5. Description and application of the LINTUL-POTATO crop growth model

5.1. Agro-ecological description of LINTUL-POTATO

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5.1.1. Introduction

The specific environment for potato growth and production is mainly determined by temperature. Potato is not cultivated in environments with mean monthly temperatures below 5°C or above 28°C. The growing season should exceed a minimum duration, equivalent to an accumulated temperature requirement of about 1250 degree days, Cd with a base temperature of 2°C. Degree days are calculated as the accumulated number of days with a positive difference between the daily average temperature and the base temperature. This means that potato requires a minimum growing season of about 100 days when the daily mean temperature is 14.5°C and 50 days when the daily mean temperature is around 27°C. The maximum duration of potato crop growth is equivalent to an accumulated temperature requirement of 2000 degree days, °Cd. A spatial and temporal distribution of potato production throughout the world can be made just by using temperature and the above mentioned crop characteristics, see Figure 5.1. Approximate cropping management characteristics as planting and harvesting can be also estimated by using these crop specific temperatures. Beside temperature, other factors may determine the length of the cropping season such as timing of the rainy seasons and market requirements. Different potato cultivars possess different properties which makes them suitable for a specific abiotic, biotic and economic environment. These cultivars can be classified according to their environmental requirements into ideotypes.

Ideotypes have a length of the growth cycle characterized by a green leaf area that intercepts solar radiation for as long as possible during the available growing season to accumulate as much dry matter as possible. Earlier genotypes, too early divert dry matter to the harvestable parts (grains, tubers) so that not sufficient assimilates are available for the foliage that then senesces and dies. Genotypes that are too late still have full ground cover with green leaves at the end of the available growing season indicative of an unfavorable distribution of dry matter to the foliage and to the harvestable parts of the crop. Figure 5.2 schematically represents the three situations of a potato crop under northern European conditions.

