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

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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 Fig. 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 (Fig. 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 (Fig. 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.

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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

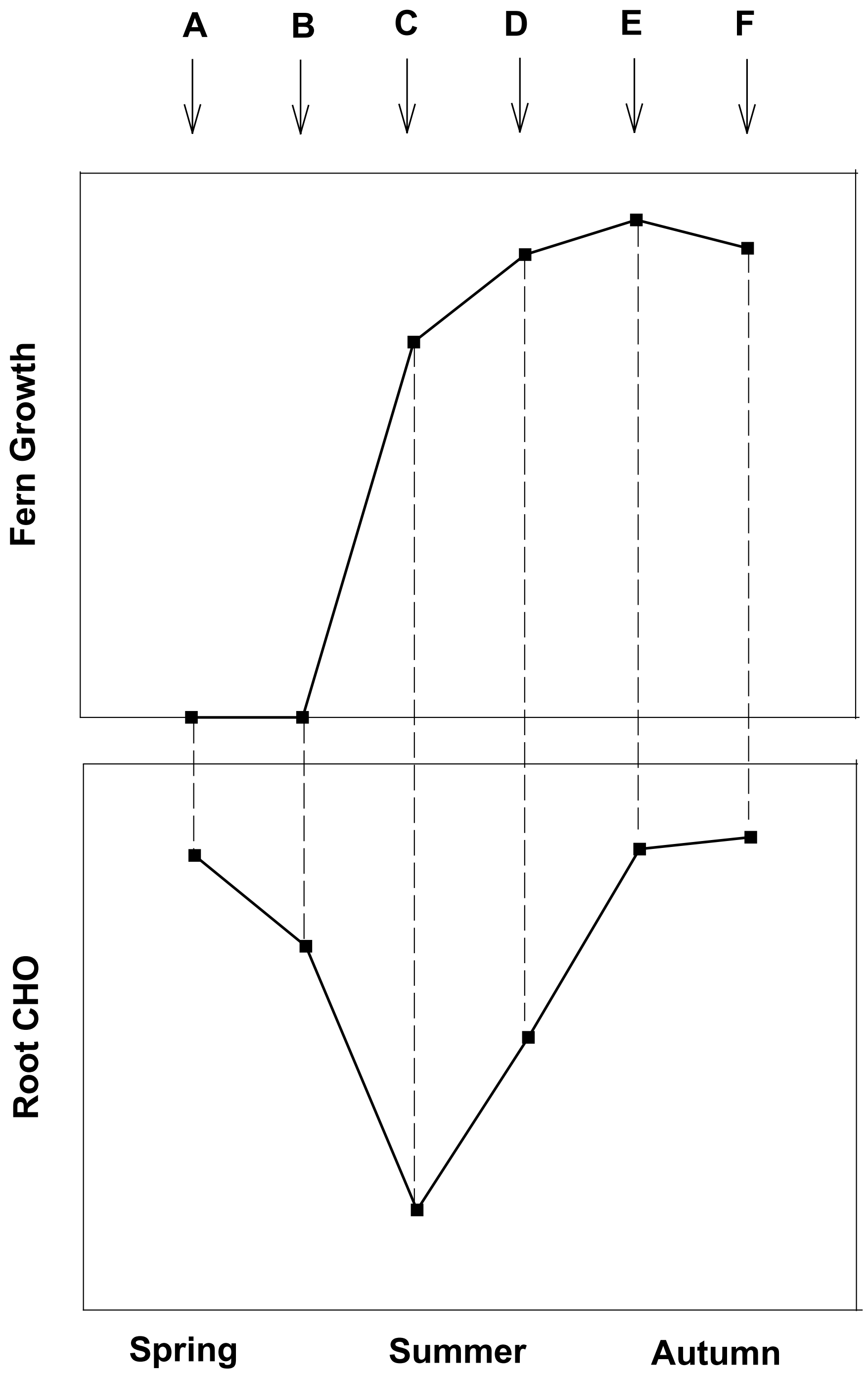

Fig. 1. Typical patterns of fern growth and CHO content in the root system of asparagus during an annual growth cycle in a temperate climate. The arrows indicate six key stages when root sampling is recommended: A = Dormancy (1); B = Close-up; C = Fern established; D and E = Fern growth (1) and Fern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

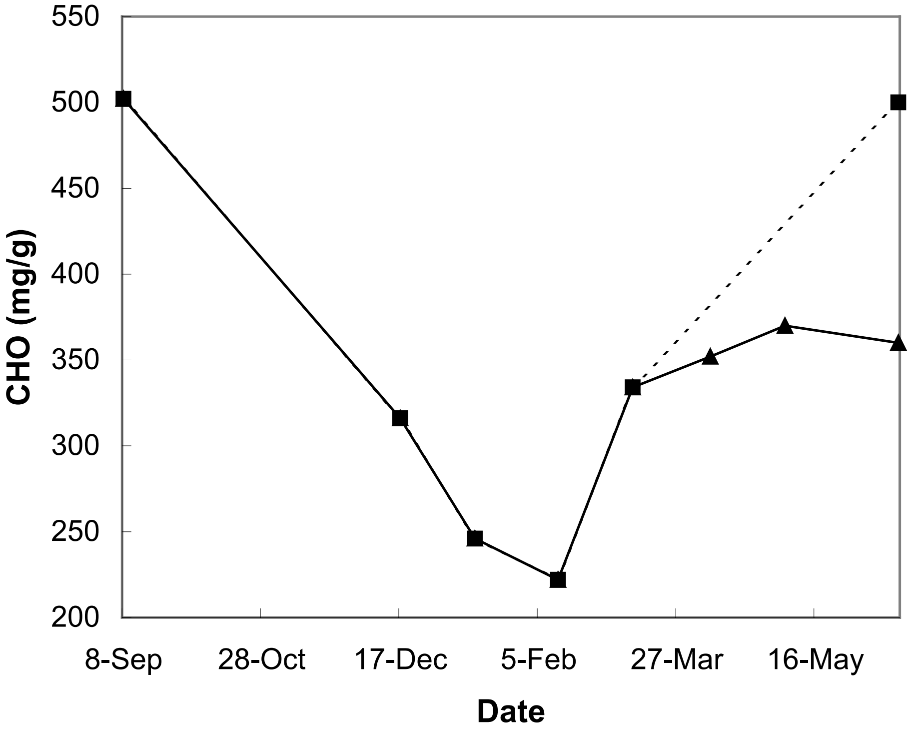

Fig. 2. Pattern of root CHO content in a crop that was damaged by *Stemphylium* (triangles, solid line), and the expected pattern (squares, dashed line).