BBRO 04/15: Factors influencing crown size and the implications for crown tare

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Summary

Two factors determine the crown tare of delivered beet - the total amount of crown that is present on the growing beet (the biological crown size) and the proportion removed by the topping process when the beet are lifted.

The 4-year study reported here examined the differences in biological crown size and crown height in the varieties currently being trialled for the Recommended Lists on a silt loam and a sandy loam.

The effects of agronomic practices (especially nitrogen use, plant population density, and stand uniformity) were examined on varieties with contrasting large (Wildcat) and small (Stallion) biological crown sizes.

The effectiveness of different topping mechanisms (skew bar, feeler wheel & knife, and continental comb & scalper) in removing crown material was compared under experimental conditions and in commercial crops.

The study showed that the crown tares of delivered beet are primarily determined by the size of the biological crown. This is a varietal characteristic that is not over-ridden by the small effects due to agronomy, soil fertility or seasonal growing conditions.

The three topping mechanisms removed different proportions of the biological crown. The feeler wheel & knife removed the most (49%) and the comb & scalper - the most popular commercial mechanism – the least (33%). All three topping mechanisms removed less of the biological crown in large-crowned varieties than in small-crowned ones, but did not over-ride the dominant effect of varietal differences in biological crown size on crown tare.

The proportion of over-topped beet increases when crown tares fall below 6% and a noticeable decrease in delivered yield below 4%. On average, commercial harvesters remove one-third of the crown material of medium to large-crowned varieties, and even more of that of small-crowned varieties. There is, therefore, a greater risk of over-topping and yield loss with such small-crowned varieties unless great care is taken in setting up the harvester.

The downward trend in the biological crown sizes of recently-introduced varieties is of concern. The biological crown sizes of only 5 of the 28 varieties on the current 2009 Recommended List are known. Thus there is a strong case for continuing to monitor biological crown size in candidate varieties for the Recommended List.

Introduction

The crown tares of delivered beet have large financial implications for both grower and processor. Their lower concentrations of sugar and higher concentrations of amino-N, potassium and sodium in the crown affect the efficiency and cost of sugar extraction in the factory[1] and, because growers are now paid for part of the delivered crown tare, very low tares mean a potential loss of income if beet are over-topped leaving potentially deliverable yield in the field. The risk of overtopping increases greatly when beet with small biological crowns are grown or topping mechanisms are set too low and result in crown tares of less than 6%[2]. There has been no quantitative analysis of the causes of the variation in crown tare and no biological standards against which to assess the quality of commercial beet topping practices.

The crown is, anatomically, the compressed stem of the plant (Fig. 1). The amount left on the delivered beet (the *crown tare*) will depend on how large the original crown was (the *biological crown size*), and the proportion removed by the topping mechanism during harvesting. The effectiveness of topping primarily depends on harvesting conditions and how the machines are set up and operated. But it will also be influenced by the size of the biological crown and its height above the soil - which are not necessarily correlated. Improperly adjusted harvesters machines, could result in large or high crowns being under-topped, and small or low crowns being excessively topped. Crown height is also likely to influence the susceptibility of the beet to frost. It has been shown that frosts are more likely to damage the crowns of beet than the main part of the storage root within the ground, especially when crowns stand proud of the ground and beet are stored in the field and harvested late[3].

Biological crown size and crown height are varietal characteristics. In fact, a major factor that instigated the present study was grower concern over extremely large crown tares being reported for the widely-grown variety, Wildcat, that was introduced 6-8 years ago. Because it is biologically part of the shoot, the size of the crown is affected by growing conditions and agronomic practices that favour shoot growth, especially the availability of nitrogen and plant population density[2]. It is not known whether large and small-crowned varieties respond differently, in terms of their crown tare, to growing conditions and agronomic practice, or whether the effects are large enough to override any varietal difference. Although it is commonly believed that large-crowned varieties produce large crown tares, it is not always appreciated that small-crowned beet are more likely to be over-topped with consequential yield loss.

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[1] **Harvey CW & Dutton JV (1993).** Root quality and processing. In: *The Sugar Beet Crop.* pp. 571-617. Eds DA Cooke and RK Scott. Chapman & Hall: London.

[2] **Milford GFJ & Houghton BJ (1999).** An analysis of the variation in crown size in sugar beet (*Beta vulgaris*) grown in England. *Annals of Applied Biology* **134**, 225-232.

[3] **MIlford GFJ, Armstrong MA & Patchett M (2002).** Frost damage to sugar beet – estimating the risk. *British Sugar Beet Review*, Autumn 2002, (in press).

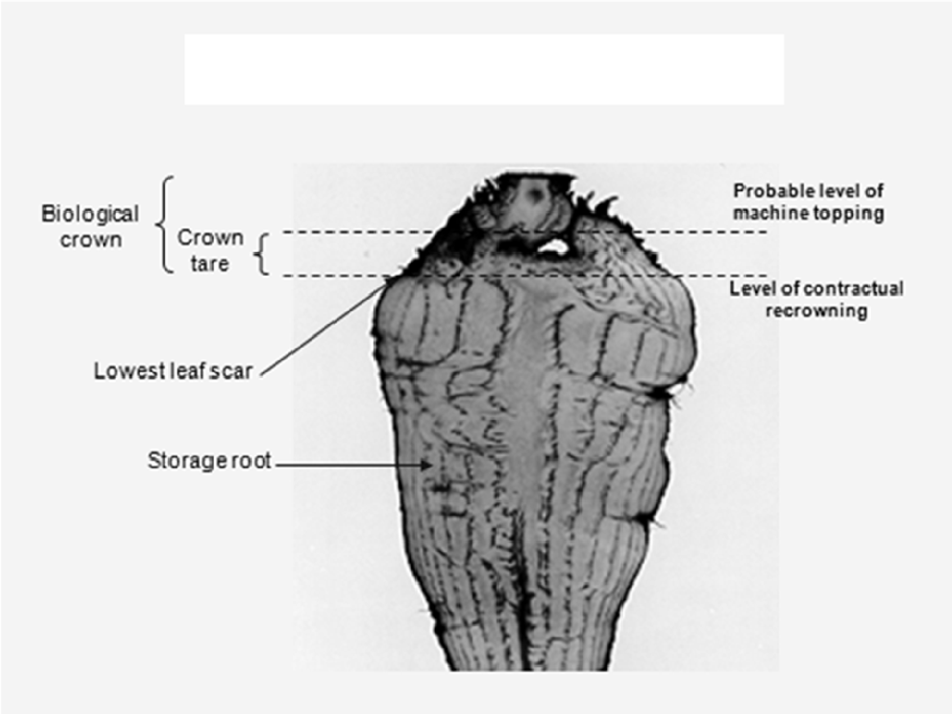

Fig. 1. *Anatomy of the sugar beet illustrating the biological crown and its relationship to topping practice and crown tare.*

The objectives of the present study were to:

(a) quantify the differences in biological crown size in sugar beet varieties currently grown in the UK;
(b) examine the effects of agronomic practices and growing conditions on biological crown size;
(c) establish the relationship between biological crown size and crown height and to quantify the effects of differences in crown size and height on crown tare with different topping mechanisms; and
(d) examine the usefulness of biological crown size measurements in assessments of the efficiency of beet-topping practices in the 'Quality Harvesting' programme.

