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Effect of dose and timing of application of different plant growth regulators on lodging and grain yield of a Scottish landrace of barley (Bere) in Orkney, Scotland

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Abstract— *The effects of dose and the timing of the application of three different types of plant growth regulators on lodging and grain yield of a landrace of barley (Bere) were investigated. Results indicated that the application of full dose of plant growth regulators at Zadoks growth stage 31 had improved lodging resistance by reducing the stem length. Amongst plant growth regulators Upgrade caused the highest reduction in stem length and lodging index compared with other plant growth regulators while Adjust was the least effective plant growth regulator. The results indicated that Upgrade was less effective in lodging control at the higher nitrogen level (90 kg ha^{-1}). Although this plant growth regulator improved lodging resistance, grain yield was not enhanced in any of the trials. This outcome was due to a delayed lodging and/or absence of severe lodging in the control plots. Further investigations on the effect of timing of lodging incidence on grain yield would be useful extension of the present study. A separate trial investigating the effectiveness of Upgrade in lodging control under a range of nitrogen levels is recommended.*
Keywords—landrace, Bere, plant growth regulator, dose, timing of application.

I. INTRODUCTION

Bere is a landrace of barley (Jarman, 1996) and has been an important part of Orkney's Agriculture for hundreds, possibly thousands of years (Theobald *et al.*, 2006). In Scotland particularly during 18th and 19th centuries it was a versatile crop that provided flour for baking, malt for brewing and distilling and straw for animal bedding and thatching (Newman, 2006). Once widely grown, Bere is now only grown on a very small scale in Orkney, Caithness, Shetland and a few areas on the Western Isles (Scholten *et al.*, 2007). This decline was partly due to changes in market demand from grain production to grass for the beef industry and the introduction of high yielding modern varieties of barley (Thompson, 2001). The Agronomy Institute, Orkney College, Scotland, which opened in 2002 has put considerable efforts in the development of high value niche products in order to revive the demand for Bere's grain. Until today, two new products, *Bere* whisky and *Island beer*, have been developed in collaboration with *Bruichladdich distillery-Inverness* and *Valhalla distillery-Shetland* respectively (Martin, Wishart and Scott, 2013; Martin and Wishart, 2015). As a result of this development, Bere is now an economically viable crop and a few farmers are interested in growing Bere because they can get a higher price for their produce than they could before. However, farmers are concerned about Bere's susceptibility to lodging due to its long and weak straw (Martin *et al.*, 2010). Severe lodging can interfere with the speed and efficiency of harvesting operations (Tripathi *et al.*, 2003) and, most importantly, it can cause significant economic losses by reducing grain yield (GY) (Pinthus, 1973) and grain quality of barley (Stanca *et al.*, 1979; Birggs, 1990). In order to avoid lodging related negative effects on harvesting and grain yield, Bere is presently grown with no or low nitrogen inputs (30 kg N ha^{-1}) on marginal land in Orkney (Dr. Peter Martin, personal comm.). Plant growth regulator (PGR) can reduce stem length and improve the standing ability of the barley (Kust, 1985; Sanvicente *et al.*, 1999) and wheat (Jung, 1964; Tripathi *et al.*, 2003). Amongst PGRs *Ethephon* (2-chloroethyl phosphonic acid) (ET) and *Chlormequat chloride* (CCC) have been effective in decreasing plant height and reducing lodging incidence in wheat (Crook and Ennos 1995). However, the effectiveness of PGRs in controlling lodging depends on many factors including variety, type of growth regulator, its application rate (Bahry, 1988), crop growth stages at the time of application (Caldwell *et al*., 1988) and its dose (Simmons *et al*., 1988). There was no published information on the effects of timing, type

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and dose of PGRs on lodging and yield of Bere. This paper is first of its kind which reports the results obtained from three different trials carried-out in 2008 and 2009. In *Trial 1*, the effectiveness of different doses of PGRs in lodging control and yield enhancement was investigated. *Trial 2* examined how the timing of application of PGRs affected lodging related trait, yield and yield components of Bere. These two trials were carried out under low N-level (30 kg N ha^{-1}). *Trial 3* was essentially a repetition of *Trial 2* except that it was carried-out at a higher N-level (90 kg ha^{-1}).

