Improving targeting of potato producing areas with process-based modeling

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Abstract

The International Potato Center (CIP) has targeted countries and regions (highlands, lowlands, temperate) where potato technologies could improve the livehoods of poor people, but in these huge geographical areas it is difficult to identify specific sites suitable for growing potato. An approach to identify and assess the areas with potential for potato production is described and applied to improve the targeting process. The potential potato areas were identified by the combined use of the Solanum simulation model and georeferenced databases. These databases included minimum temperature, maximum temperature and solar radiation. Monthly minimum and maximum temperatures were downloaded from www.worldclim.org; while solar radiation was estimated as a fraction of the extraterrestrial solar radiation for each geographical position. The model was run for 12 planting times (planting the first day of each month) for a standard potato cultivar. The sites and the cropping seasons with the highest yields were selected. Estimated potato yields were then complemented with livehood indicators for targeting CIP priority regions in Africa, Asia and Latin America.

Keywords: Simulation model, Geographic Information Systems, Targeting.

Introduction

CIP has conducted a global targeting exercise using indicators of livelihoods in areas where potato is an important crop (CIP, 2004, Theisen and Thiele, 2008). The target countries were divided into three regions, each with similar potato technology needs, which are: i) temperate zones – defined by geographical position, ii) Sub-tropical lowlands – a region that prioritized cereal-based systems where potato could be introduced to increase the system's productivity and iii) tropical and sub-tropical highlands – tropical and sub-tropical areas with altitudes above 800 meters above sea level (CIP, 2009). This type of exercise is limited by the quality of the reported production data of potato. In the present work, we tried to reduce the dependence on reported data and substitute them with data generated with process-based simulation models. This approach opens new possibilities since it is feasible to run alternative scenarios in the targeting exercise such as the inclusion of new genotypes with tolerance to heat or drought stress or the expected impact of climate variability and change.

Previous attempts to evaluate potato agro-ecology zoning for potato production have been done using potato simulation models (Van Keulen and Stol, 1995, Hijmans *et al*, 2003, Haverkort *et al*, 2004). Nevertheless the information generated is not available for use or analysis. In this work we used a Geographic Information System (GIS) linked to a potato simulation model to explore spatially the potential potato production using a standard cultivar and the effect of using a frost tolerant potato.

Methodology

Simulation model

Solanum is a slightly modified version of the LINTUL model (Stol *et al*, 1991), which was validated in the Bolivian highlands (Condori *et al.,* 2009). Solanum comprises a group of mathematical equations that uses daily weather variables (minimum, maximum temperature and solar radiation) and crop physiological parameters to simulate the development and growth of potato. Solanum is formed by three basic equations: thermal time, canopy cover and dry matter allocation. Thermal time or heat units are expressed in growing degree-days (GDD). There are many ways to calculate GDD (Raes *et al.,* 2009; Kropff *et al.*, 1994; MacMaster and Wilhelm, 1997); for our purposes the method proposed by Kropff was used. This method takes into account three cardinal temperatures: base temperature, optimum temperature and maximum temperature. For potato, these values are 2, 20, and 30°C, respectively. Canopy cover is used to calculate the intercepted photosynthetic active radiation (PAR) and transformed into dry matter through algorithms representing physiological processes.

Weather data

Monthly temperature and precipitation data - with a resolution of 10 arc-minutes (~18 km) were obtained from internet (Hijmans, *et al.*, 2005) and downscaled to daily intervals using a linear interpolation method. Solar radiation was estimated using the extraterrestrial radiation (Spitters *et al.*, 1986) and assuming an atmospheric transmissivity of 50 % and that the photosynthetic active radiation (PAR) is also 50 % of the radiation received by the plant.

Spatial version of Solanum

The potential production routine of the Solanum model (Condori *et al.*, 2009) and the methods to create weather input data (daily temperature and solar radiation) were programmed in a script language (Python) linked to a GIS program (ArcGIS). The final program named GeoSolanum was used to generate worldwide layers of potential potato production.

Growing season and cultivar

For each pixel 12 planting dates were run in order to obtain the potential productivity in each month. Simulation was initiated at emergence and run for a period of 140 days. The model was run with parameters of frost tolerant (*Solanum tuberosum ssp. andigena*) and non-tolerant germplasm (*Solanum tuberosum ssp. tuberosum*). The frost non-tolerant cultivar was used to identify regions with single and double growing seasons, and the difference between tolerant and non tolerant cultivars was used to estimate the possible impact of introducing frost resistant materials into the target countries identified by CIP (Theisen and Thiele, 2008).

