# Development of a crop scheduling program for babyleaf spinach in the major growing regions of Australia

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Project Number: VG08167

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# Development of a crop-scheduling program for baby leaf spinach in the major growing regions of Australia

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## Media Summary

Accurate prediction of time from planting to harvest is critically important for baby spinach production. This is because the crop grows rapidly and is normally only suitable for harvesting on a single day. Harvesting too early reduces yield, while harvesting too late results in leaves which are too large and outside of specification. Growers supplying processors need to be able to develop a planting plan to allow for a regular supply of harvested product in the face of varying weather conditions, which have a significant impact on the rate of development of the crop.

This project examined the relationship between planting date and the time required for baby leaf spinach to reach commercial maturity. Data collected from Gympie in QLD, Camden and Cowra in NSW, and Boisdale and Maffra in VIC were used to create a reliable harvest and sowing prediction model. The model enables growers and processors to estimate the time required for baby leaf spinach to reach commercial maturity throughout different growing seasons and across different locations.

This crop-scheduling model will be used by growers, processors and other members of the industry and can be used for different varieties and over different growing locations. It assumes a certain number of thermal units are required for the crop to reach maturity. This means the model has a wide potential user-base, and allows for easy implementation in current farm management systems. The model was developed using Microsoft® Excel®; no other software is required. The model is able to predict the harvest date of baby leaf spinach, which is a useful management tool for industry.

## Technical Summary

Accurate prediction of time from planting to harvest is critically important for baby spinach production. This is because the crop grows rapidly and is normally only suitable for harvesting on a single day. Harvesting too early reduces yield, while harvesting too late results in leaves which are too large and outside of specification. Growers supplying processors need to be able to develop a planting plan to allow for a regular supply of harvested product in the face of varying weather conditions, which have a significant impact on the rate of development of the crop.

The purpose of this project was to understand the relationship between ambient temperatures and the time taken for baby leaf spinach to reach commercial maturity. This information was then used to develop a practical model that can predict the harvest or sowing date of a crop, based on regional long-term temperature averages.

The number of Growing Degree Days (GDD) required before plants reach commercial maturity was determined by examining a range of spinach planting and harvest dates. This information was collected over several years from major growing regions around Australia. The average GDD value was then used in combination with actual temperatures to predict the amount of time required until spinach crops reach maturity.

The prediction model assumes that the crop accumulates Daily Thermal Units (DTU), and that the accumulation of these DTUs is required up until the GDD value is reached. At this point the crop is considered commercially mature. This type of thermal modelling has been widely used in horticultural production systems, particularly for head lettuce and broccoli. The model assumes plant growth does not occur below a minimum or above a certain maximum temperature. These cut-off temperatures change depending on species and can be determined using regression modelling.

The harvest prediction model was created using 30-year temperature averages for seven growing regions. These were: Cowra, East Gippsland, Gatton, Gympie, Manjimup, Mornington Peninsula and Sydney. A simple user interface was created in Microsoft® Excel®. Users select: location; variety growth rate; and planting date. The model then uses historical temperatures for the selected region and sowing date to calculate the number of days required for cumulative DTU to reach the average GDD.

# Introduction

The baby leaf salad sector in Australia is now a significant part of the leafy vegetable market, with an estimated wholesale value of $M25. This sector is made up of independent members including: growers; grower-processors; growers supplying processors; and processing companies. All of these members require accurate information about harvest date and yield estimates in order to fulfil demand.

Growth in this sector is estimated to continue as it is a convenient product, perceived as being nutritious. The increasing demand for these crops means it is increasingly important to estimate supply windows and/or fulfil contractual agreements. One management tool which can help members estimate harvest date is a prediction model. This can be developed by estimating the time required from planting to harvest, based on regional ambient temperatures. This management tool will be very useful for growers as baby leaf spinach develops quickly, with a small window for optimal harvesting. Harvesting too early or too late either reduces yields, or results in leaves that are either smaller or larger than permissible size specifications. This sensitivity to harvest date is further compounded by the short postharvest shelf-life of baby spinach, which means harvested produce cannot be held over and used to satisfy market demand or fulfil orders (Everaarts, 1999).

There are a number of different crop models available for predicting the harvest date. They vary in complexity, which is reflective of the number of variables considered important in the prediction of harvest date. The harvest models work on the principle of the accumulation of Daily Thermal Units (DTU). This is directly related to ambient minimum and maximum temperatures for a given region. It is therefore calculated that a given crop requires a certain number of Growing Degree Days (GDD) to reach commercial maturity. The harvest date is predicted by calculating how many days it takes for cumulative DTUs to reach the GDD value. This information can then be modelled using historical temperature averages for a given region.

Predicting the harvest date is a function of the daily accumulation of thermal units and the total number of thermal units required to reach maturity. The primary factor in all these models is to determine minimum and maximum temperature limits for a specific crop. Variations in the lower and upper temperature limit affect the accuracy of the model and are generally incorporated into the model after calculating the total GDD required to reach maturity. This means that as production shifts from cooler to warmer conditions the accumulation of thermal units also progressively increases.

Establishing these temperature cut-offs is crucial to the accuracy of the model and can be different between developmental stages and crop types. In lettuce for example, a base temperature of 6°C during pre-transplant and 10°C during post-transplant was effective in harvest estimation (Brunini et. al., 1976). However, a lower thermal base temperature of 4°C was still accurately able to predict the harvest date of lettuce (Kristensen et. al., 1987). In project VG06144 (Development of a Crop Scheduling Program for Cos and Iceberg Lettuce in the Major Growing Regions in Australia) a base temperature of 3.3°C was used. This variation in base temperatures illustrates the flexibility of this type of crop modelling, as it can be customised for regional and local climatic conditions.

The maximum temperature for effective growth in lettuce is 31°C (Frantz et al., 2004a,b). This temperature cut-off is much higher than that used in earlier studies, which showed that the growth rate decreased at temperatures above 22°C (Brunini et. al., 1976). A similar relationship has been shown between the minimum temperature cut-off, with studies using a temperature between 0 and 5°C. This variation in model parameters illustrates the inherent difficulties in matching ambient temperatures with physiological stages of plants. This variation in minimum, maximum or base temperatures between studies is not necessarily a bad thing, as this type of harvest modelling has the flexibility to fit with local, cultural and production techniques.

The aims of this project were to:

1. Better understand and define the relationship between average daily temperature and the maturity of baby leaf spinach in the major growing regions of Australia.
2. Develop a practical model that growers, processors and partners of industry could use to better predict the harvest or sowing date of baby leaf spinach.

# Methods

The methods used in this project are outlined in the following sections.

## *Review data*

The first stage of the project was to review data collected in a previous project that was broadly focussed on baby leaf spinach agronomy, VG05068. The planting dates and harvest dates were reviewed and modelling was attempted using this data combined with weather data collected during the same project. A heat unit model was applied to this data and some preliminary cut-off temperatures, base temperatures and GDD requirements for baby leaf spinach were determined. The review was then used as a basis for collecting new and targeted data from specific regions. This review and supplementary information provided a comprehensive data set, from which a more robust harvest and sowing prediction model could be developed.

## *Setting up a system to collect information*

The key growing regions of baby leaf spinach in Australia were identified as: Cowra, East Gippsland, Gatton, Gympie, Manjimup, Mornington Peninsula and Sydney. Growers in these locations were approached as collaborators for the collection of planting, harvest and management data. A simple recording sheet was provided to growers to facilitate accurate collection of data. Data was collected using the form shown as Appendix 1.

The sites used for data collection and which were included in the final model development were:

1. Camden NSW (Grech Farms). The main varieties being grown there are Rijk Zwaan Whale, Parrot, Roadrunner and Crocodile. Weather data was collected from the Bureau of Meteorology Automatic Weather Station (AWS) at Camden airport, adjacent to the farm.

2. Maffra, Vic (Taylor Farms). Data collection included some historical data that was useful. Weather data was collected from Sale, which is nearby and provides excellent data. AHR has previously collected weather data on this farm and we know it is comparable with the Bureau of Meteorology data from Sale.

3. Cowra NSW (Mulyan Farms). AHR has a weather station installed on the farm. The weather station collects temperature, %RH, solar radiation, wind speed and direction.

These three sites cover the climatic range under which baby leaf spinach is grown in Australia. The project team also collected data from Gympie, in Qld, but the early data was unreliable so we omitted that site from the analysis.

The most dominant soil type at each location was a sandy loam; this is the most common soil type used for cultivating spinach in Australia. Crops were managed commercially by the collaborating growers and were harvested mechanically. Crops were sown using a commercial baby leaf seeder (Seed Spider Seeding Systems, New Zealand). The seeder is designed to sow high-density baby leaf crops, using electronic seed metering to achieve a consistent seeding rate and distribution. This type of sowing equipment is the most common type currently used by Australian baby leaf growers. All field experiments were sown at commercial densities (300 to 500 plants $m^2$) using the same seed batch number for individual species cultivars. The crops were sown into growing beds, 1.2 m in width.

## *Setting up monitoring sites*

At each collection site, reliable weather data was collected, including:

- Daily minimum and maximum temperatures
- Wind speed and direction
- Day length
- Soil type
- Irrigation strategy

## *Data collection*

Data was collected in close association with the growers. Meetings were held with the growers on a regular basis to review the data and ensure accurate and reliable information was collected. The following data was collected at the respective sites:

- Variety
- Sowing date
- Harvest date
- Crop management factors which may influence growth rate

A total of 126 sowing and harvest dates were collected from the different regions (Maffra/Boisdale (Vic), Camden (NSW) and Cowra (NSW) over a total of seven separate growing seasons. Meteorological data was collected from Bureau of Meteorology (BOM) sites and for Maffra/Boisdale (Sale) and Camden (Camden airport). The meteorological data for Cowra came from a weather station (Davis, Australia) located on the farm.

## *Development of a crop-scheduling model*

In order to develop a model, actual sowing and harvest dates were collected across multiple years from different growing regions. This information was required to establish the amount of time taken for crops to reach commercial maturity across different seasons. GDD is the most widely used formula to calculate the amount of thermal heat units required for crops to reach commercial maturity.

$GDD = ((T_{max} + T_{min})/2)-T_{bas}$

Where:

$T_{max}$ = daily maximum air temperature (°C)

$T_{min}$ = daily minimum air temperature (°C)

$T_{base}$ = base temperature below which no significant growth occurs (°C)

## *Test and validate the model*

After a working model was developed growers were asked to continue collecting planting and harvest dates. This information was fed into the model to measure its accuracy. Modifications to the minimum and maximum temperature cut-offs were then made to improve the accuracy of the predicted date.

