Contract report for the
Horticultural Development Council

Asparagus: Validation of *AspireNZ* for the UK

FV 271

March 2006

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Project co-ordinator:	P. Langley
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The results and conclusions in this report are based on a series of experiments conducted over one year. The conditions under which the experiments were carried out and the results have been reported in detail and with accuracy. However, because of the biological nature of the work it must be borne in mind that different circumstances and conditions could produce different results. Therefore, care must be taken with interpretation of the results, especially if they are used as the basis for commercial product recommendations.

AUTHENTICATION

I declare that this work was done under my supervision according to the procedures described herein and that the report represents a true and accurate record of the results obtained.

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1 GROWER SUMMARY

1.1 Headline

In the first year of crop monitoring, the carbohydrate (CHO) content of asparagus roots followed the expected pattern of depletion and accumulation during the annual growth cycle, for the majority of crops sampled. As expected, there were deviations from the 'ideal' CHO pattern. The challenge in the rest of the project will be to determine the causes and consequences of these deviations, and include their interpretations in the form of recommendations in the ***AspireUK*** decision support system.

1.2 Background and expected deliverables

Asparagus is a perennial crop with a large storage root system. The performance and economic life of a crop is driven by the gain and loss of soluble carbohydrate (CHO) in the storage root system. A characteristic pattern of accumulation and depletion of CHO in the roots occurs during the crop's annual cycle (Figure 1). Deviations from the normal pattern can indicate that performance is below optimum and can be used to help diagnose and resolve problems, and sustain crop performance. Despite its importance, information about root CHO content and the significance of CHO levels is seldom available to asparagus growers. To address this problem, the New Zealand Institute for Crop & Food Research (NZICFR) has developed a web-based decision support system (***AspireNZ***) that can be used to improve asparagus crop performance, through better knowledge and management of root CHO dynamics.

The ***Aspire*** model is already being used by subscribing asparagus growers in New Zealand and North America, and other European countries are currently collaborating with NZICFR to validate the decision support system for their own production conditions.

The overall aim of this project is to develop and deploy a decision support system tailored to UK environmental conditions and asparagus production methods, based on a prototype system (***AspireNZ***) developed in New Zealand.

The specific objectives are:
1. Prepare protocols and procedures for crop sampling.
2. Sample crops at selected key times in crop growth over two growing seasons.
3. Collate and incorporate technical information required for ***AspireUK*** into the existing prototype.
4. Develop prototype software for the ***AspireUK*** decision support system.
5. Develop and deploy commercially a final version of ***AspireUK.***
6. Disseminate information about ***AspireUK*** to UK asparagus growers.

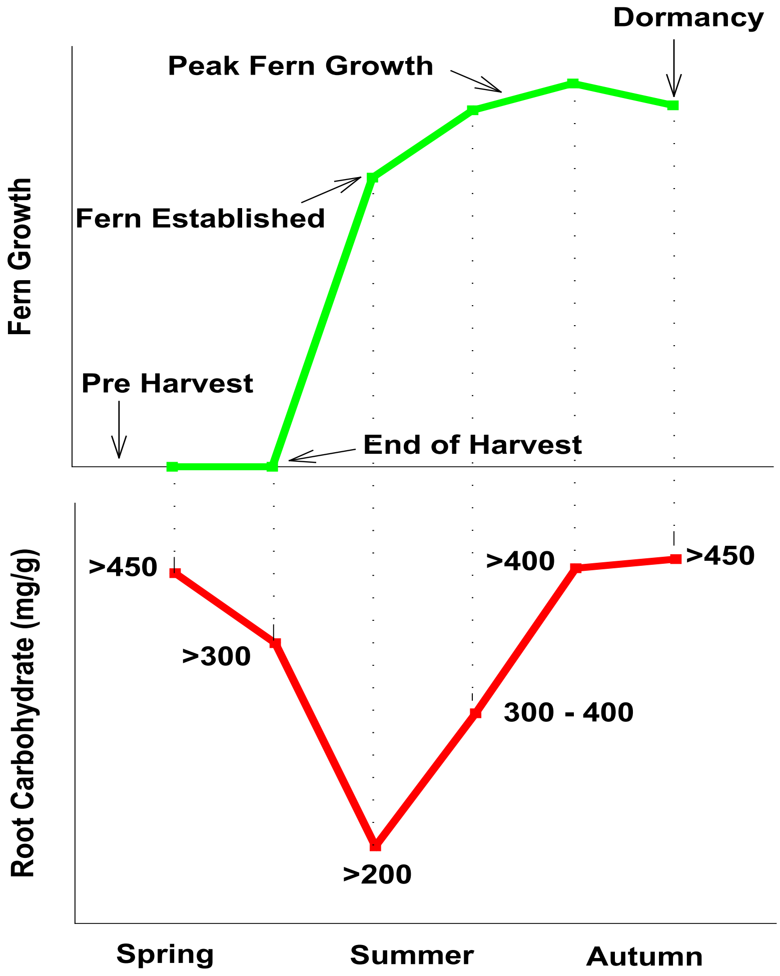


Figure 1. Annual growth cycle of asparagus.

1.3 Summary of the project and main conclusions

1.3.1 Site Selection

Twelve asparagus crops to be monitored over a two-year period were selected, with four crops in each of the main production areas of England (east, south and west). Four of the sites (E2, E4, S4 and W1) were categorised as young crops, planted in 2002 or later, with a first full harvest planned for 2005. The others were classed as established crops, having previously had at least one full harvest. Dutch varieties are being grown at all of the sites except E4 where an American variety, Jersey Giant, is grown. The previous performance of the crops in terms of yield and fern growth was contrasting. Growers noted various production constraints including phytophthora (S1, S2 and E1) and stemphylium (e.g. W4). Polythene covers to promote early harvesting are being used on crop W1.

1.3.2 Crop Sampling

The sampling schedule for the duration of the project is shown below:

Sampling Time	Measurement					
	Root CHO		Fern Biomass		Root Biomass	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Dormancy, Pre-Harvest	✓	✓				
End of Spear Harvest	✓	✓				
End of Fern Establishment	✓	✓	✓	✓		
Peak of Fern Growth	✓	✓	✓	✓		
Dormancy, End of Autumn	✓	✓			✓	

1.3.3 Root Carbohydrates and Root Biomass

The root CHO content for almost all of the test crops follows the expected pattern of depletion and accumulation as demonstrated from previous work in New Zealand and the USA (Figure 2). Root CHO accumulation at site S4 showed a deviation from the normal pattern (Figure 2B), with a particularly high value at peak fern growth, followed by a decrease at the end of the season. The likely reason for this was a severe stemphylium attack after the peak fern growth assessment in August, that led to fern die-back and limited movement of CHO to the roots. This is a good example of the type of deviation that the ***Aspire*** system helps to identify and, because it often indicates a problem with crop performance that needs to be diagnosed and resolved, alerting growers to seek local expert advice to identify the causes.

In general, high spear yields were obtained from crops for which root CHO levels throughout the year, root CHO recharge (kg/ha) and root biomass provided indicators of overall good crop health (e.g. E2 and W4). Conversely, low yields were obtained from crops where the same indicators suggested that the crop might be under stress (e.g. E4 and S1). The exception to this was the crop at W1 where the highest yield was taken (extended harvest and more prolific harvest due to polythene covers) but with data suggesting low root CHO levels and low root biomass. The limited CHO recharge at W1 may impact on yield of this crop in 2006.

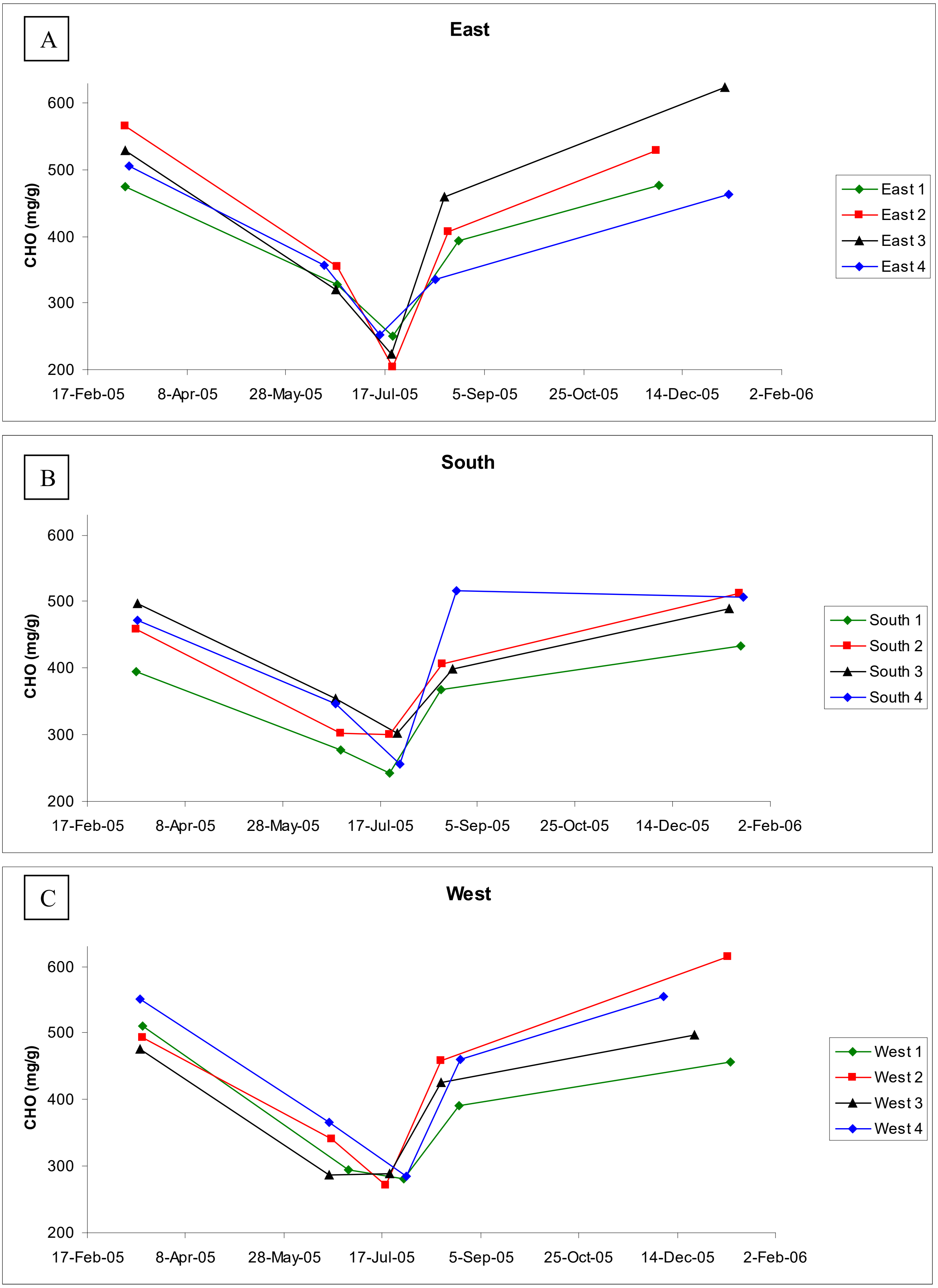
1.3.4 Fern Growth

Increasing amounts of fern growth did not necessarily produce higher CHO recharge. Two crops (E3 and W2) with only average fern growth achieved the highest CHO recharge (625 and 614 mg/g). Conversely, the crop with the highest fern biomass (S1) had the lowest recharge at 434 mg/g. These results correspond with findings from New Zealand and the USA which have shown that large amounts of fern growth are not necessary for building up high levels of root CHO. In fact, a crop's capacity to accumulate CHO in the roots can be reduced by diversion of too much energy into fern growth.

1.3.5 AspireUK on the Internet

A prototype of ***AspireUK***, which is currently the same as ***AspireUS***, is available on the Internet at www.aspireuk.org, providing background information on the project. Project participants including collaborating growers have been given a Username and Password to allow access for testing and familiarisation during the project.

Figure 2. Root CHO content values for 12 asparagus crops sampled at five stages of crop growth in three regions, east (A), south (B) and west (C).



