# THE APPLICATION OF MODELLING IN THE POTATO PRODUCTION CHAIN

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## Summary

This paper illustrates a mathematical model describing growth and development of the potato crop LINTUL-POTATO. The model is used firstly to identify suitable potato growing areas and seasons anywhere in the world through agro-ecological zonation. Then the model allows the identification of the genetic requirements of potato crops to achieve the highest yields in the identified zones and seasons through the exercise of ideotyping. The degree of adaptation of existing cultivars and new genotypes is examined through exploration. Special adaptations of LINTUL-POTATO are used in decision support for planning of e.g. applications of water and nitrogen. The model is used for quality monitoring (e.g. dry matter concentration and tuber size), yield prediction and scenario studies. The methods involved are explained and examples of the various applications are given.

## Introduction

Potato in the Netherlands is an important economic commodity. The total amount harvested of 180 000 ha grown annually exceed 8 million tonnes. About a third is processed by the starch industry, a quarter is used as seed for national production and mainly for export and the remainder is used as ware potato of which a major proportion is processed as crisps and deepfrozen French fries. Almost 1 million tonnes are exported annually to growing areas that often have substantial different growing conditions than hose in the Netherlands. In recent years the development of models of crop growth and development has received increased attention and gradually is moving from research to application in the potato industry. Modelling has become important in practically all links of the potato production chain. This chain starts at the identification of the suitable environment and ends at the application of the potato and its derivatives in consumer products. The full chain of quantitative research of potato is represented schematically in Figure 1.

Modelling is a tool that receives increasing attention and is being applied rapidly by users in the potato industry. The use of crop growth modelling with the aid of LINTUL-POTATO (Kooman & Haverkort, 1995) allows the identification of suitable potato growing areas and suitable periods of the year expressed as the length of the duration of the growing season in daydegrees. The model subsequently calculates the total and tuber dry matter that can be produced under non limiting (potential production) and under rainfed conditions when precipitation and soil moisture often is not enough to reach potential production. Incidence of other abiotic (e.g. lack of mineral nutrients) or biotic factors (e.g. foliar diseases or soil borne nematodes) can also be modelled. After setting the temperature bounderies of potato growth, the model indicates the length of the growing season then calculates potential and attainable yields. Subsequently genotype characteristics are defined allowing the highest yields. It is also possible to explore the yielding ability of existing

**Identification of suitable growing areas**
*Agro-ecological zoning*
⇓
**Plant type design of the ideal genotype for a given environment**
*Ideotyping*
⇓
**Breeding of new cultivars**
*Exploration of adaptability*
⇓
**Production of seed and ware potatoes**
*Decision support systems, precision agriculture, yield prediction*
⇓
**harvest, storage processing and application**
*quality monitoring*
⇓
**Explorations throughout the whole chain: interaction of biophysical and socio-economic environment**
**Scenario studies**

**Figure 1** Complete chain of quantitative research on potato

cultivars once their sensitivity of dry matter distribution to temperature and daylength is known.
Once the model has assisted in the strategic planning (when and where to grow and with which cultivar and rainfed irrigated) the model then assists in tactical decision making during the growing season. The model is being developed to assist growers to use the model in decision support (e.g. supplemental nitrogen application and irrigation planning and is a basic tool in precision farming. For yield prediction purposes the model is used to calculate yields and often more important, the quality characteristics such as tuber size distribution, based on meteorological data, on an ecoregional base, aided by sensing data from satellites or aeroplanes. The quantitative approach, finally, allows the study and comparison of several scenarios on e.g. the use of water or organic versus current farming practices. The potato crop growth model in the potato production chain is useful for breeders, farmers, processing and tools industry and policymakers at political and research levels.

The objectives of this paper are to briefly describe the potato model and to illustrate its use in the various links of the potato production chain.