# Results and Discussion

## *Review of data from previous work*

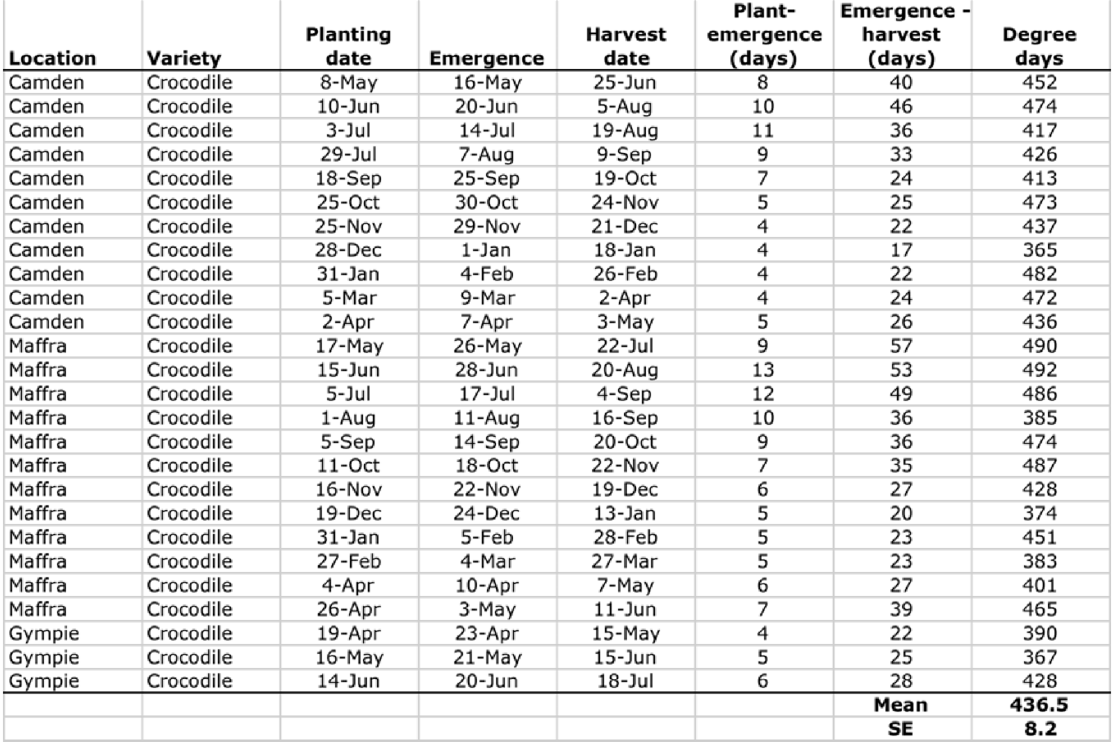
The following data was collected as part of the HAL baby leaf project VG05068. This data was collected under stringent trial conditions, and had the accompanying climatic data to support it. It was therefore an excellent resource, and could be used to make a solid start to the scheduling project. The re-analysis of this data is shown below.

## *Degree day model for slow growing spinach types*

### (i) Slow growing variety

A degree-day model was developed for the slow growing cultivar Crocodile. 0°C was used as the base temperature as well as the minimum cut-off temperature and 27°C as the maximum cut-off temperature. A similar model was developed without a high temperature cut-off.

***Table 1. Degree-day data for Crocodile from emergence to harvest***



| Location | Variety | Planting date | Emergence | Harvest date | Plant-emergence (days) | Emergence - harvest (days) | Degree days |
|---|---|---|---|---|---|---|---|
| Camden | Crocodile | 8-May | 16-May | 25-Jun | 8 | 40 | 452 |
| Camden | Crocodile | 10-Jun | 20-Jun | 5-Aug | 10 | 46 | 474 |
| Camden | Crocodile | 3-Jul | 14-Jul | 19-Aug | 11 | 36 | 417 |
| Camden | Crocodile | 29-Jul | 7-Aug | 9-Sep | 9 | 33 | 426 |
| Camden | Crocodile | 18-Sep | 25-Sep | 19-Oct | 7 | 24 | 413 |
| Camden | Crocodile | 25-Oct | 30-Oct | 24-Nov | 5 | 25 | 473 |
| Camden | Crocodile | 25-Nov | 29-Nov | 21-Dec | 4 | 22 | 437 |
| Camden | Crocodile | 28-Dec | 1-Jan | 18-Jan | 4 | 17 | 365 |
| Camden | Crocodile | 31-Jan | 4-Feb | 26-Feb | 4 | 22 | 482 |
| Camden | Crocodile | 5-Mar | 9-Mar | 2-Apr | 4 | 24 | 472 |
| Camden | Crocodile | 2-Apr | 7-Apr | 3-May | 5 | 26 | 436 |
| Maffra | Crocodile | 17-May | 26-May | 22-Jul | 9 | 57 | 490 |
| Maffra | Crocodile | 15-Jun | 28-Jun | 20-Aug | 13 | 53 | 492 |
| Maffra | Crocodile | 5-Jul | 17-Jul | 4-Sep | 12 | 49 | 486 |
| Maffra | Crocodile | 1-Aug | 11-Aug | 16-Sep | 10 | 36 | 385 |
| Maffra | Crocodile | 5-Sep | 14-Sep | 20-Oct | 9 | 36 | 474 |
| Maffra | Crocodile | 11-Oct | 18-Oct | 22-Nov | 7 | 35 | 487 |
| Maffra | Crocodile | 16-Nov | 22-Nov | 19-Dec | 6 | 27 | 428 |
| Maffra | Crocodile | 19-Dec | 24-Dec | 13-Jan | 5 | 20 | 374 |
| Maffra | Crocodile | 31-Jan | 5-Feb | 28-Feb | 5 | 23 | 451 |
| Maffra | Crocodile | 27-Feb | 4-Mar | 27-Mar | 5 | 23 | 383 |
| Maffra | Crocodile | 4-Apr | 10-Apr | 7-May | 6 | 27 | 401 |
| Maffra | Crocodile | 26-Apr | 3-May | 11-Jun | 7 | 39 | 465 |
| Gympie | Crocodile | 19-Apr | 23-Apr | 15-May | 4 | 22 | 390 |
| Gympie | Crocodile | 16-May | 21-May | 15-Jun | 5 | 25 | 367 |
| Gympie | Crocodile | 14-Jun | 20-Jun | 18-Jul | 6 | 28 | 428 |
|  |  |  |  |  |  | **Mean** | **436.5** |
|  |  |  |  |  |  | **SE** | **8.2** |

The average degree-day requirement for this variety was 437 GDD with a SD of 8.2 days, which is good. The growing regions varied slightly with Gympie the most variable. The data is uniform and not skewed.

### *Table 1a. Descriptive statistics on GDD data in Table 1*

**Normality Tests**

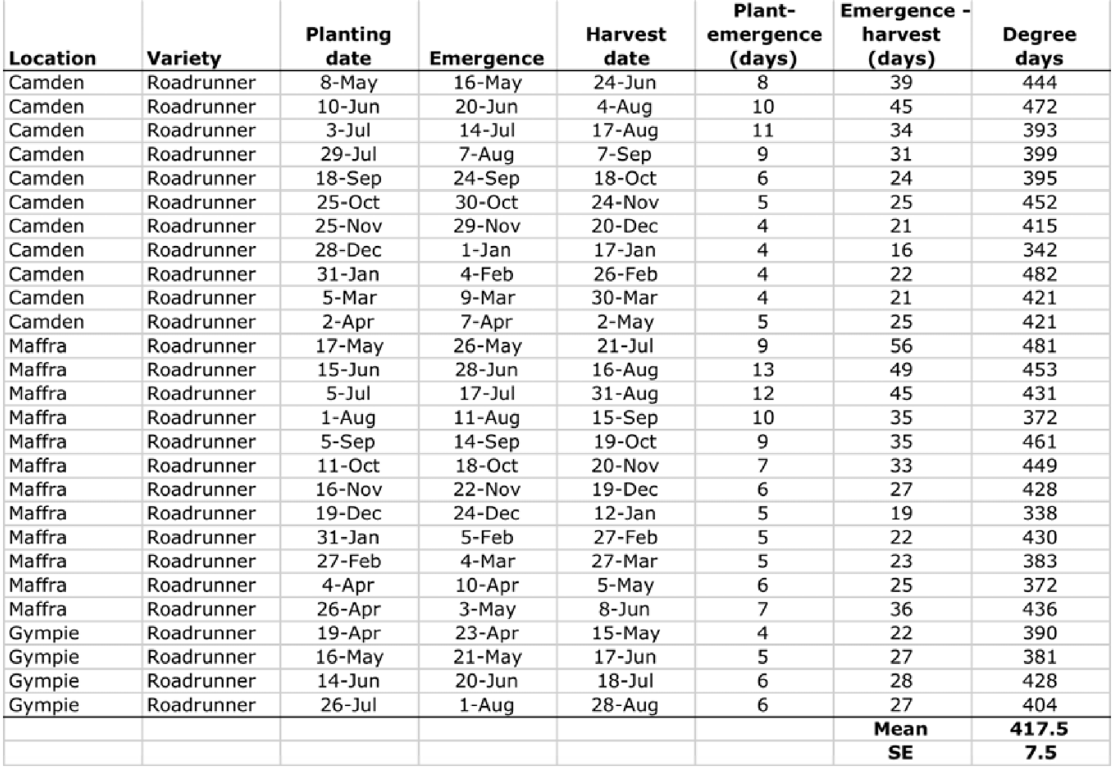
| *Variable #1 (Var1)* | | | |
|---|---|---|---|
| *Sample size* | 26 | *Mean* | 436.46154 |
| *Standard Deviation* | 41.7873 | *Median* | 436.5 |
| *Skewness* | -0.28008 | *Kurtosis* | 1.76221 |
| *Alternative Skewness (Fisher's)* | -0.29753 | | |

| | **Test Statistics** | **p-level** | **Conclusion: (2%)** |
|---|---|---|---|
| *Kolmogorov-Smirnov/Lilliefor Test* | 0.09767 | 0.7552 | *No evidence against normality* |
| *Shapiro-Wilk W* | 0.92362 | 0.05469 | *Accept Normality* |
| *D'Agostino Skewness* | 0.6876 | 0.4917 | *Accept Normality* |
| *D'Agostino Kurtosis* | -2.222 | 0.02628 | *Accept Normality* |
| *D'Agostino Omnibus* | 5.41008 | 0.06687 | *Accept Normality* |

## (ii) Intermediate growth-rate variety

A degree-day model was developed for the medium growth rate variety Roadrunner. 0°C was used as the base temperature as well as the minimum cut-off temperature and 27°C as the maximum cut-off temperature. A similar model was developed without a high temperature cut-off.

