

# LINTUL-POTATO model revisited

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## Abstract

The LINTUL-POTATO model is revisited in this work. Recent findings on quantification and description of potato crop phenology are incorporated into the original model framework. The results presented in this work may be included in a number potato models to improve the prediction of the time of crop growth and development processes.

## Keywords

Crop modelling, crop yield, phenology, thermal-time, *Solanum tuberosum* L, yield parameters.

## Introduction

A common approach to modelling crops is to segment the processes of crop growth and development in discrete periods in which structure and the size (mass) of specific organs changes (Squire 1990).

Kooman and Haverkort (1995) used a relative timescale to describe the potato crop development or crop ontogeny in their LINTUL-POTATO model. This model simulates the Light INTerception and Utilisation, temperature and daylength reactions of potato crops grown under different climates. To do that they divided the length of the growth cycle into four phases, each starting and ending with a characteristic stage of crop development. At planting (Phase 0) the rate of sprout growth is solely determined by temperature accumulation. At crop emergence (start of Phase 1) foliar expansion is linearly related to temperature. Phase 1 finishes at tuber initiation. Phase 2 is from tuber initiation until the end of leaf growth. In Phase 2 leaves compete with the tuber for assimilates. The beginning of Phase 3 coincides with the moment when 90% of assimilates produced daily are partitioned to tubers. However, during Phase 3 all assimilates are partitioned to the below-ground tubers. The end of this phase characterises the end of crop growth.

The development of the crop canopy for radiation interceptance and daily partitioning of dry matter to tubers is described concomitantly for these phenological phases. As in a number of potato models (e.g. Wolf and Van Oijen 2003), temperature is used as the main driver of crop development.

This work compiles recently published data on potato crop growth and development to quantify some of the phenological phases in the LIINTUL-POTATO model (Kooman and Haverkort 1995). The inclusion of other interrelated porcesses of potato growth and development into the model framework is also proposed.

## Methods

The work presented here uses data from two field experiments and one storage potato experiment, with two or three potato cultivars, conducted in Canterbury, New Zealand, in 2011 and 2012. Both field experiments were conducted under best management practices and non-limiting growth conditions for potato crops.

Briefly, the storage experiment measured the sprouting behaviour of 'Bondi' and 'Fraser' potato cultivars under different storage conditions prior to planting. A full description of the materials and methods used in this experiment is detailed in Oliveira (2015).

In the first field experiment, aboveground and belowground growth behaviour of three potato cultivars ('Bondi', 'Fraser' and 'Russet Burbank') were reported (materials and methods used in this experiment is fully described in Oliveira et al. (2016a)). Comparisons of canopy development, radiation interception, radiation use efficiency (RUE), and dry matter partitioning to tubers (or harvest index; HI) and aerial organs were made to explain yield differences among the cultivars. The relationship between individual tuber growth, node position, and stolon length, to which the tuber is attached, were also described. The second field experiment was conducted to measure the patterns of crop growth, development and tuber yield from

the different seed potato storage treatments (materials and methods detailed in Oliveira et al. 2016b). This also detailed the components of potato canopy expansion at the individual leaf level (materials and methods provided in Oliveira 2015).

The data published from these experiments (Oliveira et al. 2012; b; Oliveira et al., 2016a, b) were used to quantify (based on a thermal-time;  $T_t$ , scale), some of the phenological processes defined in the LINTUL-POTATO model (Kooman and Haverkort 1995). In addition, changes to the original model framework are proposed from these recent findings.

## Results and Discussion

### *Thermal-time ( $T_t$ )*

Oliveira (2015) performed a sensitivity analysis on the rate of leaf appearance (phyllochron) across cultivars and found a potato base temperature ( $T_b$ ) of 2 °C. This is in agreement with the  $T_b$  used in the LINTUL-POTATO model. The examination of an accurate temperature threshold for leaf appearance represented the first step to determine the relationship between developmental events and temperature for potato phenology prediction.

The proposed modification to the LINTUL-POTATO model involves the division of the growth cycle in five phases instead of four, as originally established, each starting and ending with a characteristic stage of crop development (Figure 1). Essentially, phases 0-2 were maintained as the original template. However, phase 3 was reduced to accommodate for the inclusion of an extra phase (phase 4). Phase 4 was included to account for two aspects not considered in the model: 1) biomass remobilisation within the plant, and, 2) a phase of zero crop growth. This is described as follows.

### *Phase 0*

At planting (Phase 0) the time until crop emergence is initially determined by the presence versus absence of sprouts on the seed potato (Figure 1) (Oliveira et al. 2016b). These authors found that potatoes planted with sprouts were found to require 301-328°Cd to emerge compared with 398-428°Cd for potatoes planted with no sprouts (or when sprouts had been removed from the seed potato prior to planting) for a wide range of different sprouting patterns (e.g. sprout length varying from 11 to 104 mm; Oliveira et al. 2012).

