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Yield response of Bere, a Scottish barley landrace, to cultural practices and agricultural inputs

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Abstract: There is very little documented about the response of cereal landraces to modern agricultural practices. Bere is a Scottish barley (*Hordeum vulgare* L.) landrace which is grown in Orkney to supply meal for baking. A recent research programme has improved yields and the security of the Bere harvest, making it possible to supply a new market for grain to produce specialist whiskies. At the start of this research, a survey of Orkney farmers who had grown Bere since the 1980s showed that most had planted it at the traditional time in mid-May, used few inputs and considered the main constraints of the crop to be low yield (2.8 to 3.8 t/ha) and susceptibility to lodging. Three years of trials in Orkney between 2003 and 2005 showed very significant increases in grain yield (17-76%) and thousand grain weight from planting Bere earlier, in the second half of April. This also had the advantage of an earlier and more secure harvest. Yields showed smaller, but often significant, increases (5-11%) from applying mineral fertiliser, growth regulator or fungicide, while combinations of growth regulator and fungicide increased yields from 10-22%. In spite of usually increasing grain yield, growth regulator did not always control lodging. Although the use of inputs often increased the gross margins of growing Bere, a trial in 2005 showed that early planting was a more cost effective single intervention than either the use of fungicide or growth regulator. By increasing grower profits and reducing harvesting risks, these results have made it viable for more farmers to grow Bere in its region of origin, providing growers and end-users with additional income and contributing to the *in situ* conservation of this landrace.

Keywords: Bere, landrace, input, yield

Introduction

Although cereal landraces have been grown for hundreds or thousands of years, there is usually very little documented information on their growth and yield under modern agricultural conditions because very few are still cultivated in countries with advanced agriculture. Nevertheless, because they are well adapted to specific localities (Camacho Villa *et al.*, 2005), have high yield stability, an ability to tolerate stress and a capacity to give reasonable yields under low input systems, a few like emmer wheat (Marino *et al.*, 2009) and Bere barley (Scholten *et al.*, 2009) continue to be grown under less intensive or organic agricultural systems.

Bere is a barley (*Hordeum vulgare* L.) landrace which was once widely grown in the northern parts of Britain and which is still grown on a small scale in Orkney and a few other remote parts of the Highlands and Islands of Scotland (Jarman, 1996; Scholten *et al.*, 2009). It has been suggested (Jarman, 1996) that it may have been introduced to Britain by Norse invaders in the 8th century. Bere was a multi-purpose staple crop which provided meal for baking, malt for brewing and distilling and straw for animal bedding and thatching and was a currency used for paying land rents (Pringle, 1874). In Scotland's Western Isles, Bere was of considerable economic importance during the 18th and 19th centuries (Walker, 1812) when large quantities were supplied as malt to the Campbeltown distilleries (Pacy 1873). The decline in the cultivation of Bere probably resulted from the agricultural improvements of the 19th century which included liming and the use of higher yielding varieties. By the end of the 20th century, only about 10 ha of Bere were being grown in the north of Scotland (Jarman, 1996; Scholten *et al.,* 2009).

In spite of Bere's long history of cultivation, there is little documented information about the plant or its cultivation. It is a 6-row barley (Jarman, 1996) which is planted late in the spring and because of its rapid growth, it has been described as a 90-day variety (Jarman, 1996). Traditionally, it was one of the last crops sown but was usually the first to be harvested (Wright *et al.*, 2002). Although tolerant of acidic soils, it also grows on more alkaline manganese-deficient sandy coastal soils (machair) derived from beach sands (O'Dell, 1935). Bere is susceptible to both powdery mildew disease (*Blumeria graminis* DC. Speer f. sp. *hordei* Marchal) (Wright *et al.*, 2002) and leaf stripe (*Pyrenophora graminea* Ito et Kuribayashi) (Cockerel, 2002) and has weak straw (Peachey, 1951) making it very susceptible to lodging.

Until recently, the only market for Bere was for milling and Bere meal (flour) is still used on a small scale in a range of bakery products like bread, biscuits and bannocks in Orkney (Theobald *et al.*, 2006). Since 2004, as a result of research results described in this paper, it has also been possible to develop a new market for Bere, supplying grain for specialist beer and whiskies (Martin and Chang, 2007; Martin and Chang, 2008). In an area where large quantities of straw are required as bedding for over-wintering animals, straw is also a valuable by-product from the Bere crop.

At the start of research on Bere in 2002, it was recognised that it would only be possible to develop new markets for the crop if a reliable supply chain could be developed and if growers could receive a price for the grain which reflected the low yield of the crop and yet was still affordable for end users. The aims of the research described in this paper were therefore to identify agronomic practices used recently in Orkney by growers of Bere, to quantify on-farm yields and to investigate ways of raising them to increase the profitability of the crop. Results from field trials with Bere between 2003 and 2005 are reviewed and discussed with reference to studies on other landraces and both old and modern varieties.

Materials and Methods

Diagnostic study of recent farmer practices and on-farm yields

To identify recent farming practices with Bere and priority research areas, seven farmers who had grown Bere in Orkney since the 1980s were interviewed, in January 2003, about the cultivation practices they had used and the main problems encountered with the crop. These included most farmers who had recently grown Bere for Barony Mills, the main purchaser of the crop over this period.