### *Table 2. Degree-day data for Roadrunner from emergence to harvest*



| **Location** | **Variety** | **Planting date** | **Emergence** | **Harvest date** | **Plant-emergence (days)** | **Emergence - harvest (days)** | **Degree days** |
|---|---|---|---|---|---|---|---|
| Camden | Roadrunner | 8-May | 16-May | 24-Jun | 8 | 39 | 444 |
| Camden | Roadrunner | 10-Jun | 20-Jun | 4-Aug | 10 | 45 | 472 |
| Camden | Roadrunner | 3-Jul | 14-Jul | 17-Aug | 11 | 34 | 393 |
| Camden | Roadrunner | 29-Jul | 7-Aug | 7-Sep | 9 | 31 | 399 |
| Camden | Roadrunner | 18-Sep | 24-Sep | 18-Oct | 6 | 24 | 395 |
| Camden | Roadrunner | 25-Oct | 30-Oct | 24-Nov | 5 | 25 | 452 |
| Camden | Roadrunner | 25-Nov | 29-Nov | 20-Dec | 4 | 21 | 415 |
| Camden | Roadrunner | 28-Dec | 1-Jan | 17-Jan | 4 | 16 | 342 |
| Camden | Roadrunner | 31-Jan | 4-Feb | 26-Feb | 4 | 22 | 482 |
| Camden | Roadrunner | 5-Mar | 9-Mar | 30-Mar | 4 | 21 | 421 |
| Camden | Roadrunner | 2-Apr | 7-Apr | 2-May | 5 | 25 | 421 |
| Maffra | Roadrunner | 17-May | 26-May | 21-Jul | 9 | 56 | 481 |
| Maffra | Roadrunner | 15-Jun | 28-Jun | 16-Aug | 13 | 49 | 453 |
| Maffra | Roadrunner | 5-Jul | 17-Jul | 31-Aug | 12 | 45 | 431 |
| Maffra | Roadrunner | 1-Aug | 11-Aug | 15-Sep | 10 | 35 | 372 |
| Maffra | Roadrunner | 5-Sep | 14-Sep | 19-Oct | 9 | 35 | 461 |
| Maffra | Roadrunner | 11-Oct | 18-Oct | 20-Nov | 7 | 33 | 449 |
| Maffra | Roadrunner | 16-Nov | 22-Nov | 19-Dec | 6 | 27 | 428 |
| Maffra | Roadrunner | 19-Dec | 24-Dec | 12-Jan | 5 | 19 | 338 |
| Maffra | Roadrunner | 31-Jan | 5-Feb | 27-Feb | 5 | 22 | 430 |
| Maffra | Roadrunner | 27-Feb | 4-Mar | 27-Mar | 5 | 23 | 383 |
| Maffra | Roadrunner | 4-Apr | 10-Apr | 5-May | 6 | 25 | 372 |
| Maffra | Roadrunner | 26-Apr | 3-May | 8-Jun | 7 | 36 | 436 |
| Gympie | Roadrunner | 19-Apr | 23-Apr | 15-May | 4 | 22 | 390 |
| Gympie | Roadrunner | 16-May | 21-May | 17-Jun | 5 | 27 | 381 |
| Gympie | Roadrunner | 14-Jun | 20-Jun | 18-Jul | 6 | 28 | 428 |
| Gympie | Roadrunner | 26-Jul | 1-Aug | 28-Aug | 6 | 27 | 404 |
| | | | | | | **Mean** | **417.5** |
| | | | | | | **SE** | **7.5** |

The average degree-day requirement for this variety was 418 GDD with a SD of 7.5 days, which is good. The growing regions varied slightly with Gympie the most variable. The data is uniform and not skewed.

***Table 2a. Descriptive statistics on GDD data in Table 2***

**Normality Tests**

| *Variable #1 (Var1)* | | | |
|---|---|---|---|
| *Sample size* | 27 | *Mean* | 417.51852 |
| *Standard Deviation* | 38.83037 | *Median* | 421. |
| *Skewness* | -0.23524 | *Kurtosis* | 2.39313 |
| *Alternative Skewness (Fisher's)* | -0.24931 | | |

| | **Test Statistics** | **p-level** | **Conclusion: (2%)** |
|---|---|---|---|
| *Kolmogorov-Smirnov/Lilliefor Test* | 0.04818 | 1. | *No evidence against normality* |
| *Shapiro-Wilk W* | 0.97476 | 0.73002 | *Accept Normality* |
| *D'Agostino Skewness* | 0.58741 | 0.55693 | *Accept Normality* |
| *D'Agostino Kurtosis* | -0.4578 | 0.64709 | *Accept Normality* |
| *D'Agostino Omnibus* | 0.55463 | 0.75782 | *Accept Normality* |

## (iii) Fast growing variety

A degree-day model was developed for the fast growing cultivar Parrot. 0°C was used as the base temperature as well as the minimum cut-off temperature and 27°C as the maximum cut-off temperature. A similar model was developed without a high temperature cut-off.

### *Table 3. Degree-day data for Parrot from emergence to harvest*

| Location | Variety | Planting date | Emergence | Harvest date | Plant-emergence (days) | Emergence - harvest (days) | Degree days |
|---|---|---|---|---|---|---|---|
| Camden | Parrot | 8-May | 16-May | 22-Jun | 8 | 37 | 422 |
| Camden | Parrot | 10-Jun | 20-Jun | 1-Aug | 10 | 42 | 443 |
| Camden | Parrot | 3-Jul | 14-Jul | 15-Aug | 11 | 32 | 367 |
| Camden | Parrot | 29-Jul | 7-Aug | 5-Sep | 9 | 29 | 374 |
| Camden | Parrot | 18-Sep | 24-Sep | 16-Oct | 6 | 22 | 359 |
| Camden | Parrot | 25-Oct | 30-Oct | 24-Nov | 5 | 25 | 452 |
| Camden | Parrot | 25-Nov | 29-Nov | 20-Dec | 4 | 21 | 415 |
| Camden | Parrot | 28-Dec | 1-Jan | 18-Jan | 4 | 17 | 365 |
| Camden | Parrot | 31-Jan | 4-Feb | 25-Feb | 4 | 21 | 460 |
| Camden | Parrot | 5-Mar | 9-Mar | 29-Mar | 4 | 20 | 403 |
| Camden | Parrot | 2-Apr | 7-Apr | 1-May | 5 | 24 | 406 |
| Maffra | Parrot | 17-May | 26-May | 20-Jul | 9 | 55 | 474 |
| Maffra | Parrot | 15-Jun | 28-Jun | 16-Aug | 13 | 49 | 453 |
| Maffra | Parrot | 5-Jul | 17-Jul | 28-Aug | 12 | 42 | 398 |
| Maffra | Parrot | 1-Aug | 11-Aug | 11-Sep | 10 | 31 | 326 |
| Maffra | Parrot | 5-Sep | 14-Sep | 15-Oct | 9 | 31 | 411 |
| Maffra | Parrot | 11-Oct | 18-Oct | 19-Nov | 7 | 32 | 431 |
| Maffra | Parrot | 16-Nov | 22-Nov | 18-Dec | 6 | 26 | 411 |
| Maffra | Parrot | 19-Dec | 24-Dec | 10-Jan | 5 | 17 | 320 |
| Maffra | Parrot | 31-Jan | 5-Feb | 28-Feb | 5 | 23 | 451 |
| Maffra | Parrot | 27-Feb | 4-Mar | 26-Mar | 5 | 22 | 368 |
| Maffra | Parrot | 4-Apr | 10-Apr | 6-May | 6 | 26 | 387 |
| Maffra | Parrot | 26-Apr | 3-May | 5-Jun | 7 | 33 | 412 |
| Gympie | Parrot | 19-Apr | 23-Apr | 14-May | 4 | 21 | 373 |
| Gympie | Parrot | 16-May | 21-May | 13-Jun | 5 | 23 | 337 |
| Gympie | Parrot | 14-Jun | 20-Jun | 15-Jul | 6 | 25 | 380 |
| Gympie | Parrot | 26-Jul | 1-Aug | 26-Aug | 6 | 25 | 364 |
|  |  |  |  |  |  | **Mean** | **398.6** |
|  |  |  |  |  |  | **SE** | **8.0** |

The average degree-day requirement for this variety type is 399 GDD with a SE of 8, which is good. The data is uniform and not skewed.

### *Table 3a. Descriptive statistics on GDD data in Table 3*

**Normality Tests**

*Variable #1 (Var1)*

|  |  |  |  |
|---|---|---|---|
| *Sample size* | 27 | *Mean* | 398.59259 |
| *Standard Deviation* | 41.70617 | *Median* | 403. |
| *Skewness* | -0.04298 | *Kurtosis* | 2.17457 |
| *Alternative Skewness (Fisher's)* | -0.04555 |  |  |

|  | **Test Statistics** | **p-level** | **Conclusion: (2%)** |
|---|---|---|---|
| *Kolmogorov-Smirnov/Lilliefor Test* | 0.07954 | 0.93197 | *No evidence against normality* |
| *Shapiro-Wilk W* | 0.97164 | 0.64563 | *Accept Normality* |
| *D'Agostino Skewness* | 0.10804 | 0.91397 | *Accept Normality* |
| *D'Agostino Kurtosis* | -0.95525 | 0.33945 | *Accept Normality* |
| *D'Agostino Omnibus* | 0.92418 | 0.62997 | *Accept Normality* |

As an example, the days from emergence to harvest for the three cultivars follow a similar shaped curve taking a maximum of 46 days during the cooler months, being as fast as 16-17 days in mid summer, and increasing to 26-30 days in the spring and autumn. A quadratic model accounted for 86-87% the variability in the duration from emergence to harvest.

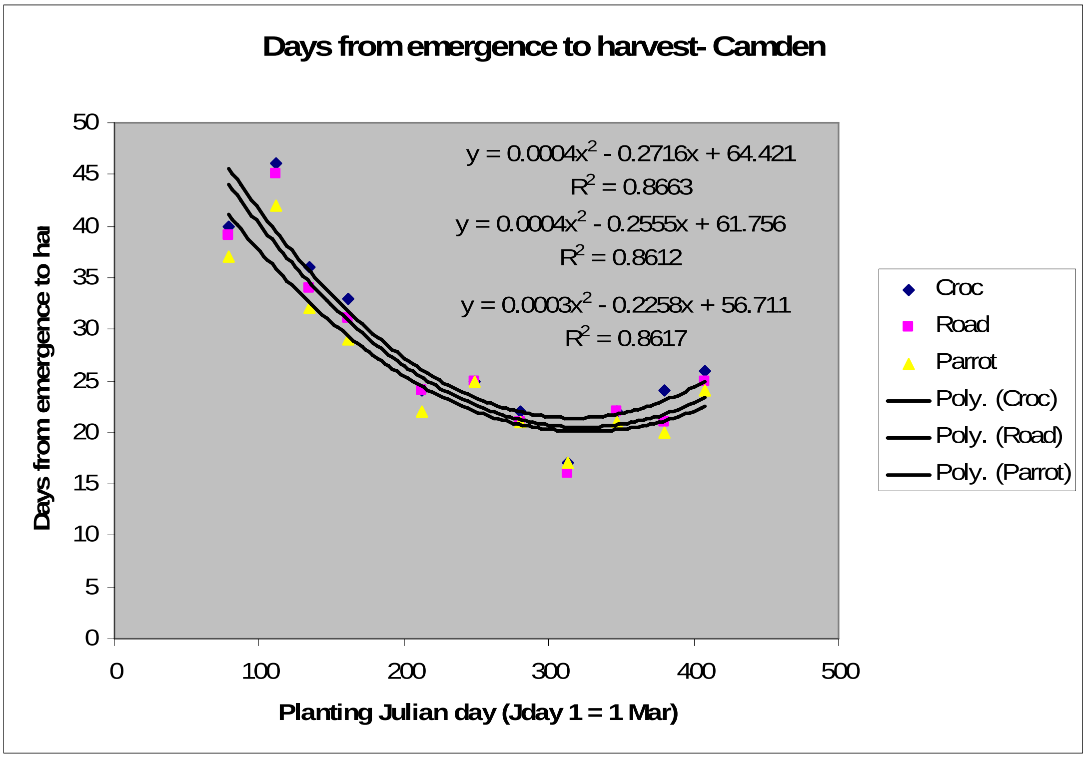


*Figure 1. Days from emergence to harvest – Camden, NSW*

## *Conclusions based on review of existing data*

The formula for calculating Growing Degree Days (GDD) appears to be adequate to describe the relationship between days from emergence to harvest and temperature. More work needs to be done to verify this data, and to adequately account for the period from sowing to emergence.