## Modelling approach

The basic modelling tool is the LINTUL-POTATO summary model (Spitters and Schapendonk, 1990; Kooman and Haverkort, 1995, van Haren and Haverkort, 1997). This model of potato growth and development is based on the interception and utilisation of light to produce dry matter and on the distribution of the dry matter over tubers and other plant parts. The model assumes that potatoes can be grown when monthly mean temperatures are between 5´ and 28´C. An adequate length of the growing season should exceed 1250 daydegrees and when longer that 2500 daydegrees two crops may be grown per year. The development of the crop is dependent on temperature (determines leaf extension thus light interception) and daylength which determines the moment of tuber initiation thus crop earliness. To calculate tuber production a fixed conversion rate between intercepted light and dry matter production is assumed that only varies with light intensity and temperature. Under temperate conditions 1 megajoule of intercepted dry photosynthetically active solar radiation is converted into 2.5 g of dry matter. At very high light intensities the conversion rate declines due to saturation and at temperatures exceeding 25 'C it declines due to respiration. Crops are further affected by cultivar and biotic and abiotic (especially water availability) factors of which many reactions have been quantified and linked to crop growth processes such as leaf growth, conversion efficiency and dry matter distribution. Figure 2 shows a relational diagram of the model with its various parameters. Depending on the objectives of its application, the model needs more (e.g. for ideotyping) or less (e.g. for yield prediction) detail. Input in the model is planting and harvest date (although the model may derive these dates itself for agro-ecological zoning purposes), soil water holding capacity, daily maximum and minimum temperature, solar radiation, evapotranspiration and precipitation. The model can be linked to other models describing dynamic processes such as nitrogen availability. Examples of output of the model are total leaf area per unit soil area (leaf area index), total and tuber dry matter.

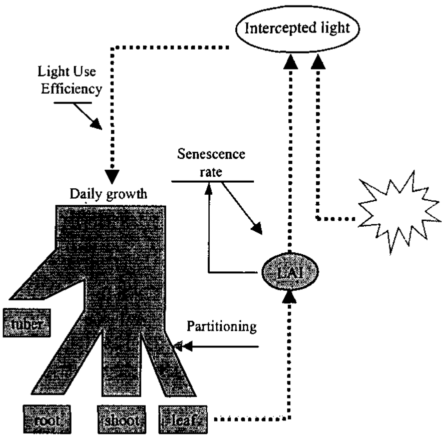


**Figure 2** Relational diagram of LINTUL-POTATO, solar radiation is intercepted by the plant leaves and converted into biomass which is allocated to the different plant organs.

## Agro-ecological zoning

Agro-ecological zoning is an activity aimed at identifying the areas where growing conditions of a particular crop are suitable for production. Crop requirements need to be known such as its temperature requirements. Potato has a lower temperature optimum than rice and a higher optimum than wheat. Its tolerance of abiotic stresses such as drought and frost are important characteristics. Whether the crop is a C3 or a C4 crop (influences the conversion efficiency) and the sensitivity of its dry matter distribution pattern to environmental factors such as daylength are equally important. Once the temperature requirements and the other physical constraints are know the potential (no limiting conditions) and attainable (supplied with nutrients and water) yields can be calculated. Where the crop is actually grown these data can be confronted with actual yields that farmers obtain that are usually somewhat lower because of diseases and pests. The difference between potential and actual yields is often referred to as yield gap. Analysis of factors determining the yield gap can reveal critical key-factors which can explain the major part of the differences. Figure 3 shows an example of global potential potato yields.

Agro-ecological zoning of potato may be used to optimise resource use efficiency. For instance, in Asia there is a large belt around 30 ' latitude where during the monsoon rice is grown without irrigation and where in the dry season irrigated crops can be grown. Farmers may then grow rice in the hot period just prior to the monsoon or potato during the coolest part of the year. When water is limiting, the model shows how much more efficient potato is using water than rice: almost four times more efficient. The model also shows the comparative advantage of one commodity over the other and where then to put emphasis of research efforts based on overlays of maps of agro-ecological zonation and population density.