1.4 Financial benefits

The project will benefit the industry by developing and deploying a tool (relevant to UK production conditions) which, in other asparagus growing regions, is already providing growers with a sound technical basis for making crop management decisions. Based on experiences of asparagus growers in New Zealand and North America, UK growers are expected to benefit from the following potential uses of the ***Aspire*** system:

- Aid decisions on when to stop harvesting, based on the CHO content of the roots.
- Identify root CHO recharge during the summer and autumn.
- Determine if pest or disease outbreaks (e.g. phytophthora, stemphylium) are influencing CHO movement to, and storage in the roots.
- Determine the impact on yield and long-term crop sustainability of harvesting early in the life of a crop.
- Confidently extend the harvest season without a deleterious effect on the capacity of a crop to replenish its CHO levels adequately for the next season.

1.5 Action points for growers

- Gain understanding of the important role of root CHO in determining yield formation in asparagus.
- Develop an appreciation of the potential to improve short and long term crop performance by using root CHO monitoring as a tool to assess the condition of crops and as an aid to management decisions.
- Learn how to sample root systems and measure CHO content.
- Look at the prototype ***AspireUK*** website (www.aspireuk.org).
- Monitor plant populations, especially in establishing crops, to identify ones that are losing plants and therefore capacity to accumulate CHO; plant losses often result from excessive depletion of root CHO caused by high harvesting pressure.

2 SCIENCE SECTION

2.1 Introduction

AspireNZ is an internet-based interactive decision support system (DSS) designed to help growers achieve high asparagus yields through better knowledge and management of root CHO dynamics. A detailed description of ***AspireNZ*** is given in a paper that was presented at the 10th International Asparagus Symposium and is appended to this report (Wilson *et al*., 2002; Appendix 1).

The system has five main elements:

- A simple method for assessing the CHO status of roots.
- Information about interpreting the CHO values and using them to help make crop management decisions. The system does not make decisions – it interprets information about crops and suggests options to help users reach the best decisions.
- An interactive delivery system that is deployed on the internet (www.aspirenz.com).
- A database which retains information about each crop registered with the system. This information can be retrieved at any time so that users can retrospectively evaluate the effects on crop performance of previous management decisions.
- Secure user and crop registration. Each subscriber can register and operate the system for several crops, and their information is protected by a secure username and password system.

The aim of this project is to develop and deploy ***AspireUK***, a version of the ***Aspire*** system tailored for UK environmental and production conditions.

The project has five main stages:

- At the start of the project, deploy the ***AspireUS*** version of the system on the internet as an ***AspireUK*** prototype for use by project personnel.
- Conduct a crop sampling programme for two years to:
  - determine whether crops in the UK have patterns of CHO content and 'ideal' root CHO contents that are the same as those found in crops in New Zealand.
  - Define the CHO patterns of UK crops if they are different from crops in New Zealand.
  - Identify crops with deviations from the normal CHO pattern, identify the causes, and determine how they are associated with above-ground growth irregularities.
- Based on the collated data and grower feedback, determine how CHO deviations can be interpreted to help diagnose and resolve problems in UK crops.
- Progressively adapt technical information in the system during the project to create ***AspireUK.***
- Complete the decision support system ready for commercial deployment in the UK.

This Annual Report provides a summary of data obtained from project year 1 and preliminary interpretation of root CHO dynamics in relation to spear yield, fern growth and root biomass.

2.2 Methods

2.2.1 AspireUK on the internet

At the start of the project, NZICFR made available a prototype of ***AspireUK***, which is currently the same as ***AspireUS***, on the internet at www.aspireuk.org. Project participants including collaborating growers have been given a Username and Password to allow access for testing and familiarisation during the project. Training in use of the system was provided at a project start-up meeting in March 2005.

2.2.2 Site Selection

Twelve asparagus crops to be monitored over a two-year period were selected, with four crops in each of the main production areas of England (east, south and west). Growers in each region who were interested in participating in the project were each asked to provide details of three of their crops that could potentially be included for monitoring (see Appendix 2 for questionnaire). Crops were selected based on the information provided by growers, with the aim of including three fully established crops (5-10 years old) and one establishing crop (2-4 years old) per region, with a range of yields. It was decided that monitoring would focus on crops of varieties known to perform consistently well in UK conditions (Dutch varieties), but with one crop of a more recently introduced variety (Jersey Giant). The crops that were selected were being managed using similar agronomic practices with the exception of one crop, for which polythene covering was used to promote early harvesting.

2.2.3 Crop Sampling Programme

Crop monitoring started in March 2005. Prior to this, a project start-up meeting was held in early March 2005 to present the sampling protocols (detailed in a training manual) and train project participants. The protocols were developed by NZICFR based on techniques used to develop ***AspireNZ*** in New Zealand and to validate the system for the USA. Growers were advised at the meeting that an estimate of spear yield from the crop, preferably separated into marketable and reject components, would be required at the end of harvest. It was also noted that 12 plants (crowns and roots) would need to be removed from each site for root biomass measurements in autumn 2005, and that assistance with sample digging would be gratefully received. The crop sampling schedule for the duration of the project was planned as follows.

Sampling Time	Measurement					
	Root CHO		Fern Biomass		Root Biomass	
	Year 1	Year 2	Year 1	Year 2	Year 1	Year 2
Dormancy, Pre-Harvest	✓	✓				
End of Spear Harvest	✓	✓				
End of Fern Establishment	✓	✓	✓	✓		
Peak of Fern Growth	✓	✓	✓	✓		
Dormancy, End of Autumn	✓	✓			✓	

2.2.3.1 Dormancy, Pre-Harvest

The selected crops were sampled in March 2005, before dormancy had broken and before the first spears started to emerge. Within each selected crop, an area of approximately 1 ha (for crops larger than this area) was designated for subsequent sampling activities, ensuring that this area contained a single variety, and trying to avoid atypical soil conditions. A map of the field area to be used was placed on the project file.

Root samples from 20 random positions in the field were collected, labelled and stored in a cool box following the standard sampling protocol (Appendix 3). Features of root growth and health were noted as well as observations on crop management (by the assessor and the grower if present). In the laboratory, the root samples were processed and the Brix% of their sap solution measured following the standard sampling protocol (Appendix 3) and the data were recorded. The Brix% scale provides a measure of the sugar content of a solution at a given temperature and can be measured using a refractrometer. Use of Brix% readings for determining asparagus root CHO content is described in Section 2.2.4 and Appendix 1.

2.2.3.2 End of Spear Harvest

The selected crops were sampled within two to three days before or after the end of harvest, before spears had started to elongate and grow into ferns.

Root samples from 20 random positions in the field were collected, labelled and stored in a cool box following the standard sampling protocol (Appendix 3). Features of root growth and health were noted as well as observations on crop management (by the assessor and the grower if present). In the laboratory, the root samples were processed and the Brix% of their sap solution measured following the standard sampling protocol (Appendix 3) and the data were recorded.

Between the end of spear harvest and fern establishment, areas with representative soil conditions suitable for future fern and root biomass sampling were identified. Six areas in each crop, each four rows wide and 10 m long, were marked (plastic markers in each end of row 1, markers at the field edge, and location map). Rows and plants within the six areas were then allocated for sampling on successive occasions, as follows:

Row 1: Fern growth at the end of fern establishment in year 1.
Row 2: Fern growth at the peak of fern growth in year 1.
Pair of plants at one end of the area: Root biomass at the end of autumn in year 1.
Row 3: Fern growth at the end of fern establishment in year 2.
Row 4: Fern growth at the peak of fern growth in year 2.

2.2.3.3 End of Fern Establishment

The crops were sampled in July, about one month after the end of spear harvest. At this stage, ferns had established fully, “feathered” out and no more were emerging. Root samples from 20 random positions in the field were collected, labelled and stored in a cool box following the standard sampling protocol (Appendix 3). Features of root growth and health were noted as well as observations on crop management (by the assessor and the grower if present). In the laboratory, the root samples were processed and the Brix% of their sap solution measured following the standard sampling protocol (Appendix 3) and the data were recorded.

Fern growth was measured as follows: The numbers of small, medium and large ferns in 10 m of row 1 in each of the six sampling areas were counted. Ten representative small, medium and large ferns (i.e. a total of 30 ferns) from each of the measured rows were cut and the fresh weight of each group of 10 ferns was measured. A representative combined sub-sample of the ferns was retained. After measuring fresh weight, the sub-samples were dried to a constant weight in a drying oven (100ºC/48 h), prior to dry weight measurement and calculation of percentage dry matter content.

2.2.3.4 Peak of Fern Growth

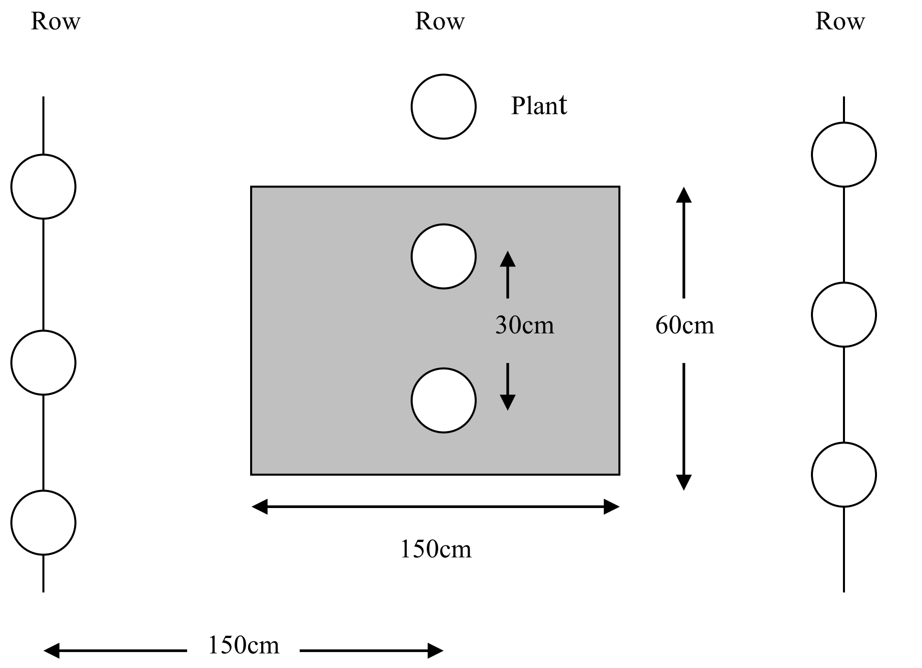
Crops were sampled in August, when the fern was fully active and prior to senescence (approximately one month after end of fern establishment).

Root sampling and processing was done as described in Section 2.2.3.3 except that sampling from areas where fern had previously been cut was avoided. The same tasks were completed as at the end of fern establishment for fern biomass (Section 2.2.3.3), except the fern growth measurements were taken from row 2 of each sample area. In addition to counting the ferns in each of the six 10 m lengths of row, the number of missing plants within each 10 m row was recorded. The two plants at the end of each sampling area (twelve in total) to be excavated at the end of autumn for measuring root biomass were identified, selecting representative plants with typical fern growth.

2.2.3.5 Dormancy, End of Autumn

Crops were sampled in December/January, when fern had senesced fully. Root samples were collected and processed as described previously (Section 2.2.3.3) except that sampling from areas where fern had previously been cut was avoided. Root biomass was measured as follows: The six pairs of representative plants, chosen at the previous sampling time, and all their associated roots were excavated from an area defined as shown in Figure 3. The roots and crowns were washed to remove soil, and excess water allowed to dry-off. The dead/hollow roots were separated from healthy roots and crown material. The total fresh weight of dead roots and the total fresh weight of healthy roots were recorded. For both the dead root material and the healthy root/crown material, a combined sample was retained to fit in an oven tray. The fresh weight of the dead root representative sample and the fresh weight of the healthy root representative sample were recorded. The dead and healthy root representative samples were dried to a constant weight in a drying oven (100ºC/48 h), dry weights measured, and the results were used to calculate the dry matter content of each root type.

Figure 3. Diagram of area excavated (shaded) around pairs of sample plants at the dormancy (end of autumn) sampling occasion.



2.2.3.6 *Crop Performance Questionnaire*

A questionnaire was sent out to participating growers in autumn 2005 (Appendix 4) to obtain information on yields for 2005, harvest dates and other relevant cropping information (e.g. pest and disease issues).

2.2.4 Data Handling

The 20 Brix% readings from each sampling occasion were converted to equivalent root CHO contents on a dry weight basis using the linear regression equation from ***AspireNZ*** and ***AspireUS***. An initial mean of the 20 values was calculated, then the final mean CHO content was calculated after discarding any values that were more than two standard deviations away from the initial mean. This procedure for obtaining a reliable estimate of mean CHO content, and the need for at least 20 root samples on each sampling occasion, was developed to account statistically for the fact that there is substantial variation among plants within most asparagus crops.