To quantify yields under farm conditions, three on-farm trials, each of about 0.5 ha, were established in 2003 under standard management practices. The trials were located in South Ronaldsay, Birsay and Burray - all sites were within a radius of 20 km of Orkney College and had sandy loam soils. Growers were provided with Bere seed and instructions for growing the crop. Land was prepared by ploughing and power harrowing, seed was drilled at 160 kg/ha and N, P (P_2O_5) and K (K_2O) were applied at planting at a rate of 20, 40 and 40 kg/ha, respectively. Herbicide was applied as described below, but no other agrochemicals were used. All fields were measured to determine their area and the harvested grain was weighed on a weigh bridge and moisture content determined.

Standard experimental practices

All Orkney College trials were established on Weyland Farm (58° 59’ N and 2° 57’ W) on land which was about 25 m above sea level on a North facing slope and about 0.6 km from the sea. The soil at the site was a sandy loam belonging to the Canisbay series with a pH of 6.2. Meteorological data were obtained from the Loch of Hundland meteorological site, about 20 km north west of Orkney College. As long-term data were not available for this site, these were obtained for Kirkwall airport, about 6 km south east of Orkney College.

Bere seed used in this research was from a stock maintained by the Agronomy Institute and originated from seed obtained from Barony Mills in 2002. Jarman (personal communication 2002) confirmed that sample plants from this material were the same as the Bere he had examined earlier (Jarman, 1996).

In the trials described below, a number of common practices were used which are outlined in this section. Prior to ploughing in the spring, an application of cattle slurry was made to fields at about 10 000 l/ha. Fields were planted with a Massey Ferguson combination drill (MF30) using a seed rate of 160 kg/ha with N, P and K fertiliser being applied in the drill. Herbicide (15 g/ha Ally (20% w/w metsulfuron-methyl) and 1 litre/ha Optica (600 g/l mecoprop-P), both in 200 litres/ha of water) were applied by a tractor-mounted hydraulic nozzle sprayer (Andereau) with a 12 m boom at growth stage (GS) 30 (Zadoks *et al.* 1974). Experimental plots were 16 m long by 6 m wide and at harvest a sample area of 73.6 m^2 was cut from the middle of each plot with a small-plot combine (Sampo 2025 with a 2.3 m cutter bar). The grain from each sample area was weighed on the combine and a 500 g subsample taken for moisture content measurement and thousand grain weight (TGW) determination. The mass of grain harvested from each plot and the sample area were then used to calculate grain yield in t/ha which was converted to 15% moisture content. TGW was determined from two samples of grain drawn from a sample retained from each plot. The grain was dried in an oven to constant weight and then passed through a grain counter (Pfeuffer, Contador).

Planting date and seed rate trials

Two trials investigating these factors were established at Orkney College in 2003 and 2004. The 2003 trial used a split plot design with five replicates. There were two main plot treatments for time of planting - early planting (15 April 2003) and a traditional mid-May planting (16 May 2003) - and three subplot treatments for different seed rates (130, 160 and 190 kg/ha). At planting, compound fertiliser was applied to all treatments (N, P (P_2O_5) and K (K_2O) at 28, 56 and 56 kg/ha respectively). Main plots were 48 m wide by 16 m long.

A similar split plot design with five replicates was used in 2004 with two main plot treatments for time of planting - early planting (26 April 2004) and a mid-May planting (15 May 2004) - and two subplot treatments for different seed rates, (160 and 190 kg/ha). Apart from this and the use of a slightly different fertiliser rate (40 kg/ha of each of N, P (P_2O_5) and K (K_2O)), the trial was laid out and managed in the same way as the 2003 trial.

Inputs trials

Two trials investigating inputs were established at Orkney College in 2003 and 2004 while a third, in 2005, investigated both inputs and different planting dates. The 2003 trial used a split plot design with four replicates and was planted on 24 April 2003. There were four main plot treatments for different application rates of N, P (P_2O_5) and K (K_2O) (Fert0: 0, 0 and 0 kg/ha; Fert1: 15, 30 and 30 kg/ha; Fert2: 30, 60 and 60 kg/ha; Fert3: 45, 60 and 60 kg/ha). Compound fertiliser (11:22:22) was applied at planting, with an additional 15 kg/ha of N applied as a top dressing to the Fert3 treatment on 15 May. There were three subplot treatments for different fungicide and growth regulator treatments (O, no growth regulator or fungicide; F, fungicide; G, growth regulator). The fungicide, BAS 493 F (kresoxim-methyl, epoxiconazole and fenpropimorh), and growth regulator, Cerone (2-chloroethylphosphonic acid), were applied to the crop, at rates of 0.25 and 0.5 litres/ha of product, respectively in 200 litres/ha of water by knapsack sprayer (Cooper Peglar CP30) with 1.5 m boom at GS 37-39. The fungicide treatment was included in the trial because high levels of powdery mildew occurred in an observation plot of Bere grown in 2002.

At GS 73, plants from each plot were sampled to measure stem length and leaf senescence. From each plot, a single mainstem was sampled from each of five rows which were approximately mid-way across the plot. Stems were cut at ground level, wrapped in polythene bags, stored in a refrigerator and then measured on the following day. On each stem, length from the base to the collar of the ear, peduncle length, top internode length and percentage senescence of the flag leaf and leaf below it were measured. Percentage senescence was determined by reference to leaf area keys (MAFF, 1975).