For our model, the base temperature = 0°C and if the measured $T_{max}$ ever exceeded 27°C, then 27°C was used in place of the actual maximum for calculating degree-days.

In summary, the growing degree-day requirements for the three spinach types used in the project are given in table 4. The preliminary GDD requirements were determined as 437 ± 8 GDD for slow growing types (e.g. Crocodile), 418 ± 8 GDD for intermediate growing types such as Roadrunner and 399 ± 8 GDD for fast growing types such as Parrot.

***Table 4. Baby leaf spinach growing degree-day (GDD) requirement from emergence to harvest.***

|  | Growing degree days emergence to harvest |  | $T_{base}$ | $T_{max}$ |
|---|---|---|---|---|
| Variety | GDD | ± SE | (°C) | (°C) |
| Slow growing type<br>(e.g. Crocodile) | 437 | 8 | 0 | 27 |
| Intermediate growing type<br>(e.g. Roadrunner) | 418 | 8 | 0 | 27 |
| Fast growing type<br>(e.g. Parrot) | 399 | 8 | 0 | 27 |

**Note**: These GDD data relate to days from *emergence to harvest* and not from *sowing to harvest*. In this preliminary development stage, removal of the sowing to emergence part of the crop cycle improved the accuracy of the model. In the second stage of this project, the period from sowing to emergence will also be examined in an attempt to produce a more robust model which covers the whole cropping period.

## *Develop crop-scheduling model*

A total of 126 sowing and harvest dates were collected from the different regions (Maffra/Boisdale (Vic), Camden (NSW) and Cowra (NSW) over a total of seven separate growing seasons. Meteorological data was collected from Bureau of Meteorology (BOM) sites and for Maffra/Boisdale (Sale) and Camden (Camden airport). The meteorological data for Cowra came from a weather station (Davis, Australia) located on the farm.

A range of upper temperature cut-offs, lower temperatures cuts-offs and base temperatures based on similar models for leafy vegetables, together with the previous work, were evaluated. The combination of temperatures resulting in the best prediction of days from sowing to harvest and with the least variability were chosen for use in the final model. These temperature cut-offs were verified using regression modelling. This combination of temperatures resulted in the least variability within GDD data and the best predictions, based on planting dates and temperature.

There key temperatures were:

- High temperature cut off = 25°C (temperatures above this were regarded as 25°C)
- Minimum temperatures cut off = 2°C (temperatures below this were regarded as 2°C)
- Base temperature = 0°C

An overall model was developed which did not take into account the effects of cultivar and associated variations in growth rate. This general model can be used in the absence of varietal data or knowledge of the growth-rate category that applies to that variety.

The average GDD for baby leaf spinach is 524 (Figure 2). This means that in the absence of information about the growth-rate category of a variety, and regardless of location or sowing date, a crop should accumulate a total of 524 GDD before it reaches commercial maturity.

Julian days were used to represent dates. The definition of Julian days for this work is taken as Julian day 1 = 1st January each year. In relation to the plotting of data on figures, the data plots start at Julian day 59 (1st March) and end is on Julian day 415 (28th February, except for leap years). The reason for this is to provide a smooth curve where crop development times initially decline, and then increase in a smooth fashion over a 12-month period.

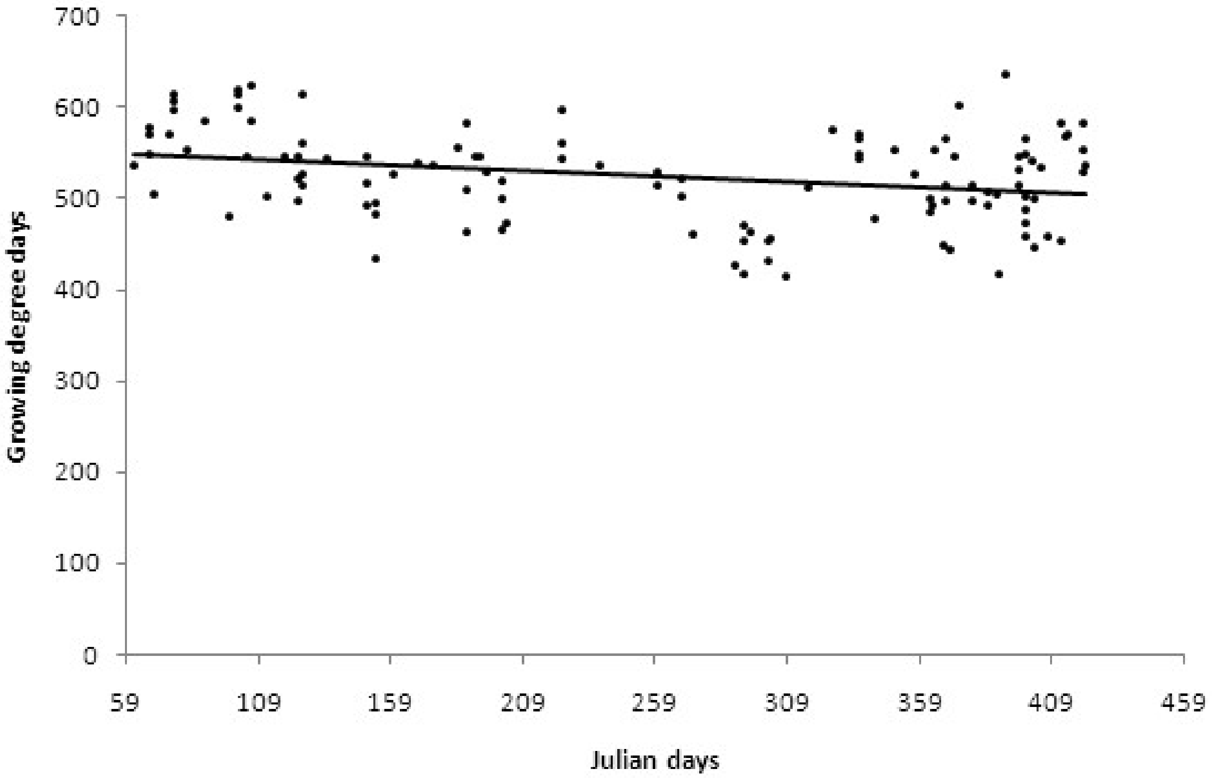


**Figure 2.** Average growing degree-days required for baby leaf spinach to reach commercial maturity. Data starts at Julian day 59 and ends at Julian day 415 (= 1 full year).

The general relationship between planting date and days from sowing to harvest was shown to fit a regression model with 77% of the interaction between these factors explained (Figure 3). The relationship of this trend is a longer period of time required from sowing to harvest during March (~ Julian day 59) and a shorter period of time during October (~ Julian day 300).

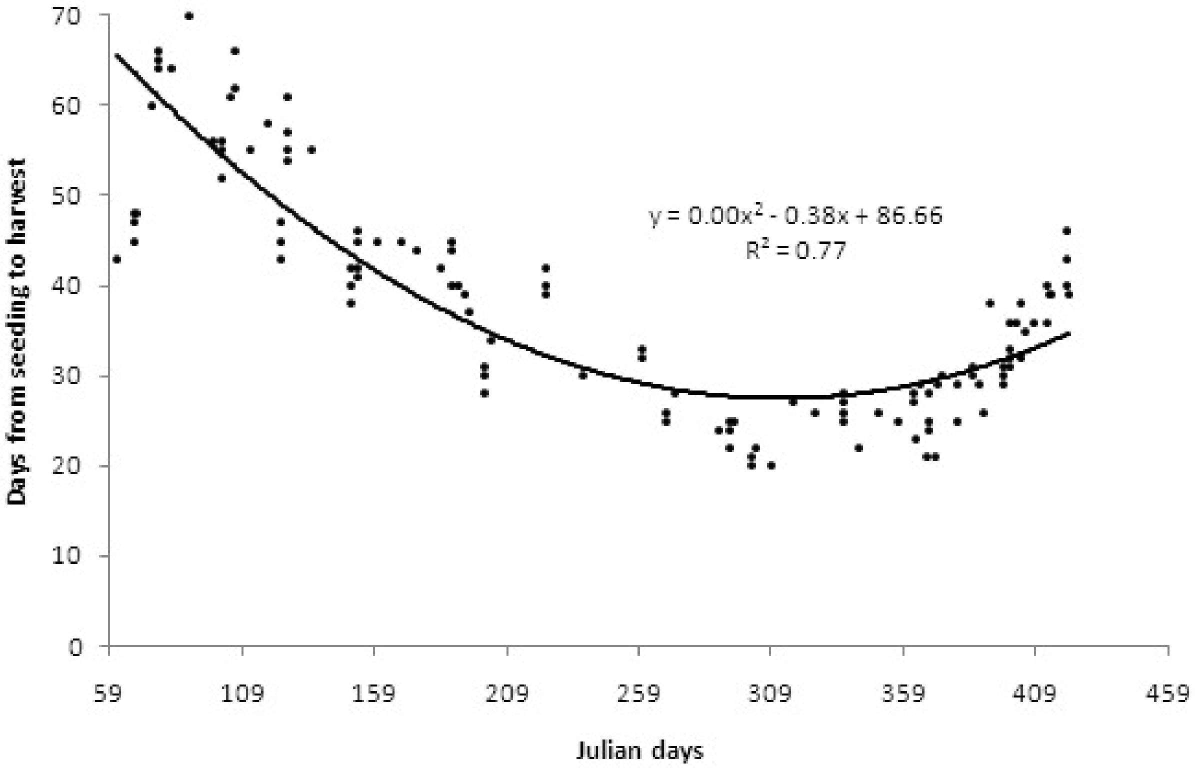


**Figure 3.** The relationship between planting date and days from sowing to harvest for baby leaf spinach. Data starts at Julian day 59 and ends at Julian day 415 (= 1 full year).

## Cultivar specific models

There are many commercial cultivars of baby leaf spinach available in Australia. These cultivars have been selectively bred for different seasons of production, and hence develop at difference rates.

To account for these varietal differences, the model was refined to allow varietal growth-rate to be included as a variable in the model, increasing the accuracy of planting or harvest date predictions.

Spinach varieties can be classified as either slow-, intermediate- or fast-growth cultivars. Table 5 shows a selection of spinach cultivars currently being grown in Australia. Growers are urged to check the current varietal information provided by seed companies and consult with their representatives to make sure which growth-rate category their varieties fit into.