II. METHODS AND MATERIALS

Bere was sown using standard seed rate (160 kg ha^{-1}) recommended by Martin *et al.* (2010) at an experimental site near Orkney College, Kirkwall, Orkney (Grid reference: HY 456 114) in two successive growing seasons (2008 and 2009). The soil of the experimental plot was classified as clay loam, with organic matter (3.9 %), NO_3-N (17.25 mg kg^{-1}) and NH_4^+ (0.96 mg kg^{-1}), P (28.2 mg kg^{-1}), K (70mg kg^{-1}) and acidic in nature (pH=5.5). Plots were planted using a Pneumatic Accord Combine Seed Drill. Weed control was achieved in all trials by applying a mixture of Mecoprop (1.5 l ha^{-1}) and 4-chloro-2-methylphenoxy acetic acid (MCPA) (1.0 l ha^{-1}) in 200 l of water. The plant growth regulators (PGRs) used were *Adjust* {[chrolmequat chloride], Mandops, a.i 620 gl^{-1}}, *Cerone* {[2-chloroethylephosphonic acid], Bayer CropScience, a.i 480 gl^{-1}} and *Upgrade* {[chrolmequat chloride + 2-chloroethylephosphonic acid], Bayer CropScience, a.i 360:180 g l^{-1}}. All PGRs were sprayed using Knapsack sprayer in sufficient water (160 l ha^{-1}) and with a wetting agent "Banca" at the manufacturer's recommended rate (10 ml 20 l^{-1}) to give good foliage coverage. The agronomic details of all the trials are illustrated in Table 1.

Table.1: Agronomic detail for 2008 and 2009 trials

	Trial 1	*Trial 2*	*Trial 3*
Date Sown	6th May 08	6th of May 08	27th April 09
Seed Rate	160 kg ha^{-1}	160 kg ha^{-1}	160 kg ha^{-1}
Row Spacing	9.5 cm	9.5 cm	9.5 cm
Previous crop	Bere	Bere	Bere
Fertilizer (N-P-K kg ha^{-1})	30-30-40	30-30-40 kg	90-30-40
Date Harvested	24th Sep 08	9th Sep 08	11th Sep 09

Since the trials were not complete factorial experiments, it was not possible to statistically compare means across PGRs, growth stages or doses. However, means were manually calculated to aid in the interpretation of the effect of treatments. In all the trials, ears m^{-2} (EPSM) was recorded in a representative 50 cm x 50 cm quadrat. A representative sample of 20 stems was manually harvested from each treatment plot. A sub-sample of 10 stems was used to record stem length from the bottom of the stem to the base of the ear as described by Schittenhelm and Hartmann (2006). The ears of the remaining stems (10 stems) were then manually threshed to record grains ear^{-1} (GPE). All plots were visually monitored after every rainfall event to record the onset of lodging. Final lodging assessments were made just before final harvest in the un-sampled half of each plot area. A frame marked with different angles was used to visualize the angle of deviation of stems from vertical. These observations were then converted into lodging index (LI) with slight modification to the formula developed by Berry *et al.* (2003) so that intermediate angles of 0-15, 15-30, 30-45, 45-60, 60-75, and 75-90 could be included.

Lodging Index = {1/6 (% at 0^0-15^0) +2/6(% at 15^0-30^0)+3/6(% at 30^0-45^0)+ 4/6(% at 45^0-60^0)+5/6(% at 60^0-75^0)+(% at 75^0-90^0)}.