Approaches

Varietal differences in *biological crown size* and *crown tare* of varieties were evaluated for 10 varieties from the Recommended List in two 3-year series of strip trials, one on a silty loam at Coddenham, Suffolk and the other on a sandy loam at Bracebridge, Lincs. The varietal strips were six rows wide (allowing for two 3-row subplots) and replicated four times. Three varieties (Stallion, Roberta and Wildcat, representing small, medium and large-crowned types) were grown as standards in each trial, other varieties changed as they entered the Recommended List. In October, beet were lifted by hand from one subplot to measure biological crown size, and the other subplot harvested by machine and beet samples taken for measurement of crown tare.

The effects of agronomy were tested in the first two years in randomized strip trials at the same two sites that compared the effects of factorial combinations of three rates of N (60, 120 and 180 kg N/ha) and three target plant population densities (60, 90 and 120 thousand/ha) on a large and a small-crowned variety (Wildcat and Stallion, respectively). Additional strips were sown with a 30:60 mixture of dead and live seed at 90 thousand plants/ha and 120 kg N/ha to test the effect of an irregular plant stand. Beet samples were taken for measurement of biological crown size and crown tare.

The effects of different topping mechanisms on the crown tares of Stallion and Wildcat were examined at the same two sites in a further series of strip trials in the third year that were drilled at 90 thousand seed/ha and given 120 kg N/ha. Replicated areas of each variety were lifted with harvesters fitted with a skew bar, a feeler wheel & knife, or a continental comb & scalper topping mechanism.

For measurement of biological crown size, the 25-plant sample lifted by hand from each subplot of the above experiments was cleaned and carefully scalped by hand to retain the entire biological crown. This was separated from the storage root at the contractual point (*i.e.* level with the lowest leaf scar) by a trained operator, and the crowns and roots weighed separately. For measurement of crown tare, a 10-m length of 3 adjacent rows of each subplot was lifted by machine, and a 25-beet sample taken, cleaned and contractually topped. Biological crown size and crown tare are expressed as a percentage by weight of the clean, contractually-topped root.

The mean height of the crown above soil level was measured in some of the machine-lifted subplots using a prototype, harvester-mounted crown height analyzer.

Efficiency of topping in commercial crops. Recent research has quantified most of the effects of harvesting and storage practices on the losses of deliverable sugar, but the effectiveness of topping is one aspect of harvesting practice that has been difficult to assess objectively. Comparisons of biological crown size (as a measure of what is originally present) and crown tare (a measure of what is left) should provide an objective measure of the effectiveness of growers' and contractors' topping practices. Such measurements were made at harvest on hand-lifted beet (biological crown size) or harvester samples (crown tare) from commercial fields that were surveyed as part of the 2007/08 BBRO-funded 'Quality Harvesting' programme.

Variation of crown tare in commercial beet

Figure 2 shows the frequency distributions of crown tare in individual loads of beet delivered in recent British Sugar plc processing campaigns. Crown tares ranged from less than 3 to over 20% and, between 2004/05 and 2006/07, the national average crown tares were between 11.5 and 12.5%. However, the average crown tare in 2007/08 was only 10.3%.

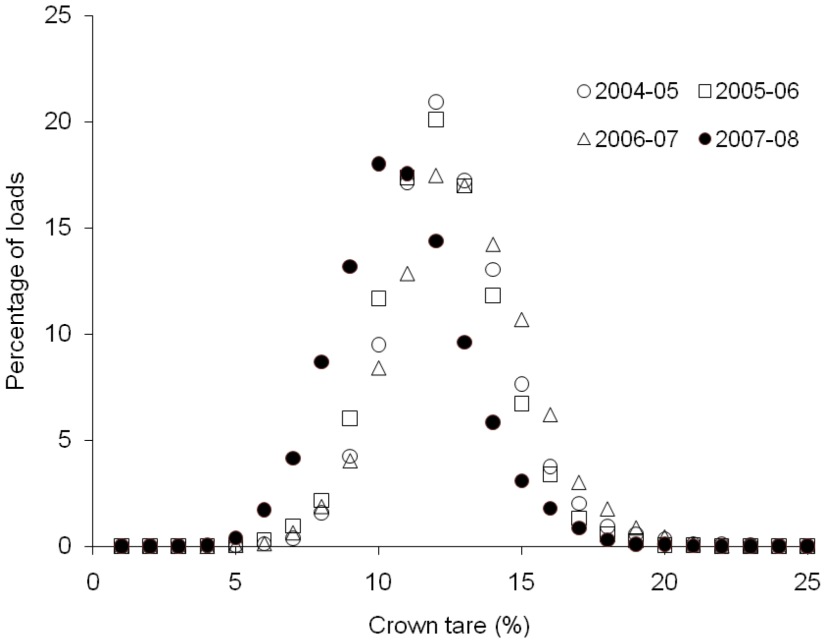

Fig. 2. *Frequency distributions of commercial crown tares in recent processing campaigns.*

Varietal differences in biological crown size

Opinions differ on the extent to which varietal choice has influenced delivered crown tare. A review of Broom's Barn data argued that the decrease in factory crown tare from 13 to 7% between the mid 1970s and the mid 1990s was due to the smaller crowns of new varieties introduced during that period[4], whereas a review of a much wider range of varieties and sites for the same period showed there was still wide variation in crown tare and little overall evidence of any consistent downward progression in crown size[5].

The present series of experiments examined the biological crown sizes and the resulting crown tares of some of the varieties from the 2004-06 Recommended Lists on a silt loam and a sandy loam soil. The cvs Stallion, Roberta and Wildcat were included in each of the trials as representative of varieties with small (< 10%), medium (11-14%), and large biological crowns (> 17%), respectively. Of the other varieties examined, Gandalf, Palace, Radar and Rayo had relatively small crowns, Bobcat, Dominika, Giovanna, Mars, Pernilla and Salvador had medium-sized crowns, and Buxom and Cinderella had relatively large crowns. These varietal differences in biological crown size were consistent on the two soil types and across seasons (Table 1).

Figure 3 places these recently-examined varieties into a wider historic context by ranking them against data obtained from earlier British Sugar work. The biological crown sizes of many of the more recently-introduced varieties (notably Gandalf, Raskal, Radar, Palace, Salvador, Mars and Dominika) are at the smaller end of

[4] **Jaggard KW, Clark CJA & Draycott AP (2000).** The weight and processing quality of components of the storage root of sugar beet (*Beta vulgaris* L). *Journal of Science of Food and Agriculture*

[5] **Milford GFJ & Houghton BJ (1999).** An analysis of the variation in crown size in sugar beet (*Beta vulgaris*) grown in England. *Annals of Applied Biology* **134**, 225-232

range and are all diploid. However, a small crown size is not restricted to the diploid genome because large and small crowns occur in both diploid and triploid varieties (Fig. 4). Appendix Table 1 lists the provenance of the varieties in Fig. 1 in order of their biological crown size which highlights the fact that recent small-crowned varieties primarily originate from the Danisco and Syngenta seed companies.