Single versus double growing seasons

As explained above, 12 planting dates were tested for each pixel. To determine the primary cropping season, the planting month that produced the highest simulated yield was labeled. To eliminate sub-optimal yields of the same planting season, two months prior and after the labeled month were excluded from the search of the secondary season. The secondary season, wherever feasible, was selected from the remaining 7 months, based on the highest attainable yield in that period. Potential fresh tubers production exceeding 40 t ha^{-1} was the selection criterion. An additional water availability criterion, as described below, was also used. A map identifying single and double season target areas was produced

Masking non suitable potato areas

The potential potato production map was streamlined through the removal of the areas where potato cannot be produced due to either heat or frost risks and/or extreme droughts or water logging. Heat and frost prone areas in levels not tolerated by the potato crop were removed using masks. The masks consisted of retaining areas with minimum and maximum temperatures ranging from 0 to 30 °C, during at least four consecutive months. The cumulative rainfall for those consecutive months had to be within 300 and 800 mm for a pixel to be retained as a rain-fed potato producing area. Areas with adequate temperature but limited rainfall were incorporated assuming irrigation water is at least partially available. At some sites potato production was not possible and a global geo referenced potato distribution was used to remove these areas (http://research.cip.cgiar.org/confluence/display/wpa/Home).

Results

The results of the simulated yields were expressed in tons of fresh matter per hectare. The simulated yield was classified into four classes, low (20-30 t ha^{-1}), medium (30-40 t ha^{-1}), high (40-50 t ha^{-1}), and very high (> 50 t ha^{-1}). Although maximum yield can be achieved in most regions of the world, temperate areas stand out as the more homogeneous. Cool tropics and subtropics are variable (Figure 1). This variability seems to be explained by climate anomalies. It is noteworthy that African highlands seem to be more homogeneous than the Andean highlands, variations that correspond to wider temperature amplitudes in the Andes that confer more variability to the simulation of potential productivity. It is then hypothesized that biotic factors explain better the gap between potential and attainable yields in African highlands whereas in the Andes abiotic factors seem to be limiting under actual conditions.

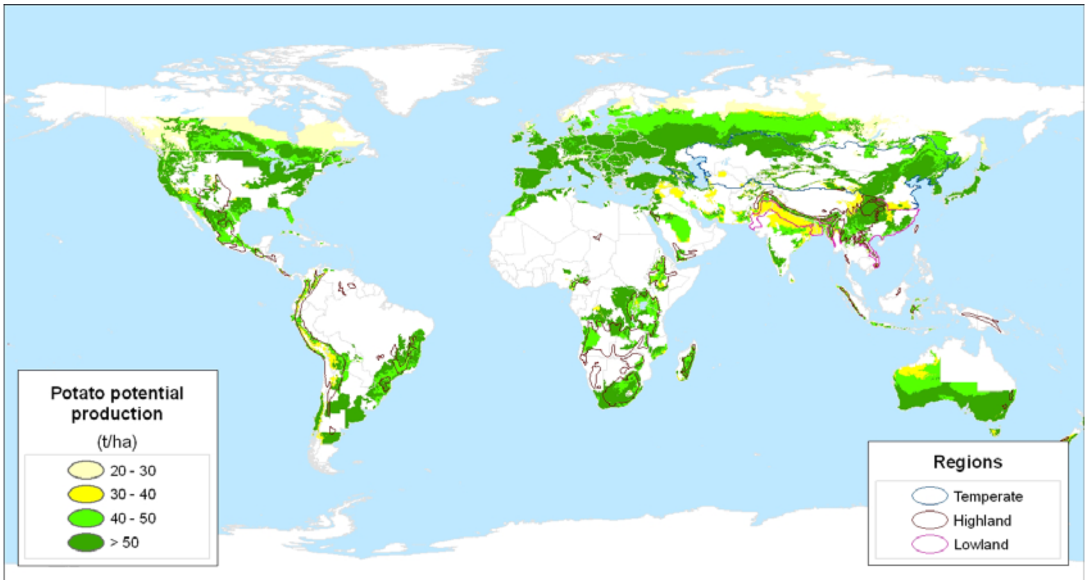

Figure 1. Potato global productivity limited by radiation and temperature, estimated with the Solanum model using the physiological parameters for *S. tuberosum spp. tuberosum*

Single versus double growing seasons

Double growing season areas were predominantly located in the highlands and subtropical lowlands, while in temperate regions a single growing season dominated (Figure 2).