Grain yield (GY) was estimated by harvesting the plots either manually or by combine harvester. A sub-sample (100 g) of grain was drawn to measure grain moisture content (GMC). A Contador counter (Hoffman Manufacturing Inc, Germany) was used to count the grains required for 1000-grain weight (TGW). The GY and TGW were adjusted to 15 % GMC. Statistical analysis of the data was performed separately for each of the trials using Genstat 9.1. Means of treatments were compared using Fischer's protected least significant differences (LSD) at 5% level of probability. The relationships between yield, yield components, lodging and lodging related traits were investigated by regression analysis.

2.1 *Trial 1*

The seven treatment combinations for this trial are provided in Table 2. These treatments were applied when 75% of the plants were at ZGS 33 while 25% at ZGS 37 on individual subplot plot 6 m x12 m (72 m^2). In all plots,

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data were collected for stem length (StL), lodging index (LI), ears m^{-2} (EPSM), grains ear^{-1} (GPE), grain yield (GY) and 1000-grain weight (TGW). Plots were assessed for lodging on 11th Sep 2008. GY was estimated by combine harvesting two strips, 2.3 m wide and 12 m long on 24th September 2008.

Table.2: List of plant growth regulators and their abbreviations

Treatment	**Abbreviation**
Adjust (half dose)	A ½
Cerone (half dose)	C½
Upgrade (half dose)	U½
Adjust (full dose)	A1
Cerone (full dose)	C1
Upgrade (full dose)	U1
Control	No-PGR

2.2 *Trial 2*

This trial was sown along with *Trial 1* on similar date. A list of treatments is shown in Table 3. The treatments were applied at two different growth stages i.e ZGS 31 (1st node detectable) and ZGS 37 (flag leaf just visible) on 19th and 30th June 2008 respectively. All the treatments were replicated 5 times and randomly assigned to individual plots of size (2 m by 3 m) in a randomized block design. Soon after the onset of stem elongation, 5 main stems of the plants in each plot were tagged with cable ties to ensure that main stems were used for recording stem diameter (SD) and stem length (StL) at maturity. The tagged main stems were harvested on 6th September 2008. The leaves and ears were removed from the stems and StL was recorded. SD was measured using calipers at 1 cm above the stem base. Plots were assessed for lodging before being manually harvested on 9th Sep 2008 to record yield and other parameters.

Table.3: List of plant growth regulators and their abbreviations applied at different growth stages in 2008

Treatment	**Abbreviation**
Adjust at ZGS 31	A31
Cerone at ZGS 31	C31
Upgrade at ZGS 31	U31
Adjust at ZGS 37	A37
Cerone at ZGS 37	C37
Upgrade at ZGS 37	U37
Control	No-PGR

2.3 *Trial 3*

This trial was a randomized block design with 4 replications. Seven treatments (Table 4) were applied to individual sub-plots (3 m x 6 m). All the PGRs were sprayed at ZGS 31 and ZGS 37 on 15th June 15th and 21st June 2009 respectively. Plots were mechanically harvested using combine on 11th Sep 2009. Data recorded for this trial were StL, LI, TGW and GY.

Table.4: List of plant growth regulators and their abbreviations applied at different growth stages in 2009

Treatment	**Abbreviation**
Adjust at ZGS 31	A31
Cerone at ZGS 31	C31
Upgrade at ZGS 31	U31
Adjust at ZGS 37	A37
Cerone at ZGS 37	C37
Upgrade at ZGS 37	U37
Control	No-PGR