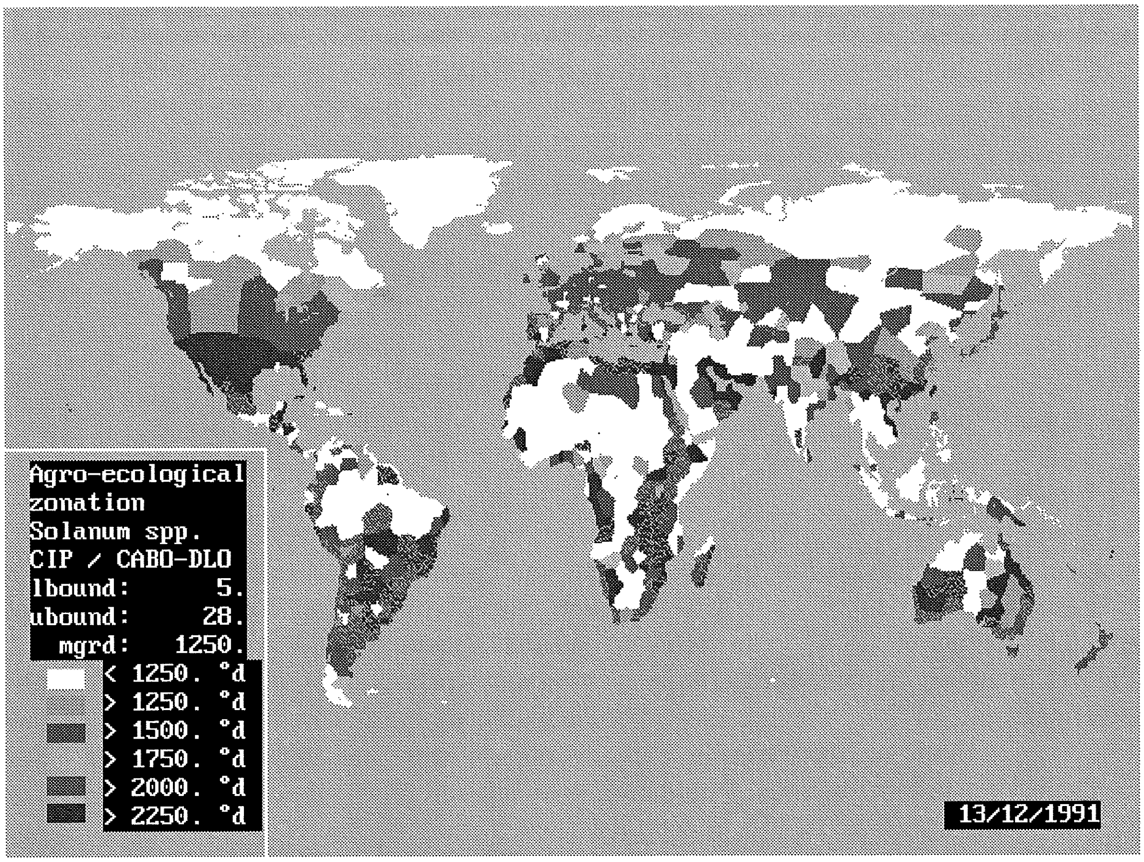

Figure 5.1 Lengths of the growing seasons (Van Keulen and Stol, 1996)

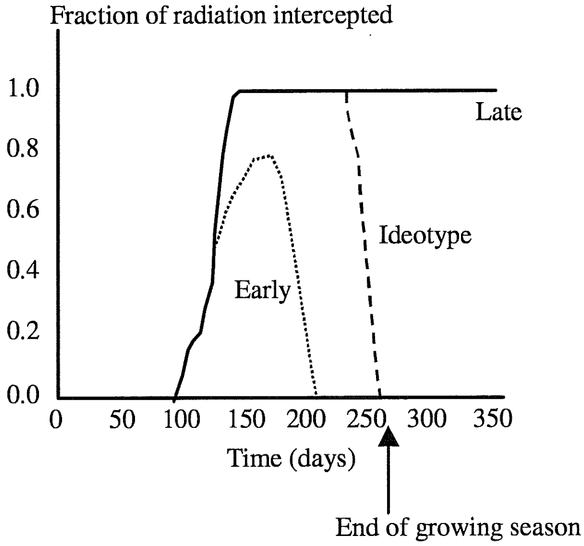

Figure 5.2. Schematical representation of the course of light interception by green crop foliage of ideotypes versus early and late genotypes. Planting is on day 75, emergence on day 100 and harvest on day 260.

To describe ideotypes with the desired length of the growth cycle one needs firstly to determine the length of the available growing season as it is delimited by growing conditions or market demands. Secondly, an assessment is needed of the yield determining factors (temperature, radiation, daylength) that cannot be changed nor influenced by the farmer once the crop is planted, with emphasis on the influence of such factors on the length of the growth cycle. Thirdly, the presence of yield limiting factors such as water and nutrients need to be studied. What is the influence of drought and lack of nutrients on the length of the growth cycle? Finally, it should be evaluated and quantified whether there is a risk of crop yield reducing factors such as pests, diseases and weeds.

The influence of the yield defining, limiting and reducing factors on crop growth parameters and their repercussions on the length of the growth cycle and how to match the length of the cycle with that of the season is important in crop production. To that end we'll discuss an appropriate model of potato growth and development with temperature and solar radiation as driving forces and we'll show how daylength and water availability may influence development and growth as well.

5.1.2 Modelling approach

Three types of crop yields are currently simulated with dedicated models. These models differ in their ranking with respect to the number of limiting factors to simulate crop production. The first type of models simulates the potential yield. Potential yield is the theoretical upper limit of crop yield and is based upon the limitations of available radiation and temperature. Attainable yield is simulated by taking the limiting factors of water and nutrients (nitrogen and phosphorus) into account. The actual yield is simulated by taking limiting biotic factors as weeds pests and diseases into account. The simulated actual yield has the most correspondence with the on-farm harvested yield.

A simple model describing growth and development of crops is based on light interception, utilization of light to produce dry matter, allocation of dry matter to the harvestable parts and of the percentage of water in the harvestable parts. Schematically this is represented in Figure 5.3. The growth cycle is shown in the graph (Figure 5.3) of which the abscissa (thermal) time) starts at planting. Then the course of light interception or ground cover from planting until crop senescence is shown. Cumulation of the amount of daily intercepted radiation over time versus total and tuber dry matter yields the efficiency coefficients for total and tuber dry matter production. The simplest potato growth model that can be derived from the observation of light interception and dry matter accumulation over time is:

$$Y = \frac{R * E * H}{D}$$

where: **Y = tuber fresh yield, R = the amount of intercepted radiation, E = conversion efficiency, H = the harvest index and D = the dry matter concentration of the freshly harvested tubers.**

These parameters can easily be derived from potato experiments in which periodic harvests are taken and fresh and dry matter of haulm and tubers is determined, where the percentage ground cover is measured weekly and where daily solar radiation is recorded. Figure 5.4 illustrates the effect of (a combination of) a yield reducing factor (potato cyst nematodes) and a yield limiting factor (drought) on ground cover, thus light interception, and on the conversion efficiency of intercepted light into total and tuber dry matter.