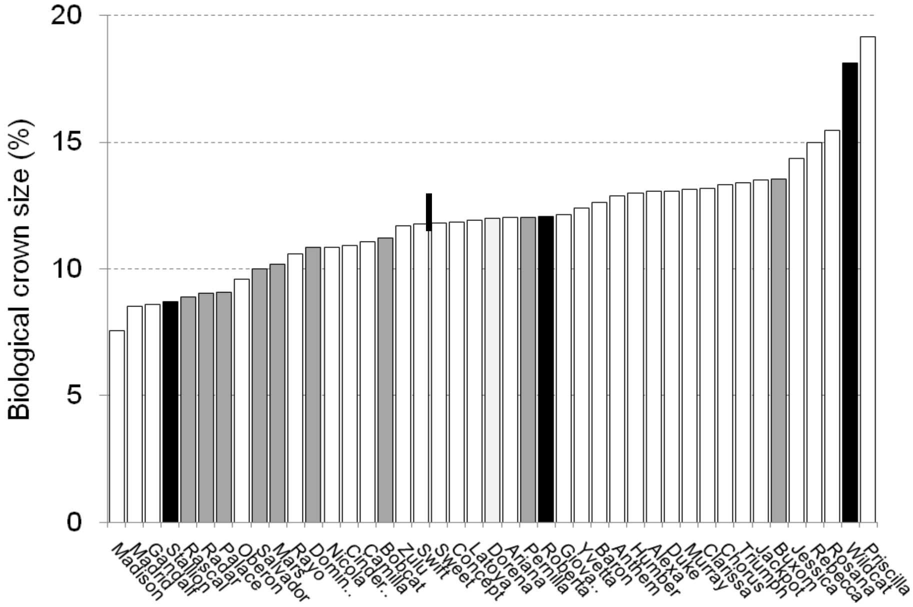

Fig. 3. *The varietal ranking of biological crown size. The black colums indicate the small (Stallion), medium (Roberta) and large (Wildcat) crowned varieties that were grown as standards, and the grey columns the more recent varieties examined in this project referred to in Table 1. (The vertical bar indicates the standard error of the differences between means).*

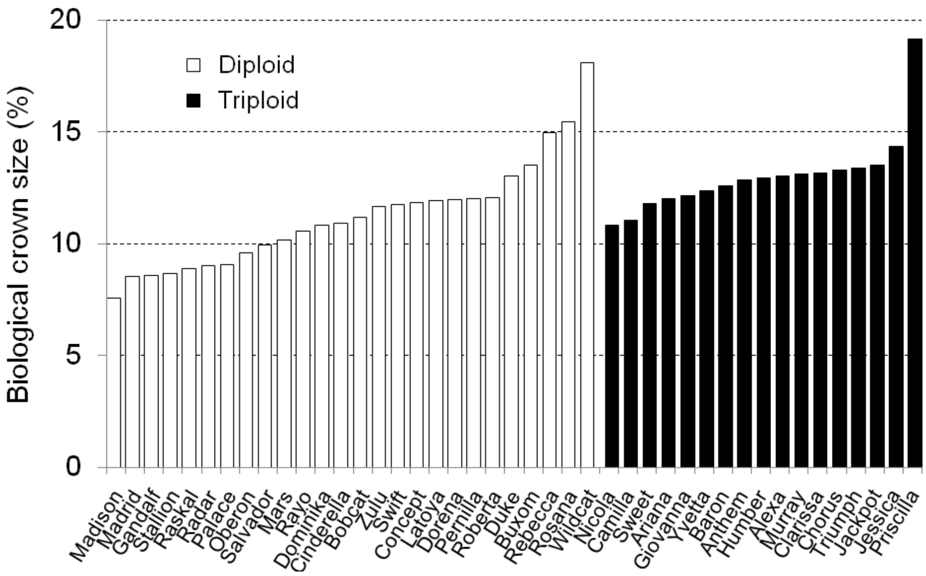

Fig. 4. *The biological crown sizes of diploid and triploid varieties.*

Table 1. *Varietal differences in biological crown size, crown tare and crown height on sandy loam and silt loam soils*

		2004/05			2005/06				2006/07			
		Biological crown size (%)	Crown tare (%)	Crown height (mm)		Biological crown size (%)	Crown tare (%)	Crown height (mm)		Biological crown size (%)	Crown tare (%)	Crown height (mm)
Sandy loam	Raskal	7.0	4.4	50	Gandalf	9.5	6.1	66	Palace	8.4	3.1	-
	Stallion	8.5	5.4	47	Stallion	9.9	7.2	81	Bobcat	8.5	5.4	-
	Dominika	9.1	8.2	46	Mars	10.1	8.6	68	Salvador	8.6	4.0	-
	Radar	9.5	5.8	48	Radar	10.1	8.1	72	Stallion	8.7	6.1	-
	Gandalf	9.9	7.2	53	Dominika	10.3	8.1	65	Mars	10.4	5.9	-
	Rayo	10.4	6.3	44	Pernilla	11.5	8.7	72	Buxom	11.0	8.0	-
	Roberta	11.6	8.8	54	Giovanna	12.0	9.5	66	Dominika	11.0	6.3	-
	Giovanna	13.2	9.1	48	Roberta	12.4	11.1	73	Pernilla	11.7	7.6	-
	Cinderella	13.4	10.4	47	Raskal	13.8	7.4	69	Roberta	11.9	9.6	-
	Wildcat	18.7	13.7	48	Wildcat	16.8	13.5	75	Wildcat	16.4	13.2	-
Silt loam	Raskal	8.5	5.4	38	Stallion	9.0	4.6	-	Palace	10.7	6.4	22
	Rayo	9.4	7.1	31	Dominika	9.7	7.1	-	Mars	11.5	8.3	29
	Stallion	9.5	5.8	29	Mars	9.8	7.2	-	Stallion	11.6	8.4	26
	Gandalf	10.1	6.8	38	Radar	10.0	4.0	-	Salvador	13.0	8.3	30
	Radar	10.2	5.1	32	Gandalf	10.5	4.1	-	Bobcat	13.9	9.1	20
	Roberta	10.6	7.7	38	Raskal	11.0	5.1	-	Roberta	13.9	12.3	27
	Dominika	11.5	8.7	43	Pernilla	11.3	6.3	-	Dominika	15.5	11.7	21
	Giovanna	12.4	9.2	30	Roberta	11.9	7.8	-	Pernilla	16.0	12.4	27
	Cinderella	12.9	8.2	23	Giovanna	12.0	8.1	-	Buxom	19.2	14.0	25
	Wildcat	20.3	12.9	35	Wildcat	17.5	12.9	-	Wildcat	22.3	18.7	29
Soil type	Sandy loam	11.1	8.0	49		11.6	8.8	71		10.7	6.9	-
	Silt loam	11.5	7.7	38		11.3	6.7	-		14.8	11.0	25
SED (57 df)	Soil type	0.49 ns	0.31 ns	0.9 ***		0.42 ns	0.37 ***			0.43 ***	0.32 ***	
	Variety	1.10 ***	0.69 ***	2.1 ***		0.94 ***	0.82 ***	7.3 ns		0.96 ***	0.72 ***	4.3 ns
	Soil type x variety	1.55 *	0.98 ns	3.0 **		1.33 ns	1.16 ns			1.36 *	1.01 ns	

Effects of agronomy on biological crown size

The effects of varying the plant population density and N supply on biological crown size, the height of the crown above the soil, and on the crown tares of a small (Stallion) and a large-crowned variety (Wildcat) grown on a sandy (Bracebridge) and silty loam (Coddenham) were examined in 2003/04, 2004/05 and 2005/06. All of the N at the lowest rate (60 kg/ha at Bracebridge and 45 kg/ha at Coddenham) was applied at the 2-4 leaf stage, and the same amount from the highest rate with the balance of the highest rate being applied as two equal dressings in mid June and mid-July. These timings were intended to prolong leaf expansion and shoot growth in order to simulate the effects of growing the crop on highly-N fertile soils.