III. RESULTS

3.1 *Trial 1*

The data recorded for this trial are presented in Table 5. StL was significantly (*P= 0.016*) affected by the PGR treatments. *Upgrade* was the most effective PGR which caused the greatest reduction in StL compared with *Cerone* and *Adjust* (averaged over both doses). The control treatment resulted in the highest StL. Interestingly, the half dose and full dose of the PGRs produced almost identical StL. Visual assessments of the crop made on 16th and 30th August 2008 showed no apparent sign of lodging-flat (angle of deviation of stem from vertical > 76^0). However crop leaning (angle of deviation between 16^0-45^0) was seen in all the plots and was comparatively higher in the control than in the PGR treatments. PGR treatments had a significant (P< 0.001) effect on LI. *Upgrade* was the most effective PGR in reducing the LI followed by the *Cerone* and *Adjust* treatments. When the effects of individual doses of the PGRs were examined, it was observed that the full dose gave a better lodging control than the half dose. PGR treatments had significant (*P= 0.027*) effect on EPSM and full dose of the PGRs resulted in higher EPSM than half dose and the control. The highest EPSM was produced by the plots treated with *Cerone* followed by *Upgrade* (averaged over both doses). *Adjust* was the least effective PGR. GPE was also significantly (*P= 0.009*) affected by the PGRs. The highest GPE was recorded from the *Upgrade* treatment followed by the *Adjust* while the lowest was from the *Cerone*. When the effects of individual doses of the PGRs were examined, it was noted that the full dose of *Cerone and Adjust* reduced the GPE by 16% and 13% respectively compared with the half doses. The correlation analysis revealed that there was a significant (*P= 0.007*) negative association between

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EPSM and GPE (Fig 1). TGW differed (*P= 0.002*) between the treatments. The plots treated with *Adjust* produced the highest TGW, followed by the control and *Upgrade* treated plots while the lowest from *Cerone*. It was also noted that the full dose of *Cerone* reduced the TGW by 6% compared with its half dose. The correlation analysis indicated that there was a negative association between EPSM and TGW (Fig 2). GY was not significantly affected by the PGR treatments.

Table.5: Effect of half and full dose of plant growth regulators on selected parameters of Bere in 2008

Trial 1			**2008**			
Treatments	StL (cm)	LI	EPMS	GPE	TGW (g)	GY (kg/ha)
A1	91.4	43.5	404.3	30.9	35.6	3596
C1	89.6	28.5	443.7	28.8	33.8	3254
U1	76.6	27.8	416.0	36.5	35.1	3418
A ½	89.8	45.3	336.0	35.1	36.5	3080
C ½	86.3	44.0	412.8	33.6	35.9	3368
U ½	78.2	40.2	382.9	34.9	34.9	3548
Control	94.1	67.5	362.7	34.4	36.1	3192
Probability	0.016	<0.001	0.027	0.009	0.002	0.384
LSD(0.05)	10.70	11.4	61.8	4.0	1.2	519.4
S.E	3.7	3.9	21.2	1.4	0.41	177.9