Fern biomass was estimated from the counts and dry weights of small, medium and large ferns in the six 10 m lengths of row measured in each crop. The biomass of fern in each size class was calculated, then they were aggregated and, finally, the total was scaled up to kg/ha by assuming that there were 6667 m of row length per ha (i.e. rows were 1.5 m apart).

Biomasses of healthy and dead roots were calculated by scaling up the measurements made on two plants per plot to kg/ha. The weights were scaled using the plant populations that were counted at the peak of fern growth. In some cases, these populations were considerably lower than the original established population.

The weight of CHO in the root system at the end of autumn was calculated as the product of healthy root biomass and the CHO content. The rest of the root weight was taken to be structural biomass, and this was assumed to be a stable quantity during the year. On the basis of this assumption, backwards calculations were done to estimate the weight of CHO in the root system at each time of root sampling during the year.

2.2.5 Environmental Conditions

For each region, monthly meteorological data for 2005 was downloaded from the Meteorological Office website www.metoffice.gov.uk to view trends in weather patterns during the year.

2.3 Results and Discussion

2.3.1 Site Details

The characteristics of the sites selected for monitoring during the project are summarised in Table 1. Four of the sites (E2, E4, S4 and W1) were categorised as young crops, planted in 2002 or later, with a first full harvest planned for 2005. The others were classed as established crops, having previously had at least one full harvest. Dutch varieties are being grown at all of the sites except E4 where an American variety, Jersey Giant, is grown. The sites include a range of soil types, with the lightest soil being at E4, and field sizes range from 0.6 ha to 37.0 ha. Planting material types included crowns and transplants. The previous performance of the crops was contrasting, with S1, W2 and W3 having low gross yields in 2004 (2.5 t/ha or less) compared with high yields for E2 (despite a short harvest season), S2 and W4 (4.2 t/ha or more). Previous fern vigour also varied with site. Growers noted various production constraints including phytophthora (S1, S2 and E1) and stemphylium (e.g. W4). Polythene covers to promote early harvesting are being used on crop W1.

2.3.2 Sampling Programme

Sampling dates at the different stages of crop development during project year 1 are shown in Table 2. The end of harvest sampling dates were within +/- 4 days from when the grower stopped harvest, except for S1 (+ 9 days) where the grower closed earlier than expected. End of fern establishment sampling (mid-late July) took place approximately one month after the end of harvest, and peak fern growth sampling approximately one month later (mid-late August). Dormancy sampling did not commence until December since fern senescence was delayed due to unusually mild autumn weather.

2.3.3 Root Carbohydrates

Root CHO contents are presented in tabular form (Table 3) and also in graphical form (Figure 4), to demonstrate depletion and accumulation during the year.

The root CHO content for almost all of the test crops follows the expected pattern of depletion and accumulation as demonstrated from previous work in New Zealand and the USA. There was consistency among the crops in the east and west regions with all crops starting the season between about 470 and 570 mg/g, which are considered high values at that stage. All crops dropped to somewhere between 300 and 400 mg/g at the end of harvest (the recommended end of harvest value is 300 mg/g in ***AspireNZ*** and ***AspireUS***). Then all of these crops dropped to between 200 and 300 mg/g at the end of fern establishment. This drop was notably smaller than corresponding decreases observed in New Zealand and the USA, especially in the crops in the west region. Root CHO content recovery differed among the crops, with values at the end of autumn ranging from <400 mg/g to >600 mg/g.

The crops in the south showed a different pattern from the east and west ones, with generally lower CHO values prior to the start of harvest and at the end of autumn. Values at the end of harvest and fern establishment were similar to the other regions, although more variable. Root CHO accumulation at site S4 showed a deviation from the normal pattern (Figure 4B), with a particularly high value at peak fern growth, followed by a decrease at the end of the season. The likely reason for this is as follows: the crop showed excellent fern development at the time of peak fern growth, hence the high root CHO level at this stage. There was no secondary flush of fern growth but from mid-August onwards there was a severe stemphylium attack that was left untreated and resulted in defoliation and extensive fern die-back. This will have limited movement of CHO from the fern to the root system in the latter part of the year and leading to the reduced root CHO content at the end-of-year dormancy sampling. This observed pattern for root CHO depletion and accumulation at S4 corresponds closely with data obtained for crops affected by stemphylium in New Zealand (Wilson *et al*., 2002). This is a good example of the type of deviation that the ***Aspire*** system helps to identify and, because it often indicates a problem with crop performance that needs to be diagnosed and resolved, it alerts growers to seek local expert advice to identify the causes.

Another anomaly in the CHO patterns was that for three sites (S2, W1 and W3) there was only a slight decrease (increase for W3) in root CHO content between the end of harvest and end of fern establishment. Furthermore, the drop during this period was smaller than expected for several of the crops. The reason for this is not clear, but the most likely explanation is that the timing of the sampling, which aimed to coincide with the minimum CHO content, was not optimum in those cases. The timing appeared to be closest to ideal in the east crops. For the 2006 season, modifications to the sampling protocol may be required.

Results from New Zealand and Germany have shown that there can be a reduction in root CHO content between between pre- and post-winter root CHO values. The reasons for the decline are uncertain, but there are several possibilities (Wilson *et al.*, 2006). They could result from utilisation of CHO in respiration processes to maintain the root system during winter. It could be that during winter CHO is transformed into insoluble storage forms that are not detected by Brix% assessments. A third possibility is that the reduction could be an artefact resulting from dilution of soluble CHO in the sap solution due to hydration over winter leading to increased root water content. This effect will be discussed in more detail in the next project report when root CHO data for March 2006 is available for the UK.

Table 1. Characteristics of sites selected for monitoring over a two year period.

Site	Area (ha)	Soil-type	Year planted	Category*	Population at planting (plants/ha)	Variety	Planting material	No. days harvest in 2004	Gross yield (t/ha) in 2004	Fern growth in 2004	Other issues
E1	6.0	Silty loam	1997	Established	21,500	Geynlim	Crowns	55	4.0	Average	Phytophthora and poor drainage
E2	2.7	Sandy silt loam	2002	Young	21,500	Geynlim	Crowns	45	4.9	Excellent	None
E3	15.0	Sandy clay loam	2000	Established	24,000	Geynlim	Transplants	51	1.7 (net/tips)	Excellent	Waterlogging (in places)
E4	37.0	Loamy sand	2002	Young	25,000	Jersey Giant	Crowns	43	Data not available	Average	-
S1	5.0	Sandy loam	1998	Established	20,000	Geynlim	Transplants	60	2.5	Average	Phytophthora in 2003
S2	3.0	Sandy loam	1996	Established	22,250	Venlim	Transplants	60	4.2	Good	Phytophthora
S3	1.8	Sandy loam	1998	Established	21,700	Geynlim	Transplants	58	3.8	Average	Slight beetle
S4	0.6	Sandy loam	2002	Young	22,500	Geynlim	Crowns	Data not available	Data not available	Excellent	Beetle. Rubble in crop
W1	9.3	Sandy loam	2003	Young	24,000	Geynlim	Crowns	50	3.3	Good	Polythene covered; Stemphylium and beetle
W2	1.2	Sandy loam	1999	Established	20,000	Geynlim	Transplants	55	1.2	Poor	Small spears
W3	1.8	Sandy loam	1999	Established	25,000	Geynlim	Transplants	55	2.3	Poor	Beetle; very thin spears in 2004
W4	3.2	Sandy loam	2001	Established	22,200	Backlim	Transplants	57	4.5	Average	Stemphylium – high in Sept 2004; Weeds during establishment

*Established: at least one full harvest taken prior to 2005
Young: first full harvest to be taken in 2005

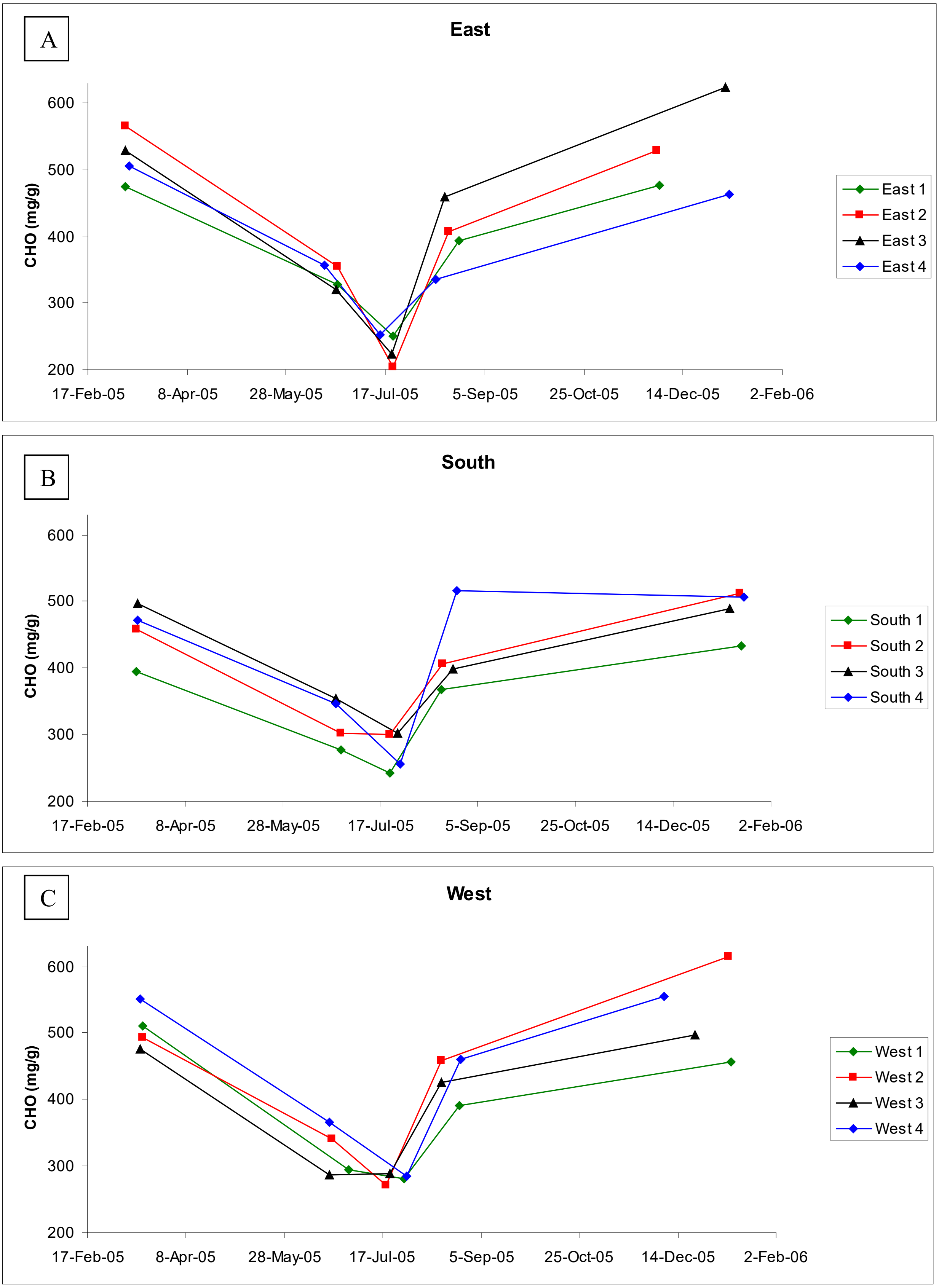
Table 2. Sampling dates at different stages of crop development (2005-2006).

Region	Site code	Pre-harvest sampling	End of harvest sampling	End of fern establishment sampling	Peak fern growth sampling	Dormancy Sampling
East	E1	08/03/05	23/06/05	21/07/05	23/08/05	02/12/05
	E2	08/03/05	23/06/05	21/07/05	18/08/05	01/12/05
	E3	08/03/05	22/06/05	20/07/05	16/08/05	04/01/06
	E4	10/03/05	16/06/05	14/07/05	11/08/05	06/12/05
South	S1	14/03/05	27/06/05	22/07/05	17/08/05	18/01/06
	S2	14/03/05	27/06/05	22/07/05	18/08/05	17/01/06
	S3	15/03/05	24/06/05	26/07/05	23/08/05	12/01/06
	S4	15/03/05	24/06/05	27/07/05	25/08/05	19/01/06
West	W1	17/03/05	30/06/05	28/07/05	25/08/05	10/01/06
	W2	17/03/05	21/06/05	19/07/05	16/08/05	19/01/06
	W3	16/03/05	20/06/05	19/07/05	16/08/05	13/12/05
	W4	16/03/05	20/06/05	28/07/05	26/08/05	07/12/05

Table 3. Root CHO content values for 12 asparagus crops monitored at five stages of crop growth in 2005/2006.