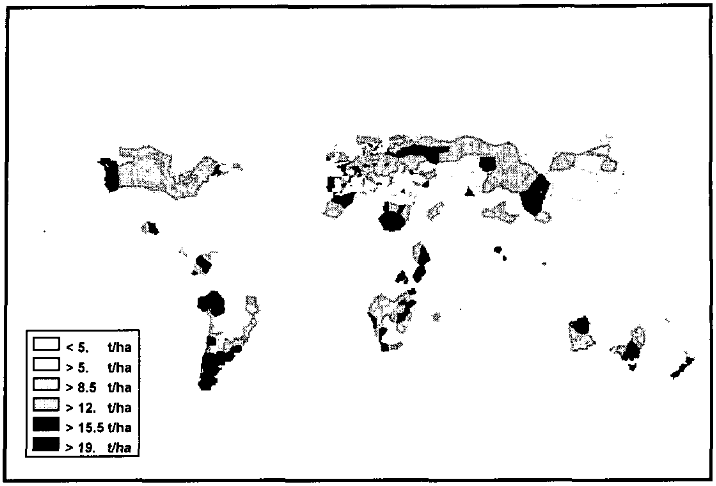


**Figure 3** Calculated potential potato dry matter yields (Van Keulen and Stol)

## Ideotyping

Once the area, season and temperature, precipitation, daylength regimes in agro-ecological zoning have allowed the calculation of potential and attainable yields, subsequent ideotyping uses the potato model to identify the genetic traits that will lead to the highest yields in the target agro-ecological zone. Species differ greatly in a number of traits. Examples are the soil temperature dependent sprout growth rate determining the time of emergence, the leaf area at emergence, the leaf area extension rate, the temperature and photoperiod dependent moment of initiation of reproductive organs and their subsequent growth rate. The cessation of growth and plant death is often determined by internal competition for assimilates (carbon) or nutrients (e.g. nitrogen.). Between genotypes of the same potato species (*Solanum tuberosum*) there is little variation regarding most characteristics. The genotypes (beside tuber number and dry matter concentration) mainly differ in their length of the growth cycle (lateness). Therefore the length of the growth cycle depends on the moment of tuber initiation and the subsequent tuber growth rate. With increasing size the daily tuber growth rate increases until it reaches the same value as the daily total crop growth rate. From then on the leaves receive no more assimilates and die after a fixed number of daydegrees. In ideotyping it is most important, therefore, to create genotypes with a length of the growth cycle that matches that of the growing season. The ideal moment of tuber initiation and dry matter allocation to the tubers as to arrive at a crop that is not too early nor too late are crucial characteristics of the ideotypes.

Genotypes may differ in other characteristics, or should in order to increase the yielding ability. The traits that have been tested and the relative influence on yields in conditions are shown in Table 1. More +'s in Table 1. Indicate a greater exertion of influence of the parameter on the yield. Some characteristics, however, with a grate influence such as light and water use efficiencies, although when genetically modified would exert a great influence on yield, can not be altered as they are extremely conservative following physical limitations. Other characteristics should not be singled out and be altered alone. The early development of the foliage would lead to increased water use early in the season. When the winter water storage is depleted then, water scarcity may be more serious at maximum tuber growth. So often two or three characteristics should be altered at the same time (increased early development coupled with increased rooting depth. Management practices aimed at early ground cover to increase interception of solar radiation have only limited effect as low spring temperatures lead to low development rates and only few days earlier canopy closure.

**Table 1** Some examples of sensitivity analysis of characteristics of management, genotype and environment under conditions in the Netherlands (Haverkort and Grashoff 1996, unpublished)

| Characteristic | influence on yield | Characteristic | influence on yield |
|---|---|---|---|
| planting date | + | relative leaf expansion rate | ++ |
| planting depth | + | start of leaf death rate | + |
| relative sprout growth rate | + | maximum leaf area index | ++ |
| base temperature for development | + | light use efficiency | +++ |
| plant density | + | water use efficiency | +++ |
| number of stems per plant | ++ | moment of tuber initiation | +++ |
| leaf mass at emergence | ++ | relative tuber growth rate | ++ |
| specific leaf area | + | rooting depth | +++ |
| light extinction coefficient | + | drought induced leaf death rate | ++ |