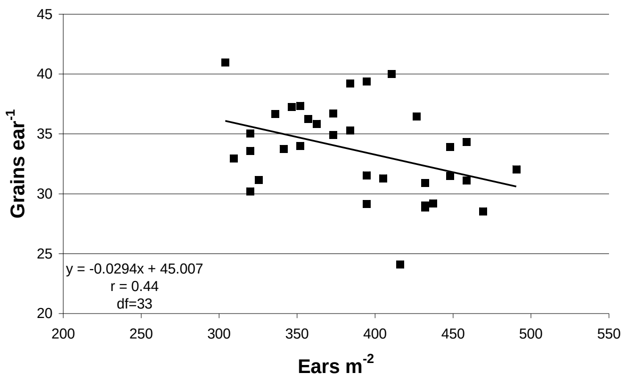

Fig.1: Correlation between grains ear^{-1} and ears m^{-2}

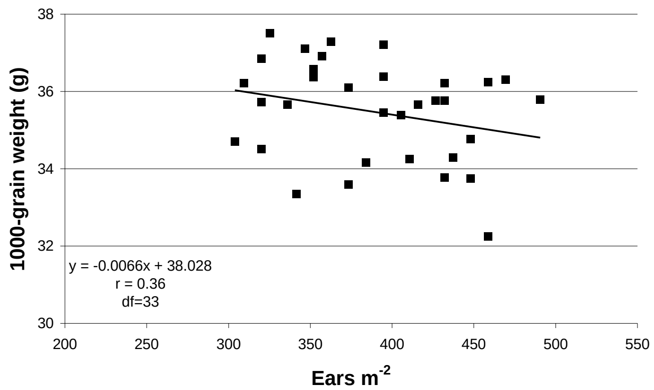

Fig.2: Correlation between 1000-grain weight and ears m^{-2}

3.2 *Trial 2*

SD was not significantly affected by the timing of application and the type of PGRs (Table 6). There were significant (*P= 0.007*) differences in the StL between the treatments. Amongst PGRs, *Adjust* was the least effective treatment in reducing StL (averaged over all growth stages). When the effects of the timing of application were examined it was noted that the earlier application of

Adjust and *Upgrade* at ZGS 31 caused more reduction in StL than their later applications (ZGS 37). SWCM was significantly (*P= 0.033*) affected by the PGR treatments. Early application at ZGS31 tended to reduce SWCM than at ZGS 37 (average of all three PGRs). *Upgrade* applied at ZGS 31 was the only treatment that showed significant decrease in the SWCM compared with the control. This treatment reduced the stem dry weight proportionally more than the length. In contrast, the remaining PGR treatments had a higher SWCM than the control. The LI assessment made on 9th September 2008 showed significant (*P< 0.001*) differences between the treatments. All the three PGRs reduced the LI compared with the control, and were more effective at ZGS 31 than ZGS 37. *Adjust* was the least effective PGR at ZGS 37. The highest LI was observed in the control (70) while the lowest value was recorded for the U31 treatment. The PGRs had a significant effect (*P< 0.001*) on EPSM. Earlier application of PGR at ZGS 31 increased the number of EPSM compared with those plots treated at ZGS 37 (average of all three PGRs) and the control. The highest EPSM was from the U31 treatment followed by the C31 treatment while the lowest was in the U37 treatment. EW was significantly affected by the treatments. The earlier application of the PGRs reduced the EW more than the later application. The highest was from the control treatment while the lowest from the U31 treatment. GPE was also significantly (*P< 0.001*) altered by the treatments. Earlier application of PGRs at ZGS 31 produced lower GPE than later application. The highest GPE was from the control treatment followed by the A37 and A31 treatments while the lowest GPE was from the U31 treatment. TGW was significantly (*P= 0.002*) affected by the treatments. Earlier application at ZGS 31 resulted in a lower TGW than at ZGS 37 (averaged over PGRs). Among the PGRs treatments, the *Adjust* treatment produced the highest TGW followed by *Cerone* treatment and the lowest was from the *Upgrade* treatment (averaged over growth stages). The control treatment had the heaviest TGW followed by the A37 treatment and the lowest was from the U31 treatment. It was noted that none of the plant growth regulators caused any significant effect on GY irrespective of the timing of application when compared with control. Simple linear regression analysis revealed that the interrelationships between yield and its components were not significant (Table 7). This was due to the negative correlations between EPSM and both GPE (Fig 3) and TGW (Fig 4). There was no significant association between GPE and TGW (Table 4.3). The multiple regression analysis, considering all the yield components as yield predictive variables, showed that EPSM together with EW explained 56% of the variations in grain yield (Table 7). There were no significant correlations between SWCM or SD and LI (Table 8). A step wise inclusion of additional variables in a multiple regression model improved the correlation and a regression model comprised of StL, EW and SD as predictive variables correlated most closely with the LI (Table 8).

