# Modelling potato growth and development with parameters derived from remotely sensed data

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## Abstract

Light interception models are conveniently used for simulating crop development and growth. The light interception mechanism is generally approximated using canopy cover (CC) or leaf area index (LAI). This paper introduces the use of vegetation indexes as a reliable, low-cost alternative to parameterize tuber crops models or to directly assess plant behavior. Data from experiments conducted in the Peruvian coast both within a growth chamber to generate the parameters and in the field for validation, were used to prove the concept. The growth chamber was furnished with 3 large pots 3x4x0.8m containing sand, and the air temperature was maintained between 11 and 23 ºC whereas the soil temperature varied between 10 y 20 ºC. Potato seeds were planted at a density of 4.17 plants $m^{-2}$ and received fertigation through a solution equivalent to 215-90-370 N-P-K units. Photosynthetic active radiation (PAR) inside the chamber fluctuated between 0.77 y 7.55 MJ $m^{-2}$ $d^{-1}$. Reflectance data were measured through orthogonal photographs registered with the Dycam Inc. agricultural camera at about 2 m above the canopy on 18 plants randomly selected. The digital values registered in the red and near infrared region of the spectrum were used to estimate the Normalized difference vegetation index (NDVI). The model predicted yield within the growth chamber with less than 5 % error. Results in the field trials were variable.

**Keywords:** Modeling, potato, remote sensing, NDVI

## Introduction

Plant growth, defined as dry matter increment over time, is governed by physiological processes and can be described quantitatively, using empirical models, including regressions. The parameterization, calibration, and validation of this type of models, of simple structure, can contribute to the forecast of the expected plant growth and yield in different future scenarios (Spitters, 1990).

Monteith and Moss (1977) define the efficiency of crop production in thermodynamic terms as the ratio of energy output (carbohydrate) to energy input (solar radiation). Total production of dry matter by barley, potatoes, sugar beet, and apples is strongly correlated with intercepted radiation.

The light interception mechanism is generally approximated using canopy cover (CC) or leaf area index (LAI). However, remote sensing techniques might improve our capacity to estimate the radiant energy intercepted by the plant through the measurement of the spectral reflectance and the construction of vegetation indexes. Bouman, et al., 1992a; 1992b, highlighted the advantages of using the values of reflectance as a simple, fast and non-destructive indicator to estimate light interception by the plants. They suggested that reflectance data is more appropriate than canopy cover and leaf area index to quantify light interception by the canopy.

The spectral response of the crop, defined as the proportion of incident energy that is reflected, depends on the interaction of the electromagnetic energy with the plant canopy. This information indicates the vigor of the plants that in turn, depends on the agronomic management and on the genotype-environment interaction.

In this research, the parameters of a potato growth model, based on interception and utilization of light, were determined using canopy cover and reflectance. The predictive capacity of the potato model, parameterized with reflectance information, was compared in terms of fresh and dry matter production with the growth and yield of potato grown under controlled environment and field conditions.

## Materials and methods

An experiment was carried out in a growth chamber with controlled temperature at CIP headquarters in Lima. The aim of the work was to determine the parameters of a growth model based on light interception (Spitters, 1990). Commercial seed of potato cv. Canchán was planted on June 2006. The growing period lasted 150 days, until November 2006. The crop was managed assuming potential growth conditions, that is, with no limitations of water and nutrients, and without the effect of pests or diseases of importance.

The growth chamber was furnished with 3 large pots 3x4x0.8m containing sand, and the air temperature was maintained between 11 and 23 ºC whereas the soil temperature varied between 10 y 20 ºC. Potato seeds were planted at a density of 4.17 plants $m^{-2}$ and received fertigation through a solution equivalent to 215-90-370 N-P-K units. Photosynthetic active radiation inside the chamber fluctuated between 0.77 y 7.55 MJ $m^{-2}$ $d^{-1}$.

## Data collection and analysis

Temperature, radiation, and the crop's phenological stages were registered as input data every 10 days, according to Kooman et al. (1996). Canopy cover, light reflectance and the dry matter of plant organs were also measured every 10 days for monitoring the growth and development of the crop.

Canopy cover was estimated on 18 plants, using a grid adapted to the spacing between plants (Haverkort at al., 1991). The grid, of dimensions 0.8*0.3 m and 100 cells, was placed approximately 30 cm above the canopy. The cells with more than 50% coverture of green plant material were counted.

In order to obtain reflectance data, orthogonal digital photographs were taken with an agricultural camera Dycam, Inc. placed some 2.10 m above the plants. The information recorded in the red (635-667 nm) and near infrared (835-870 nm) bands, were calibrated and used to calculate the normalized difference vegetation index (NDVI), using the software ENVI.

Plant dry matter weight was obtained from 6 plants, taken at random in each sampling date. The dry weights of leaves, stems, roots, and tubers were obtained periodically and the energy partitioning was estimated as the ratio of the organ DM to total DM.