Site	Root CHO content (mg/g) at different crop growth stages				
	Dormancy (pre-harvest) (March)	End harvest (End of June)	End of fern establishment (late July)	Peak fern Growth (late August)	Dormancy (end of season) (Dec/Jan)
East 1	475	327	250	393	477
East 2	567	355	203	407	530
East 3	529	320	223	459	625
East 4	507	357	253	335	464
South 1	394	278	242	367	434
South 2	459	303	300	408	513
South 3	497	354	302	398	490
South 4	472	346	255	516	506
West 1	511	295	281	391	457
West 2	494	341	271	459	614
West 3	476	287	289	426	496
West 4	551	365	285	460	554
Mean	494	327	263	418	513

Figure 4. Root CHO content values for 12 asparagus crops sampled at five stages of crop growth in three regions, east (A), south (B) and west (C).



2.3.4 Root Biomass and Weight of CHO

The biomass of healthy roots at the end-of-year dormancy sampling ranged from about 8000 to 26000 kg DM/ha (Figure 5A). This corresponds closely with typical ranges of root biomass found in asparagus crops in other countries (Wilson *et al.*, 2006). The amount of dead roots was small in most crops, although dead biomass values were over 2000 kg DM/ha in four crops (S1, S2, S3 and W3). The weight of CHO in the roots at both the start of harvest and the end of fern growth varied over a large range, from about 3000 to 14000 kg/ha (Figure 5B).

Crops with higher values for root biomass and weight of CHO (Figures 5A and 5B) were at sites E1, E2, S3 and W4. E1 is a mature crop with a large root system that has performed well despite poor growth in some parts of the field and a history of phytophthora. S3 is also a well established crop but is showing some evidence of decline, as indicated by the higher proportion of dead roots. Both E2 and W4 are vigorous, younger crops with large root systems with high CHO levels, despite being less than five years old. W4 also had a shorter harvest season (52 days) compared with other high yielding sites (see Table 4).

Four crops with consistently lower indicators for root health (lower healthy root biomass and weight of CHO) were E4, S1, W1 and W3. Possible explanations are as follows: E4 is an establishing crop of a variety that shows variable performance in the UK. S1 and W3 are both established crops for which the cropping history indicates poor performance, with W3 in particular having more dead roots. W1 is a young crop and the low root system indicators may have resulted from stress caused by the extended first full harvest.

Crops that showed a substantial increase in weight of root CHO between March and December 2005 were E3 and W2. There was no clear explanation for why this occurred, given that there was a full harvest season at both sites. Two sites that showed a reduction in weight of CHO during the year were E4 and W1, due possibly to reasons given above.

2.3.5 Fern Growth

At fern establishment, about one month after the end of harvest, fern biomass at the 12 sites ranged from about 1500 to 5400 kg DM/ha (Figure 6A), with a mean of 2700 kg/ha. Most crops were in the 2000 to 3000 kg/ha range.

By peak fern growth (approximately one month after fern establishment), fern biomass ranged from about 1500 to 6000 kg DM/ha (Figure 6A), with a mean of 3700 kg/ha. By this stage, only one crop was less than 2000 kg/ha, five were between 2000 and 3000 kg/ha and the other six were all over 4000 kg/ha. In one case (site W1), fern biomass was lower at peak fern growth than it was at fern establishment. This is most likely to be due to fern damage resulting from a herbicide application in early August (grower observation). The highest fern biomass values were recorded for S1 and S2. Despite observations at the time of sampling (end of establishment) that there was large fern growth at E4, the biomass was among the lowest at this site. This occurred because the variety was Jersey Giant which has a much lower fern dry matter content than the other varieties. Growth at this site was also characterised by toppling, breakage and subsequent death of larger ferns.

Variability was quite high among the six measurement rows (each a 10 m long segment) in all of the 12 crops. The average standard deviation from the overall biomass yield (3200 kg/ha) at both fern growth stages was 660 kg/ha. At some sites the fern biomass in one row was up to three times more than in other rows.

Previous measurements from NZ and USA (California), countries which have longer fern-growing seasons, have shown that average growth was generally heavier than reported here, with some crops producing up to 10,000 kg DM/ha (D. Wilson, D. Drost, pers. comm.). However, as in the UK, variability among crops is high.

The percentage of plants missing in the measurement rows ranged from 0-23% (data not presented), the highest being in a crop that was planted as double rows (S2). Approximately half of the crops had fewer than 10% plants missing.

The number of ferns increased by an average of 10% between fern establishment and peak fern growth. One of the biggest increases was 37% at site W3 (Figure 6B) which had a high proportion of small and medium ferns (Figures 6C and 6D), so this was unlikely to have been much of a drain on CHO recharge. The other large increase was at S1 (47%) where there was a high proportion of medium and large ferns. The only site for which there was a decrease in fern number was W1, perhaps due to herbicide damage. The relatively high number of ferns per 10 m row length at S2 is accounted for by the double rows of plants per ridge at this site. There were also high fern numbers at sites W2 and W3, mainly accounted for by production of many small and medium ferns (Figures 6C and 6D).

Generally, the proportion of small ferns rose between the two growth stages (13 to 24%), and the proportion of large ferns dropped from 35 to 25%. On average, half the ferns observed in the measurement rows were of medium size throughout fern growth. W2 and W3 were unusual in having a higher proportion of small ferns than medium or large. This corresponds with reports of thin spear production at these sites.

Figure 5. Root biomass and CHO weight in the 12 asparagus crops, (A) healthy and dead root biomass at the end of fern growth and (B) CHO weights at the start of harvest and at the end of fern growth.

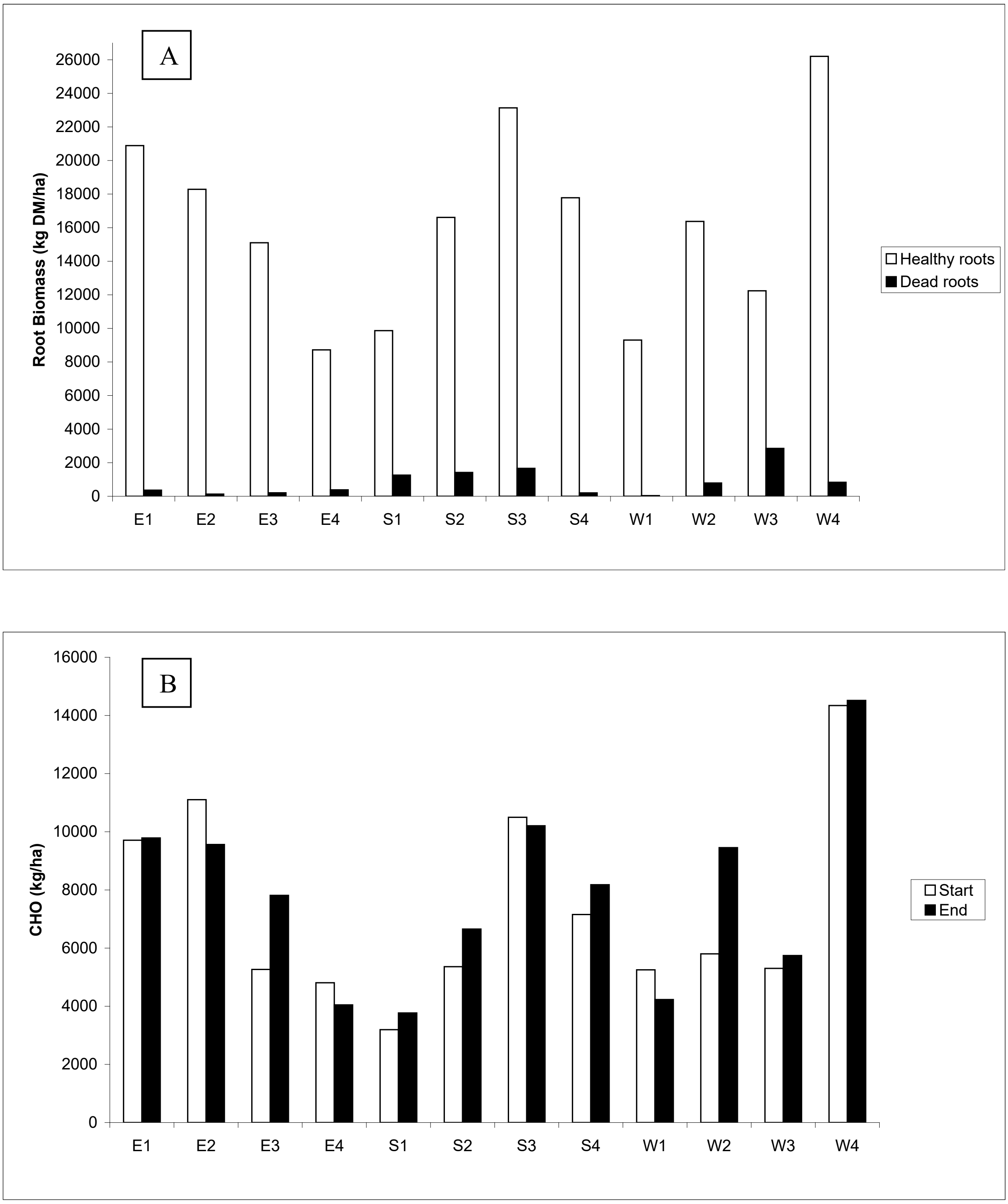
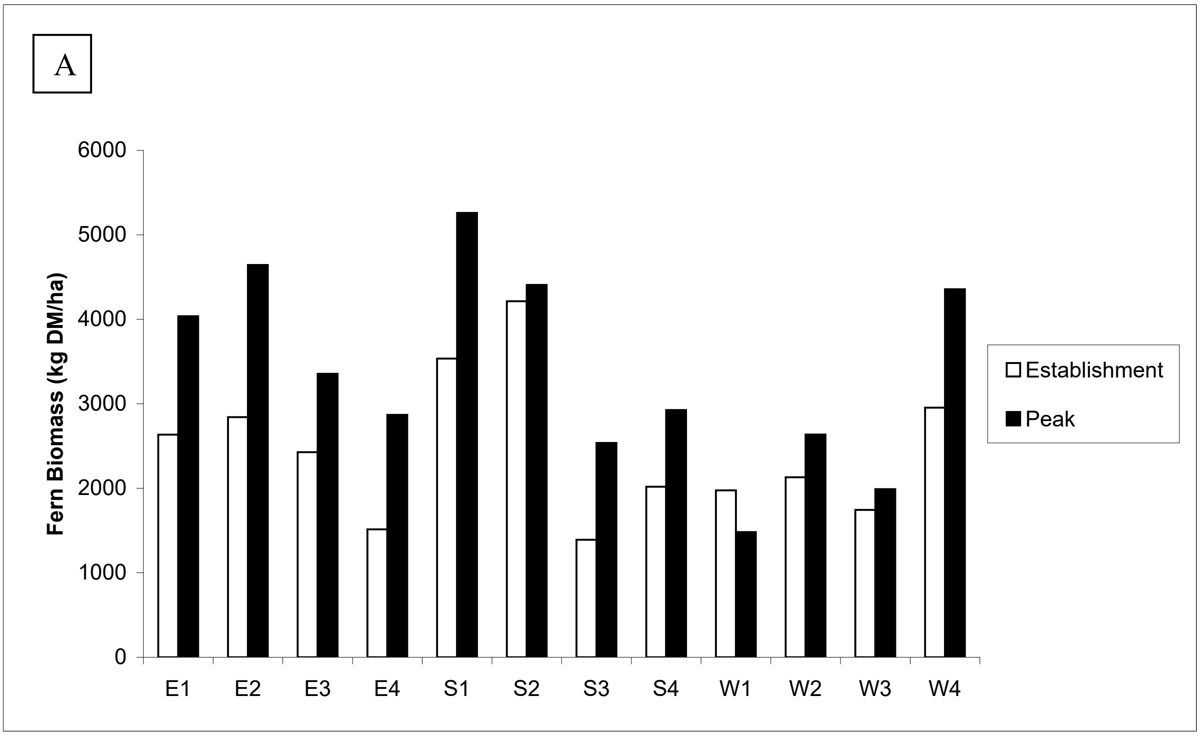
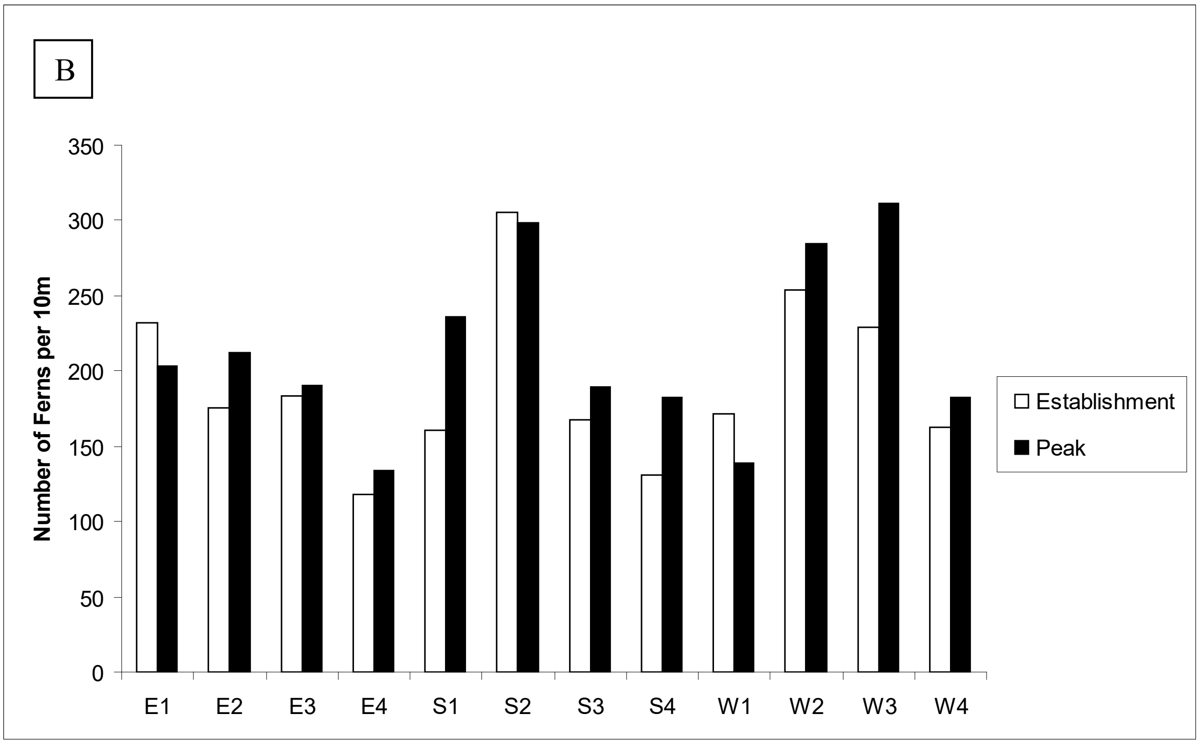
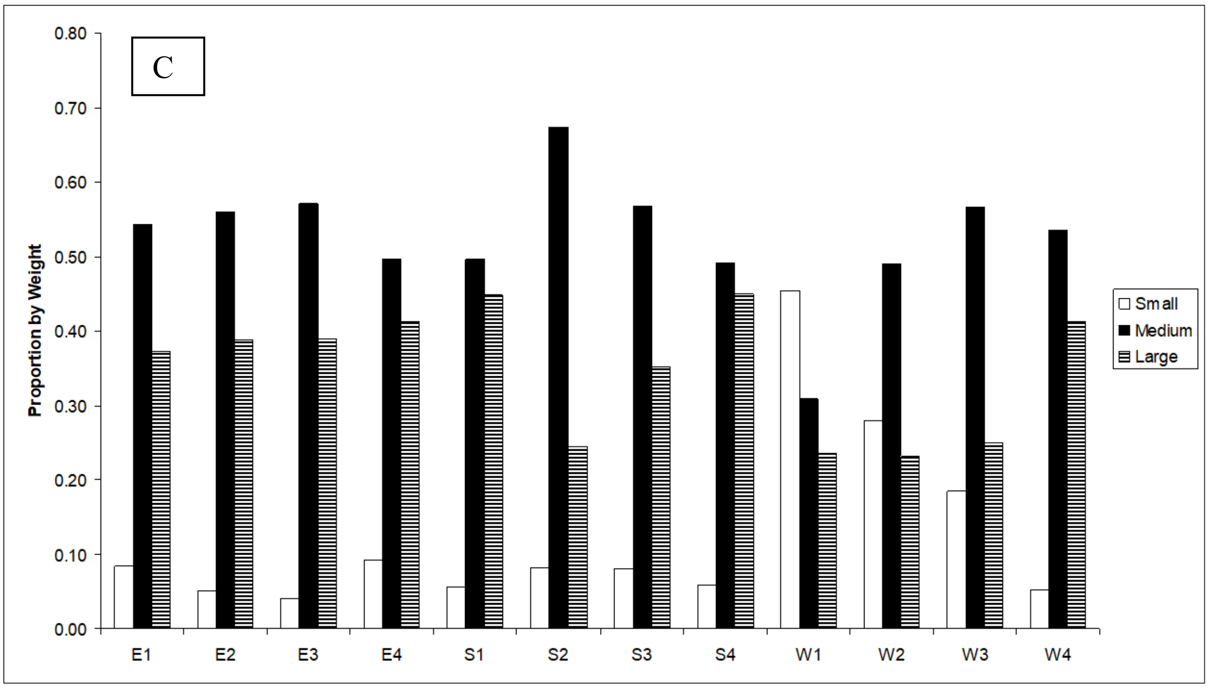