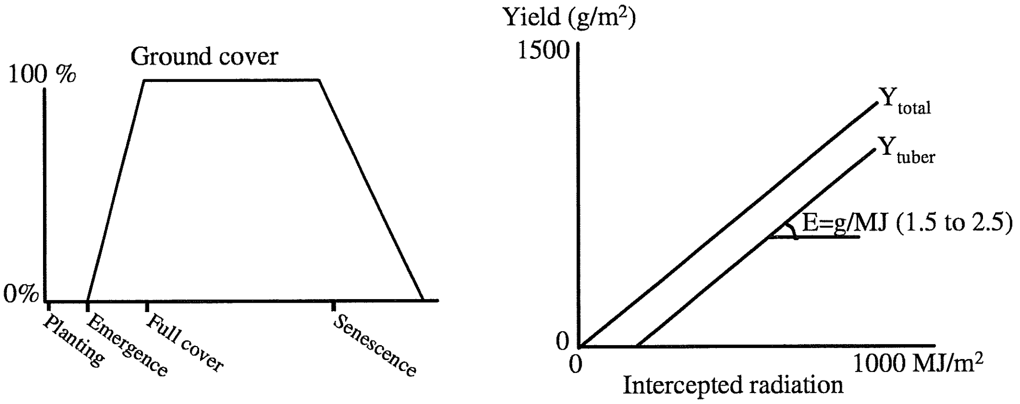

Figure 5.3 Schematical representation of tuber production in potato based on ground cover (and) light interception and conversion of intercepted into total and tuber dry matter