## Model parameterization

The growth model, based on light interception and utilization as proposed by Spitters (1987, 1990) and Kooman (1995), was used to simulate the daily accumulation of dry matter, through the following general equation:

$\Delta Wt = ft*PARt*E$

Where:
$\Delta Wt$ = the growth rate at day t (g DM $m^{-2}$ $d^{-1}$)
ft = the fraction of PAR intercepted by the foliage
PARt = the incoming amount of photosynthetically active radiation (MJ $m^{-2}$ $d^{-1}$)
E = the average light utilization efficiency (g DM $MJ^{-1}$ PAR)

The model uses 10 parameters that describe the principal processes involved in the capacity of intercepting light, the efficiency of light utilization and the partition of assimilate to the tubers.

A logistic function describes the capacity of the leaves to intercept light, from emergence to maximum canopy cover. The parameters were in turn estimated using a non-linear regression between the measured canopy values and the cumulative thermal time. The decline in light interception, during foliage senescence, was described by a linear function.

The light use efficiency was determined as the slope of the linear regression between the total dry matter weight and cumulative intercepted PAR radiation, passing through the origin.

The dry matter partition to tubers was estimated as a function of the cumulative thermal time from emergence. The parameters were estimated through a non-linear regression.

## Highlands field data

The commercial potato cv. Canchán was planted in field plots in the highlands of Peru in order to obtain data to validate the previously parameterized model. The crop was grown under non-limiting conditions of water and nutrients, between January and April 2008. During the growing period, minimum temperatures of 6º C and maximums of 19º C and average levels of global solar radiation of 18 MJ $m^{-2}$ $d^{-1}$ were recorded.

Plant population was 3.7 pl $m^{-2}$. No pests or diseases of economic importance were observed.

Temperature, radiation and NDVI, calculated on the basis of the reflectance measured in field were used as input variables for simulating the growth of the crop.

## Results and discussion

Table 1 shows the coefficients obtained for the parameterization of the model. Differences in the parameters associated with the capacity of the plant to intercept light and the light use efficiency, with predictions based on canopy cover or NDVI, are noteworthy.

**Table 1. Parameters for the model**

| Potato cv. Canchán | GC1 | NDVI 1 | NDVI 2 |
|---|---|---|---|
| Maximum fraction of radiation intercepted (fcl) | 0,973 | 0,807 | 0,760 |
| Initial light interception capacity (f0) | 0,006 | 0,002 | 0,002 |
| Initial relative leaf growth rate (R0) | 0,007 | 0,013 | 0,013 |
| Duration of leaf senescence (od) | 612 | 907 | 907 |
| Time when light interception was reduced to 50% (t50) | 1718 | 1718 | 1718 |
| Light utilization efficiency (AND) | 5.5 | 6.3 | 6.3 |
| Asymptotic maximum of the harvest index (M) | 0.8 | 0.8 | 0.8 |
| Initial slope of the harvest index curve (b) | -2.4 | -2.4 | -2.4 |
| Thermal time at the initial harvest index curve (A) | 722.6 | 722.6 | 722.6 |
| Tuber dry matter content (DMc) | 0.2 | 0.2 | 0.2 |

1 Growth chamber (CIP, Lima)
2 Field (Huancayo, Peru)

The results of the simulations under controlled conditions showed that a greater prediction approximation to yield was found using NDVI (Figure 1). On the other hand, when canopy cover was used as estimator of the light interception capacity, yield was slightly overestimated. This can be explained by the fact that reflectance provides not only estimates of canopy cover but it is also affected by the vigor of the plant, which might be the end effect of many factors. Overall, both approaches provided adequate probabilistic yield estimates, shown by the overlapping confidence intervals. Fresh tuber average yields were 80 kg $10m^{-2}$, 89 kg $10m^{-2}$, and 77 kg $10m^{-2}$ for measured, canopy cover based prediction and NDVI based prediction, respectively.