Table.6: Effect of timing of application of plant growth regulators on selected parameters in 2008

Trial 2	2008							
Treatments	StL (cm)	SD (mm)	SWCM (mg cm^{-1})	LI	EPSM	GPE	TGW (g)	GY (kg ha^{-1})
A31	85.3	3.98	11.6	52.5	400.8	32.3	36.1	4407
C31	83.1	3.88	10.7	25.5	471.2	25.5	33.9	4200
U31	68.3	3.49	9.5	17.5	544.0	23.1	33.5	4221
A37	87.8	3.78	12.0	65.5	367.2	32.9	36.6	4400
C37	75.5	3.5	10.3	33.7	413.6	29.6	36.1	4270
U37	77.6	3.83	11.2	37.2	357.6	30.8	34.9	4172
Control	94.1	3.52	10.2	69.7	376.8	33.8	37.4	4616
Probability	0.007	0.411	0.033	<0.001	<0.001	<0.001	0.002	0.150
LSD(0.05)	13.5	0.57	1.52	10.5	68.8	2.7	1.9	575.2

Table.7: Values of the co-efficient of determination (R^2) and probability (P) for linear regressions of yield and its different components of yield.

Yield components	No. of independent variables	R^2	Probability (P)
Ears m^{-2} (EPSM)	1	0.0698	NS, df=33
Grains ear^{-1} (GPE)	1	0.0201	NS, df=33
1000-grain weight (TGW)	1	0.0828	NS, df=33

EPSM, GPE	2	0.4945	<0.001, df=32
EPSM, TGW	2	0.2857	=0.004, df=32
EPSM, EW	2	0.5692	<0.001, df=32
GPE, TGW	2	0.0341	NS, df=32
EPSM, GPE,TGW	3	0.5546	<0.001, df=31

NS: Not significant (*P> 0.05*)

Table.8: Values of co-efficient of determination (R^2) and probability (P) for linear regression of lodging index and lodging related traits

Lodging related trait	No. of independent variables	R^2	Probability (P)
Ear weight (EW)	1	0.6601	<0.001, df=33
Stem length (StL)	1	0.2863	<0.001, df=33
Stem diameter (SD)	1	0.0011	NS, df=33
Stem weight per cm (SWCM)	1	0.0920	NS, df=33
EW, SD, StL	3	0.7635	<0.001, df=31

NS: Not significant (*P> 0.05*)

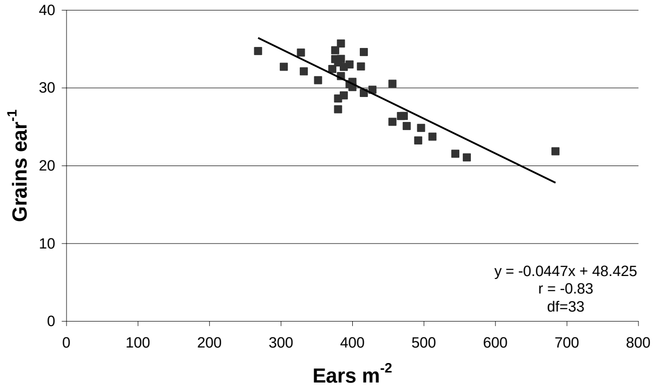

Fig.3: Correlation between grains ear^{-1} and ears m^{-2}

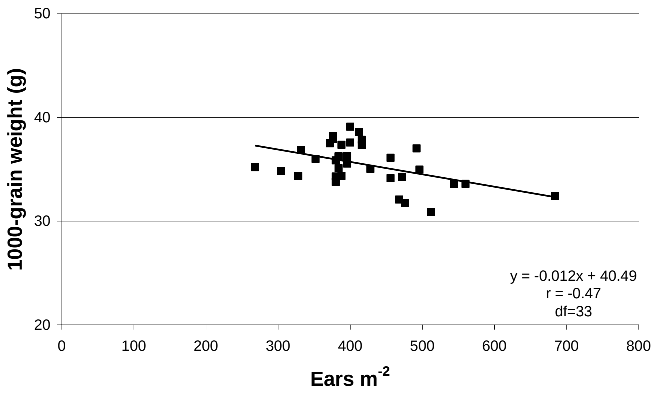

Fig.4: Correlation between 1000-grain weight and ears m^{-2}

3.3 *Trial 3*

Results for the C31 treatment are not reported because this treatment was contaminated with a chemical herbicide which resulted in severe damage to the plants. *Upgrade* and *Cerone* reduced the length of stem and LI more than the control plots (average over both application times) while *Adjust* was the least effective PGR (Table 9). GY was not affected by any of the PGR treatments. A simple regression analysis revealed that LI had no significant associations with GY or TGW and it was also not related to StL (Table 10).