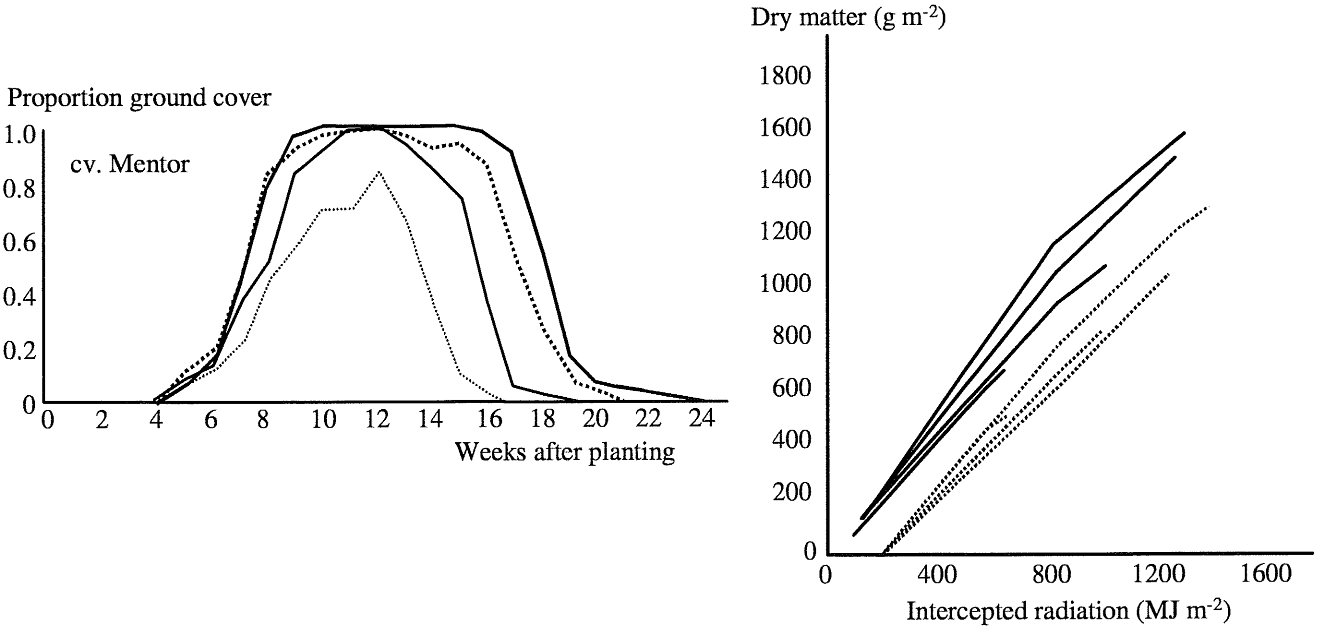

Figure 5.4 The effect of drought and potato cyst nematodes on light interception and dry matter production (bold lines: treatment with nematicides (soil fumigation), regular lines: no treatment with nematicides, drawn lines: irrigated, broken lines unirrigated. Dry matter production: continuous lines indicate total dry matter of the first three harvests, dashed lines indicate tuber dry matter of the last 3 harvests. (Haverkort *et al.*, 1992)

Van Keulen and Stol (1995), used this model approach to calculate potential yields at about 1000 meteorological sites. They assumed that no potato crop grows below 5° nor above 28°C and that the conversion rate is 2.5 g MJ^{-1} · They also assumed that each site is grown with a cultivar of the appropriate length of the cycle fitting the length of the season. This means that for each site a harvest index of 0.75 at crop senescence was assumed. Thus they calculated potential yields as shown in Figure 5.5. Around the equator at sea level potato production does not take place because it is too warm year round. At higher latitudes than about 55° no potatoes are grown because not sufficient thermal time is accumulated to allow one growth cycle. Yields are highest in the tropical highlands where potato production is feasible year round, followed by Mediterranean climates where two cropping seasons are possible followed by the temperate areas with one long single growth cycle.

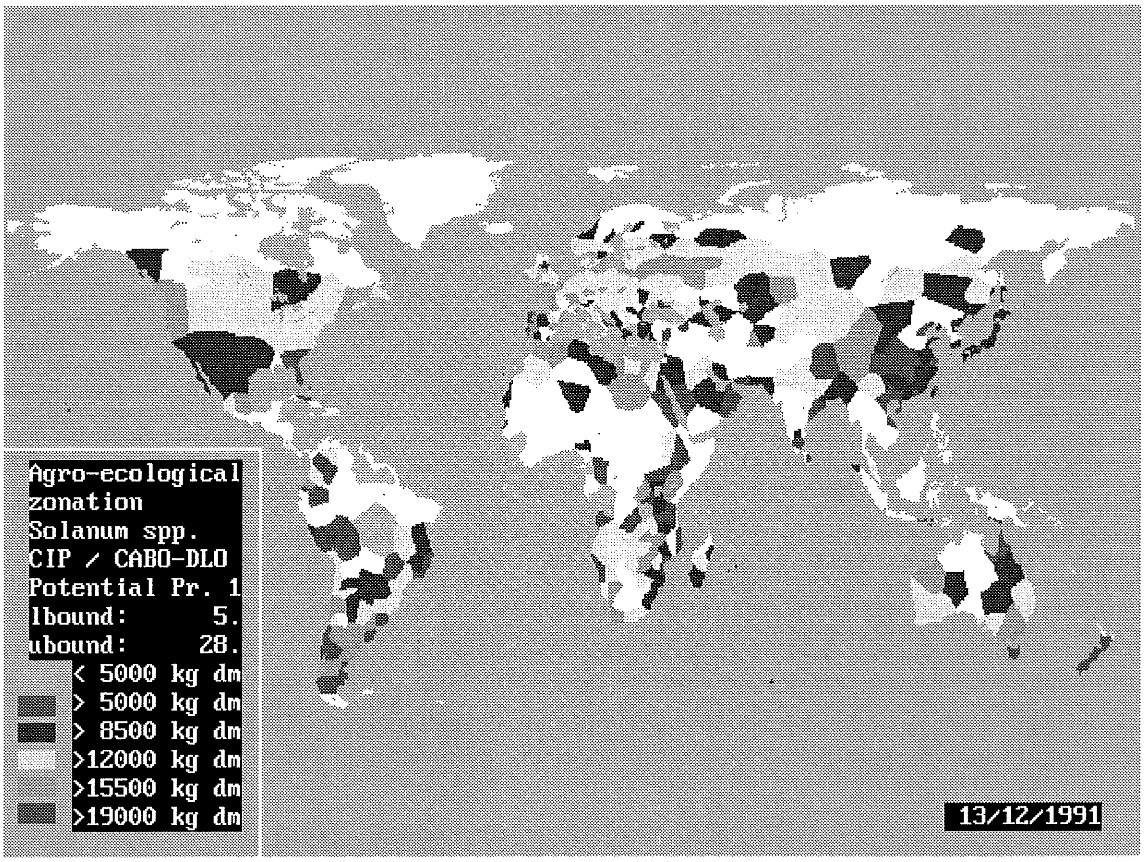

Figure 5.5 Calculated potential potato dry matter yields (Van Keulen and Stol, 1995)

