Potato Modeling

14

Mukhtar Ahmed, Zartash Fatima, Pakeeza Iqbal, Thaira Kalsoom, Kashif Sarfraz Abbasi, Farid Asif Shaheen, and Shakeel Ahmad

Abstract

Potato (*Solanum tuberosum*) is the most significant food crop next to rice and wheat. Climate change could exert critical influences on supply of food; consequently, key challenge for modern agriculture is to develop approaches to handle its harmful impacts for confirming food security by 2050 as well as afterward. Climate variability in the form of higher temperature, rainfall variability, and increased frequency of drought have shown significant impact on potato production. Thus, it is essential to design adaptation strategies that can mitigate influence of climate change for long-term basis. Different process-based models such as Decision Support System for Agrotechnology Transfer (DSSAT), Agricultural Production Systems Simulator (APSIM), CropSyst (CropSyst VB–Simpotato), and STICS (Simulateur mulTIdisciplinaire pour les Cultures Standard) have

M. Ahmed (✉)
Department of Agricultural Research for Northern Sweden, Swedish University of Agricultural Sciences, Umeå, Sweden

Department of Agronomy, Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi, Pakistan
e-mail: mukhtar.ahmed@slu.se; ahmadmukhtar@uaar.edu.pk

Z. Fatima · S. Ahmad
Department of Agronomy, Bahauddin Zakariya University, Multan, Pakistan

P. Iqbal
Department of Botany, University of Agriculture, Faisalabad, Pakistan

T. Kalsoom
Department of Horticulture, Pir Mehr Ali Shah Arid Agriculture University, Rawalpindi, Pakistan

K. S. Abbasi
Institute of Food & Nutritional Sciences, PMAS-Arid Agriculture University, Rawalpindi, Pakistan

F. A. Shaheen
Department of Entomology, PMAS Arid Agriculture University, Rawalpindi, Pakistan

M. Ahmed (ed.), *Systems Modeling*, https://doi.org/10.1007/978-981-15-4728-7_14

shown great potential to develop sustainable agronomic practices as well as virtual potato cultivars to have good potato crop for future.

Keywords

Potato · Climate change · Higher temperature · Rainfall variability and increased frequency of drought · Process-based models

14.1 Introduction

Potato is an important crop in the world after rice and wheat with an annual production of 330 MT (FAO 2017). Major changes are going on in the world potato sector, and until early 1990s, most of the world potato was produced and consumed in Europe, North America, and former Russia. However, after 2005, most of the world potato is produced by developing countries with China at the first place and India at the third place. Almost a third of all potatoes are harvested in these two places (Fig. 14.1). Average share of potatoes production (1994–2018) by regions has been shown in Fig. 14.2. This crop is the source of income besides food security for developing countries (Lutaladio and Castaidi 2009), while burgeoning population is

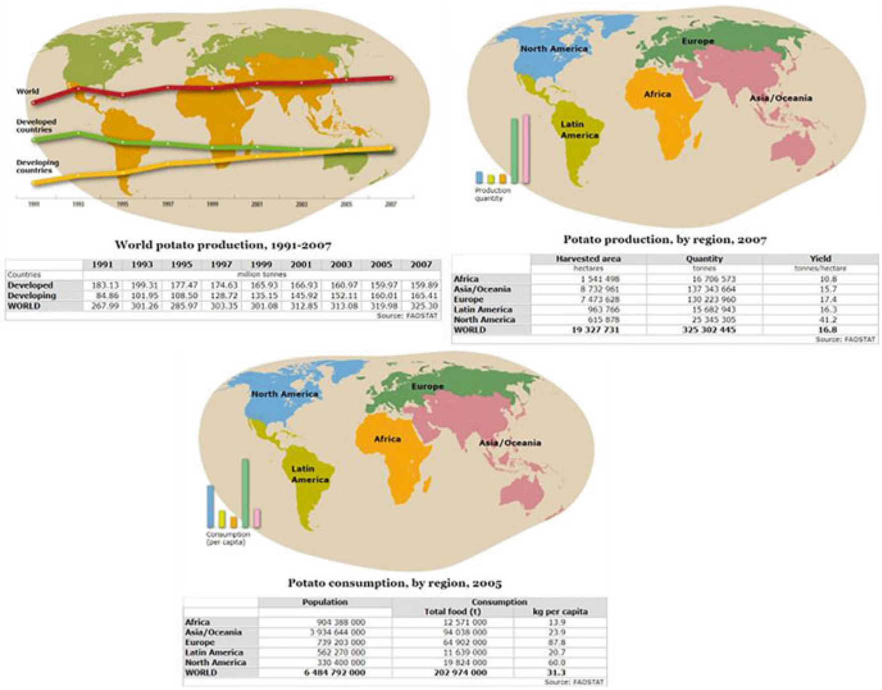

Fig. 14.1 Global scenarios of potato production and consumption. (Source: FAO; http://www.fao.org/potato-2008/en/world/)