The inputs trial established in 2004 used a split block design with five replicates. Each replicate contained 9 plots arranged in three columns and three rows. There were three growth regulator treatments (G0, none; G1, half-rate; G2, full-rate) which were randomised amongst the columns of plots, and three fungicide treatments (F0, none; F1, half-rate; F2, full-rate) which were randomised amongst the rows of plots. The growth regulator used was Cerone (2-chloroethylphosphonic acid) and the full rate of application was 1.0 litre/ha of product in 200 litre/ha of water. The fungicide used was Corbel (fenpropimorph) and the full rate of application was 1.0 litre/ha of product in 200 litres/ha of water. Both chemicals were applied by knapsack sprayer. The trial was planted on 26 April and harvested on 8 September. A standard fertiliser rate of 40 kg/ha of each of N, P (P_2O_5) and K(K_2O) was used for all treatments in the trial.

The 2005 input and planting date trial used a split block design with six replicates. Each replicate contained 12 plots arranged as three columns of four rows. One of each of four chemical spray treatments (O, no fungicide or growth regulator; F, fungicide; G, growth regulator; FG, fungicide and growth regulator) was applied to each of the four rows of plots. There were three planting date treatments (P1, 25 April 2005; P2, 4 May 2005; P3, 13 May 2005) which were randomised amongst the three columns of plots. The fungicide and growth regulator used were Opus Team (BASF; 84 g / l epoxiconazole and 250 g / l fenpropimorph) and Terpal (mepiquat chloride and 2-chloroethylphosphonic acid), respectively. Both were applied at 1.5 litres/ha with 0.38 litres/ha of sticker (Banka) in 150 litres/ha of water. The planting date treatments reached GS 37 on different dates and so the growth regulator and fungicide treatments were applied on different dates (P1 on 24 June, P2 on 30 June and P3 on 15 July).

Gross margin calculations

These were based on a price of GB£150/t for Bere grain (the price in Orkney between 2003 and 2005 which was about twice the UK price for malting barley at that time) less the cost of seed (GB£300/t), fertiliser and any chemical used plus a cost of GB£10/ha per application (SAC, 2006). Costs of fertiliser in GB£/t were as follows: 11:22:22, £174; 33:0:0, £152; 17:17:17, £168. The cost of chemicals applied in GB£/l were: Cerone, £19.50; BAS 493 F, £38.00; Corbel, £27.30; Terpal, £11.00; Opus Team, £27.70; Banka, £20.00.

Data analysis

Yield data from the trials were analysed by ANOVA using Genstat Release 9.1 (Lawes Agricultural Trust). The statistical significance of main effects was determined from *F* ratios in the ANOVA table while that between treatments was tested by the Student t-test using the appropriate standard error of the difference (SED) between means.

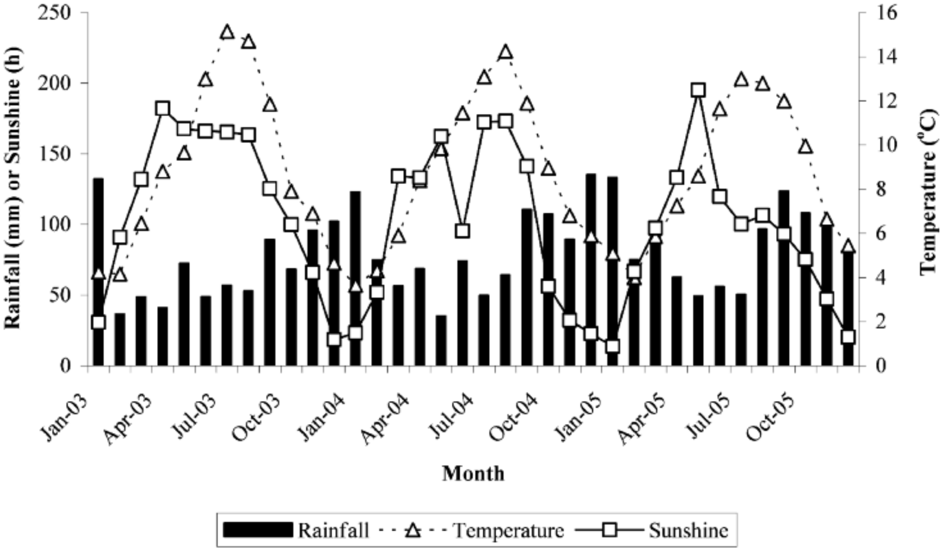

Fig. 1 - Monthly rainfall and monthly average daily temperature and sunshine hours from the Hundland climate station in Orkney from 2003 to 2005

Results

Meteorological data

Figure 1 shows monthly rainfall and monthly averages for sunshine hours and average daily temperature at the Hundland climate station from 2003 to 2005. Compared with long-term averages (1961 to 1990), the 2003 growing season (April to August) was sunnier (845 h of sunshine compared with 710 h) and in April, June, July and August the monthly average daily temperature was at least 2°C higher than the average. In 2004, rainfall was particularly low in May (35 mm compared with 50 mm) and although sunshine in June was below average (95 h compared with 156 h), it was above average in July and August (172 and 173 h, respectively compared with averages of 129 h for each month). Of the three years, climatic conditions from April to August were closer to the long-term average in 2005 and this year was wetter, less sunny and cooler than the others.