5.1.3. Yield defining factors: temperature and daylength

In Figure 5.5 potential yields are shown globally assuming that cultivars exist that fit the local conditions regarding temperature and daylength responses. Potato is known to react to shorter days and lower temperatures: such conditions hasten tuber formation and favour tuber growth at the expense of haulm growth. LINTUL-POTATO (Kooman and Haverkort, 1995) was developed to quantify the effect of temperature and daylength on tuber initiation and subsequent dry matter partitioning over tubers and haulms. The main features of the LINTUL-POTATO model are shown in Figure 5.6

The model subsequently contains routines describing:

Phase 0 between planting and emergence assuming a sprout growth rate of 1 mm per daydegree. This means that a tuber planted at 12 cm depth with a sprout length of 2 cm emerges after 10 days when the average soil temperature is 10 °C. Once emerged (defined when the initial leaf area per plant is 0.0155 m^{-2} m^{-2} x the number of plants per plants per m^2) the relative leaf extension rate is 0.012 m^2 per m^2 per day degree and the leaf area is formed to build up the leaf area index. Light is extinguished according to Beer's Law with an extinction coefficient of 1. Leaf classes that are formed have a temperature dependent longevity.

Other temperature dependent rates, but with an optimum around 20° are the sprout growth rate, light use efficiency (see Figure 5.4, optimally 2.5 g MJ^{-1}) and most importantly the tuber initiation and tuber growth rates. The latter optimally is assumed to be 0.37 g g^{-1} d^{-1}. Most crucial in this model approach is the moment of tuber initiation and subsequent tuber growth rate. The tuber initiation rate (inverse of the number of days between emergence and tuber initiation (defined as the presence of 1 g of tuber dry matter per m^2) also depends on the daylength: longer days reduce the relative effect of optimal temperatures, so plants continue to grow for a longer period.

When tubers are initiated early (with an early cultivar) and when conditions for tuber growth are optimal, soon all daily accumulated assimilated will be allocated to the tubers and the crop will die early. Figure 5.7 shows the different phases of a crop: 0 is between planting and emergence (the sprout growth rate is temperature dependent), 1 is between emergence and tuber initiation (the tuber initiation rate is temperature and daylength dependent), phase 2 is between tuber initiation and the moment when 90 % of all daily produced assimilates are partitioned to the tubers (the tuber growth rate is temperature and daylength dependent) and phase 3 is between the moment when 90 % of the assimilates are partitioned to the tubers and crop senescence (the leaf senescence rate is temperature dependent).

With LINTUL-POTATO it is possible to explore what happens to a standard cultivar when grown under different temperature and daylength conditions. For model parameterization experimental results were obtained of 8 cultivars varying in lateness from very early to very late were grown under various temperature and daylength conditions in Rwanda (two altitudes), Tunisia (spring, autumn and winter seasons) and in the Netherlands (summer season). Figure 5.8. shows the expected tuber yields of a standard genotype of medium lateness with average temperature and daylength effects on tuber initiation rate. Potato crops have a considerably broader optimal temperature range at longer days. This phenomenon may explain the wide adaptability of the crop which is grown in a wide range of environments.

A second use of LINTUL-POTATO is to identify genotypes adapted to the climatical conditions at any site in the world. Figure 5.5 showed the potential yields of 1000 meteorological sites. To find out how late a cultivar should be so that the length of the growth cycle matches the length of the growing season, LINTUL-POTATO is able to calculate the ideal moment of tuber initiation for each site. If for a particular site tuber initiation takes place before the optimal moment, plants are still too small and too early all assimilates will be allocated to the tubers leaving none to the foliage that will die too early to match the length of the potential growing season (when temperatures are between 5 and 25°C). When tuber initiation takes place too late, much foliage is formed and the allocation pattern is unfavorable for tuber growth resulting in too low harvest indices. This is shown in Figure 5.9 for two sites: a spring and an autumn season in Tunisia and a s single summer season in the Netherlands.