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Table.9: Effect of application of plant growth regulators at different growth stages on lodging and yield of Bere in 2009.

Trial 3		2009		
Treatment	StL	LI	TGW (g)	GY (kg ha^{-1})
A31	118.0	95.4	30.6	4585
U31	112.6	76.0	29.7	4189
A37	123.	97.7	29.4	4186
C37	111.0	90.0	29.8	4166
U37	110.3	72.3	31.1	4870
Control	124.7	95.4	29.8	4854
Probability	<0.001	0.032	0.012	0.250
LSD(0.05)	6.8	18.1	0.93	833.9

Table.10: Values of co-efficient of determination and probability for selected parameters

Dependent variable	Independent variable	R^2	Probability (P)
GY	LI	0.005	NS, df=22
TGW	LI	0.093	NS, df=22
LI	StL	0.092	NS, df=22

NS: Not significant (*P*> *0.05*)

IV. DISCUSSION

Reduction in StL was influenced by the type of PGRs and application rate. In agreement with the work of White (1991), *Adjust* (CCC) was found to be the least effective in shortening the length of stem. This response was thought to be due to poor absorption of CCC by the barley plant (Skopik and Cervinka 1967). *Upgrade* caused the greatest reduction in the length of stem and the half of the recommended rate was as effective as the full dose. Although a half dose and full dose of PGRs produced similar StL, the LI did not follow this pattern and the lowest LI was achieved from the full dose of *Upgrade* and *Cerone*. This outcome suggested that the mechanism by which PGR increased resistance to lodging may not be related to StL alone. Other lodging related stem traits such as SD (Easson *et al*., 1993), SWCM (Zuber *et al.*, 1999) as well as EW (Tripathi *et al.*, 2003) were investigated in *Trial 2*.

It has been reported that a higher SD is an indication of lodging resistance (Mukherjee *et al.*, 1967) but the *Trial 2* results showed no evidence that PGRs affected SD. This outcome was consistent with the findings of Stanca *et al.* (1979) on different barley varieties. Dunn and Biggs (1989) suggested that lodging resistance in barley was associated with thicker stem walls rather than a larger SD. White (1991) and Zuber *et al.* (1999) considered SWCM as a measure of stem strength. These results suggest that PGRs, such as *Cerone* and *Upgrade,* might increase the stem strength by concentrating dry matter into shorter stems which would result in a lower LI. In contrast, the lowest LI was recorded in those plots which had the lowest SWCM. This outcome may suggest that lodging resistance may not be solely related to stem strength or that SWCM was not a good indicator for the stem strength. Pinthus (1967) found that EW and StL were strongly related to lodging. This was because when stems were displaced from vertical position due to the wind, a second base bending moment resulted from the centre of gravity which increased with increase in EW and StL (Pinthus, 1973). In our study, the simple regression analysis indicated that EW and StL were strongly correlated with LI and 76% of variation in LI was explained jointly by EW, StL and SD.

Higher levels of N result in higher lodging incidence in susceptible varieties (Jordan and Stinchcombe, 1986; Newton *et al.*, 1998). In *Trial 3* we used 90 kg ha^{-1} N was applied with the objective to increasing the lodging risk and to investigate the effectiveness of PGRs in controlling lodging. The results indicated that *Upgrade,* which had reduced StL by 34% and lodging by 75% than the control in *Trial 2*, caused only a 10% reduction in StL and 20% in lodging in *Trial 3*. This suggested that the stem shortening efficiency of the PGR was lower at the higher N-level which may have been reason why the PGR was less effective in reducing LI. However, differences in weather conditions during the two growing seasons and sowing date can affect StL and LI (Leitch and Hayes, 1989; Amir and Sinclair, 1994). A set of trials investigating the effect of sowing dates and seasons on lodging related traits and lodging incidence would be useful extension of the present study.