Figure 6. Fern growth characteristics in the 12 asparagus crops, (A) biomass at fern establishment and at the peak of fern growth, (B) number of ferns per 10 m of row length at fern establishment and at the peak of fern growth, (C) proportions of small, medium and large ferns at fern establishment, and (D) proportions of small, medium and large ferns at the peak of fern growth.



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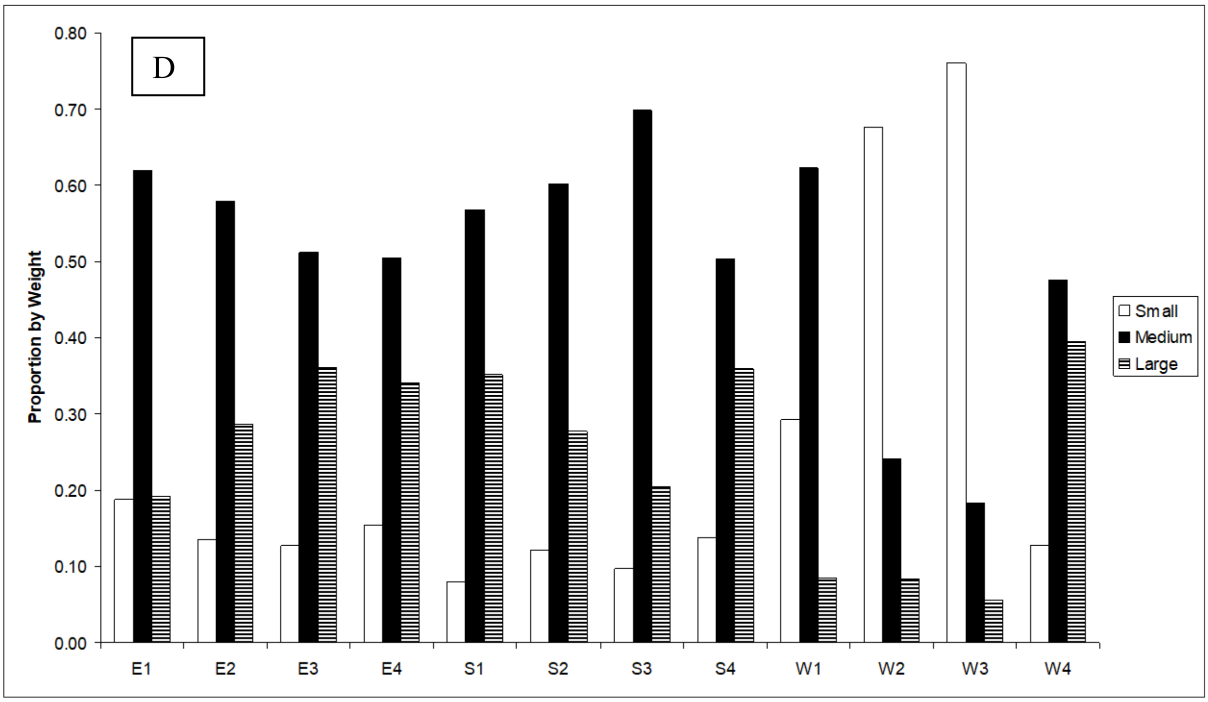
W1
W2
W3
W4
Small
Medium
Large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Proportion by Weight
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S1
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S3
S4
W1
W2
W3
W4
Small
Medium
Large

2.3.6 *Spear Yield*

Details of yields and harvest durations for 2005 are shown in Table 4. Gross yields ranged from 2.1 to 6.6 t/ha. The longest harvest season was at W1 where cutting commenced approximately 4 weeks before the other sites (under polythene) and finished 1 week later than the others. Season length was reduced at E4, S1, and W3 for a range of reasons (e.g. diminishing yields and labour issues). The highest yielding crops were E2 (young vigorous crop), S2 (well established), W1 (extended harvesting period due to polythene covers and more prolific harvest during the total period) and W4 (relatively young crop). Poor yielding crops included E4 (due possibly to the variety), S1 (cropping history suggests poor crop performance) and W2 (thin spears, severe beetle attack and poor crop establishment).

Table 4. Harvest dates and yields in 2005 for the 12 monitored sites.

Site	Harvest start date	Harvest end date	Duration of harvest (days)	Gross yield (t/ha)	Net yield (t/ha)
E1	29/04/05	21/06/05	54	3.01	2.06
E2	29/04/05	21/06/05	54	5.43	3.71
E3	29/04/05	20/06/05	53	3.05	2.30
E4	?	15/06/05	?	2.96	Not available
S1	01/05/05	18/06/05	49	2.10	1.85
S2	27/04/05	22/06/05	57	5.30	4.10
S3	26/04/05	20/06/05	56	3.58	3.01
S4	25/04/05	20/06/05	57	4.38	Not available
W1	29/03/05	26/06/05	86	6.60	4.42
W2	24/04/05	22/06/05	60	2.75	1.65
W3	?	17/06/05	?	?	?
W4	30/04/05	20/06/05	52	5.09	Not available

? – data not yet provided by grower

2.3.7 *Crop Observations*

Observations on the appearance of root samples and crop performance in the first project year are summarised in Tables 5 and 6.

Table 5. Observations on appearance of root samples.

Site	Root health
E1	Hollow roots and root discolouration abundant
E2	Healthy
E3	Mainly healthy
E4	Hollow roots abundant at some sampling times Roots straight (light soil) and thinner than for other varieties
S1	Variable
S2	Hollow roots abundant but areas where root health is very good
S3	Variable
S4	Healthy
W1	Mainly healthy
W2	Variable
W3	Variable
W4	Mainly healthy

Table 6. Observations on crop issues noted by assessors and growers.