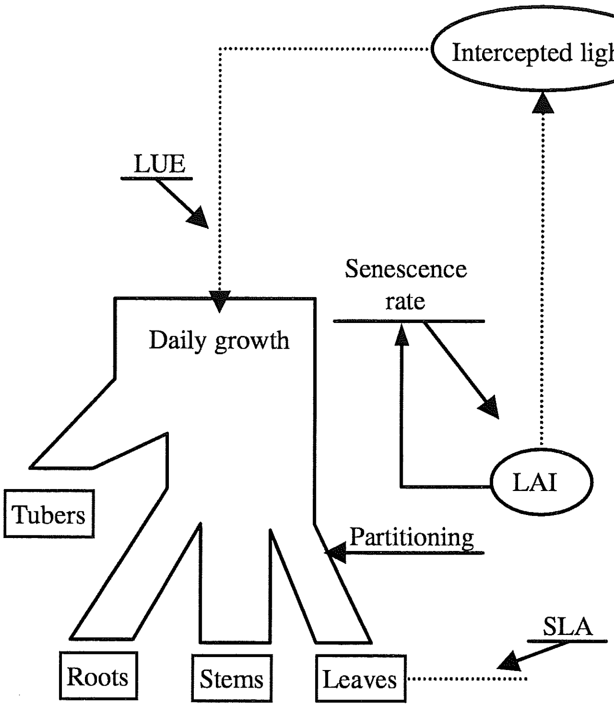

Figure 5.6 LINTUL-POTATO, Schematical representation of the modelling approach

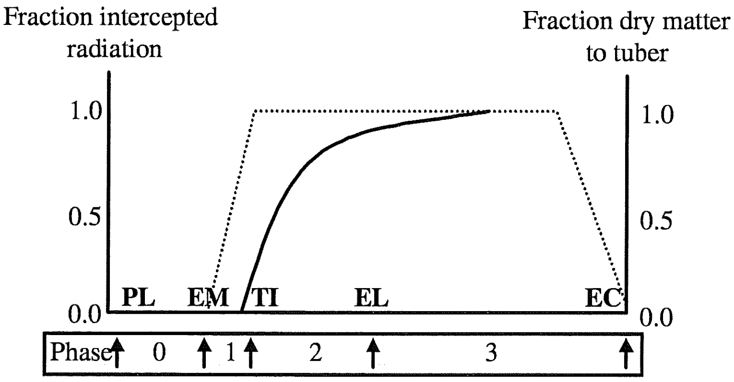

Figure 5.7 The phases of crop growth and development of potato (PL = planting, EM = emergence, TI = tuber initiation, EL = end of leaf growth, EC = end of crop growth, f_{int} = fraction of incoming solar radiation intercepted by the crop (broken line) and f_{tub} = fraction of daily accumulated dry matter allocated to the tubers (unbroken line))

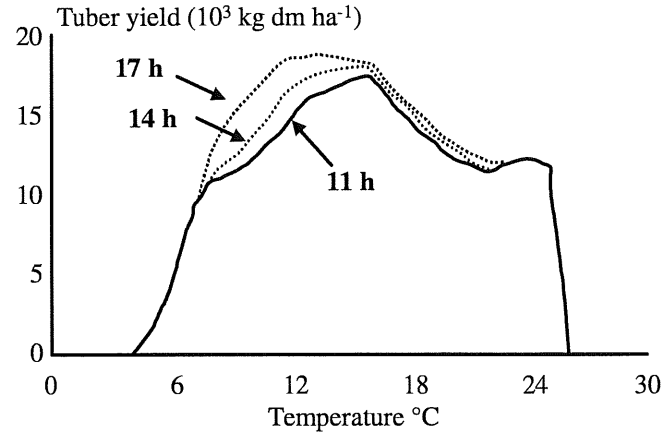

Figure 5.8 Tuber yields of a standard genotype of potato grown at different temperature and daylength combinations (Kooman and Haverkort, 1995)