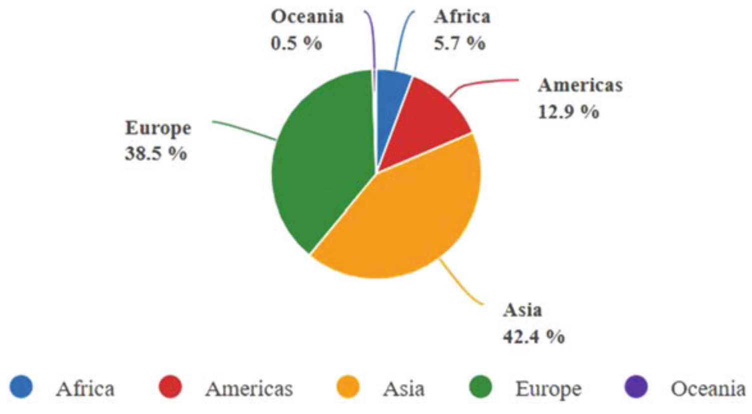

Fig. 14.2 Production share of potatoes by region (average 1994–2018)

increasing at alarming rates compared to other regions across the world (Lutz and Samir 2010). This crop is consumed as vegetable and used for food purposes. Its productivity is dependent on cultivar, management practice, and environmental condition (Dalla Costa et al. 1997; Miglietta et al. 1998; Kooman et al. 1996a, b). High temperature diminishes potato tuberization while injuries due to frost have also been reported for this crop (Hijmans 2003). Increased yield was predicted for England and Wales (Davies et al. 1996), Scotland (Peiris et al. 1996), and Finland due to higher temperature and longer growing season while an overall decreased yield was predicted for USA (Rosenzweig et al. 1996). Increased frequency of drought is another issue, which affects potato yield significantly. Costa et al. (1997) reported greatest reductions in photosynthesis, total biomass and yield when drought was imposed during tuber initiation. Similarly, they concluded that earliest stress resulted in the lowest water use effeciency and nitrogen uptake. Increasing atmospheric CO_2 concentration, increased daily mean temperature, and increased seasonal variability in rainfall are projected by IPCC (2007) worldwide during the twenty-first century. Variability in rainfall is a major concern for rain-fed potato where management practices are already major concern due to limited water availability. Seasonal solar radiation levels can also affect potato growth by potentially inducing drought. Hence, it is vital to understand the effect of short-term "cyclic" water-stress on potato growth besides elevated CO_2.

14.2 Phenological Development of Potato

The description of potato plant is shown in Fig. 14.3. Phenological development of potato is controlled by temperature (Kooman and Haverkort 1995), which will ultimately change the crop growth, development, yield, and quality (van Oort et al. 2012). It grows best at about 20 °C. It is fundamentally a "cool weather crop," as temperature being the key limiting factor for productivity; tuber growth is inhibited at temperatures lower than 10 °C (50 °F) and exceeding 30 °C (86 °F),