Site	Harvest period	Fern development
E1	• Slight phytophthora; metalaxyl-M applied pre-harvest • Weed problems (bindweed, marestail)	• Average fern growth but decline in places (also observed in previous years) • Slight stemphylium and slight beetle attack
E2	• Good yields	• Excellent fern growth • Slight stemphylium
E3	• Slight phytophthora	• Good fern growth • Waterlogging in parts • Some fern die-back in wet areas
E4	• Harvesting commenced late • Asparagus beetle • Weed problems	• Large ferns, with collapse common (and associated browning) • Moderate stemphylium • Late emerging weeds (nightshade) problematic
S1	• Harvest stopped early (low yields and labour problems) • 80% spears <10 mm diameter	• Average fern growth • Moderate stemphylium and slight beetle attack
S2	• Slight phytophthora; metalaxyl-M applied pre-harvest	• Good fern growth but missing plants • Some waterlogging • Slight stemphylium, fusarium and beetle attack
S3	• Some weed problems	• Average fern growth, some decline • Slight stemphylium, fusarium and beetle attack • Some weed problems
S4	• Slight phytophthora	• Average fern growth, some stem toppling and secondary growth (August) • Severe stemphylium • Slight fusarium and rust
W1	• Harvest commenced early (approx. 4 weeks) and was extended (approx. 1 week), crop appeared stressed at end of harvest • Some waterlogging in gulleys between polythene, at end of June	• Average fern growth • Herbicide spray scorch in early August (some stem deformation) • Slight stemphylium, fusarium and beetle attack
W2	• Spears small (a high percentage <10 mm)	• Average fern growth • Slight stemphylium • Severe asparagus beetle attack despite chemical treatment
W3	• Slow start to season • No major problems	• Some weed problems (thistles and black nightshade)
W4	• No major problems	• Good fern growth • Slight stemphylium, fusarium and beetle attack • Patchy weed problem (mallow, nettles willowherb)

2.3.8 Meteorological Data

Meteorological data for 2005, summarised by sampling region, is shown in Appendix 5. Major trends for the year were as follows:

Pre-harvest (March-April) Temperatures were above average. There was higher than average rainfall in the west in April and lower maximum temperatures compared with the other two regions.

Harvest (May-June) Maximum temperatures for the east and south were similar but they were cooler by approximately 1 degC in the west. Mean temperatures were close to average making this the coolest May since 1996 and, correspondingly, a slow start to the asparagus harvest season. The rainfall in the south was lower than in the east and west, and it was below average for all regions.

Fern growth During the main fern growing period (July-August), the south had higher mean temperatures, more sunshine and less rainfall than the east and west regions.

Senescence/dormancy Mean temperatures were higher than average in September (1.8-1.9 degC higher) and October (2.7-2.9 degC higher). As a result fern senescence and crop dormancy were later than usual in 2005. Temperatures dropped in November but sunshine hours were higher than average.

When comparing UK weather patterns with New Zealand, in relation to asparagus production, the major contrast is the much longer growing season (and shorter winter dormant period) in New Zealand. A more detailed comparison of accumulated incident radiation over the period of fern growth may be needed. In general, however, conditions in New Zealand give greater flexibility for harvest season length, and availability of time (and solar radiation opportunity) for fern growth and CHO recharge. This difference may impact on the recommendations incorporated into ***AspireUK***.

2.3.9 Interaction Effects

In general, high yields were obtained from crops for which root CHO levels throughout the year, root CHO recharge (kg/ha) and root biomass provided indicators of overall good crop health (e.g. E2 and W4). Conversely, low yields were obtained from crops where the same indicators suggested that the crop might be under stress (e.g. E4 and S1). The exception to this was the crop at W1 where the highest yield was taken (extended harvest) but with data suggesting low root CHO levels and low root biomass. It will be interesting to observe whether similar yields can be maintained in 2006.

Large amounts of fern growth were not necessarily associated with higher CHO recharge. Two crops (E3 and W2) with only average fern growth achieved the highest CHO recharge (625 and 614 mg/g; Table 3). Conversely, the crop with the highest fern biomass (S1) had the lowest recharge at 434 mg/g. These results correspond with findings from New Zealand and the USA which have shown that large amounts of fern growth are not necessary for building up high levels of root CHO. In fact, a crop's capacity to accumulate CHO in the roots can be reduced by diversion of too much energy into fern growth.

2.3.10 Preliminary Benchmarks

From the first year of data, preliminary benchmarks for root CHO levels at different stages of the asparagus growth cycle can be suggested for UK conditions. However, these may need revision after the second year's data have been collected:

- Root CHO content recovery differed among the crops, with values at the end of autumn ranging from <400 mg/g to >600 mg/g. Based on the upper end of this range, the target 'full' root CHO content is about 600 mg/g. This is higher than the values in New Zealand and the US. Many of the crops were below this value, especially at pre-harvest in March 2005, however, at each site there is considerable variability among individual readings.

- Target end of harvest CHO is about 300 mg/g, which is the same as in New Zealand and the US). Several crops that were at 300 mg/g at the end of harvest produced very good initial fern growth whereas others produced less vigorous fern growth.

- The 'empty' root system target (at the end of fern establishment) is less clear, but it likely to be about 200 mg/g. It is a less important decision benchmark, but experience in New Zealand and the US is that depletion below 200 mg/g should be avoided.

A balance between achievable benchmarks and the timing of crop development will be key. For example, a recommendation to harvest until root CHO levels decrease to 300 mg/g could be unwise if it affects the prospect of CHO recovery in the autumn. Recovery in the autumn of 2005 was very variable in the monitored crops and it will be interesting to see the consequences of this in crop performance during 2006, particularly if there are contrasting weather patterns (for example a shorter colder autumn period).

2.4 Overall Conclusions

- Root CHO content for most of the 12 British crops followed the expected pattern during the annual growth cycle in the first year of testing. This augurs well for the prospect of successfully adapting ***Aspire*** for the UK because the results support the principle that, fundamentally, asparagus crops behave similarly wherever they are grown (Wilson *et al.*, 2006).

- As expected, there were deviations from the 'ideal' CHO pattern. The challenge in the rest of the project will be to determine the causes and consequences of these deviations, and include their interpretations in the form of recommendations in ***AspireUK***.

- In general, root CHO levels (kg/ha) and biomass data provided useful indicators of crop health, with sites that had the highest CHO levels and larger healthy root systems giving the highest yields and vice-versa.

- In agreement with findings from New Zealand and the US, increasing amounts of fern growth did not necessarily reflect increasing CHO recharge.

- Results from the first year give preliminary indications of benchmark CHO values for UK asparagus crops.

- An ideal scenario will be to experience a contrasting season in year 2, in particular with the crops challenged more by less favourable environmental conditions during fern growth.

2.5 References

Wilson, D.R., Cloughley, C.G. & Sinton, S.M. 2002. ***AspireNZ***: A decision support system for managing root carbohydrate in asparagus. *Acta Horticulturae* **589***:* 51-58.

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2.6 Technology transfer

- Project start-up meeting attended by S. Sinton (NZICFR), K.Green (ADAS), J. Carpanini (ADAS), W. Dyer, J. Petchell (Hargreaves Plants) and nine participating growers, at ADAS Arthur Rickwood, March 2005.
- Prototype ***AspireUK*** website (www.aspireuk.org) deployed on the internet, access provided to participants for testing and familiarisation during the project, training in use of the system provided at the start-up meeting, March 2005.
- Project training manual produced by NZICFR distributed to all participants, March 2005.
- Presentation at the AGA agronomy day (March 2005) by V. Aveling and subsequent article in HDC News.
- HDC/AGA Seminar for asparagus growers, with presentations by D. Wilson, S. Sinton and K. Green on 29 June 2005 and subsequent update in HDC News.
- Visits to some growers by S. Sinton, NZICFR (March and June 2005) and D. Wilson, NZICFR (June 2005).
- %Brix readings supplied to participating growers on request (ongoing).
- 'Validation of ***AspireNZ*** for the UK', presentation by K. Green at the AGA Agronomy Day (March 2006).

2.7 Acknowledgements

The continuing support and cooperation of participating growers is gratefully acknowledged.

3 APPENDIX 1

Paper from *Acta Horticulturae 589:* *51-58* (Proceedings of the 10th International Asparagus Symposium).

AspireNZ: A Decision Support System for Managing Root Carbohydrate in Asparagus

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Keywords: *Asparagus officinalis* L., www.aspirenz.com, database, storage roots, Brix%, annual growth cycle

Abstract
The gain and loss of soluble carbohydrate (CHO) in the storage roots drives the performance of asparagus (*Asparagus officinalis* L.). Growth of spears and ferns during the crop's annual cycle is associated with a characteristic pattern of depletion and accumulation of root CHO content. Deviations from the normal pattern usually indicate that crop performance is below optimum, and can be used to help diagnose and resolve problems. This paper describes ***AspireNZ***, a decision support system (DSS) that uses these principles to help increase the yield of asparagus crops through better management of root CHO. The system does not make decisions – it interprets information about crops and suggests options to help users reach the best decisions. The DSS has three main elements: a simple method for assessing the CHO status of roots; information about how to interpret the results and use them to help make management decisions; and an interactive computer system that is deployed on the Internet (**www.aspirenz.com**). Other features include a database which retains information about each crop registered with the system. The information can be retrieved at any time so that users can retrospectively evaluate the effects on crop performance of previous management decisions. Examples are presented illustrating the benefits of using ***AspireNZ*** to help make crop management decisions. The DSS is being used by growers in New Zealand. In the future, after appropriate testing and modification, it could be made available in other asparagus production areas of the world.

INTRODUCTION
Growth of spears and ferns during the annual cycle of asparagus is associated with a characteristic pattern of depletion and accumulation of soluble carbohydrate (CHO) in the storage root system (Shelton and Lacy, 1980; Robb, 1984; Haynes, 1987; Pressman et al., 1993; Drost, 1997). The general features of this cycle are well known, and growers appreciate that high yield potential depends on high CHO availability from the root system for spear growth during harvest. Our studies (Cloughley et al., 1999; Wilson et al., 1999) have highlighted the role of the root system in determining crop performance, both in the current year and in the long term. To use an automotive analogy, the root system is the 'fuel tank' that drives asparagus performance, and the size of the system is the capacity of the tank. The CHO content of the root system indicates how full, or empty, the tank is at any time. High yield requires a full tank.

Knowing how much fuel is in the tank during the annual cycle enables growers to make better crop management decisions to ensure that there is a high level of CHO in the roots to drive spear production during harvest. Deviations from the normal pattern, which usually indicate that crop performance is below optimum, can be used to help diagnose and resolve problems. However, growers seldom know the CHO status of the root system and, even if they do, they cannot easily interpret the information. Therefore, the traditional focus of crop management practices has been on above-ground growth, assuming that production of healthy, vigorous fern will lead to high spear yield and quality in the following season.

In this paper we describe ***AspireNZ***. It is a new web-based interactive decision support system (DSS) that we have developed to help asparagus growers achieve high yields through better management of root CHO during the annual growth cycle. First, we briefly review the key features of the annual cycle. Then we describe the three research-based elements that make the system feasible. These are a simple, reliable method for assessing the CHO content of roots; information about how to interpret the results and use them to help make crop management decisions; and an interactive computer system that is deployed on the Internet. Finally, we present two examples illustrating the benefits of using ***AspireNZ*** to help make crop management decisions.

ASPARAGUS GROWTH CYCLE

There are usually three phases in each annual cycle:

- Dormancy, which occurs either when the soil temperature is low or during drought.
- Harvest, when spear growth is driven by temperature and the availability of CHO.
- Fern growth, when the spears are allowed to grow and form a fern canopy. The canopy is either removed to start a harvest or left to senesce when the crop enters dormancy.

These three phases occur in most climates and crop management systems. However, their order and timing may differ, and there is no dormant phase in tropical and sub-tropical climates. The usual order in places with temperate climates, such as New Zealand, is for dormancy in winter followed by harvest in spring-summer, and then fern growth in summer-autumn before the next dormant period.

The growth cycle includes a sequence of characteristic patterns of above-ground growth and of depletion and accumulation of CHO in the root system. The patterns for a temperate climate are shown in Figure 1. Stored CHO is usually at a maximum during dormancy. It is depleted during spear growth and fern establishment, and is then replenished before winter by assimilate production by the established fern canopy. Crops are most likely to produce high yields if they follow these patterns consistently. ***AspireNZ*** operates on the principle that knowledge of these patterns, and especially deviations from them, can be used to help make crop management decisions. The status of a crop can be evaluated at any time to help make decisions. However, there are six key times when evaluations are highly recommended (Figure 1):

- *Dormancy (1).* At the end of winter, before spear growth starts. This assesses how full of CHO the root system is and indicates whether the potential size and duration of the spear harvest are likely to be more or less than normal.
- *Close-up.* In late spring-early summer, at the end of harvest when the crop is closed up to allow fern growth to start. This assesses the extent of CHO depletion during harvest, and whether fern establishment could be restricted. The latter would indicate a need for extra agronomic inputs, such as fertilizer or irrigation, to stimulate fern establishment.

Additional CHO evaluations before close-up can be used to help decide whether harvest duration should be reduced or could be extended, depending on levels of root CHO.