A full analysis of these treatments is given in Appendix Tables II-IV, and a summary of the main treatment effects (ignoring minor site-to-site interactions) in Table 2. The two varieties reacted similarly to soil type, plant population density and N rate. The size of the biological crown was increased by giving the crops more fertilizer N or growing them on the more-fertile silt loam. The overall effects of the agronomic treatments and site fertility on biological crown size were, however, small relative to the varietal differences. Increasing the plant population density did not affect the size of the biological crown size but consistently decreased its height above the soil.

Table 2. E*ffect of agronomic factors on biological crown size, crown tare and the height of the crown above the soil.*

		Biological crown size (%)			Crown tare (%)			Crown height (mm)		
		2004/05	2005/06	2006/07	2004/05	2005/06	2006/07	2004/05	2005/06	2006/07
Variety:	Stallion	8.0	9.2	9.9	6.2	5.0	6.4	57	57	43
	Wildcat	18.5	19.2	19.5	14.2	14.2	16.8	56	56	40
	SED (71 df)	0.32	0.40	0.48	0.31	0.43	0.66	1.0	0.9	1.8
		***	***	***	***	***	***	ns	ns	ns
Soil type:	Sandy loam	12.2	13.9	12.8	9.9	8.3	10.0	76	57	42
	Silt loam	14.2	14.8	16.6	10.6	10.9	13.2	37	-	41
	SED (71 df)	0.32	0.40	0.48	0.31	0.43	0.66	1.0	-	1.8
		***	*	***	*	***	***	***		ns
Plant population:	75	13.5	14.4	17.2	10.1	9.4	11.1	60	59	42
('000/ha)	100	13.5	13.9	14.9	10.1	9.3	11.3	58	56	43
	125	12.7	14.2	15.0	10.5	10.1	12.3	52	56	39
	SED (71 df)	0.39	0.49	0.59	0.38	0.52	0.66	1.3	1.1	1.3
		ns	ns	ns	ns	ns	ns	***	**	*
*N rate:	N_1	12.2	13.4	13.7	9.7	9.5	10.5	55	56	40
	N_2	14.3	14.9	15.7	10.8	9.7	12.6	58	58	43
	SED (71 df)	0.32	0.40	0.48	0.31	0.43	0.66	1.0	0.9	1.8
		***	***	***	***	ns	**	***	*	ns

* The low and high rates of N were 45 and 90 kg/ha, respectively, on the silty loam at Coddenham and 60 and 120 kg/ha on the sandy loam at Bracebridge.

Relationships between biological crown size, crown height and crown tare

The variety and agronomy trials were machine-harvested using a continental comb & scalper topping mechanism which removed, on average, 25-35% of the crown material In both series of experiments. The actual crown tare was, consequently, determined principally by the initial size of biological crown (Fig. 5).

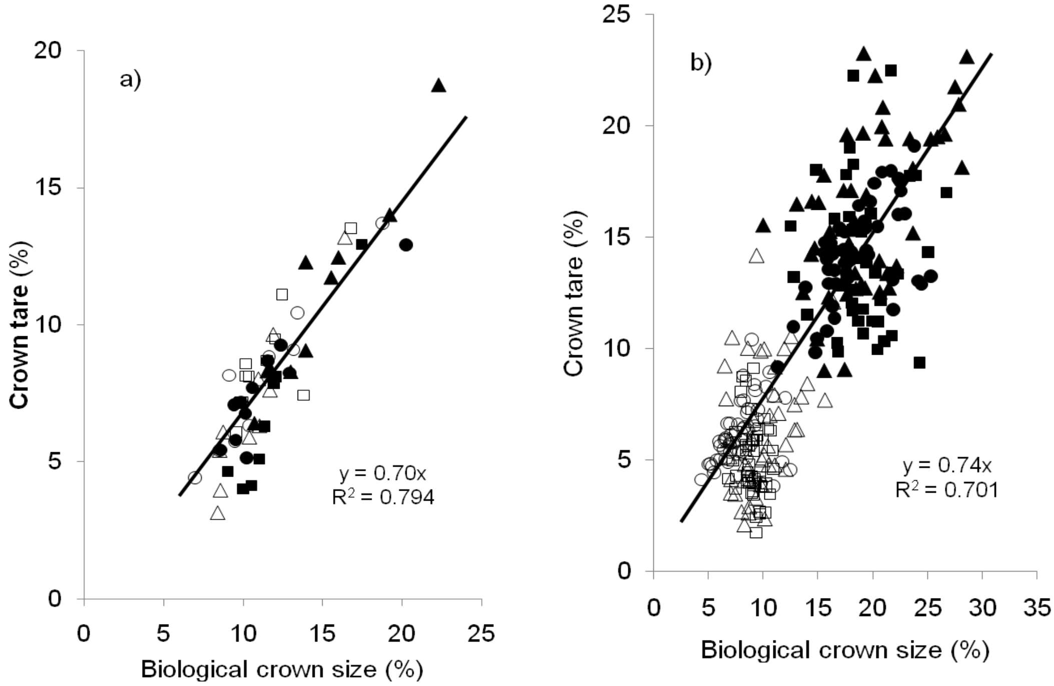

Fig. 5. *Relationships between the crown tare and biological crown size from the variety (a) and agronomy (b) trials of 2004/05 (circles), 2005/06 (rectangles) and 2006/07 (triangles). The open and closed symbols in Fig. (a) indicate trials on sandy and silty loam soils, respectively, and those in Fig. (b) the small and large-crowned varieties Stallion and Wildcat.*

The relationship between biological crown size and crown tare was not influenced by soil type in the variety experiments (Fig. 5*a*) or outweighed by the effects of the agronomic treatments in the agronomy experiments (Fig. 5*b*). There was little correlation between the size of the biological crown and crown height and, hence, no correlation between crown height and crown tare.

Effect of different topping mechanisms

Recent British Sugar plc surveys show that 8% of UK sugar beet are harvested using a skew bar topper, 19% using a feeler wheel & knife mechanism and 69% using a comb & scalper mechanism. The effects of these three topping mechanisms on the crown tares of six varieties with differently sized biological crowns was examined in two experiments on sandy loam soils at Bracebridge and Tinwell. The full analysis of the experimental data is given in Appendix Table V, and the main effects are summarized in Table 3.

The three topping mechanisms removed different proportions of the biological crown. Overall, the feeler wheel & knife mechanism removed the most (49%) and the most popular commercial mechanism – the comb & scalper the least (33%). All three mechanisms removed more of the biological crown of small-crowned variety, Stallion, than of the larger-crowned varieties.

As with agronomic practices, the effects of using different topping mechanisms did not over-ride the dominant effect of the initial varietal differences in biological crown size on crown tare.