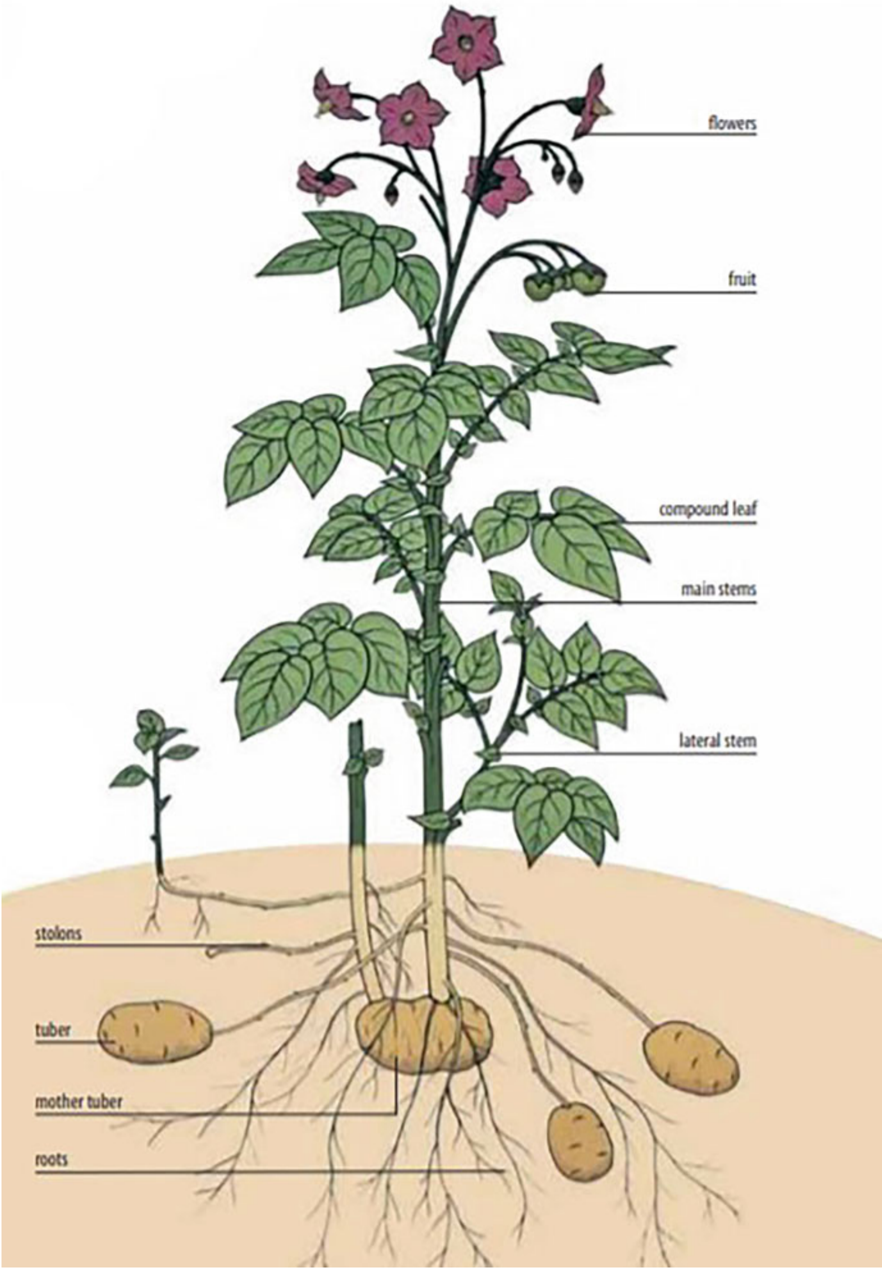

Fig. 14.3 Description of the potato plant

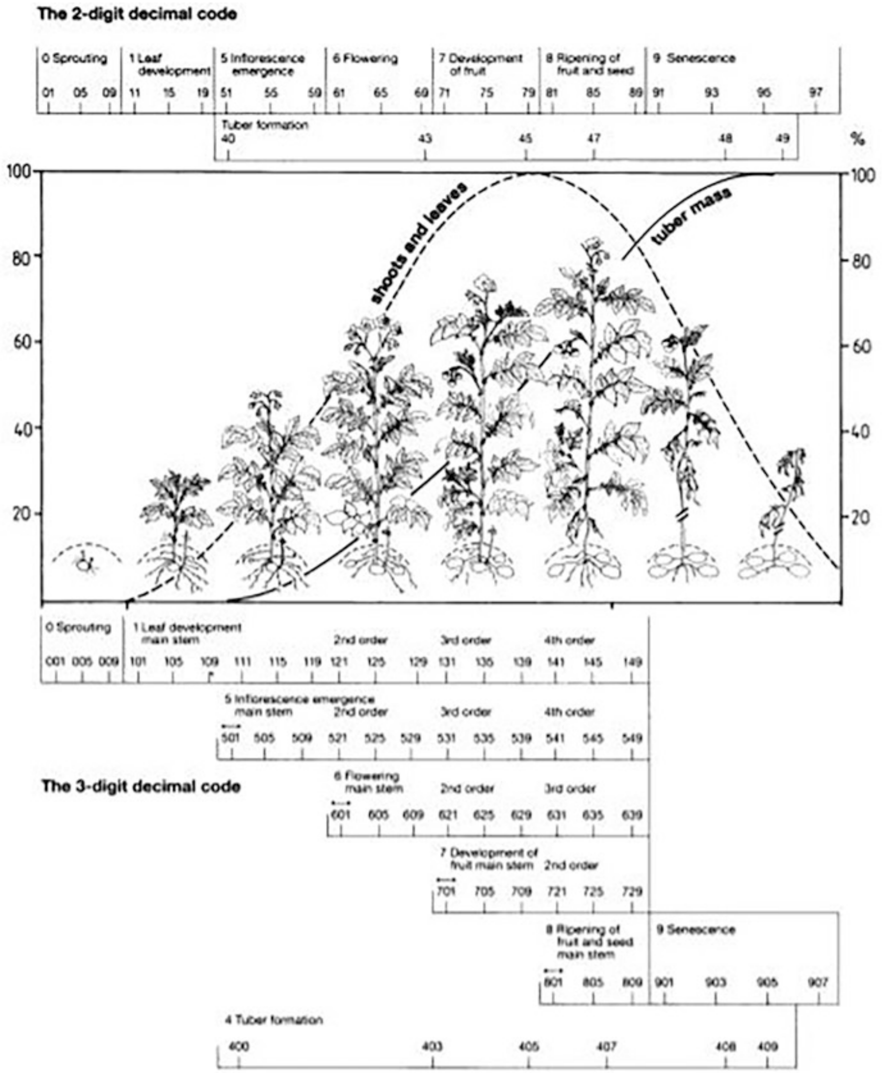

Fig. 14.4 Phenological stages of potato. (Source: Hack et al. 2001)

whereas optimal productivity is attained when daily mean temperature is in the range of 18–20 °C (64–68 °F). Due to this reason, it is planted in early spring in temperate regions while late winter in warmer areas and sown in cooler months in hot-tropical-climate. In some subtropical highlands, mild temperature and higher solar radiation permit growers to produce potatoes all over the year and produce tubers within 90 days of planting. High temperature during growing season causes changes in potatoes resulting in severe decrease in productivity (Rykaczewska 2015). Earlier work reported that the development of haulm is high at 20–25 °C while optimum array for tuberization and tuber development is 15–20 °C. The phenological stages of potato have been presented in Fig. 14.4.

Inhibition in tuberization and reduction in photoassimilate partitioning of tuber were studied by Lafta and Lorenzen (1995). Wahid et al. (2007) concluded that transitory or constant high temperature causes an array of morpho-anatomical, physiological, and biochemical changes in plants which affect plant growth, development, and yield reduction. A rising temperature leads to higher transpiration in plants which in turn increase their water demand. In several areas, drier potato sowing causes water stress, resulting in reduced yield. This effect will be further intensified by variations in rainfall distribution. In numerous countries, mainly in tropics and subtropics, productivity declines up to 20–30%. Night-time temperature has critical effect on deposition of starch in potato tubers. Ideal temperature