It is often reported that PGRs enhance GY by increasing EPSM (Ramos *et al*., 1989). In this research, whilst full dose and earlier application of PGRs at ZGS 31 increased EPSM, GY was not significantly enhanced. This was due

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to a negative association between EPSM and GPE. The increase in EPSM decreased TGW resulting in non-significant effects of PGRs on GY. Although higher N-level increases GY (Pietola *et al.,* 1999), severe lodging can significantly reduce yield in susceptible varieties (Tripathi *et al.,* 2004). The results obtained from *Trial 3* revealed that GY between the PGR treated plots and the control was not different. This outcome suggested GY was not affected by the detrimental effect of lodging at the higher N-level (90 kg ha^{-1}). This may have been due to late lodging which occurred after crop had lost its green colour. It has been reported that lodging at the early milk stage can cause the greatest yield losses while lodging at the soft dough to hard dough stages has a negative effect on grain weight but a less severe effect on yield reduction (Jedel and Helm, 1991). However the duration between the lodging event and harvesting must not be overlooked. A long duration between pre-harvest lodging and harvesting operation due to wet conditions may result ear sprouting. In Orkney controlling pre-harvest lodging is very important because rain can delay the harvesting operation for several days which may result in severe yield and quality losses. The present study indicated that PGRs (*Cerone* and *Upgrade*) application always resulted in low LI. Although, in the absence of severe lodging or significant yield enhancement, the PGR may not justify its expenditure, it may facilitate easier harvesting operations.

One of the objectives of this paper was to identify suitable PGR and the optimum growth stage for its application on Bere. It was not possible to definitively identify and recommend a PGR suitable for all conditions from the results of the limited number of trials undertaken in this study. But taking into account the effects of ET (*Cerone*) and CCC (*Adjust)* on StL, LI and yield components, the most suitable choice seems to be the *Upgrade* which is a mixture of ET and CCC. The presence of CCC in a commercial formulation of *Upgrade* can antagonize the negative effect of ET on TGW and GY (Caldwell *et al.,* 1988). Also a combination of CCC and ET has been recommended for the varieties that are sensitive to brackling (buckling of middle internodes) (Sanvicente *et al.,* 1999) which could be beneficial to Bere. The results revealed that *Upgrade* consistently caused the highest reduction in StL and LI under the lower N-level (30 kg ha^{-1}) but its application at the higher N-level (90 kg ha^{-1}) was not so effective in lodging control. A set of trials investigating the effectiveness of this PGR under different fertility levels ranging from medium (60 kg ha^{-1}) to high (90 kg ha^{-1}) would help to determine its potential use.

V. CONCLUSION

The findings reported in this paper have implications for the use of PGR. Whilst PGR may be required to control lodging in Bere, its use may reduce the economic benefit and profitability unless the PGR increases yield. Since lodging was not severe in trials 1 and 2, it can be commented that Bere does not require PGR application under low N-level (30 kg ha^{-1}). Whilst at a higher N-level (90 kg ha^{-1}), the PGR,*Upgrade* improved the standing ability of Bere, had no effect on GY. This suggests that in the absence of severe lodging, the economic benefit of PGR is likely to be low. However, considering the susceptibility of Bere to lodging, PGR may be considered for yield protector rather than yield enhancer. It application may be recommended to avoid lodging-flat and to facilitate the harvesting operation. Further investigation on the effectiveness of *Upgrade* on lodging incidence and grain yield under a range of N-levels would assist in estimating the cost-benefit of integrating PGR in the production guidelines for growing Bere in Orkney.

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