Table 3. *Effect of topping mechanism on crown tare*

	Stallion	Roberta	Baron	Alexa	Chorus	Wildcat	Topping mechanism mean
Biological crown size (%)	6.5	10.4	10.5	11.3	12.1	18.7	
			Crown tare (%)				
Skewbar	3.5	6.3	6.6	7.5	6.8	12.9	7.3
Feeler wheel & knife	3.3	4.5	5.0	5.0	7.3	11.9	6.2
Comb & scalper	4.3	7.0	6.2	8.0	8.2	13.5	7.9
Variety mean:	3.7	5.9	5.9	6.8	7.4	12.8	

SED (108 df) for Variety = 0.26***; Topping mechanism = 0.18***; Interaction = 0.44***
LSD (P=0.05) for Variety = 0.51***; Topping mechanism = 0.36***; Interaction = 0.88***

	Stallion	Roberta	Baron	Alexa	Chorus	Wildcat	Topping mechanism mean
			Percentage of crown removed				
Skewbar	45	40	37	34	43	30	38
Feeler wheel & knife	51	57	52	56	40	36	49
Comb & scalper	35	34	42	29	31	27	33
Variety mean:	44	43	44	40	38	31	

SED (108 df) for Variety = 2.5***; Topping mechanism = 1.8***; Interaction = 4.3**
LSD (P=0.05) for Variety = 4.9***; Topping mechanism = 3.5***; Interaction = 8.5**

Analysis of commercial harvesting practices

British Sugar is conducting a programme of BBRO-funded ‘Quality Harvesting’ studies on commercial fields to assess grower and contractor harvesting practices. In the final year of the present project, representative samples of beet were hand-lifted from some of these fields to measure biological crown size and a parallel series of samples of machine-lifted beet taken at intervals from the trailer during harvesting to measure crown tare. The ratio of crown tare to the initial size of the biological crown provided an objective measure of the quality of the topping process which was related to variety, the topping mechanism of the harvester, and whether the grower or contractor harvested the field.

A total of 199 fields were examined, 144 of which were lifted by contractors and 55 lifted by the growers using their own or group-owned harvesters. All but eight of the fields were lifted by machines fitted with a comb & scalper topping mechanism. The full results are given in Appendix Table VI. Figure 6 shows the overall relationship between the percentage of crown removed and the initial size of the biological crown for the fields that were harvested using a comb & scalper topping mechanism for contractors or growers separately. There were no differences between the proportions of crown removed by growers and that removed by contractors in the 'Quality Harvesting' evaluations; both removed a similar proportion to that removed in our more-controlled variety and agronomy experiments. In commercial practice, a greater proportion of the biological crown is removed in small-crowned varieties than in larger-crowned varieties (Fig. 6). Too few fields were lifted using disc and feeler wheel and knife topping mechanisms for realistic comparisons to be made between the disc, feeler wheel and knife and comb and scalper mechanisms.

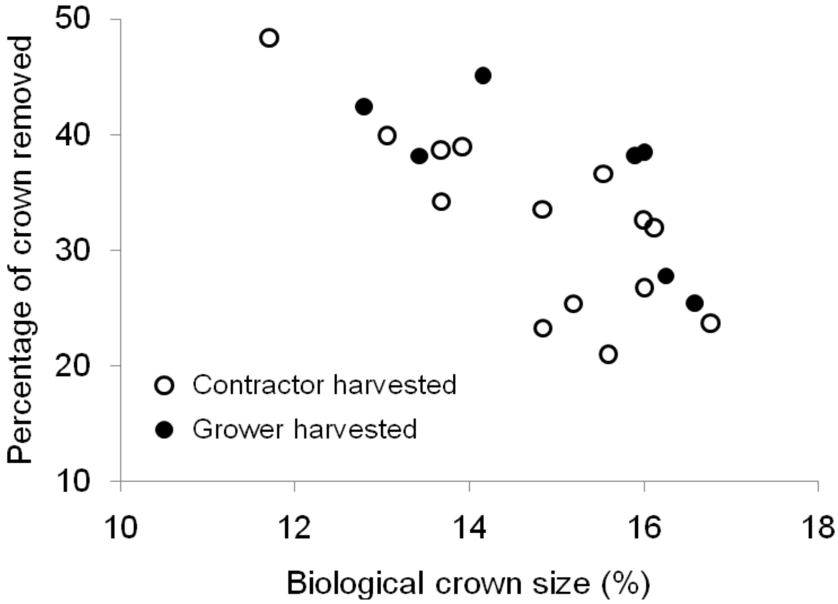

Fig. 6. *The relationship between biological crown size and the percentage of crown removed by contractors or growers in commercial sugar-beet crops assessed for the quality of harvesting.*

Discussion

The present study has shown that the crown tares of delivered beet are primarily determined by the initial size of the intact biological crown. Biological crown size is a varietal characteristic that is not over-ridden by the small effects of agronomy, soil fertility or seasonal growing conditions. A large majority of UK beet is now lifted by harvesters fitted with a comb and scalper topping mechanism which removes about a third of the crown material in medium and large-crowned varieties. However, a much greater proportion may be removed when crowns are particularly small with considerable implications for yield and grower profitability.

Figure 7 - reproduced from the earlier British Sugar studies reported by Milford & Houghton[5] - shows that the proportion of over-topped beet increases exponentially when crown tares fall below 6%, with corresponding decreases in the delivered yield becoming particularly noticeable when crown tares fall below 4%. Given that modern

sugar-beet harvesters remove approximately one-third of the crown material - or more in small-crowned varieties - the risks of over-topping and yield loss are greater when small-crowned varieties are grown, unless great care is taken in setting up the harvester.

It is, therefore, of increasing concern that there has been a downward trend in biological crown size in varieties entering recent Recommended Lists (Fig. 8). The trend can be attributed to some relatively small-crowned varieties introduced by Danisco and Syngenta prior to 2008 (Appendix Table I) and an accompanying increase in the seed market share of these two companies in recent years relative to that of breeders of medium or large-crowned varieties, such as KWS (Fig. 9). NB This information may be regarded as commercially sensitive so permission should be sought from the Project Leader before it is released to third parties. This shift in varieties may partly account for the markedly smaller crown tares of the 2007-08 beet processing campaign (Fig. 1). Consequently, there is a strong case for continuing monitoring the biological crown sizes of new varieties, especially in light of the accelerating pace at which varieties are changing. We currently only have information on 5 of the 28 varieties on the Recommended and Provisionally Recommended Lists for 2009.