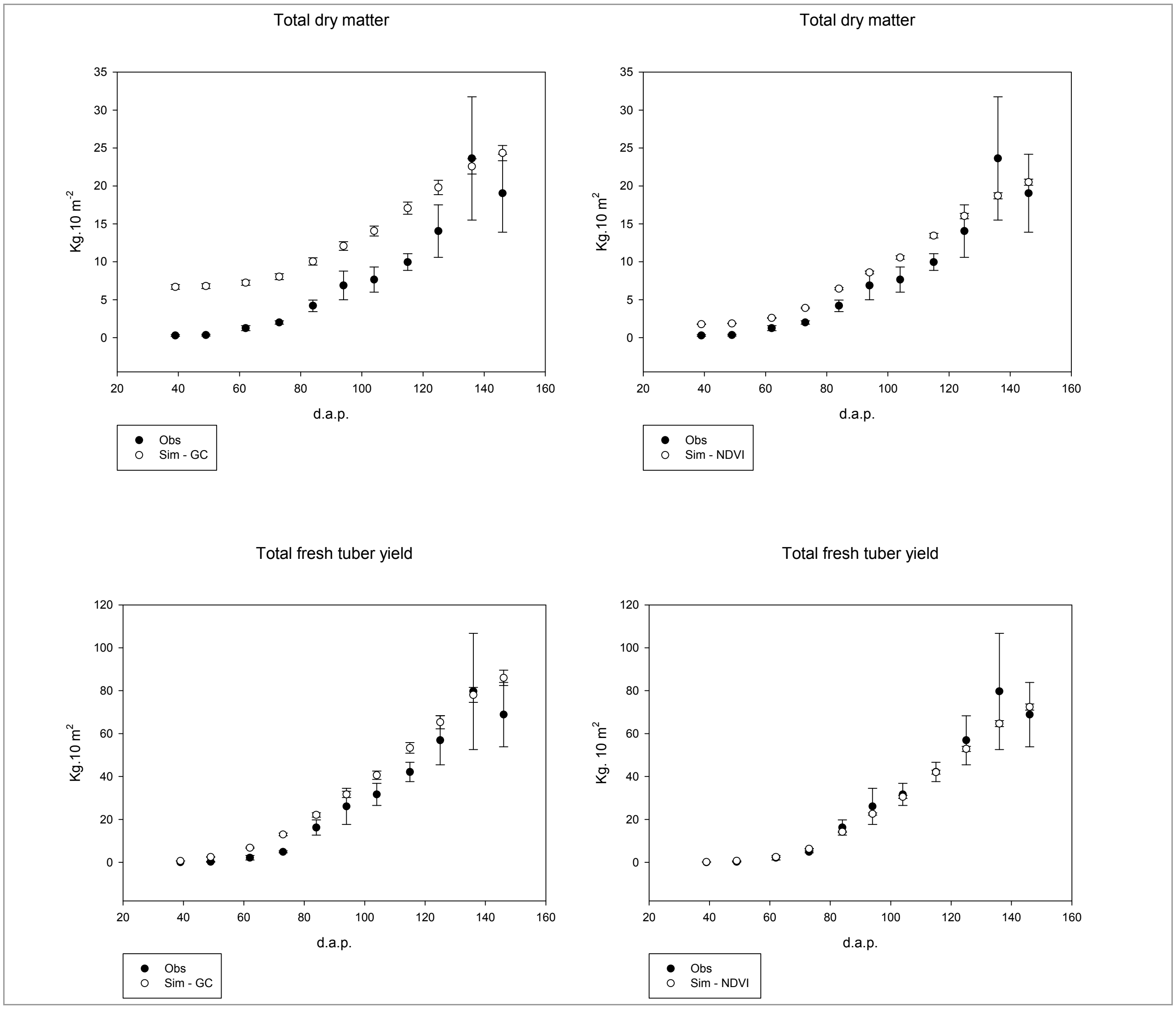


**Figure 1. Estimating potato growth and tuber yield under controlled conditions, using simulation models**

The model parameterized with NDVI was further validated with data from a field in the highlands of Peru. Measured fresh yield 105 d after emergence was 40 t $ha^{-1}$ whereas the simulated yield was 44 t $ha^{-1}$. The 99 % confidence interval worked out by the simulation model includes the measured yield (Figure 2).

Results have shown the adequacy of light interception based models parameterized with remotely sensed data from potato crops without significant biotic and abiotic stressors. Our lab is conducting research to streamline the same concept for improving our capacity to estimate yield under the stresses faced by the potato crop in different parts of the world.

## Conclusions

The growth and yield of potato grown under non-limiting conditions in both controlled growing chambers and in the field was satisfactorily estimated by means of a light interception based model. All ten parameters needed to drive the model were adequately inferred from remotely sensed data. Yield predictions were improved when the light harvesting capacity of the plants was estimated on the basis of the normalized difference vegetation index calculated throughout the phenology of the crop.

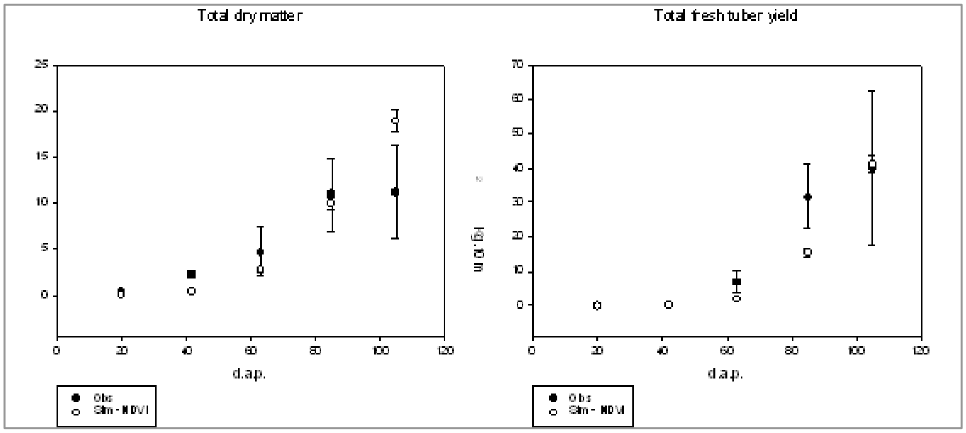


**Figure 2. Estimating potato dynamics and tuber yield under field conditions, using simulation models**

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