- *Fern established.* In mid-summer, about a month after close-up, when the fern canopy is fully established. This assesses the maximum depletion of root CHO content, before recharge starts.
- *Fern growth (1)* and *Fern growth (2).* In late summer and autumn, at successive intervals of about a month after full fern establishment. These assess the level of CHO recharge, which is vital for potential spear yield the following season. Lower recharge than normal could result from poor fern growth caused by factors such as water deficit or a foliar disease such as *Stemphylium*, and may require additional agronomic inputs. Low recharge could also be caused by excessive resource allocation to fern growth, especially to growth flushes in late autumn which are undesirable because they deplete CHO.
- *Dormancy (2).* At the end of autumn, when ferns have senesced. This assesses whether the CHO content of the root system is fully replenished, and indicates the potential for spear production in the following spring.

MEASURING ROOT CHO STATUS

There have been many studies of the CHO changes that occur in asparagus during the annual cycle. The CHO physiology of the crop was reviewed recently by Drost (1997). Most CHO in the root system consists of fructans. These storage CHOs are synthesized from simple sugars (sucrose, glucose and fructose) produced from photosynthesis in the ferns and translocated to the roots. They accumulate in the roots, and are hydrolyzed when they are required for spear growth, fern establishment or root and crown growth.

Measurement of root CHO content by growers for use in ***AspireNZ*** is based on results from our research (Wilson et al., 1999). We have used the anthrone method (Quarmby and Allen, 1989; see description in Wilson et al., 1999) to measure total root CHO content in commercial and experimental crops over several seasons in the main asparagus production regions of New Zealand. About 400 samples were analyzed, with CHO contents ranging from about 150 to 600 mg/g (i.e. 15 to 60%). It is not feasible to use the anthrone method for large numbers of routine CHO analyses, so we tested a simpler, more practical method. The Brix% of solution extracted from the same 400 root samples was measured with a refractometer. Statistical analyses showed a strong correlation between the two sets of data ($r = 0.91$). Therefore, we concluded that Brix% can be used with confidence in place of analytical measurement of CHO content.

There is substantial variation in Brix% among plants within an asparagus crop. We determined statistically that Brix% values are needed from a minimum of 20 root samples collected randomly from a crop to obtain a reliable estimate of its mean CHO content. Therefore, ***AspireNZ*** requires users to provide at least 20 values from a crop for each assessment.

INTERPRETING CHO INFORMATION

Knowledge about how to interpret root CHO content was developed from our extensive measurements of experimental and commercial crops, and associated measurements of crop performance (spear yield, fern growth and root biomass). Root CHO content values are evaluated taking into account the age of a crop and the stage of its annual cycle. The system identifies and quantifies deviations from the ideal crop condition by comparing the data with built-in performance benchmarks. Deviations usually indicate a potential problem. It then comments on the condition of the crop, suggests possible causes of deviations, and recommends management options to optimize crop performance. ***AspireNZ*** contains a library of responses and uses logic to extract the one that is appropriate for each set of circumstances. Currently the performance benchmarks and associated responses apply only to conditions in New Zealand. It is likely that they will be different in other situations, and research will be needed to modify them for other environments and production systems before ***AspireNZ*** can be implemented elsewhere.

INTERACTIVE DEPLOYMENT ON THE INTERNET

AspireNZ is on the Internet at www.aspirenz.com. The homepage has an index of general information that can be viewed in the public section of the system. However, the interactive section is only available to registered users who have been provided with a Username and Password to gain access. These ensure that each user's information is secure, and not accessible to anyone else. New subscribers may register on-line or by mail. Registered subscribers may register as many crops with the system as they wish, and may add new crops at any time. The system provides detailed instructions about how to sample root systems and measure Brix% correctly.

When a user has logged into an interactive session, ***AspireNZ*** requires a sequence of responses. These include a crop identifier, age of the crop, stage of the annual cycle and the corresponding Brix% values. A minimum of 20 values is required; it will accept a maximum of 40. These data are evaluated statistically to determine whether a reliable estimate of mean root CHO content can be obtained. If variability is high, measurements that are more than two standard deviations from the mean are omitted and the data are re-evaluated. If variability is still high, a warning message appears, advising that a reliable estimate of root CHO content cannot be made and that more root samples should be obtained and measured for Brix%.
The system then estimates the mean root CHO content and displays the result along with associated comments and recommendations. The CHO content value is stored automatically in the database for the crop (see below).

The ***AspireNZ*** system uses Java-based servlet/JSP and JDBC technology coupled with a MS SQL Server database to provide its functionality. It can be accessed with recent versions of any of the standard Internet browsers.

DATABASE AND DIARY

Another element of ***AspireNZ*** is its database. It maintains a record of all registered users and of the crops registered by each user. Thus, all information is retained for future reference, including historical information provided when the crop was registered. The accumulated records of the past performance of a crop can be used retrospectively to evaluate the consequences of earlier management decisions. An optional feature of the database is a crop diary facility which subscribers can use to record information about each registered crop. Information can be retrieved from the database at any time in text, graph or table form.

BENEFITS OF USING *AspireNZ*

In this section we present two examples of how yield increases were achieved by using ***AspireNZ*** to help make crop management decisions.
In the first case, a substantial yield advantage was obtained by extending the harvest duration. ***AspireNZ*** was used to support the decision, and gave confidence that it was unlikely to adversely affect crop performance in the short or medium terms. The result was obtained from an experiment where harvest was extended by 10, 17 and 24 days after a normal 15 week harvest. About 650 kg/ha of additional saleable spear yield, or over 1100 kg/ha of total yield,

was obtained for each extra week of harvest (Table 1). Root CHO content was greater than 300 mg/g at the end of the longest harvest, indicating that the crop was not harmed. Fern growth was reduced following the extended harvests (Table 1), but it was more than enough to produce good CHO recharge during autumn in all treatments.

In the second example, failure to control *Stemphylium* infection of the fern in response to signals from ***AspireNZ*** substantially reduced the yield of an established crop. In previous years with no incidence of *Stemphylium*, the crop had root CHO contents that were consistently about 500 mg/g at the start of harvest, and produced spear yields of about 7 t/ha. In mid-autumn 1999, it suffered a severe attack of *Stemphylium* during fern growth. Tests indicated that root CHO content was still low (about 340 mg/g) and ***AspireNZ*** recommended that measures should be taken to control the disease. However, fungicide was not applied and the fern canopy lost its photosynthetic capability; fern biomass declined from 3.3 to 1.3 t/ha as complete needle loss occurred. Consequently, root CHO recharge, which would usually continue into May, ceased prematurely in March (Figure 2). At the end of autumn, ***AspireNZ*** predicted a much reduced spear yield the following spring, and recommended a shortened harvest to allow the crop to recover. The result was a spear yield that was about 50% lower than the long term mean for the crop (3.8 t/ha total; 2.8 t/ha saleable).

CONCLUSIONS

AspireNZ is a novel DSS that transfers technology effectively by putting knowledge derived from research into the hands of end-users in a form that they can use readily. The responses from the system do not make decisions for growers – they provide information and suggest options to help them reach decisions. We have demonstrated that yield benefits can be achieved by using ***AspireNZ*** to help make crop management decisions. In New Zealand, the system is being used by growers mainly to decide when to stop harvesting.

There is scope to improve its capabilities. We envisage that it could become a central source of information about asparagus for growers. This would allow easy and rapid updating as new information becomes available. Links could be provided to other sources of information about asparagus, including to websites with information about products used in asparagus production.

Currently, the evaluation of crop condition is limited to root CHO content. Root mass is not considered, although mass is the other main determinant of the total amount of stored CHO, and it would be a better indicator of crop performance (Haynes, 1987; Drost, 1997). A new core sampling technique is showing promise for estimating root mass per plant (D.T. Drost, pers. commun., 2000) and, in the future, this measurement could be used together with CHO content to obtain a more accurate assessment of crop condition.

AspireNZ was developed with support from asparagus growers in New Zealand and, at this stage, registration is restricted to members of the New Zealand Asparagus Council. It was used by about 30 growers in the 2000-01 season, and there will be more next season. We are investigating the possibility of implementing the system in other countries. This will require joint research with local collaborators to check the system's benchmarks and associated responses in other environments and production systems. A project has already started in Washington, USA, and we are keen to explore other opportunities.

ACKNOWLEDGEMENTS
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Tables

Table 1. Effects of four harvest duration treatments on saleable and total spear yields and fern yield of an established crop.

Close-up date		Spear yield (kg/ha)		Yield increase (kg/ha)		Fern yield (kg/ha)
		Saleable	Total	Saleable	Total	
19 December		6130	10210	--	--	7890
29 December	(+10 days)	6800	11330	+670	+1120	3890
05 January	(+17 days)	7490	12470	+1360	+2260	5070
12 January	(+24 days)	8050	13850	+1920	+3640	5450

Figures

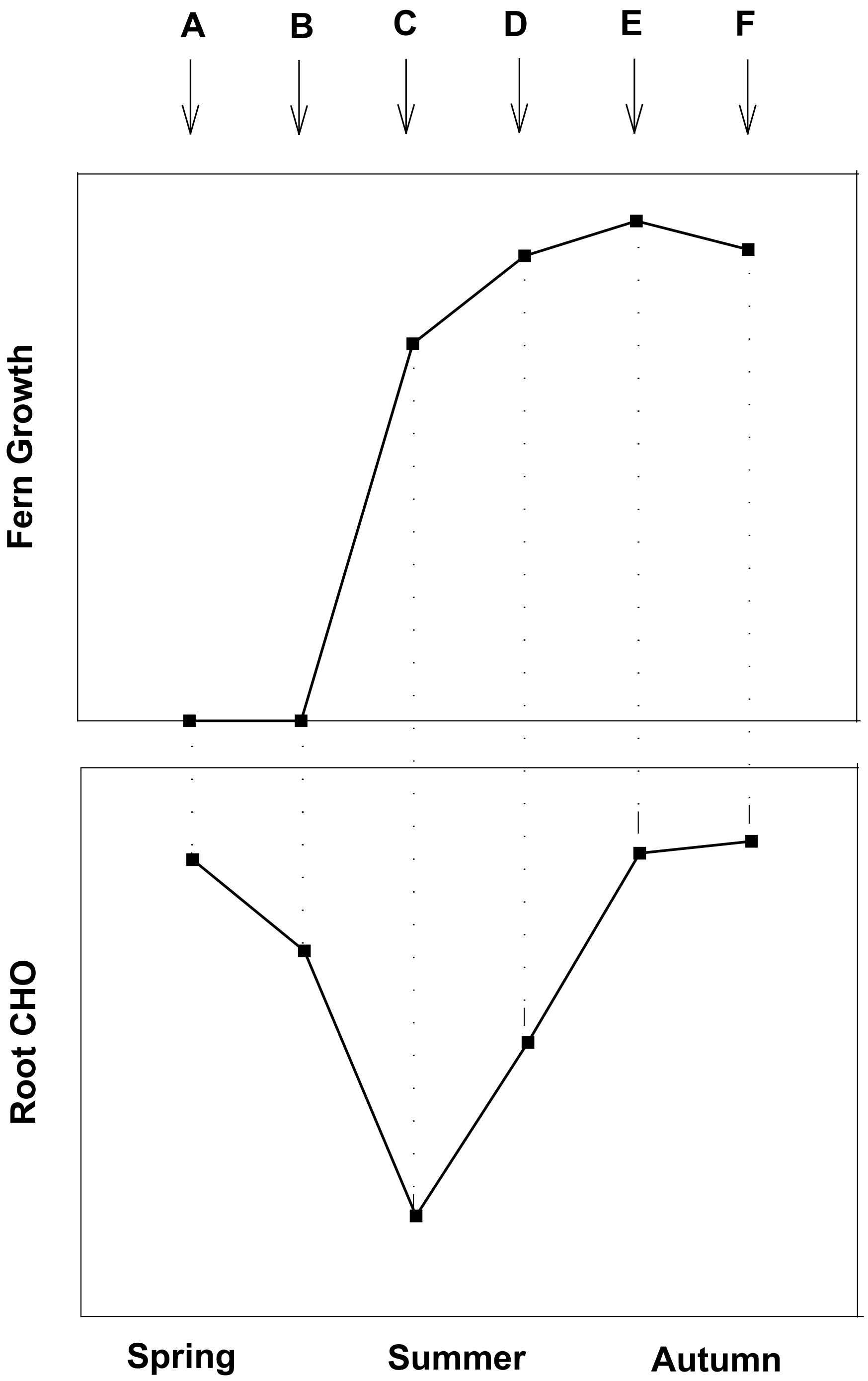

Fig. 1. Typical patterns of fern growth and CHO content in the root system of asparagus during an annual growth cycle in a temperate climate. The arrows indicate six key stages when root sampling is recommended: A = Dormancy (1); B = Close-up; C = Fern established; D and E = Fern growth (1) and Fern growth (2); F = Dormancy (2). See text for details.