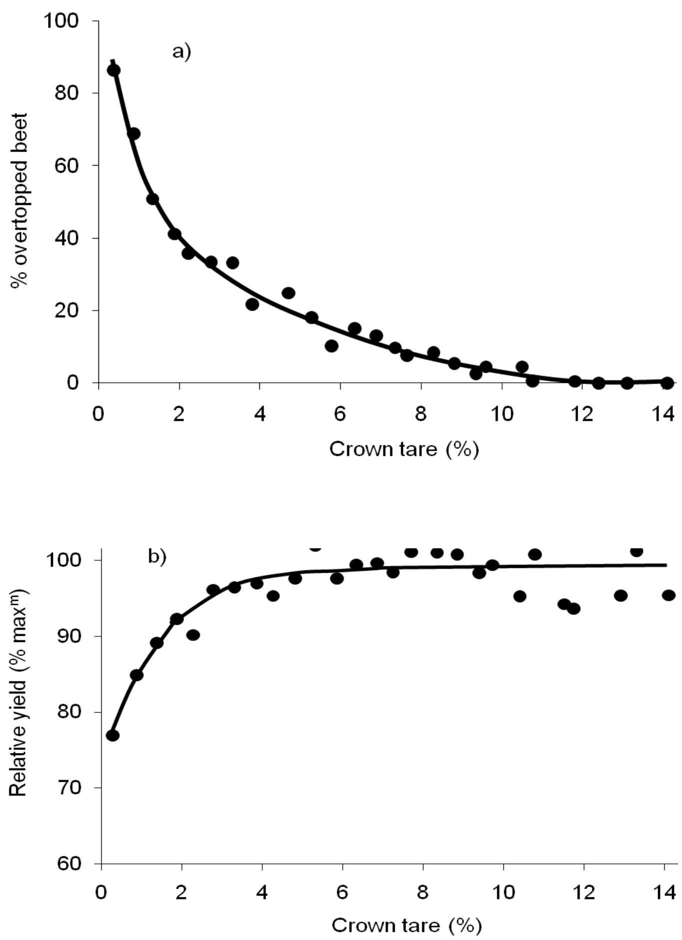

Fig. 7. *The relationships between (a) the percentage of overtopped beet and (b) the relative yield of beet topped to different levels of crown tare.*

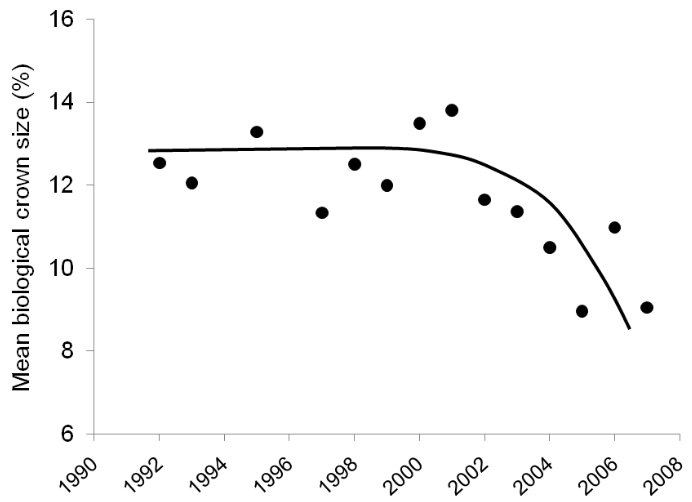

Fig. 8. *Trend in biological crown size in varieties entering recent Recommended Lists.*

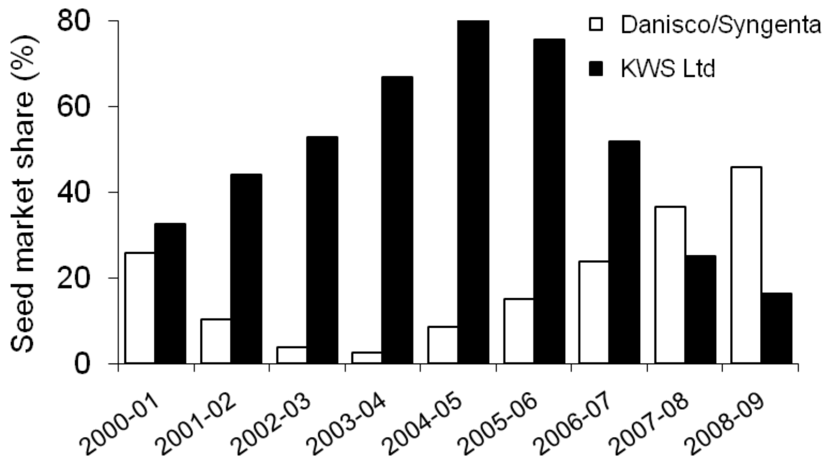

Fig. 9. *Recent trends in the seed market share of selected companies*.

Appendix Table I. *Provenance of varieties characterized for biological crown size.*

	Biological crown size (%)	Breeder/Agent	Ploidy	Date entering Recommended or Provisional list
Madison	7.57	Danisco Seed	2n	1999
Madrid	8.53	Danisco Seed	2n	1999
Gandalf	8.60	Danisco Seed	2n	2004
Stallion	8.69	Syngenta Seeds Ltd	2n	1999
Raskal	8.88	Syngenta Seeds	2n	2005
Radar	9.04	Strube/Dieckmann/Elsom Seeds Ltd	2n	2005
Palace	9.06	Danisco Seed	2n	2007
Oberon	9.59	Novartis Seeds Ltd	2n	1997
Salvador	9.98	Danisco Seed	2n	2006
Mars	10.19	Strube/Dieckmann/Elsom Seeds Ltd	2n	2006
Rayo	10.57	Advanta Seeds UK	2n	1999
Dominika	10.83	KWS UK Ltd/English Sugar Beet Seed Co. Ltd	2n	2002
Nicola	10.84	KWS/English Sugar Beet Seed Co.	3n	1998
Cinderella	10.93	KWS/English Sugar Beet Seed Co. Ltd	2n	2003
Camilla	11.06	KWS/English Sugar Beet Seed Co. Ltd	3n	1997
Bobcat	11.21	SES/Van der Have/Elsom Seeds Ltd	2n	2006
Zulu	11.68	Novartis Seeds Ltd	2n	1992
Swift	11.76	SES/Advanta Seeds UK	2n	1998
Sweet	11.79	Nickerson Sugar Beet Seed Ltd	3n	2003
Concept	11.84	Nickerson Sugar Beet Seed Ltd	2n	2001
Latoya	11.92	KWS UK Ltd/English Sugar Beet Seed Co. Ltd	2n	2001
Dorena	11.97	KWS UK Ltd/English Sugar Beet Seed Co. Ltd	2n	2002
Ariana	12.01	KWS UK Ltd/English Sugar Beet Seed Co. Ltd	3n	1999
Pernilla	12.02	Nickerson Sugar Beet Seed Ltd	2n	2006
Roberta	12.05	KWS/English Sugar Beet Seed Co. Ltd	2n	1993
Giovanna	12.14	Delitzch UK Ltd	3n	2002
Yvetta	12.40	KWS UK Ltd/English Sugar Beet Seed Co. Ltd	3n	2004
Baron	12.62	Delitzch UK Ltd	3n	2000
Anthem	12.87	Betaseed Inc./Nickersons Seeds Ltd	3n	1998
Humber	12.97	Lion Seeds Ltd	3n	2001
Alexa	13.04	KWS/English Sugar Beet Seed Co.	3n	1995
Duke	13.06	Delitzch UK Ltd	2n	1998
Murray	13.13	Lion Seeds Ltd	3n	2001
Clarissa	13.16	KWS/English Sugar Beet Seed Co. Ltd	3n	1998
Chorus	13.31	Betaseed Inc./Nickersons Seeds Ltd	3n	1998
Triumph	13.39	Delitzch UK Ltd	3n	1992
Jackpot	13.51	Delitzch UK Ltd	3n	1995
Buxom	13.53	Syngenta Seeds Ltd	2n	2006
Jessica	14.34	KWS UK Ltd/English Sugar Beet Seed Co. Ltd	3n	2000
Rebecca	14.96	KWS UK Ltd/English Sugar Beet Seed Co. Ltd	2n	1999
Rosana	15.47	Delitzch UK Ltd	2n	1999
Wildcat	18.11	Advanta Seeds Ltd	2n	1999
Priscilla	19.15	KWS UK Ltd/English Sugar Beet Seed Co. Ltd	3n	2001