***Table 5. Spinach Types***

| **Spinach growth rate category** | **Varieties** | **Seed company** |
|---|---|---|
| Slow Growing | Brava, Chica, Rotunda | South Pacific Seeds |
| | Crocodile, Racoon | Rijk Zwaan Seeds |
| | Menorca, Sardinia, Island | Monsanto |
| | El Patriot, El Toro | Syngenta |
| Intermediate Growth Rate | Torino | South Pacific Seeds |
| | Roadrunner | Rijk Zwaan Seeds |
| | Kauai, Corfu, Veno, Wallia, Palaos | Monsanto |
| | Avalanche, El Grinta, El Real | Syngenta |
| Fast Growing | Alto, Camaro | South Pacific Seeds |
| | Parrot, Donkey, Turaco, Racoon, | Rijk Zwaan Seeds |
| | Ibiza, Nighthawk | Monsanto |
| | El Rancho | Syngenta |

## Slow growth cultivars

Cultivars of baby leaf spinach that have a slower development speed required an average of 531 ± 7 GDDs, which means that regardless of season, slow growing cultivars require 531 ± 7 GDD to reach commercial maturity (Figure 4).

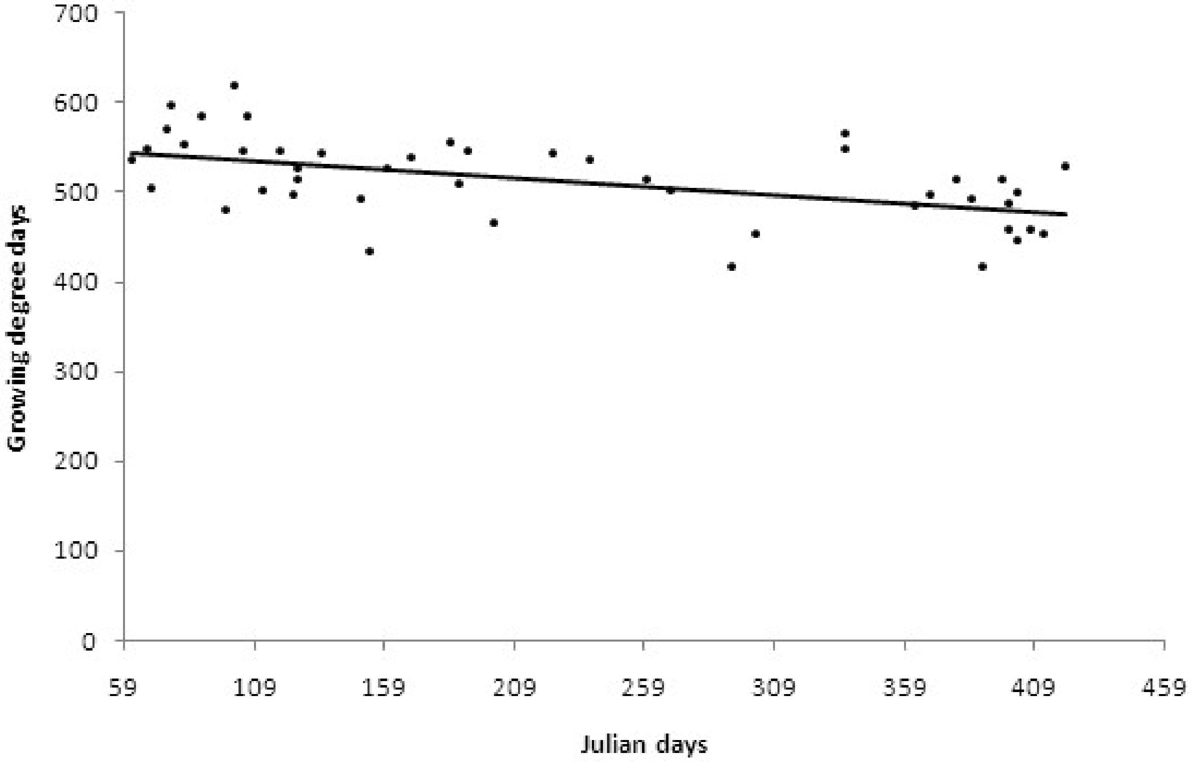


**Figure 4.** Average growing degree-days required for slow growth varieties of baby leaf spinach to reach commercial maturity. Data starts at Julian day 59 and ends at Julian day 415 (= 1 full year).

The relationship between planting date and days from sowing to harvest for slow growing cultivars is shown in Figure 5. Planting date alone explains 74% of the variability in days from sowing to harvest.

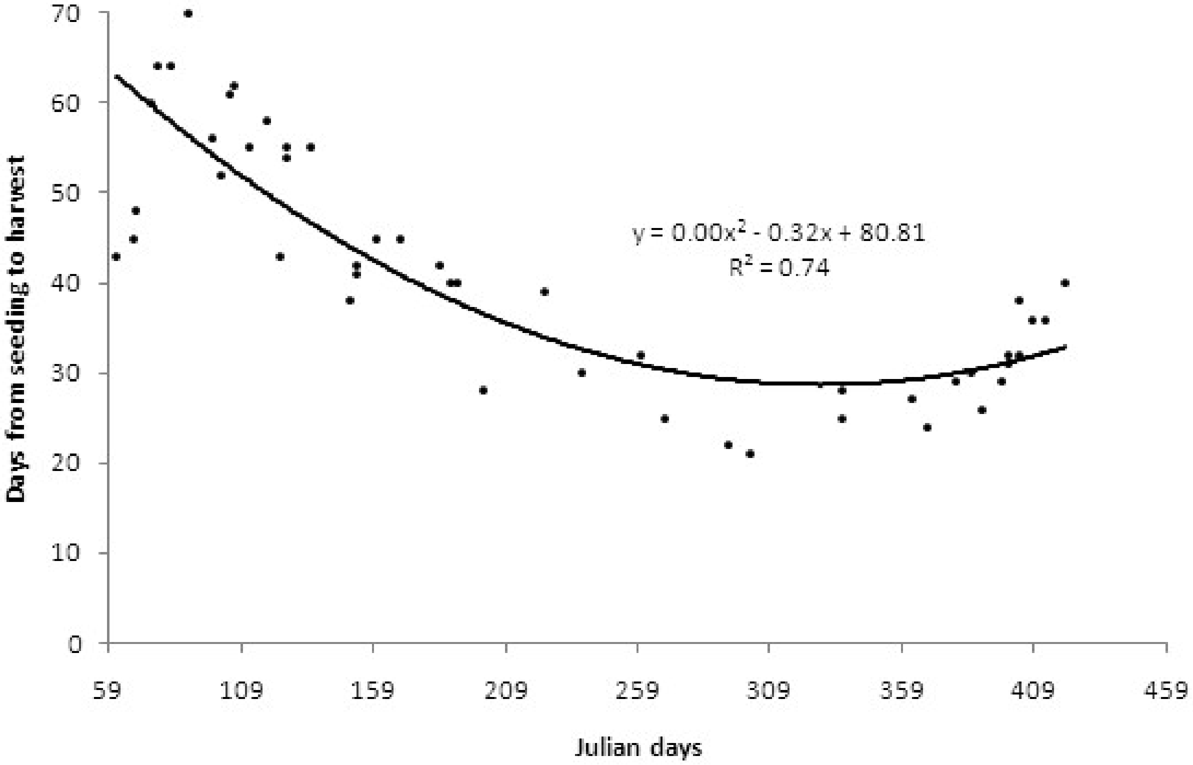


**Figure 5.** The relationship between planting date and days from sowing to harvest for slow growth varieties of baby leaf spinach. Data starts at Julian day 59 and ends at Julian day 415 (= 1 full year).

## Intermediate growth cultivars

Cultivars of baby leaf spinach with an intermediate development speed had an average GDD requirement of 531 ± 8 days to reach commercial maturity (Figure 6).

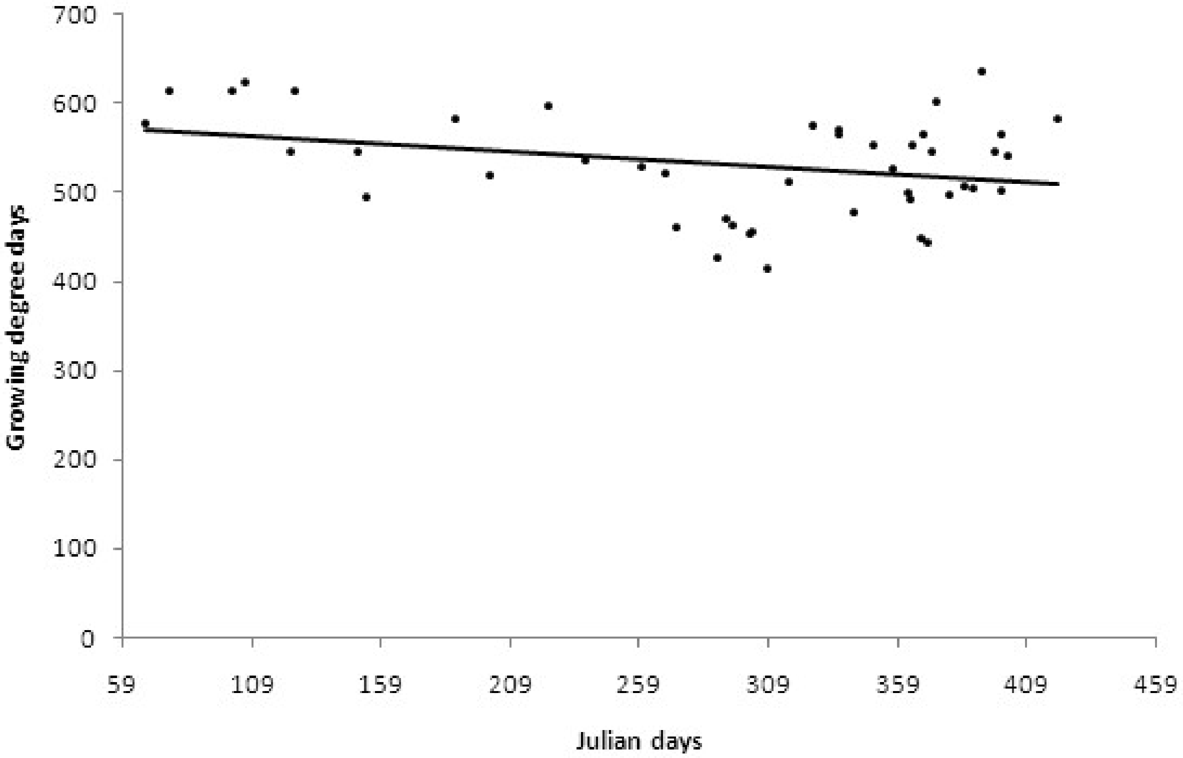


**Figure 6.** Average growing degree-days required for intermediate growth varieties of baby leaf spinach to reach commercial maturity. Data starts at Julian day 59 and ends at Julian day 415 (= 1 full year).

The relationship between planting date and days from sowing to harvest for intermediate growth rate cultivars is shown in Figure 7. Planting date alone explains 78% of the variability in days from sowing to harvest.

