·644
GLA	0·001	0·001	0·076
D.F.	17	6	9

but being less able to acquire soil nitrogen (Foulkes *et al.* 1998). Cultivars that are more suited to the nutritional regime of organic conditions are those that are capable of early season nutrient uptake, particularly of nitrogen, followed by the internal translocation at the point of, or before, grain filling (Baresel & Reents 2007; Kichey *et al.* 2007). In wheat, an extensive evaluation of a range of cultivars over

11 seasons revealed that the more modern cultivars are better adapted to exploiting large volumes of mineral nitrogen (Foulkes *et al.* 1998).

The grouping of the trial cultivars has highlighted that the yield CS, grain protein CS and protein yield CS of more modern milling cultivars is lower compared to the older feed cultivars in the low yielding environment of the organic systems. The greatest difference between the two systems is for protein yield; a correlation coefficient of 0·928 occurred among milling cultivars for protein yield CS and cultivar age under the non-organic systems but a non-significant trend with a coefficient of 0·163 was quantified for protein yield CS and cultivar age at the organic sites. These results suggest that the more modern cultivars have a relatively poor ability to take up nitrogen in organic conditions compared to non-organic conditions. This data is supported by Foulkes *et al.* (1998), who attributed the difference to the selection of phenotypes with longer tiller survival later in the season, but a slower early establishment. They suggested that increased canopy longevity is associated with greater resource capture. Analysis of GLA in the current experiment supports these findings. Cultivar GLAs taken at GSs 77–86 (across the 3 years) were significantly greater in the more modern cultivars at the non-organic sites but not the organic sites. This trend could not be wholly attributed to the incidence of *Septoria* spp. Leaf senescence is partially associated with stress, as well as genotype (Verma *et al.* 2004). The difference in genotype senescence from the assessment of GLA would indicate that the greater stress under organic conditions reduces the longevity of the flag leaf. This effect could be postulated to explain the difference between protein yield CS for the cultivars in organic compared to non-organic conditions. Increased longevity favours late season resource capture, a clear advantage under intensive management with later season nitrogen availability. However, early resource capture is advantageous in organic conditions (Addisu *et al.* 2009); a characteristic more prevalent in older cultivars. Further advantages of early crop development in organic conditions are associated with increased weed competitiveness. Weed competitive ability, and sensitivity to weeds has been found to vary in a range of winter wheat cultivars (Hoad *et al.* 2008).

Although wheat breeding in the UK over the last 50 or so years has made major advances in yield for cultivars grown in non-organic conditions, those cultivars are less well-adapted to organic conditions. Selection of cultivars under high agrochemical inputs results in cultivars that are less able to cope with environmental heterogeneity, and as a consequence have a lower stability of performance (Wolfe *et al.* 2008). The findings reported in the present paper are supported by the general observation that UK organic farmers have a greater tendency to grow older cultivars (unpublished results). However, based on the present results the recommended lists could provide a rough guide for organic farmers when selecting feed cultivars. The selection of cultivars under less intensive management with a detailed understanding of the nitrogen source at different GSs is likely to identify genotypes with characteristics associated with resource capture more adapted to organic conditions, which is in agreement with other recent work (Baresel *et al.* 1998; Ceccarelli 1996; Murphy *et al.* 2008; Wolfe *et al.* 2008).

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