Appendix Table II. *Effects of variety, agronomy,and soil type on crown characteristics in 2004/05*

Effect of plant population density

Site	Variety	Plants '000/ha	Biological crown size (% c-t root)	Crown tare (% c-t root)	Crown height (mm)
Sandy loam	Stallion	75	6.6	6.2	81
		100	6.3	7.0	78
		125	7.3	6.6	72
	Wildcat	75	15.4	16.0	80
		100	19.7	13.4	80
		125	18.1	14.1	66
Silt loam	Stallion	75	10.8	5.8	37
		100	8.2	5.3	38
		125	8.5	6.3	38
	Wildcat	75	21.4	12.3	41
		100	19.6	14.8	37
		125	16.9	14.8	32
	LSD (*P* = 0.05)		1.57	1.50	5.0
	SED (71 df)		0.79	0.75	2.53
			ns	ns	ns
Across soils	Stallion	75	8.7	6.0	57
		100	7.3	6.2	56
		125	7.9	6.5	51
	Wildcat	75	18.4	14.2	62
		100	19.7	14.1	59
		125	17.5	14.5	53
	LSD (*P* = 0.05)		1.11	1.06	3.5
	SED (71 df)		0.56	0.53	1.79
			ns	ns	ns
Across soils and varieties		75	13.5	10.1	60
		100	13.5	10.1	58
		125	12.7	10.5	52
	LSD (*P* = 0.05)		0.78	0.75	2.5
	SED (71 df)		0.39	0.38	1.26
			ns	ns	***

Effect of N rate

Site	Variety	N rate	Biological crown size (% c-t root)	Crown tare (% c-t root)	Crown height (mm)
Sandy loam	Stallion	60	6.5	5.7	76
		120	7.0	5.9	78
	Wildcat	60	16.5	12.6	73
		120	19.0	15.3	77
Silt loam	Stallion	45	8.4	6.2	36
		90	9.9	7.0	39
	Wildcat	45	17.4	14.1	34
		90	21.2	14.9	39
	LSD (*P* = 0.05)		1.28	1.22	4.1
	SED (71 df)		0.61	0.61	2.06
			ns	ns	ns
Across soils	Stallion	N_1	7.5	6.0	56
		N_2	8.5	6.5	59
	Wildcat	N_1	16.9	13.4	54
		N_2	20.1	15.1	58
	LSD (*P* = 0.05)		0.90	0.87	2.9
	SED (71 df)		0.45	0.43	1.46
			ns	*	ns
Across soils and varieties		N_1	12.2	9.7	55
		N_2	14.3	10.8	58
	LSD (*P* = 0.05)		0.64	0.61	2.0
	SED (71 df)		0.32	0.31	1.03
			***	***	***

Effect of site and variety

Site	Variety	Biological crown size (% c-t root)	Crown tare (% c-t root)	Crown height (mm)
Sandy loam	Stallion	6.8	5.8	77
	Wildcat	17.7	14.0	75
Silt loam	Stallion	9.2	6.6	38
	Wildcat	19.3	14.5	36
	LSD (*P* = 0.05)	0.90	0.87	2.9
	SED (71 df)	0.45	0.43	1.46
		ns	ns	ns
Soil type	Sandy loam	12.2	9.9	76
	Silt loam	14.2	10.6	37
	LSD (*P* = 0.05)	0.64	0.61	2.0
	SED (71 df)	0.32	0.31	1.03
		***	*	***
Variety	Stallion	8.0	6.2	57
	Wildcat	18.5	14.2	56
	LSD (*P* = 0.05)	0.64	0.61	2.0
	SED (71 df)	0.32	0.31	1.03
		***	***	ns

Appendix Table III. *Effects of variety, agronomy,and soil type on crown characteristics in 2005/06*

Effect of plant population density

Site	Variety	Plants '000/ha	Biological crown size (% c-t root)	Crown tare (% c-t root)	Crown height (mm)
Sandy loam	Stallion	75	9.4	4.0	59
		100	9.6	4.0	59
		125	9.4	4.6	56
	Wildcat	75	19.6	12.2	60
		100	19.0	12.6	54
		125	19.3	12.4	55
Silt loam	Stallion	75	9.0	5.3	-
		100	8.9	5.2	-
		125	8.6	6.7	-
	Wildcat	75	19.7	16.1	-
		100	18.0	15.3	-
		125	19.3	16.7	-
	LSD (*P* = 0.05)		1.94	2.08	3.0
	SED (71 df)		0.97	1.04	1.5
			ns	ns	ns
Across soils	Stallion	75	9.2	4.6	-
		100	9.3	4.6	-
		125	9.0	5.7	-
	Wildcat	75	19.7	14.2	-
		100	18.5	13.9	-
		125	19.3	14.6	-
	LSD (*P* = 0.05)		1.37	1.47	-
	SED (71 df)		0.69	0.74	-
			ns	ns	
Across soils and varieties		75	14.4	9.4	59
		100	13.9	9.3	56
		125	14.2	10.1	56
	LSD (*P* = 0.05)		0.97	1.04	2.1
	SED (71 df)		0.49	0.52	1.1
			ns	ns	**

Effect of N rate

Site	Variety	N rate	Biological crown size (% c-t root)	Crown tare (% c-t root)	Crown height (mm)
Sandy loam	Stallion	60	9.2	4.6	58
		120	9.7	4.6	59
	Wildcat	60	18.7	12.0	55
		120	19.9	12.8	57
Silt loam	Stallion	45	8.5	5.8	-
		90	9.2	5.6	-
	Wildcat	45	17.3	16.1	-
		90	20.7	15.9	-
	LSD (*P* = 0.05)		1.58	1.70	2.4
	SED (71 df)		0.79	0.85	1.2
			ns	ns	ns
Across soils	Stallion	N_1	8.9	4.9	-
		N_2	9.5	5.0	-
	Wildcat	N_1	18.0	14.1	-
		N_2	20.3	14.4	-
	LSD (*P* = 0.05)		1.12	1.20	-
	SED (71 df)		0.56	0.60	-
			ns	ns	
Across soils and varieties		N_1	13.4	9.5	56
		N_2	14.9	9.7	58
	LSD (*P* = 0.05)		0.79	0.85	1.7
	SED (71 df)		0.40	0.43	0.9
			***	ns	*

Effect of site and variety

Site	Variety	Biological crown size (% c-t root)	Crown tare (% c-t root)	Crown height (mm)
Sandy loam	Stallion	9.5	4.2	58
	Wildcat	19.3	12.4	56
Silt loam	Stallion	8.8	5.7	-
	Wildcat	19	16.0	-
	LSD (*P* = 0.05)	1.12	1.20	1.7
	SED (71 df)	0.56	0.60	0.9
		ns	ns	
Soil type	Sandy loam	13.9	8.3	57
	Silt loam	14.8	10.9	-
	LSD (*P* = 0.05)	0.79	0.85	-
	SED (71 df)	0.40	0.43	-
		*	***	
Variety	Stallion	9.2	5.0	57
	Wildcat	19.2	14.2	56
	LSD (*P* = 0.05)	0.79	0.85	1.7
	SED (71 df)	0.40	0.43	0.9
		***	***	*