Diagnostic study of farmer practices and on-farm yields

Most farmers (6) had used a seed rate equivalent to 157 kg/ha (range, 138 to 184 kg/ha). The most recent and reliable yield data for Bere came from fields grown for Barony Mills. From 1998 to 2003, yields from a 1.6 ha field in Birsay ranged from 2.8 to 3.8 t/ha at 15% moisture content and averaged 3.1 t/ha. This was achieved with a low level of inputs - in only one year was herbicide used, no fungicide was applied and only low levels of fertiliser were used (N, P(P_2O_5) and K(K_2O) at 34, 68 and 68 kg/ha, respectively). A second field in the same area yielded an average of 2.7 t/ha from 1999 to 2001 and a third field yielded 3.1 t/ha in 2002. None of the other farmers interviewed had used higher levels of fertiliser on Bere and some had even grown it without fertiliser or without nitrogen. The only agrochemicals they had used were herbicide (one grower) and growth regulator (one grower) although the latter had not been effective at preventing lodging. When questioned about pests and diseases, only one grower mentioned having noticed any (powdery mildew) and none thought that these constrained yields. Most farmers (4) had followed the traditional practice of planting Bere around the middle of May but a contractor had planted two fields earlier (late April and early May) which were harvested in early- to mid-September, giving growing seasons of 148 and 132 days, respectively.

The main problems encountered with Bere were crop lodging (4) and low yields (3). Apart from a belief that lodging contributed to low yields, farmers also noted that it made combine harvesting more difficult, time-consuming and risky. The latter was because lodged crops were slow to dry out after rain, creating conditions favouring germination of grains in the ear. This was increasingly likely to occur the later into September that harvesting was delayed. Growers (4) also mentioned the long, irritating awns which made it unpleasant to work with, but recognised that this had become less of a problem since the introduction of combines for harvesting.

Yields from the on-farm trials in South Ronaldsay, Burray and Birsay were 2.73, 3.38 and 3.52 t/ha, respectively (average, 3.21 t/ha). TGWs for these sites were 25.10, 26.30 and 25.15 g, respectively (average, 25.52 g).

Planting date and seed rate trials

In the 2003 trial, ANOVA (Table 1) showed there was a significant ($P<0.001$) effect of planting date but not of seed rate on both grain yield and TGW. Across seed rate treatments, the average yield and TGW for the earlier date was 4.33 t/ha

Table 1 - F statistics and P-values from the ANOVA for grain yield and TGW of Bere grown in 2003 with different planting date and seed rate treatments.

		YIELD		TGW	
Source of variation	d.f.	F statistic	P-value	F statistic	P-value
Planting date	1	15.14	0.018	61.81	<0.001
Seed rate	2	0.07	0.930	0.50	0.610
Planting date x seed rate	2	0.80	0.465	0.32	0.730

Table 2 - Grain yield (i) and TGW (ii) for Bere grown in 2003 with different planting dates and seed rates.

PLANTING DATE	SEED RATE (kg/ha)			MEANS
	130	160	190	
i. Grain yield (t/ha)				
15 April 2003	4.24*	4.34	4.44	4.33†
16 May 2003	3.70	3.67	3.60	3.66
Means	3.97‡	4.01	4.00	

*SED for planting date x seed rate means, 0.208 (8 df) except when comparing means with the same level of planting date when the SED is 0.142 (16 df)
†SED for planting date means, 0.173 (4 df)
‡SED for seed rate means, 0.100 (16 df)

PLANTING DATE	130	160	190	MEANS
ii. TGW (g)				
15 April 2003	28.97*	29.05	28.32	28.78†
16 May 2003	24.48	24.99	24.67	24.71
Means	26.73‡	27.02	26.50	

*SED for planting date x seed rate means, 0.799 (8 df) except when comparing means with the same level of planting date when the SED is 0.745 (16 df)
†SED for planting date means, 0.517 (4 df)
‡SED for seed rate means, 0.527 (16 df)

and 28.78 g, respectively, compared with 3.66 t/ha and 24.71 g for the later date (Table 2). The highest yields and TGWs all resulted from the first planting date treatment.

There was a similar result in 2004 with a significant ($P<0.001$) effect of planting date on both yield and TGW but no effect of seed rate. The mean yield and TGW of the earlier planting date treatment (4.42 t/ha and 29.97 g,) were both significantly higher ($P<0.01$ and $P<0.05$, respectively) than those of the traditional planting date (2.51 t/ha and 28.93 g).

In both trials, the earlier planting date resulted in an earlier harvesting date - 25 August compared with 28 August in 2003 and 2 September compared with 24 September in 2004.

Inputs trials

In the 2003 trial, ANOVA (Table 3) showed that both fertiliser and chemical spray had significant ($P<0.05$ and $P<0.001$, respectively) effects on yield but only chemical spray significantly affected TGW ($P<0.01$). Mean grain yields for the fertiliser levels Fert1, Fert2 and Fert3 were 4.95, 4.97 and 5.02 t/ha, respectively, and were all significantly ($P<0.05$) higher than the yield of the no fertiliser (Fert0) treatment (4.73 t/ha) with no significant differences between the means for levels Fert1, Fert2 and Fert3. Compared with the average yield for the no-spray treatment (4.73 t/ha), there were small but significant increases in yield from both fungicide ($P<0.001$; 5.06 t/ha) and growth regulator ($P<0.01$; 4.97 t/ha).

Table 3 - F statistics and P-values from the ANOVA for grain yield and TGW of Bere grown in 2003 with different input treatment

		Yield		TGW	
Source of variation	d.f.	F statistic	P-value	F statistic	P-value
Fertiliser	3	6.63	0.012	1.92	0.197
Chemical spray	2	9.79	<0.001	6.45	0.006
Fertiliser x chemical spray	6	1.34	0.279	0.87	0.532

Considering the individual treatments (Fig. 2), the application of fungicide at all levels of fertiliser and growth regulator at fertiliser levels Fert1, Fert2 and Fert3 all gave higher yields than the treatment at the same fertiliser level where no spray was applied and differences were significant ($P<0.05$) at fertiliser levels Fert1 and Fert3. TGW (Table 4) was significantly higher in the fungicide treatment (30.14 g) than in the no input (28.71 g) and growth regulator (28.91 g) treatments.