### *Phase 1*

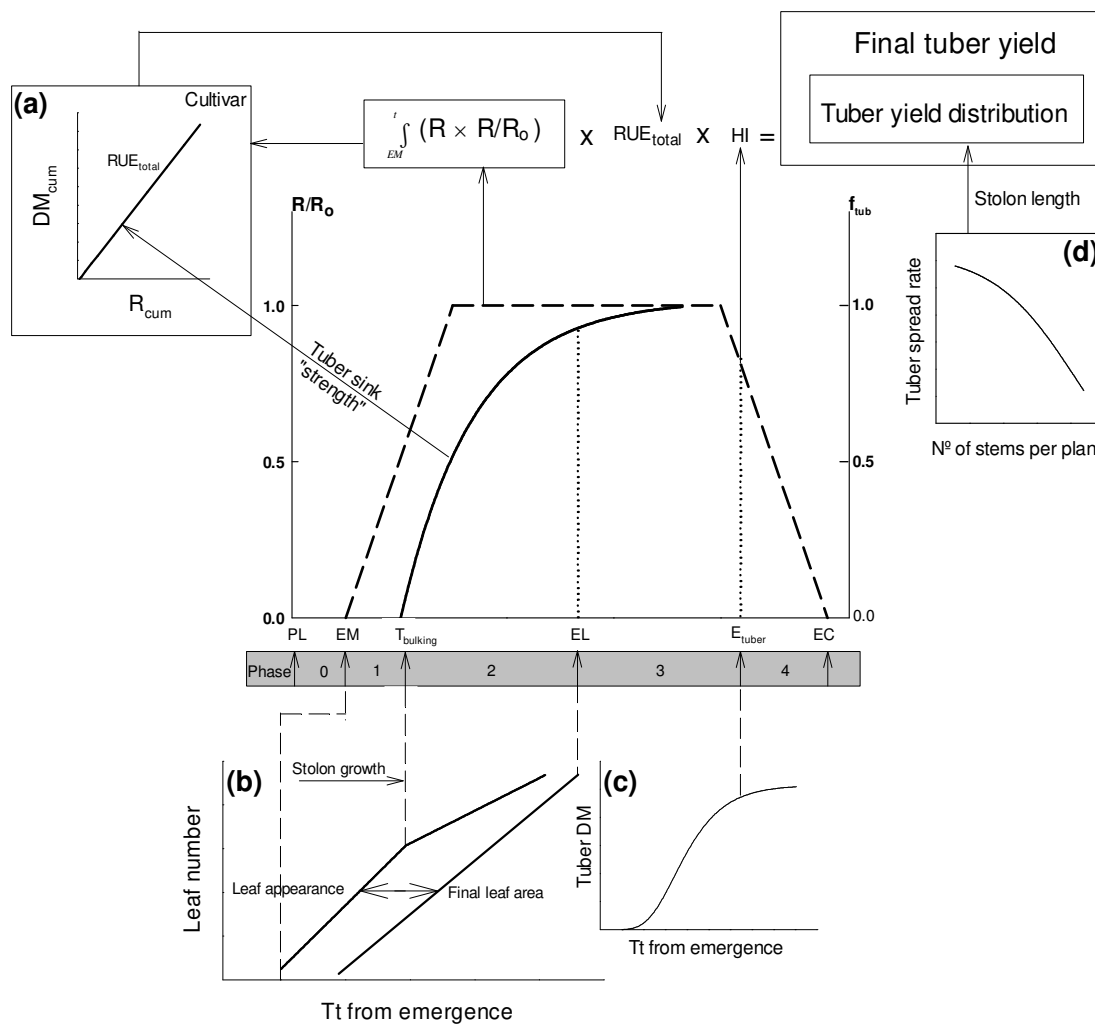
As in the original LINTUL-POTATO model, during Phase 1, foliar expansion and the fraction of radiation interception (or canopy ground cover;  $R/R_o$ ) has a linear increase in response to  $T_t$  and this continues into the subsequent phase. Oliveira et al. (2016a; b) found a constant rate of  $R/R_o$  linear increase across cultivars (~0.20% of canopy ground cover °Cd<sup>-1</sup>). Moreover this was not influenced by seed potato physiological age or differences in branching activity (Oliveira et al. 2016b).

On the below-ground stems, stolons elongate until the time of tuber initiation which is followed by tuber bulking ( $T_{bulking}$ ). According to Oliveira et al. (2016a), stolon length on the below-ground node positions, where the larger tubers are produced, has been described as the first vegetative signal of tubers sink “strength” (defined as the ability of sink organs to accumulate carbon compounds; Marcelis 1996). These authors concluded that the longer the stolons of a cultivar the later tubers initiate and bulk, and this leads the crop to a lower rate of tuber growth. In addition to that, Oliveira (2015) found that the start of the  $T_{bulking}$  phase (at ~400-500 °Cd) triggers phyllochron change (~50% increase) on the above-ground stems (Figure 1 b). The inclusion of this information in the original model can improve the prediction of the timing of these phases. This is particularly important because after tuber bulking onset, the below-ground tubers become the priority sink for the plant to the detriment of foliage growth.