## Exploration

Once bred, the exploration of their adaptability to other areas than originally designed for is carried out making use of the susceptibility of plant characteristics to environmental factors as daylength, temperature and drought. As was shown, the moment of tuber initiation determines the length of the growth cycle. In a given agro-ecological zone, e.g. the North African part of the Mediterranean basin where in January temperatures are too low and in June too high for potato growth, the season is limited to 110 days. When genotypes with varying moments of tuber initiation are tested by the model, the moment of tuber initiation shows an optimum at about 35 days after planting. Earlier tuber initiation leads to earlier senescence and later tuber initiation leads to the presence of too much foliage when high temperatures inhibit growth at the end of the season leading to a low harvest index and to reduced yields. An example of another genetic trait that can easily be explored is frost resistance. Suppose potato could support two additional degrees of frost resistance (say minus four rather than minus two degrees or that it could still produce at acceptable levels when adapted to two degree higher temperature. Where would this have the greatest impact?. Figure 3. Showed the potential yield. Water limited yields, however, are drastically lower in most part of the world where the crop is rainfed and farmers have no access to irrigation. Figure 4 shows the yield under water limited production. The difference between figures 3 and 4 indicate where irrigation would have the greatest impact, but it also shows where increased drought tolerance through breeding for increased rooting depth would have the greatest

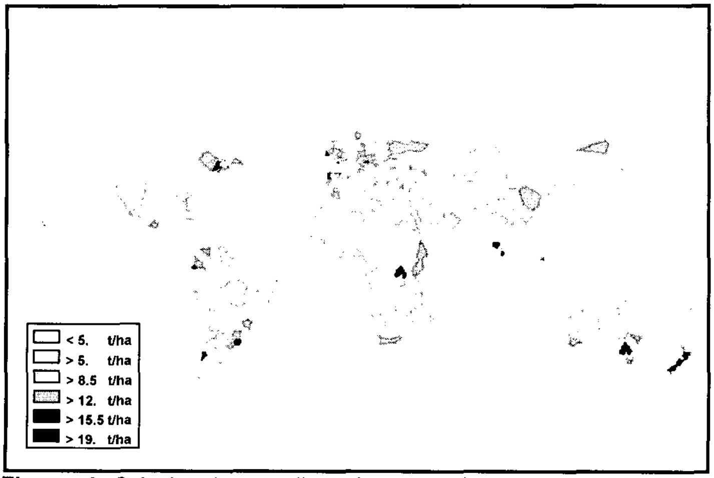


**Figure 4** Calculated water-limited potato dry matter yields (Van Keulen and Stol)

impact.

## Decision support systems

The crop model can be used for strategic and tactical decision support systems. Strategic decisions are made before actual planting and allow farm and crop management alternatives. Tactical decisions are made during the cultivation period to optimise the use of resources. To be part of a decision support system the model is further refined to calculate the effect of crop measures such as irrigation and supplemental nitrogen dressings during crop growth. When coupled to economic data growers may or may not apply
Split dose application of nitrogen is becoming increasingly popular in crop production. Part of the total expected nitrogen requirement of the crop is then applied before or at planting and another part is applied later during the crop cycle. An advantage of split application, compared to one single application before planting is that this practice reduces the environmental risk of losses through leaching, volatilisation and immobilisation and it offers the financial possibility

to reduce the total amount to be applied. Reduced nitrogen application aimed at adjusting application rates to crop needs reduces emission of nitrate and ammonia to the environment and enhances the environmental friendliness of crop production. Basic research is needed to develop methodologies for the assessment of crop nitrogen contents at the same moment that the soil is sampled for the amount of mineral nitrogen still present in the soil. Based on these two data a more sound advice for supplemental nitrogen fertilisation can be given than based on soil mineral nitrogen only. The hypothesis presently tested is the general applicability of the relationship between crop nitrogen content and its leaf area index (LAI). The leaf area index of the crop at the moment of sampling seems to be related to the total amount of nitrogen taken up by the crop. This recent finding may offer elegant possibilities to non-destructively asses the amount of nitrogen present in the crop. The expected total uptake leads to the amount that is still required. The crop requirement should be present in the soil or be applied. Two methods of LAI (thus crop nitrogen content) assessment are presently under investigation. The first is through modelling as it is known that the relative leaf extension rate as a function of temperature has a conservative value. Emergence date and the initial amount of leaf area at emergence are then crucial data. A second way is through non-destructive measuring with the aid of infrared reflectance. The second method probably will approach the LAI-value better than the first method.