Visually, the most striking aspect of the trial was the lack of lodging in the plots which received a growth regulator and this persisted up to harvest. ANOVA of straw length measurements showed there was a very significant ($P<0.001$) main effect of chemical sprays, but not of fertilizer, which was caused by the significantly shorter ($P<0.001$) straw length of the growth regulator treatment (0.97 m) compared with the no spray (1.17 m) and fungicide (1.18 m) treatments. This was caused by significant reductions ($P<0.001$) in length of the peduncle (0.34 m compared with 0.45 m for both the control and fungicide treatment) and

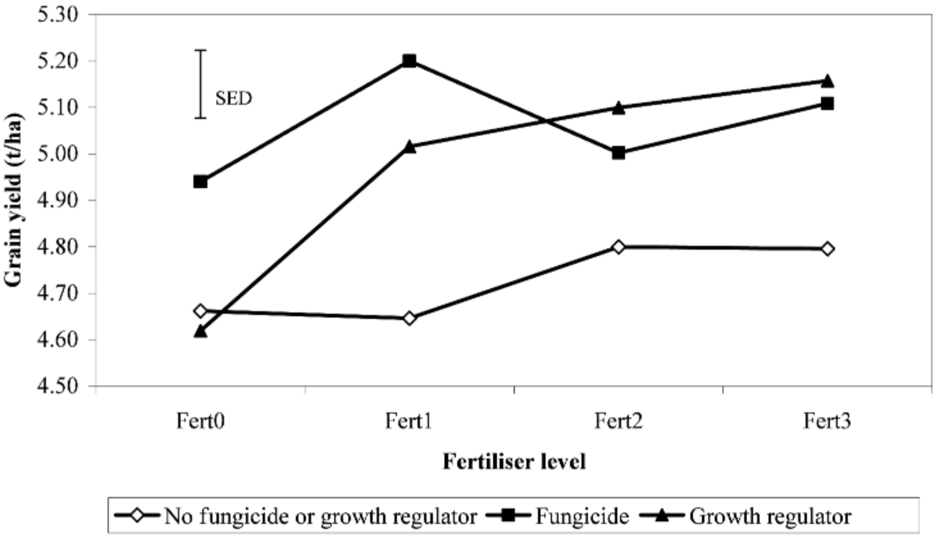

Fig. 2 - Grain yields of Bere in 2003 with different fertiliser (Fert0, Fert1, Fert2, Fert3) and spray treatments. The bar is the SED between treatment means (32 df).

Table 4 - TGW of Bere in 2003 with different fertiliser and chemical spray treatments.

Fertiliser treatment	Chemical spray			Means
	None	Fungicide	Growth regulator	
TGW (g)				
Fert0	29.85*	30.41	28.91	29.72†
Fert1	28.46	30.02	28.97	29.15
Fert2	28.35	30.79	28.62	29.25
Fert3	28.16	29.32	29.11	28.87
Means	28.71‡	30.14	28.91	

*SED for planting date x seed density means, 0.794 (32 df) except when comparing means wi the same level of fertiliser when the SED is 0.863 (23 df)
†SED for fertiliser means, 0.364 (9 df)
‡SED for chemical spray means, 0.432 (23 df)

top internode (0.22 m compared with 0.27 m for the control and 0.28 m for the fungicide treatment).

Following ear emergence, powdery mildew was very conspicuous below the flag leaf in plots which did not receive the fungicide treatment. ANOVA of an arc sine transformation of measurements of the percentage green area on the flag leaf and the leaf below it, showed a very significant (P=0.001) effect of chemical sprays on the leaf below the flag leaf which was caused by the higher percentage green areas of all the fungicide treatments. This was also observed for the flag leaf but was not significant. Untransformed treatment means for the percentage green areas of the flag leaf were 67, 81 and 73% for the no input, fungicide and growth regulator treatments, respectively. For the same treatments, the values for the leaf below the flag leaf were 37, 67 and 42%.

For the 2004 inputs trial, ANOVA of grain yield and TGW showed that the only significant effect was that of growth regulator on yield (P< 0.05) and the mean yield of the half-rate growth regulator treatment (5.06 t/ha) was significantly higher (P<0.01) than that of the treatment without growth regulator (4.63 t/ha). It was also higher (but not significantly so) than that of the full-rate treatment (4.84 t/ha).

Table 5 - F statistics and P-values from the ANOVA for grain yield and TGW of Bere grown in 2005 with different planting dates and chemical sprays.

		Yield		TGW	
Source of variation	d.f.	F statistic	P-value	F statistic	P-value
Planting date	2	10.64	0.003	9.68	0.046
Chemical spray	2	9.30	0.001	3.38	0.046
Planting date x chemical spray	4	3.74	0.007	2.87	0.109

The ANOVA for the 2005 inputs and planting date trial (Table 5) showed that both planting date and chemical sprays had a significant (P<0.01) main effect on yield but that there was also a significant interaction (P<0.01) between the two. TGW was significantly affected by chemical spray and planting date. Comparing the planting date means, yields dropped as planting date became later and the yield of the last planting date (3.82 t/ha) was significantly (P<0.01) lower than that of the first two (4.46 and 4.35 t/ha for P1 and P2, respectively) which were not significantly different. For the spray means, the no spray treatment yielded significantly less (P<0.05; 3.79 t/ha) than any of the spray treatments and, although there was no significant difference between the means of the fungicide (4.22 t/ha) or growth regulator (4.20 t/ha) treatments, these were both significantly less (P<0.05) than the mean for the combined treatment (4.63 t/ha).