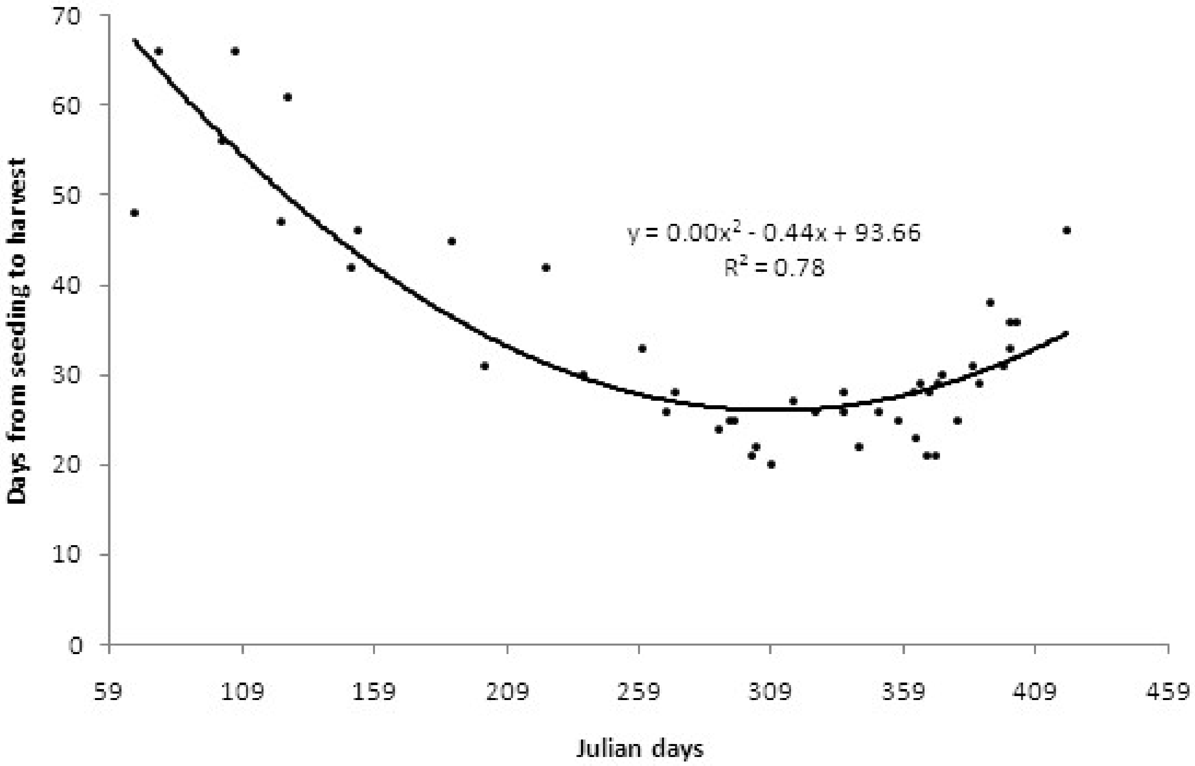


**Figure 7.** The relationship between planting date and days from sowing to harvest for intermediate growth varieties of baby leaf spinach. Data starts at Julian day 59 and ends at Julian day 415 (= 1 full year).

## Fast growth cultivars

Cultivars of baby leaf spinach with an intermediate development speed had an average GDD requirement of 512 ± 7 days to reach commercial maturity (Figure 8).

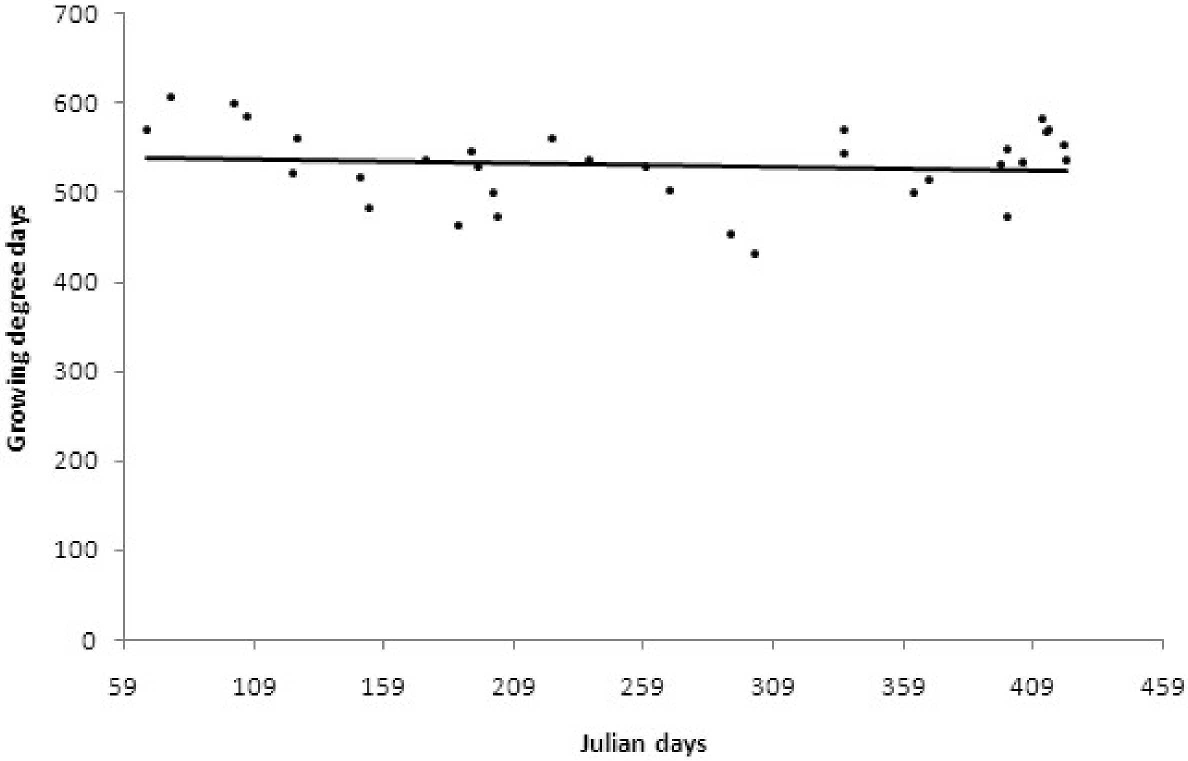


**Figure 8.** Average growing degree-days required for fast growth varieties of baby leaf spinach to reach commercial maturity. Data starts at Julian day 59 and ends at Julian day 415 (=1 full year).

The relationship between planting date and days from sowing to harvest for fast growth-rate cultivars is shown in Figure 9. Planting date alone explains 76% of the variability in days from sowing to harvest.

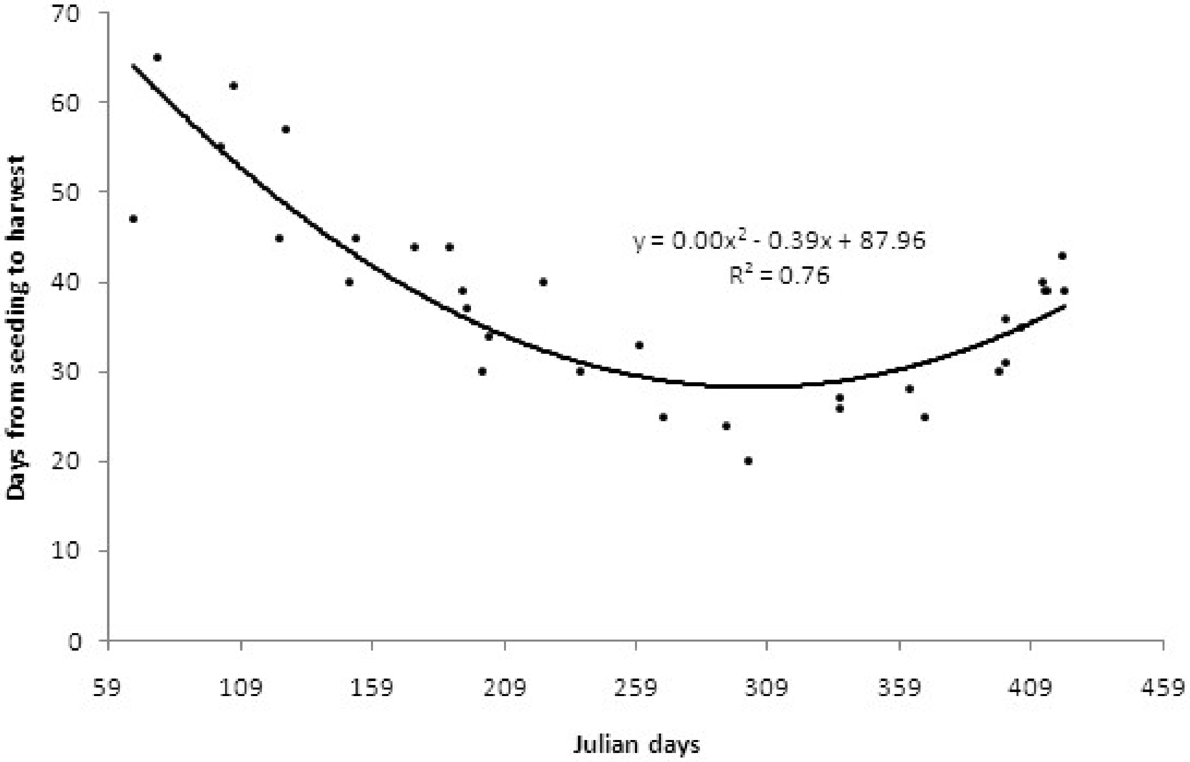


**Figure 9.** The relationship between planting date and days from sowing to harvest for fast-growth varieties of baby leaf spinach. Data starts at Julian day 59 and ends at Julian day 415 (= 1 full year).

## *Evaluate model*

The model was then evaluated using a subset of data collected in the same way as the data used for the development phase of the model. Data for 12 planting and harvest dates was obtained for slow-, intermediate- and fast-growing varieties. For each growth-rate scenario, the predicted harvest dates were first calculated by entering the actual planting dates into the model. These predicted harvest dates are shown as the unbroken lines on figures 10-12. Next, the actual harvest dates for each planting date were plotted as data points. These are shown as diamond-shaped points on figures 10-12.

The mean differences between actual and predicted harvest dates are therefore a measure of the accuracy of the model that was developed in this project. For the slow-, intermediate- and fast-growing models, these discrepancies were 3, 2 and 3 days respectively, indicating the harvest dates predicted by the model are within 3 days of the actual harvest dates.