## Yield and quality prediction

On a regional scale LINTUL-POTATO is being used to predict final yields months before the final harvest which helps trade and industry. Incorporation of aspects such as dry matter content, starch and sugar contents, starch viscosity and tuber size distribution for quality monitoring is part of present further development. The quantitative relationships include total dry matter accumulation as calculated with LINTUL, dry matter content of the tubers depending on the temperature during the growing season and amount of precipitation and or irrigation. The number of tubers is hard to predict but when the tuber number is assessed in July, the predicted tuber size distribution depends on predicted total tuber dry matter produced by the final harvest time.

## Scenario studies

The model is being used for scenario studies for policymakers both at the political level and the level of the industry. Questions that are answered relate to specific issues such as:
-what yield levels are expected when the crop is subjected to restrictions such as limited water use for irrigation or when nitrate levels at harvest should not exceed e.g. 70 kg in the soil
-when the use of biocides is restricted, e.g. no more soil fumigation, what yield levels are expected given tolerance levels and
-move into other commodities, what is the comparative advantage of one crop or the other given the agro-ecological setting and which crop makes best use the environment (climate, soil) and inputs (e.g. water)
- risk analysis an be carried out easily. What are the chances of hitting a damaging nightfrost when planting earlier or going uphill, or how often will crops suffer damage from droughts when irrigation is non existent or restricted due to scarcity or alternative use (for cities).

## Conclusions

The approach shown in this paper describing the application of modelling in the potato production chain demonstrates the wide use. Figure 5 summarises the various aspects in a schematical representation. The quantitative approach is of use for many actors involved in the potato industry.

Potato breeders make use of modelling to target the orientation of breeding programmes and to explore the modification of genotypes to reduce the costs of crop improvement and crop introduction programmes. When in a target agro-ecological zone one trait will have a greater impact than the other, breeding will aim for the former. The approach also shows that single trait improvements not always have the desired effect

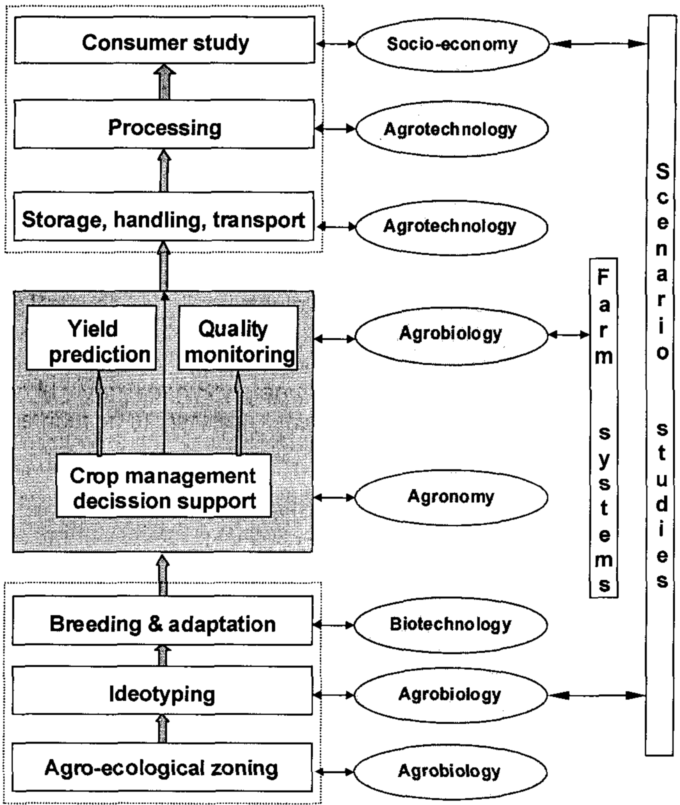


**Figure 5** Schematic representation of the use of modelling in the potato chain

and sometimes may even be counterproductive such as enhancement of early foliar development without assuring water availability later in the season.

Farmers are increasingly using crop growth models in their decision support systems. Irrigation planners and methods to optimise supplemental nitrogen dressing gradually are basing themselves on crop growth modelling and so is the industry (ideotyping and yield).

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