Amongst the individual treatment means (Fig. 3), the highest yields on the first and last planting date were from the combined fungicide and growth regulator

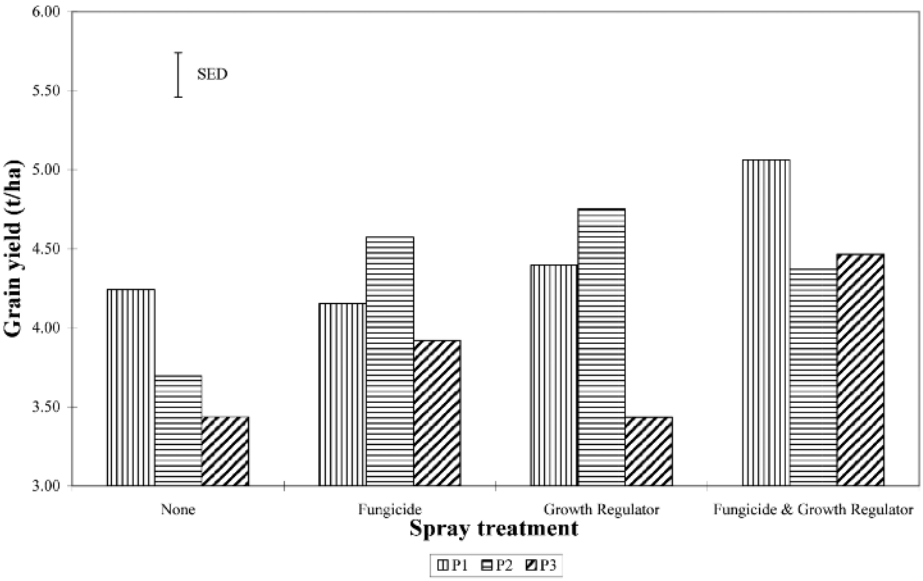

Fig. 3 - Grain yields of Bere in 2005 with different planting dates (P1, P2 and P3) and spray treatments. The bar is the SED between treatment means (49 df).

Table 6 - TGW of Bere in 2005 with different planting date and chemical spray treatments.

Spray treatment	Planting date			Means
	25 April	4 May	13 May	
TGW (g)				
None	30.86*	30.66	29.52	30.35†
Fungicide	30.87	30.81	31.42	31.03
Growth regulator	31.73	30.47	29.17	30.46
Fungicide and growth regulator	32.59	31.53	30.86	31.66
Means	31.51‡	30.87	30.24	

*SED for planting date x spray means, 0.778 (49 df) except when comparing means with the same levels of spray or planting date when the SEDs are 0.743 (40 df) and 0.733 (45 df), respectively
†SED for spray means, 0.464 (15 df)
‡SED for planting date means, 0.435 (10 df)

treatment and at the middle planting date from the growth regulator treatment alone. The lowest yields at the second and third planting dates were with the no

Table 7 - Gross margins from different treatments in input trials between 2003 and 2005.

2003 Inputs Trial			2004 Inputs Trial			2005 Inputs Trial		
Fertiliser level	Growth regulator (G) fungicide (F) nothing (O)	Gross margin (£/ha)	Growth regulator level	Fungicide level	Gross margin (£/ha)	Planting date	Growth regulator (G) fungicide (F) nothing (O)	Gross margin (£/ha)
Fert0	O	651	G0	F0	574	P1	O	550
Fert1	O	625	G0	F1	588	P1	F	485
Fert2	O	625	G0	F2	599	P1	G	546
Fert3	O	594				P1	F+G	605
			G1	F0	644			
Fert0	F	674	G1	F1	640	P2	O	468
Fert1	F	689	G1	F2	632	P2	F	548
Fert2	F	636				P2	G	600
Fert3	F	621	G2	F0	599	P2	F+G	501
			G2	F1	606			
Fert0	G	625	G2	F2	584	P3	O	429
Fert1	G	661				P3	F	450
Fert2	G	650				P3	G	402
Fert3	G	628				P3	F+G	515
Treatment	Averages							
Fert0		650	G0		587	P1		546
Fert1		658	G1		638	P2		529
Fert2		637	G2		597	P3		449
Fert3		614		F0	606		O	482
	O	624		F1	611		F	494
	F	655		F2	605		G	516
	G	641					F+G	540

input treatments. For each input treatment, the highest yield was either at the first or second planting date while the lowest yield was usually with the third planting date. In Table 6, the mean TGW for the first planting date (31.51 g) was higher than that of the later planting dates and significantly higher than the last date (30.24 g). The mean TGW for the fungicide and growth regulator treatment (31.66 g) was significantly higher than that of the other spray treatments. Generally, for each spray treatment the highest TGW occurred at the first planting date while for each planting date, the highest TGW was either with the growth regulator and fungicide or the fungicide alone treatment.

The earlier planting date treatments (P1 and P2) were harvested on 5 September and the mid-May treatment (P3) on 8 September.