### Slow growth cultivars

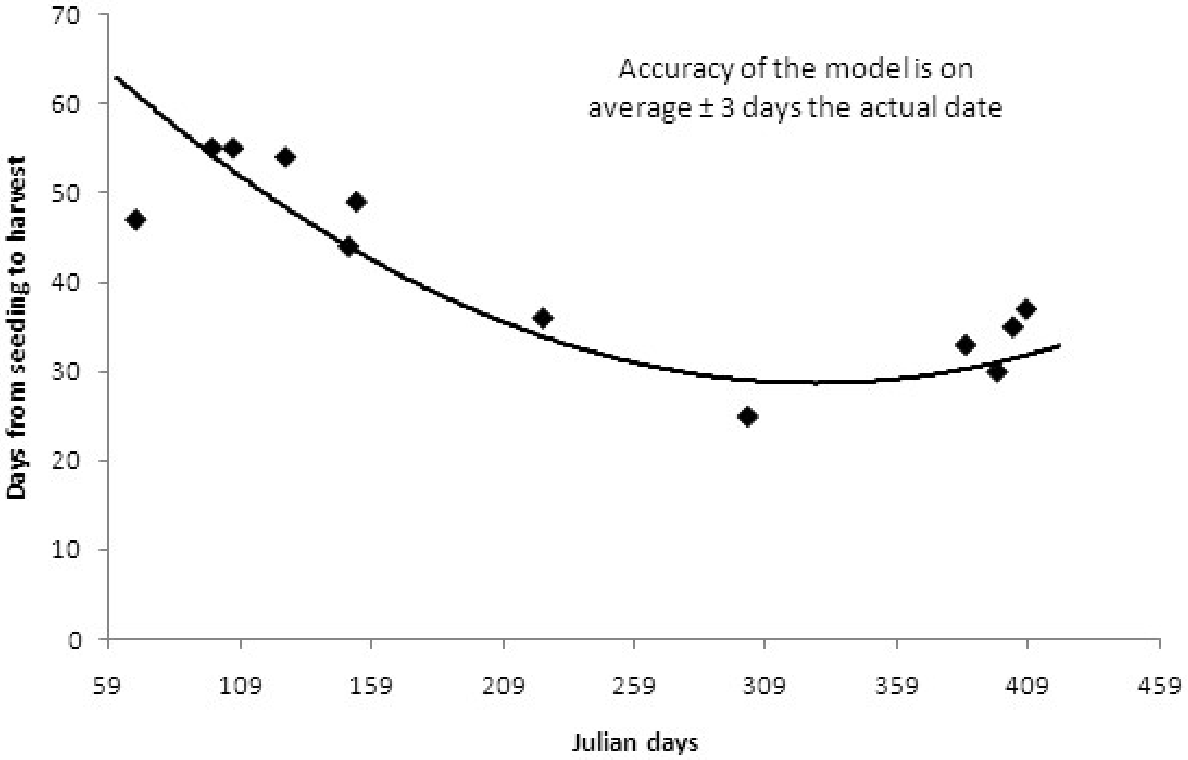


**Figure 10.** The predicted harvest dates (full line) and actual harvest dates (diamond shaped points) for slow growing baby leaf spinach cultivars. Data starts at Julian day 59 and ends at Julian day 415 (= 1 full year).

## Intermediate growth rate cultivars

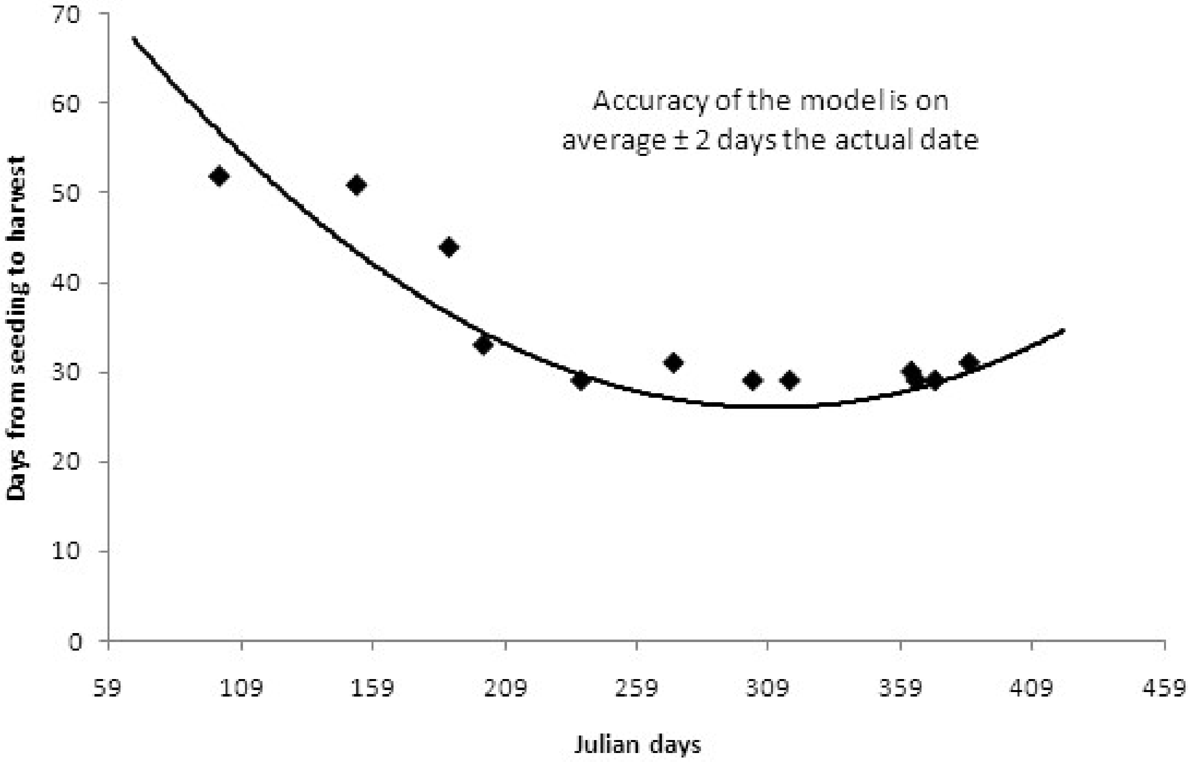


**Figure 11.** The predicted harvest dates (full line) and actual harvest dates (diamond shaped points) for medium growth rate baby leaf spinach cultivars. Data starts at Julian day 59 and ends at Julian day 415 (= 1 full year).

## Fast growing cultivars

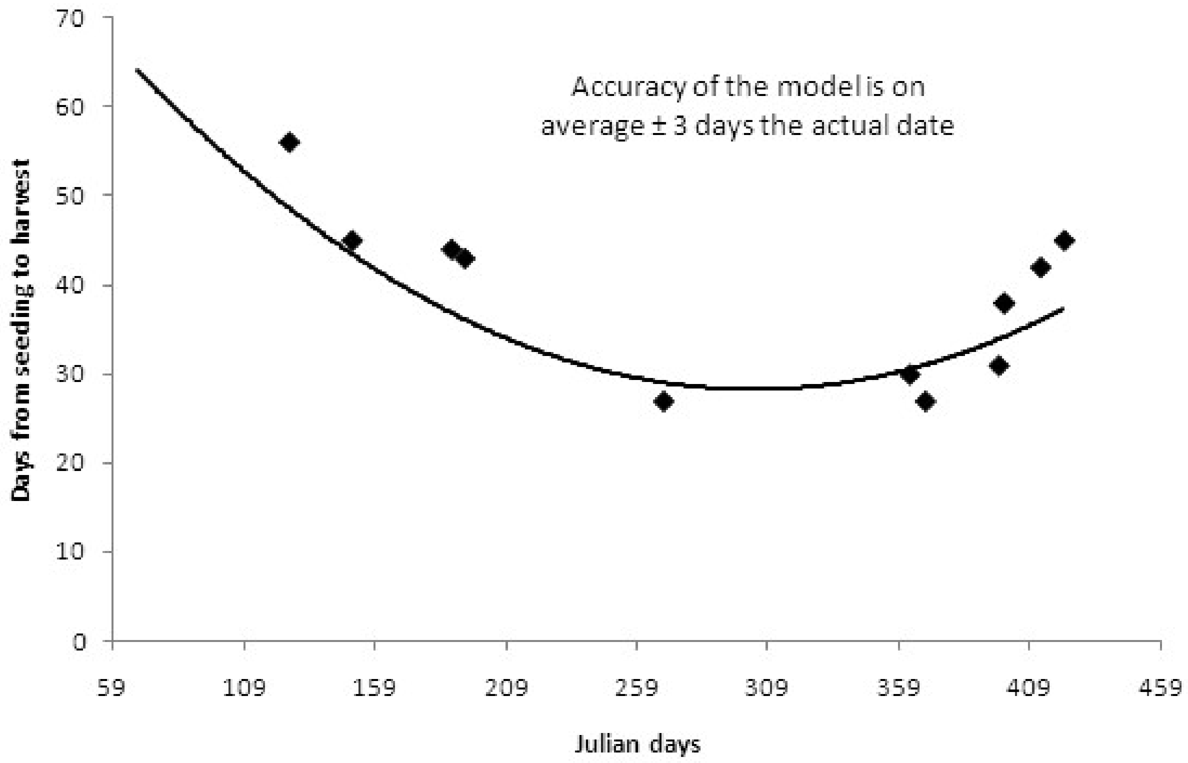


**Figure 12.** The predicted harvest dates (full line) and actual harvest dates (diamond shaped points) for fast growing baby leaf spinach cultivars. Data starts at Julian day 59 and ends at Julian day 415 (= 1 full year).

## Final model

The final model developed as a result of the project is presented in Table 6. The model can be used without knowledge of the spinach variety, and is still reasonably accurate. The model is independent of location or time of year, which means it is a robust and useable model ready to be used in the commercial sector by Australian growers. In the final model, adjusting the temperature cut offs resulted in a robust model based on sowing to harvest data, which is a much more usable model than the emergence to harvest model developed in the first stage of the project.

The model has been incorporated into an easy-to-use interface, which is described in the section below. This interface is freely available for industry members to use and evaluate.

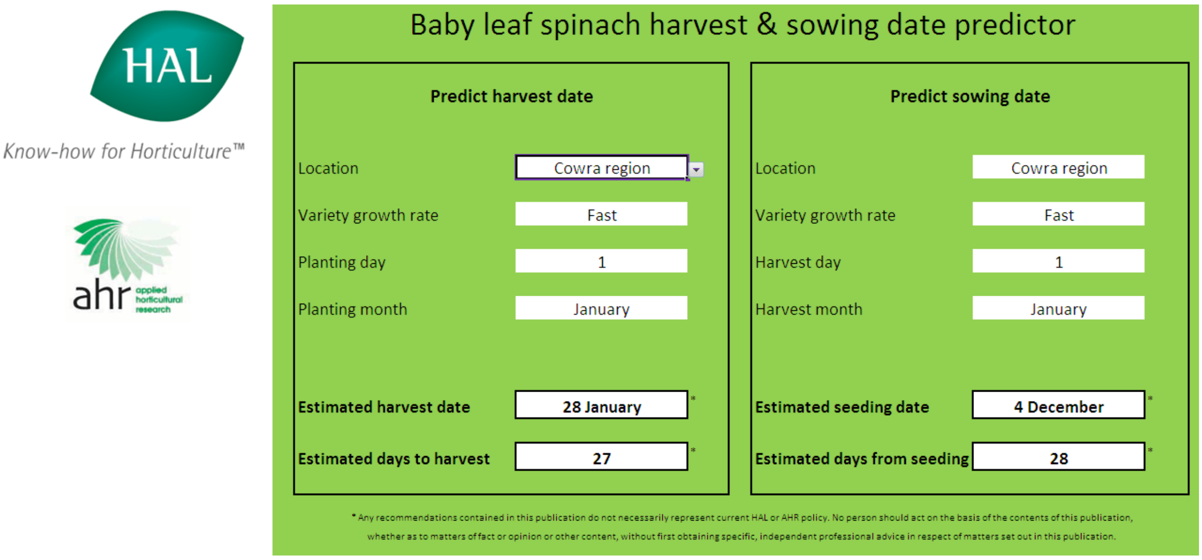
***Table 6. Final growing degree-day models for spinach types***

| | Growing degree days sowing to harvest | | $T_{base}$ | $T_{max}$ |
|---|---|---|---|---|
| Variety | GDD | ± SE | (°C) | (°C) |
| Slow growing type | 531 | 7 | 0 | 25 |
| Intermediate growing type | 531 | 8 | 0 | 25 |
| Fast growing type | 512 | 7 | 0 | 25 |
| Overall average across variety types | 524 | 4 | 0 | 25 |

### *Excel crop-scheduling model and user interface*

The model has a user interface with drop-down options for location, variety growth rate, day and month. It was developed using Microsoft® Excel® with a simple user interface. It has been designed for easy operation with minimal information and clutter. The user interface is divided into two separate areas, one for the prediction of harvest date on the left-hand side of the screen, and the prediction of sowing date on the right-hand side of the screen (Figure 13).