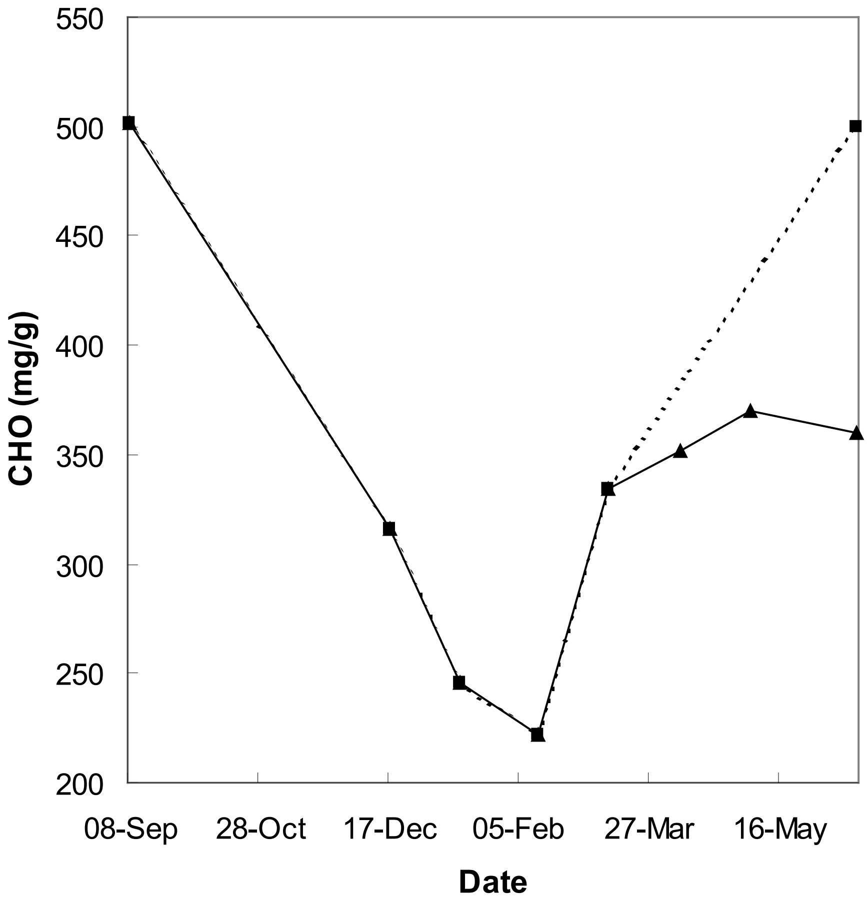

Fig. 2. Pattern of root CHO content in a crop that was damaged by *Stemphylium* (triangles, solid line), and the expected pattern (squares, dashed line).

4 APPENDIX 2.

Grower questionnaire: potential asparagus crops for *AspireUK* project

1. Site details:

Grower	
Address	
Phone	
Fax	
Email	
Annual rainfall (mm)	
Soil type	

2. Crop details (please provide details on three asparagus crops):

	Crop 1	Crop 2	Crop 3
Variety			
Planting date			
Area planted (ha)			
Crowns or transplants			
Population/ha:			
At planting			
In 2005 (approx)			
Yield (tonnes/ha) in:			
2001			
2002			
2003			
2004			
No. of days harvest in:			
2001			
2002			
2003			
2004			
Fern growth (Excellent, Average or Poor) in:			
2001			
2002 2003 2004			
Polythene covered (yes/no)			
Organic (yes/no)			
Comments on:			
Disease incidence?			
Pests?			

5 APPENDIX 3

Protocol for root sampling and measuring Brix%.

How to Collect Root Samples and Measure Brix%

AspireNZ estimates root system CHO content by assessing measurements of the Brix% of sap solution extracted from storage roots sampled from a crop. Root CHO content is variable within a crop, so at least 20 but not more than 40 root samples are needed on each measurement occasion to obtain a reliable estimate of CHO content.

A. How To Collect Root Samples

Equipment Required:
- Spade.
- 20-40 plastic bags (Minigrip 130 x 200 mm is ideal)
- Cool box (with ice packs to keep roots cool if the weather is warm)

Procedure:
- Collect samples from 20 random locations in a crop. The locations should accurately represent the whole crop. Avoid seedlings, outside rows and ends of rows.
- Take roots from a typical plant at each sampling location. Use the spade to make a vertical cut about 30 cm deep into the soil, through the roots, just outside the crown area. Then make a second vertical cut, parallel to the first one, about 15-20 cm further away from the crown.
- Lift and remove the roots from between the two cuts. Discard any hollow asparagus roots or roots from other plants such as weeds. About ten 15 cm root pieces are needed for each sample.
- Seal the roots in a plastic bag and store in the cool box.

B. How To Prepare Root Samples For Brix% Measurements

- Keep the 20 samples separate from each other throughout the procedure.
- Remove all soil by washing the roots in cold or lukewarm (not hot) water as soon as possible after collection.
- Drain excess water by laying the roots on paper for a short time.
- Rinse the plastic bag, and then place the roots back in it.
- Freeze the roots in the bags. It is difficult to extract solution from the roots if they are not frozen first. Solution is released when the cell walls break down as the roots thaw.

C. How To Measure Brix%

Equipment required:

- Refractometer (0-32% Brix, temperature-adjusted).
- Distilled water
- 20-40 small plastic beakers
- Robust garlic crusher
- Teaspoon
- Paper towel
- Scissors
- Bucket of clean water

Procedure:

- Take ten root samples from the freezer and lay them out to thaw on paper towel. They need to be thawed completely and free of surface moisture, but do not let them dry out excessively. Pat them dry with paper towel once they are thawed.
- When the first ten samples have thawed, take the next ten out and allow them to thaw while working on the first lot. If all samples are thawed at once some may dehydrate and give an incorrect result.
- Check that the refractometer reads zero with a few drops of distilled water. If not, give it time to reach room temperature (ideally about 20°C). It may be necessary to adjust it to zero (see the refractometer manual).
- Cut the roots into 1-2 cm lengths with scissors.
- Place the pieces in the garlic crusher and squeeze the solution into a plastic beaker.
- Swirl the solution around until it is mixed thoroughly.
- Use the teaspoon to place about three drops onto the prism surface of the refractometer.
- Drop the cover over the juice, avoiding bubble formation.
- Read the Brix% on the refractometer scale and record the result.
- Wipe the prism surface clean with tissues between samples. The refractometer cannot be immersed in water.
- Clean the garlic crusher and plastic beakers thoroughly between samples. Rinse in water and dry carefully. Any water left on the equipment will affect subsequent readings.

6 APPENDIX 4.

***AspireUK*: Crop Performance Questionnaire 2005**

Name:

Field/Crop:

Start of harvest date:

End of harvest date:

<table>
<tr><td>Yield t/ha</td><td colspan="2"><u>Gross</u></td><td colspan="3"><u>Net</u></td></tr>
<tr><td>Spear quality
(If information available)</td><td colspan="5">Percentage spears more than 10 mm diameter:
Percentage spears less than10 mm diameter:
Percentage spears blown & twisted:</td></tr>
<tr><td>Estimated plant
Population per ha</td><td colspan="5">Autumn 2005</td></tr>
<tr><td></td><td>POOR</td><td colspan="2">AVERAGE</td><td>GOOD</td><td>EXCELLENT</td></tr>
<tr><td>Fern Growth</td><td></td><td colspan="2"></td><td></td><td></td></tr>
<tr><td>Diseases/pest issues
(Indicate whether nil, slight, moderate or severe)</td><td>Phytophthora</td><td>Stemphylium</td><td>Fusarium</td><td>Rust</td><td>Beetle</td></tr>
<tr><td>Other Crop Issues</td><td colspan="5"></td></tr>
<tr><td>Further Comments</td><td colspan="5"></td></tr>
</table>

Post to:
Jonathan Carpanini, ADAS Arthur Rickwood, Mepal, Ely, Cambs. CB6 2BA

Or fax to:
Jonathan Carpanini, 01354 694488

7 APPENDIX 5

Meteorological data for 2005 showing regional averages (source: www.metoffice.gov.uk)

Month 2005	*Aspire* sampling regions*	Max temp (°C)		Min temp (°C)		Mean temp (°C)		Sunshine (h)		Rainfall (mm)	
		Actual	Anom	Actual	Anom	Actual	Anom	Actual	Anom	Actual	Anom
Jan	East	8.9	2.7	2.7	2.0	5.7	2.3	74.9	143	28.8	56
	South	9.0	2.4	3.1	2.1	6.0	2.2	68.5	130	39.3	51
	West	8.5	2.7	2.6	2.2	5.6	2.4	53.2	111	42.7	59
Feb	East	6.8	0.3	1.3	0.7	4.1	0.5	62.8	92	40.5	109
	South	7.0	0.1	1.4	0.5	4.2	0.3	71.1	100	24.8	47
	West	6.7	0.6	1.2	0.9	3.9	0.8	68.3	111	44.6	82
March	East	10.4	1.1	3.5	1.5	6.9	1.4	70.2	66	31.7	69
	South	10.7	1.2	3.3	1.2	7.0	1.2	95.1	83	51.3	82
	West	10.1	1.4	3.5	1.9	6.8	1.7	73.3	72	47.6	76
April	East	13.9	1.9	4.8	1.1	9.4	1.5	146.4	102	38.7	85
	South	13.7	1.5	4.9	1.2	9.3	1.3	148.5	97	50.1	96
	West	13.0	1.6	4.3	1.1	8.6	1.3	140.1	104	61.9	110
May	East	16.6	0.7	7.2	0.6	11.9	0.6	218.4	112	39.0	83
	South	16.5	0.6	7.1	0.4	11.8	0.5	223.8	113	33.0	59
	West	15.8	0.6	6.4	0.5	11.1	0.5	221.1	124	38.2	64
June	East	21.1	1.9	10.6	1.2	15.8	1.6	193.1	99	45.7	89
	South	21.1	2.0	10.9	1.3	16.0	1.6	214.7	107	34.5	63
	West	20.2	1.9	10.3	1.4	15.2	1.6	189.3	105	54.6	90
July	East	21.5	0.4	12.7	1.3	17.1	0.8	161.2	85	52.2	103
	South	22.0	0.9	12.6	1.1	17.3	1.0	202.2	100	61.5	126
	West	20.9	0.6	12.0	1.2	16.5	0.9	178.2	99	61.8	109
Aug	East	21.7	0.5	11.3	-0.1	16.5	0.2	198.0	108	54.5	103
	South	22.1	1.2	11.2	-0.2	16.7	0.5	241.7	126	55.1	93
	West	21.1	1.3	10.9	0.2	16.0	0.8	209.7	125	53.7	77
Sept	East	20.6	2.0	11.4	1.7	16.0	1.9	157.5	109	62.0	121
	South	20.6	2.2	11.0	1.4	15.8	1.8	161.2	109	40.4	61
	West	19.4	2.1	10.3	1.5	14.9	1.8	152.3	118	62.6	95
Oct	East	17.1	2.5	10.5	3.3	13.8	2.9	108.8	101	66.1	125
	South	17.1	2.4	10.2	3.1	13.6	2.7	105.6	97	98.0	131
	West	15.6	2.1	9.6	3.2	12.6	2.7	73.8	79	96.0	142
Nov	East	9.9	0.4	2.8	-0.6	6.3	-0.1	105.6	158	39.7	67
	South	10.1	0.1	2.6	-0.9	6.4	-0.4	99.4	142	53.1	67
	West	9.3	0.4	2.2	-0.7	5.7	-0.2	98.4	159	68.8	95
Dec	East	7.1	0.0	1.0	-0.6	4.1	-0.3	72.4	153	35.2	63
	South	7.7	0.0	0.8	-1.1	4.2	-0.5	74.1	151	67.5	84
	West	7.1	0.4	0.9	-0.3	4.0	0.0	62.8	145	54.8	70

The columns headed 'Anom' (anomaly) show the difference from or percent of the 1961-1990 long term average
*Corresponding to Met Office defined regions East Anglia, England SE & central S, and Midlands, respectively.