Gross margins from input trials

Table 7 shows the gross margins for treatments in the input trials. In 2003, gross margins from the fertiliser treatments were highest with the low level (Fert1) treatment and both fungicide and growth regulator gave a small increase compared with the mean for the treatments where these were not applied. In 2004, the highest gross margin was from the half-rate growth regulator treatment (G1) and fungicide gave little (F1) or no (F2) increase. In the 2005 trial, using an early planting date (P1) increased gross margins by about £100/ha compared with the traditional mid-May planting date (P3). Amongst the spray treatments, the combined fungicide and growth regulator treatment was most profitable and, alone, growth regulator was more profitable than fungicide.

Discussion

Farmer practices and on-farm yields

The diagnostic study identified lodging and low yields as the two main concerns of farmers about growing Bere. It also showed that in recent years Bere had been grown in Orkney with low levels of fertiliser and very few inputs and that grain yields were between 2.8 and 3.8 t/ha. The 2003 on-farm verification trials obtained similar yields (2.7 to 3.5 t/ha). These compare with about 6.0 t/ha for a good crop of barley in Orkney using a modern variety with herbicide, fungicide and fertiliser at a rate of about 50 kg/ha of each of N, P (P_2O_5) and K (K_2O). Most farmers indicated that they used the traditional date for planting Bere which is mid-May. Orkney farmers generally plant modern barley varieties earlier than this and, provided soil conditions are suitable, aim to plant it before the end of April. As a result of the diagnostic survey, subsequent research on Bere concentrated on investigating the effect on yield of earlier planting, seed rate and fertiliser and the use of growth regulator to control lodging.

Planting date and seed rate

Over three years, from 2003 to 2005, April planting of Bere gave significantly higher yields than the traditional (mid-May) date. In 2003 and 2005, this was about 18% higher but, in 2004, it was much larger (76%). This probably resulted from low rainfall in May 2004 (about 70% of the 1961-90 average) which may have delayed the germination and early growth of the later planted crop. It is likely that one of the reasons for higher yields from earlier planting is that this usually resulted in a longer period between planting and harvest - for the early planting treatment, this was 133, 130 and 134 days in 2003, 2004 and 2005, respectively, compared with 105, 133 and 119 days for the mid-May planting in the same years. In 2004, this period was longer for the mid-May planting than it should have been because rain delayed harvesting of this treatment. The longer duration of this period in the earlier planted crop probably resulted in greater interception of solar radiation, particularly during the critical pre- and post-anthesis period (Bingham *et al*. 2007b). It has been well-documented elsewhere (Briggs, 1978) that late planting of spring barley in the UK gives reduced yields and this has also been reported in Ireland (Conry and Dunne, 2001). For malting, a further disadvantage of late planting is higher grain N and lower TGW (Briggs, 1978; Conry and Dunne, 2001). The TGW of Bere is low (24.5 to 32.6 g) compared with modern varieties – for example, in the malting variety Pearl, this ranged from about 35 to 46 g over 17 site/year combinations (Bingham *et al*., 2007a). Planting Bere in April consistently resulted in a significantly higher TGW than a mid-May planting and this would be advantageous when Bere is being supplied for malting because of a greater potential malt extract from larger grains (Cochrane and Duffus, 1983).

In Orkney, harvesting cereals for grain becomes increasingly difficult through September as a result of increasing rainfall (see Fig. 1) and storms. Although early planting extended the period from planting to harvest, early-planted crops were always harvested earlier than those planted in mid-May, so that earlier planting is also likely to result in greater security of harvest. This was demonstrated in 2004, where the mid-May planting treatment could not be harvested until 24 September, and the crop was almost lost. Delayed harvesting also usually results in grain with a higher moisture content which increases the costs of drying.

In the past, there must have been a good reason for adopting a mid-May planting date for Bere rather than one in April and it is possible that this relates to Bere's susceptibility to frost. In the past, heavy late frosts may have been more common and the possible loss of an early planted staple crop may have been an unacceptable risk for farmers in earlier times. Alternatively, the ability of Bere to produce a crop in a short time when planted late - Walker (1812) gives an example of a crop which was ready for reaping after 85 days - may have allowed better use of labour on other farm activities. Results from the planting date trials indicate that Bere can be planted from mid-April onwards. A major attraction of this is that it requires no extra expenditure or input from the grower. The value of early planting can be seen from the gross margin data for the 2005 inputs trial in Table 7 - with mid-May planting, even the use of both fungicide and growth regulator failed to give a higher gross margin than the treatment without either of these inputs at the first planting date.

In neither of the trials in 2003 or 2004 which investigated seed rates between 130 and 190 kg/ha (approximately 430 to 630 grains/m^2) was this shown to have a significant effect on yield or TGW. Similarly, Conry (1998) found little effect of seed rate (from 120 to 240 kg/ha) on yield of spring barley in Ireland except with a later planting, when the lowest seed rate produced the lowest yields. For Bere, a standard rate of 160 kg/ha has recently been adopted, giving a seed population of about 530 seeds/m^2. This is favoured because lower seed rates tend to encourage tillering which can lead to uneven grain maturation at harvest while higher seed rates can result in increased and earlier lodging (Webster and Jackson, 1993), particularly with tall varieties like Bere.