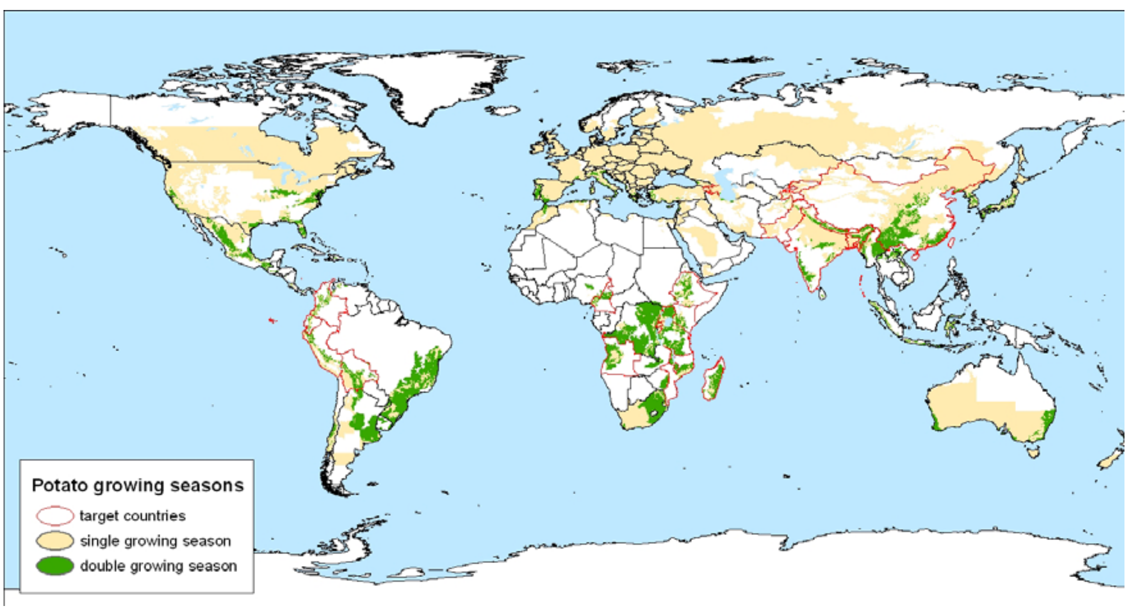

Figure 2. Growing seasons identified using the GeoSolanum model

Effect of the use of a frost tolerant potato cultivar

The analysis of the change in productivity was assessed using a frost tolerant potato cultivar in target countries and regions. This effect was quantified in areas where the minimum temperature is between 0 and 2°C, which are specially located in the highlands of South America and temperate regions. In this region the simulated yield could increase from 1 to 25% (Figure 3).

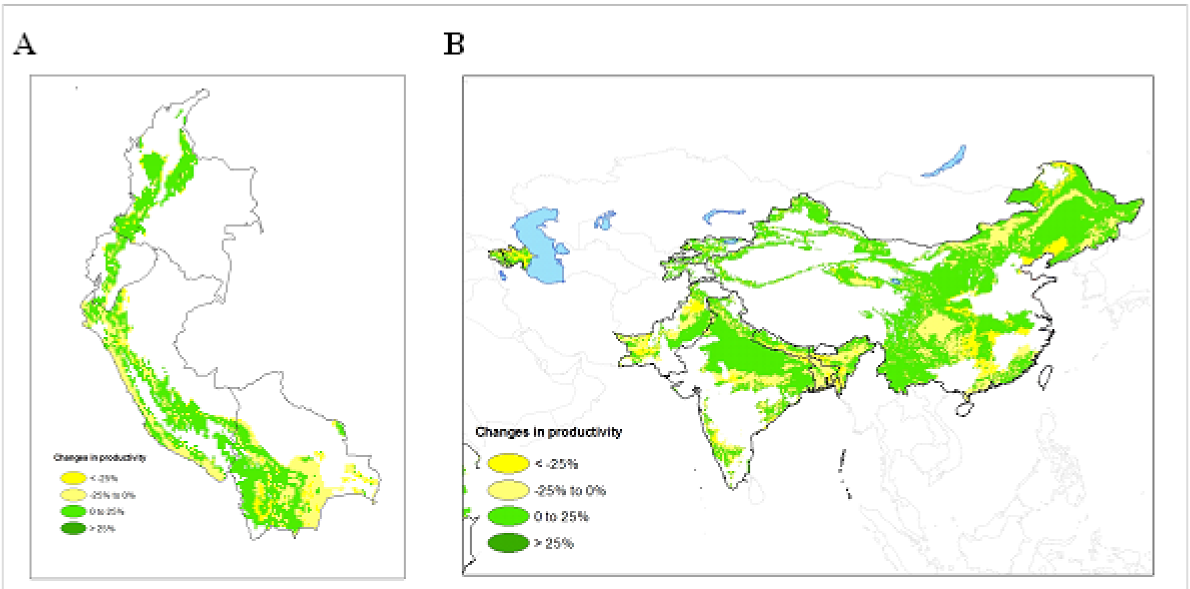

Figure 3. Changes in productivity due to the use of a frost tolerant potato cultivar in target countries of South America (A) and Asia (B).

Discusion

The GeoSolanum model is a flexible tool parameterized with physiological parameters of *S. tuberosum*, *S. andigena*, *S. ajanhuiri*, *S. juzepczukki* and their hybrids. The model does not consider the photoperiod effect, but in the future this parameter could be included. After validating these parameters in target areas around the world different scenarios can be assessed to predict the possible impact of introducing new germplasm. Water and nitrogen routines are ready to be incorporated to also simulate attainable production in target regions. Better climate downscaling procedures to incorporate climate variability and change scenarios are also being developed at CIP. The present example shows how useful geospatial modeling tools can be for targeting intervention areas where CIP can contribute to the generation of food and income through its mandate crops. Although the present example was at a global scale, a similar approach can be followed for smaller areas at a much higher spatial resolution.

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