### *Phase 2*

In this phase  $R/R_o$  reaches maximum (at 450-550 °Cd; Oliveira et al. 2016a; b) and leaves compete with tubers for assimilates. According to these authors the rate at which the fraction of assimilate is partitioned to the tubers ( $f_{tub}$ ), is associated to the tuber sink “strength” which is determined on a cultivar basis and dependent on the rate of tuber bulking (ranged from 0.90-1.22 kg ha<sup>-1</sup> °Cd<sup>-1</sup> across cultivars) and linked to radiation use efficiency (RUE) (Figure 1 a).

Differences in RUE among genotypes are usually unclear (Jefferies 1993) and therefore it is often assumed as a constant value in potato simulation models, including the LINTUL-POTATO model ( $2.5 \text{ g MJ}^{-1}$  intercepted PAR). However, recent published results suggest that further improvements could be gained from calibrating RUE on a cultivar basis (Oliveira et al. 2016a; b). These works have reported up to 20% RUE differences among potato cultivars. The authors attributed differences in RUE to differences in sink “strength” among genotypes. When the tuber has established its own sink “strength”, tuber growth results mainly from tuber size (weight) and its capacity to compete with other tubers for photosynthate. These factors combined determine the rate of tuber growth and set demand for photosynthates. Phase 2 ends when leaf growth is terminated and expansion (final leaf area) of the latest leaf appearance has been completed. According to Oliveira (2015) this happens at  $\sim 950 \text{ }^\circ\text{Cd}$  (Figure 1b, EL).



**Figure 1. Schematic representation of radiation interception ( $R \times R/R_0$ ) and the fraction of the daily assimilate that is partitioned to the tubers ( $f_{\text{tub}}$ ) from planting (PL) to emergence (EM), the start of tuber growth ( $T_{\text{bulking}}$ ), the moment that leaf expansion ceases (EL), the point when 95% of the final tuber yield is attained ( $E_{\text{tuber}}$ ) until the end of crop growth (EC). Adapted from: Kooman and Haverkort (1995). Graphs (a) and (c) are presented in Oliveira et al. (2016a), graph (d) in Oliveira et al. (2016b) and graph (b) in Oliveira (2015).**

### Phase 3

Most of the duration of Phase 3 occurs at maximum  $R/R_0$ . During this stage all assimilates are partitioned to the below-ground tubers. This finishes at  $1400 \text{ }^\circ\text{Cd}$ , when 95% of the final tuber yield has been attained and tuber dry matter content has reached a maximum value (Figure 1 c). At this point the harvest index (HI) is also around maximum (70-80% of total crop dry matter; depending on the cultivar “sink strength”) (Oliveira et al. 2016 a). The end of this phase is marked by the  $R/R_0$  linear decline from maximum (100%; at  $\sim 1300 \text{ }^\circ\text{Cd}$ ) to  $\sim 80\%$  (at a rate that will also depend on the cultivar sink “strength”; and can vary from  $0.06\% \text{ }^\circ\text{Cd}^{-1}$  to  $0.63\% \text{ d}^{-1}$ ).

#### Phase 4

This phase has been added to the original LINTUL-POTATO model. In this phase there is zero crop growth and  $R/R_0$  continues to decline until total canopy senescence ( $R/R_0=0\%$ ) (Figure 1, EC). Tuber DM increase is unsubstantial (~5% of the crop final tuber yield) during this period and results from the remobilisation of assimilates from the canopy (Oliveira et al. 2016a).

Final tuber yield is the result of radiation interception ( $R/R_0$ ), RUE and the partitioning of biomass to tubers (HI). Finally, tuber yield distribution (formed by the weight grade of each potato) has been found to be influenced by the stolon length on the below-ground stems and determined by the tuber spread rate (measured between 5% and 95% accumulated proportions of yield) which is inversely related to the number of stems produced per plant (Oliveira et al. 2016b) (Figure 1 d).

#### Conclusion

The LINTUL-POTATO model was revisited. Crucial phenological stages were quantified in thermal-time and these may be included as a default parameter in the model to predict the switch from one phase to another. In addition, new interrelated process of crop growth and development were proposed. The results showed that the original model framework would benefit from a variable RUE (currently set as a constant) and from having the time of phyllochron change set as a trigger for the  $T_{\text{bulking}}$  phase. Moreover, it was shown that a yield distribution module could be included in this framework. This could be parameterised using the number of stems produced per plant as a variable. Future potato model work could include tuber sink “strength” as a parameter associated with tuber initiation, growth rate and RUE and HI. Finally, an extra phase was included in the model (Phase 4) to describe biomass remobilisation within the plant and to contemplate a phase of zero crop growth.

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