Inputs

The 2003 inputs trial suggested that Bere shows only a small yield response to mineral fertiliser and that a low level of N, P and K (15, 30 and 30 kg/ha) produced similar yields to higher levels. Little response to N, P and K was also seen in another trial in 2005 (not reported) where the yield of the control treatment (0:0:0) was not significantly different from that of treatments where N, P and K, respectively, were applied at 30, 11 and 16 kg/ha and 60, 22 and 32 kg/ha. A fourth treatment, with N, P and K at 90, 33 and 48 kg/ha, yielded significantly less than the control (3.37 t/ha compared with 3.82 t/ha). This may have been caused by increased lodging with higher fertiliser levels, an effect which has been noticed in more recent trials (not reported), and which has been attributed in wheat to the effect of nitrogen on increasing height and ear area and decreasing both stem diameter and stem wall width (Berry *et al.*, 2000). Although the application of mineral fertiliser mostly resulted in small increases in Bere yields, sufficient fertiliser must be applied to make up for crop offtake, if fertility is not to decline. A crop of 4 t/ha of Bere grain with straw removal can be expected to remove about 34 kg of P_2O_5 and 47 kg of K_2O. Bere grain contains nitrogen at about 2.3% (dry basis) and so the crop would also remove about 78 kg of this element. Allowing for atmospheric deposition of about 12 kg/ha of N in the north of Scotland (NEGTAP, 2001), about 66, 34 and 47 kg/ha of N, P_2O_5 and K_2O, respectively, is needed to replace the offtake from a 4 t/ha crop of Bere. In Orkney, where most farms have livestock, it is usual for some of this to be supplied by an application of slurry. In more recent trials, on land which has been under arable cropping for several years, it has been necessary to apply a moderate level of nitrogen (about 45 kg/ha) to sustain yields.

In the three trials where growth regulator and fungicide were used, the results indicated that each caused a similar level of yield increase - in 2003, fungicide and growth regulator resulted in a 7 and 5% increase in yield, respectively. In 2004, the yield increases were 9% for the half dose growth regulator treatment, 5% for the full dose fungicide treatment and 16% for the highest yielding combination of the two. In 2005, the average increases in yield were 11% each for fungicide and growth regulator and 22% for the two combined. In a series of trials in North-west Germany (Yang *et al.*, 2000), application of fungicides to winter barley against leaf diseases gave an average yield increase of about 16% over 7 years. Compared with these data, the yield response of Bere to fungicide seems low and this could reflect some tolerance of Bere to mildew, lower disease pressure in Orkney or a need to apply the fungicide earlier (Conry and Dunne, 2001). Tolerance to powdery mildew has been demonstrated in barley genotypes but this has also been found to be sensitive to environmental effects, like differences between years and fertiliser levels (Newton *et al.*, 1998).

Although growth regulator gave reasonable control of lodging right up to harvest in 2003, it was much less satisfactory in 2004 and 2005 and comparison with adjacent unfertilised plots suggested that lodging of Bere was aggravated by the application of nitrogen fertiliser. Even so, significant increases in yield were usually obtained. Although the main purpose of applying growth regulator is to prevent lodging, it has also found that applications sometimes increase yields without controlling lodging and this is thought to result from greater partitioning of assimilates to the grain (Green and McDonald, 1987) or to delaying the onset of lodging or reducing its severity (Webster and Jackson, 1993). The increases in yield of Bere from using a growth regulator were within the range recorded with winter barley varieties (Green and McDonald, 1987). In 2003, growth regulator resulted in a 17% reduction in straw length which is slightly more than the 12-14% found with a mixture of Modus and Cerone on two barley varieties in Lithuania (Supronienė *et al.*, 2006).

In both 2004 and 2005, the highest gross margins were generally obtained from using a growth regulator alone or in combination with a fungicide. The greater profitability of the growth regulator resulted mainly from the lower cost of the chemical per hectare.

It is likely that the long straw length of Bere (about 1.20 m from ground level to the base of the ear) together with its rapid spring growth give it good weed suppressant ability (WSA), the ability of a crop to reduce weed growth through competition (Murphy *et al.*, 2008). It is therefore likely that Bere would be suitable for organic systems, where a high WSA is an important crop requirement.

The 2005 trial was the only one where planting date was investigated together with the application of fungicide and growth regulator and in this trial yield was raised from 3.4 t/ha for the traditional mid-May planting without fungicide and growth regulator to 5.1 t/ha for an April planting with the application of both chemicals (a 47% increase). This produced a 41% increase in gross margins and demonstrates that substantial increases in Bere yields and profits are possible by using a combination of an earlier planting date and the application of fungicide and growth regulator. Most of the increase, however, resulted from the use of the earlier planting date.

Conclusions

The research described in this paper showed that Bere gave significant, but usually not large, increases in yield as a result of the application of mineral fertiliser, fungicide and growth regulator. While this makes Bere unsuited to high input systems, gross margin data showed that the use of these inputs can sometimes increase the profitability of growing the crop. The most cost-effective and consistent single strategy for increasing yield, however, was the adoption of earlier planting, in April. This also had the advantage of giving an earlier harvest which, in Orkney, gives greater security of harvest. Lodging of Bere was not consistently controlled by growth regulator, particularly when nitrogen was applied, so that it remains a more difficult and time-consuming crop to combine than modern barley varieties.

Results from the present study have provided the basis for supplying advice to growers which has allowed them to increase yields of Bere from about 3.5 to 4.3 t/ha. This has increased gross margins, making it economically viable for farmers to grow the crop and end users, like distilleries (Martin and Chang, 2008), to purchase the grain at an affordable price. The improved agricultural practices have also resulted in greater security of harvests, allowing a reliable Bere supply chain to be developed. These developments provide a novel example in UK agriculture of the commercialisation of a cereal landrace which is also contributing to its in situ conservation by increasing the opportunities for growing it in its region of origin.

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