The model engine operates as follows. Once the options are selected from the drop-down lists, they are matched with location-specific temperature data using the day and month selected. Data for each location is the average over the last 30 years of Bureau of Meteorology data. The model then counts forward until the number of growing degrees days (GDD) are calculated for the selected variety growth rate. The number of days to achieve the required GDD is then added in the case of harvest prediction, or subtracted in the case of sowing date, from the starting date.



Baby leaf spinach harvest & sowing date predictor

**Predict harvest date**

| | |
|---|---|
| Location | Cowra region |
| Variety growth rate | Fast |
| Planting day | 1 |
| Planting month | January |
| **Estimated harvest date** | **28 January** * |
| **Estimated days to harvest** | **27** * |

**Predict sowing date**

| | |
|---|---|
| Location | Cowra region |
| Variety growth rate | Fast |
| Harvest day | 1 |
| Harvest month | January |
| **Estimated seeding date** | **4 December** * |
| **Estimated days from seeding** | **28** * |

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**Figure 13.** Example of the user interface for the harvest and sowing date prediction model.

Acknowledgements
The authors acknowledge the assistance of various growers in the collection of planting and harvest dates. Assistance with the development of the Daily Thermal Unit (DTU) models from Dr Daniel Tan and Dr Malcolm Possell from the University of Sydney is gratefully acknowledged.

## Recommendations

The prediction model generated by this project represents a useful tool for industry, which can be immediately implemented in management systems. Although the estimation of harvest date can be difficult, as many variables are involved, the use of GDD is an effective method of correlating ambient temperature averages with harvest time.

## Technology Transfer

Training sessions on how to use the model have been conducted with growers in the regions listed in Table 7. The sessions typically were carried out on a grower's property with either a small group from the same region, or in some cases with individuals if there were no other growers in the vicinity. This training was highly effective due to the small-group nature of the presentations. The growers trained are the major lettuce producers in Australia.

A typical half-day grower workshop covered: why spinach scheduling is important; and how to use the model as a planning tool, or to predict the harvest date for crops already planted. Also covered during the workshops or during other visits with these growers were topics such as: determining optimum harvest time; cool chain management; and baby leaf specifications.

The presentation is attached to this final report as Appendix 3.

***Table 7. Training sessions conducted during 2011***

| **Region** | **Spinach growers attending** |
|---|---|
| Cowra - Central West NSW | Mulyan Farm (Ed Fagan) |
| Forth – NW Tasmania | Harvest Moon (Neil Armstrong and Mark Kable) |
| East Gippsland-Bairnsdale | Bulmer Farms, Trevor Kerton and Covino Farms |
| Manjimup – southwest Western Australia | David East & Luke Edwards |
| Gatton/ Lowood – Lockyer Valley, Southeast Queensland | Durham Farms, Creekside (Barry & Troy Parchert) and Steep Gulley (Gavin Thorne) |
| Grech Farms – Camden NSW | Edgar Grech and Paul Grech |
| Melbourne Sandbelt | Russell Lamattina |

### *Article for Good Fruit and Vegetables*

An article was written for the industry magazine *Good Fruit and Vegetables* and published in the September 2011 issue of the magazine.

A copy of the article is attached to this final report as Appendix 2.

## References

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**Appendix 1.** Baby leaf spinach crop recording sheet

***Site Details***

| | | | | | |
|---|---|---|---|---|---|
| **Grower** | | **Irrigation** | | | |
| | | **Type** | **Frequency** | **Scheduling** | **Notes** |
| **Region** | | | | | |
| **Soil type** | | **Fertilizer** | **Type** | **Rate** | **When applied** |
| | | *Basal* | | | |
| **Notes** | | *Side/Foliar* | | | |

***Crop Details***

| *Block* | *Sowing date* | *Variety* | *Density (plants/m$^2$)* | *Emergence date* | *Harvest date* | *Est. optimal harvest (+/-) days* | *Crop Notes (adverse events, irrigation or nutrition changes)* |
|---|---|---|---|---|---|---|---|
| | | | | | | | |
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**Appendix 2**. Article prepared for *Good Fruit and Vegetables*

# New crop-scheduling tool now available for baby leaf spinach producers in Australia's major growing regions

Gordon Rogers and Mike Titley, Applied Horticultural Research

For producers of baby spinach, accurate prediction of time from planting to harvest is critically important. This is because the crop grows rapidly and is normally only suitable for harvesting on a single day.

Harvesting too early reduces yield, while harvesting too late results in leaves which are too large and outside of specification.

Growers supplying processors need to be able to develop a planting plan to allow for a regular supply of harvested product in the face of varying weather conditions, which have a significant impact on the rate of development of the crop.

In response to this industry need, Gordon Rogers and Mike Titley of Applied Horticultural Research (AHR) have recently completed a Horticulture Australia-funded project to develop a new crop-scheduling program. The outcome of their research is a computer-based tool that enables baby leaf spinach growers to determine the planting date required for harvesting on a particular day. It also enables them to predict the harvest date for crops already planted.

The crop-scheduling tool works for all the major baby leaf spinach-growing regions in Australia, and for the main variety types.

The project investigated the relationship between ambient temperatures and the time taken for baby leaf spinach to reach commercial maturity. This information was then used to develop a practical model capable of predicting the harvest or sowing date of a crop, based on regional long-term temperature averages.

The prediction model assumes that the crop accumulates Daily Thermal Units (DTU), and that the accumulation of these DTUs is needed until the total requirement for the crop is reached.

This type of thermal modelling has been widely used in horticultural production systems, particularly for head lettuce and broccoli. The model assumes that plant growth does not occur below a minimum or above a maximum temperature. These cut-off temperatures vary depending on species.

A harvest prediction model was created using 30-year temperature averages for seven major growing regions. The regions used in the model were: Cowra, East Gippsland, Gatton, Gympie, Manjimup, Mornington Peninsula and Sydney.

### *Excel model*

The model was developed using Microsoft® Excel® computer software and has a simple user interface.

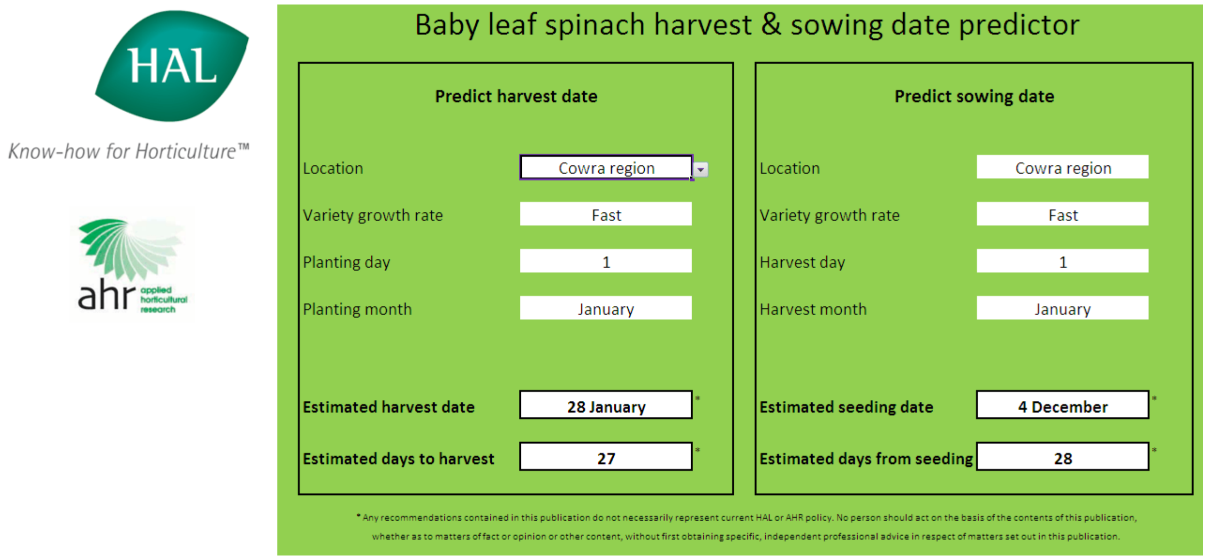
The data collected from different regions was developed for slow, medium or fast growing cultivars.

There are many commercial cultivars of baby leaf spinach available in Australia. They have been bred for different seasons of production and develop at different rates.

Growers should check the current varietal information provided by seed companies and consult with their representatives to ascertain which growth-rate category their varieties fit into.

The user interface for the model is simple, and it has two distinct functions.

One function is the ***prediction of harvest date*** and the other is the ***prediction of sowing date***.



Baby leaf spinach harvest & sowing date predictor

**Predict harvest date**

| | |
|---|---|
| Location | Cowra region |
| Variety growth rate | Fast |
| Planting day | 1 |
| Planting month | January |
| **Estimated harvest date** | **28 January** * |
| **Estimated days to harvest** | **27** * |

**Predict sowing date**

| | |
|---|---|
| Location | Cowra region |
| Variety growth rate | Fast |
| Harvest day | 1 |
| Harvest month | January |
| **Estimated seeding date** | **4 December** * |
| **Estimated days from seeding** | **28** * |

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***Example of the user interface for the harvest and sowing date prediction model.***

Users need to enter three pieces of data via a drop-down menu. These are:

- Location
- Variety growth rate
- Planting date (or harvest date)

The model offers growers a quick and easy management tool, which can be used by anyone with basic computer skills.

For more information or to obtain a copy of the program, please contact Dr Gordon Rogers (gordon@ahr.com.au) or Mike Titley (broccoli@bigpond.com) or visit the AHR website at www.ahr.com.au

## Appendix 3 User instructions

The harvest and sowing prediction model has been developed for ease of use. First the user must decide whether they wish to determine the harvest or sowing date. The user interface has been divided into two sections with the prediction of harvest date on the left and the prediction of sowing date on the right. Only regions in the drop-down list are available, so if your location does not match these options select the closest region. The flow diagram below will help users determine the desired data.