Appendix Table IV. *Effects of variety, agronomy,and soil type on crown characteristics in 2006/07*

Effect of plant population density

Site	Variety	Plants '000/ha	Biological crown size (% c-t root)	Crown tare (% c-t root)	Crown height (mm)
Sandy loam	Stallion	75	8.4	4.3	45
		100	7.7	5.0	44
		125	8.7	6.3	45
	Wildcat	75	17.6	15.5	45
		100	17.6	13.7	38
		125	16.8	15.0	35
Silt loam	Stallion	75	11.0	7.6	40
		100	11.3	7.8	47
		125	12.3	7.1	37
	Wildcat	75	19.9	17.0	40
		100	23.2	18.7	44
		125	22.1	20.8	39
	LSD (*P* = 0.05)		2.34	3.23	9.0
	SED (71 df)		1.17	1.17	4.5
			ns	ns	ns
Across soils	Stallion	75	9.7	6.0	42
		100	9.5	6.4	45
		125	10.5	6.7	41
	Wildcat	75	18.7	16.3	42
		100	20.4	16.3	41
		125	19.4	17.9	37
	LSD (*P* = 0.05)		1.65	2.28	6.4
	SED (71 df)		0.83	1.14	3.2
			ns	ns	ns
Across soils and varieties		75	17.2	11.1	42
		100	14.9	11.3	43
		125	15.0	12.3	39
	LSD (*P* = 0.05)		1.17	1.32	4.5
	SED (71 df)		0.59	0.66	2.3
			ns	ns	ns

Effect of N rate

Site	Variety	N rate	Biological crown size (% c-t root)	Crown tare (% c-t root)	Crown height (mm)
Sandy loam	Stallion	60	7.7	4.7	44
		120	8.8	5.7	45
	Wildcat	60	15.9	14.2	39
		120	18.7	15.2	39
Silt loam	Stallion	45	10.7	6.9	36
		90	12.4	8.1	47
	Wildcat	45	20.6	16.2	42
		90	22.8	21.5	40
	LSD (*P* = 0.05)		1.91	2.64	7.4
	SED (71 df)		0.96	1.32	3.7
			ns	ns	ns
Across soils	Stallion	N_1	9.2	5.8	40
		N_2	10.6	6.9	46
	Wildcat	N_1	18.3	15.2	41
		N_2	20.7	18.4	40
	LSD (*P* = 0.05)		1.35	1.86	5.2
	SED (71 df)		0.68	0.93	2.6
			ns	ns	ns
Across soils and varieties		N_1	13.7	10.5	40
		N_2	15.7	12.6	43
	LSD (*P* = 0.05)		0.96	1.32	3.7
	SED (71 df)		0.48	0.66	1.8
			***	**	ns

Effect of site and variety

Site	Variety	Biological crown size (% c-t root)	Crown tare (% c-t root)	Crown height (mm)
Sandy loam	Stallion	8.3	5.2	44
	Wildcat	17.3	14.7	39
Silt loam	Stallion	11.5	7.5	41
	Wildcat	21.7	18.9	41
	LSD (*P* = 0.05)	1.35	1.86	5.2
	SED (71 df)	0.68	0.93	1.6
		ns	ns	ns
Soil type	Sandy loam	12.8	10.0	42
	Silt loam	16.6	13.2	41
	LSD (*P* = 0.05)	0.96	1.32	3.7
	SED (71 df)	0.48	0.66	1.8
		***	***	ns
Variety	Stallion	9.9	6.4	43
	Wildcat	19.5	16.8	40
	LSD (*P* = 0.05)	0.96	1.32	3.7
	SED (71 df)	0.48	0.66	1.8
		***	***	ns

Appendix Table V. *Effect of different topping mechanisms on the crown tares of varieties of varying biological crown size on sandy and silt loam soils*

	Biological crown size (%)	Crown tare (%)				Percentage of crown removed			
		Skewbar	Feeler wheel & knife	Comb & scalper	Variety mean	Skewbar	Feeler wheel & knife	Comb & scalper	Variety mean
					Bracebridge (sandy loam)				
Stallion	7.4	4.1	4.5	5.7	4.7	45	40	23	36
Roberta	10.7	6.8	4.6	6.9	6.1	37	57	36	43
Baron	10.7	6.3	6.4	6.2	6.3	41	40	43	41
Alexa	11.9	7.6	6.0	8.6	7.4	36	49	28	38
Chorus	13.4	6.4	8.8	8.9	8.0	52	33	33	40
Wildcat	17.5	13.6	11.7	13.7	13.0	22	34	27	26
Mean	11.9	7.4	7.0	8.3	7.6	37	42	31	37
					Tinwell (silt loam)				
Stallion	5.6	3.0	2.1	3.0	2.7	46	63	47	52
Roberta	10.2	5.8	4.4	7.0	5.8	42	56	31	43
Baron	10.3	6.9	3.7	6.1	5.5	34	64	40	46
Alexa	10.8	7.5	4.1	7.4	6.3	31	62	31	41
Chorus	10.9	7.2	5.8	7.6	6.8	34	46	30	36
Wildcat	19.9	12.3	12.1	13.2	12.5	38	39	33	37
Mean	11.3	7.1	5.4	7.4	6.6	37	55	35	43
Comparison of sites:									
SED (108 df)	0.18		0.26		0.15		2.5		1.4
LSD (*P* =0.05)	0.42		0.51		0.29		4.9		3.5
Comparison of site X variety:									
SED (108 df)	0.35		0.63		0.36		6.1		3.5
LSD (*P* =0.05)	0.85		1.24		0.72		12.0		6.9

Appendix Table VI. *Quality Harvesting: Effect of variety and harvesting operations on crown removal..*

Variety grown	Topping mechanism	Mean biological crown size (%)	Percentage of crown removed	N$^{o.}$ fields
		Contractor harvested		
Ace	Comb & scalper	13.7	34.2	7
Bobcat	Comb & scalper	14.8	33.5	17
Buxom	Comb & scalper	15.5	36.6	2
Dominika	Comb & scalper	16.1	31.9	16
Goya	Comb & scalper	16.0	26.7	4
Harry	Comb & scalper	15.2	25.4	11
Justina	Comb & scalper	16.8	23.7	4
Kingston	Comb & scalper	11.7	48.4	7
Mars	Comb & scalper	13.9	39.0	4
Opta	Comb & scalper	13.7	38.7	14
Palace	Comb & scalper	13.1	39.9	26
Pernilla	Comb & scalper	15.6	21.0	18
Radar	Comb & scalper	16.0	32.6	4
Zanzibar	Comb & scalper	14.8	23.3	10
		Grower harvested		
Bobcat	Comb & scalper	15.9	38.2	4
Buxom	Comb & scalper	16.2	27.8	8
Opta	Comb & scalper	14.2	45.1	4
Palace	Comb & scalper	12.8	42.4	12
Pernilla	Comb & scalper	16.6	25.4	3
Sprinter	Comb & scalper	13.4	38.2	4
Zanzibar	Comb & scalper	16.0	38.5	12
Zanzibar	Disc	15.1	38.9	4
Zanzibar	Feeeler wheel & knifeknife	12.6	21.9	4