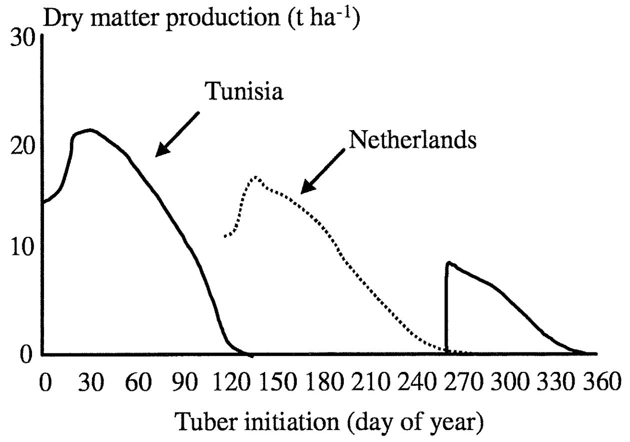

Figure 5.9 Expected potential dry matter production (30 year average temperature data) at varying moments of tuber initiation) in three varying seasons, calculated with LINTUL-POTATO (Kooman and Haverkort, 1995)

5.1.4. Yield limiting factor (water) and yield reducing factor (nematodes)

Water probably is the most yield limiting factor of most crops. The kind of drought which is expected is crucial in the strategy to increase the efficient use of water. Crops may react in different ways (and so do their producers) to limit the extent of damage. Yield analysis following the basic principles of LINTUL-POTATO (periodic observation of fresh and dry total and tuber mass and cumulative intercepted radiation by the crop) showed (Haverkort *et al.*, 1992) that yield losses are mainly due to reduced amounts of intercepted radiation by the crop and for less than 10% due to reduced conversion efficiencies (Table 5.1) or to reduced harvest indices. Also long-term effects of potato cyst nematodes are similar to those of drought: both mainly reduce yields through reduced light interception by green foliage (27 to

52 % reduction; Table 5.2) whereas the conversion efficiency is reduced by 14 % at the most but usually less than 10 %. As with drought, the harvest index is decreased slightly and the tuber dry matter increased by a few percentage points.

Table 5.1 Relative values of yield components of unirrigated versus irrigated plots (mean values of two years, after Haverkort *et al.*, 1992)

Cultivar	Y=	R x	E x	H :	D
Darwina	55	62	99	94	105
Desiree	77	88	99	94	105
Elles	80	93	90	95	101
Mentor	73	87	97	97	111

Table 5.2 Relative values of yield components of unfumigated versus fumigated plots (mean values of 3 years, after Haverkort *et al.*, 1992)

Cultivar	Y=	R x	E x	H :	D
Darwina	48	61	90	94	105
Desiree	52	71	86	93	102
Elles	73	86	95	102	107
Mentor	49	57	92	100	101

Cultivar Elles was most tolerant of both drought and of potato cyst nematodes which is not surprising. Elles was the latest cultivar tested, and when subjected to a yield limiting or a yield reducing factor made best use of the available growing season. Elles is a cultivar that initiates its tubers late allowing the plant to allocate much dry matter the foliage. When subjected to stress such a genotype makes better use of the available growing season because its length of the growth cycle better matches the length of the growing season than an earlier genotype.

Incorporation of the effect of drought stress in LINTUL was done by van Keulen and Stol (1995). The level of drought stress (S_d) is then calculated as:

$$S_d = \left(1 - \frac{T_A}{T_P}\right) - 0.2$$

where T_A (actual transpiration) falls short of potential transpiration (T_P) under limited soil moisture availability. T_A/T_P decreases linearly with soil moisture content from unity at the critical soil moisture content to zero at wilting point. The reduction by 0.2 accounts for the tolerance of leaves to low degrees of stress.

The growth rate is multiplied with increasing S_d from 1 at 0, via 0.5 at o.5 to 0 at 0.75. The effect on leaf senescence is dependent on cumulative drought stress (i.e. the integrated value of S_d) in such a way that, due to accelerated leaf senescence, the crop canopy does not expand any further beyond a cumulative drought stress value of 10. At still higher values, light interception decreases irreversibly. Beside worldwide potential yields as shown in Figure 5.5, Van Keulen and Stol in the same paper reported the water limited yields and by subtracting the two, the benefit of irrigation. This approach is know as yield gap analysis. Yield gaps are defined as the difference between the potential production and the attainable and/or actual crop production. Yield gaps illustrates the possibilities of crop and or management improvement.