range is 15–18 °C, and the temperature above 22 °C harshly hampers tuber growth. By contrast, climate change influence on potato productivity is predictable to be favorable in farming zones at high altitudes. In several zones, climatic situations for potato sowing are improving because of increasing temperature. In certain regions, it will be possible to produce potatoes as winter crop. Moreover, increase in potato sowing at high altitudes is also risky. Higher-altitude croplands are often located on steepy slopes, where sowing of potatoes could aggravate degradation of soil because of high tillage intensity. Adverse effect of heat stress can be mitigated by developing thermotolerant-potato varieties which is possible by understanding crop response to high temperature. Therefore, the main objective of this chapter is to quantify the influence of climatic factors like temperature, water stress on potato phenology, growth, yield, and quality on spatiotemporal scale. Hitherto, there is no such study available in which quantitative impact of heat, drought stress at diverse phenological stages and phases of growth, yield, and quality was conducted using remote sensing and modeling approaches.

14.3 Nutritive Values of Potato

Owing to its nutrition values, potato is a balanced food and is an important food crop in Pakistan as well as around the globe. Potato being cultivated across globe belongs to one species *Solanum tuberosum*, whereas it has four documented species besides 200 wild relatives. Around 5000 potato cultivars are sown in Andes. Potatoes chemical composition is effected by several elements, such as area of production, cultivar, climate and soil, husbandry practices, preparation, and cooking. Even though fundamental importance of potato being staple diet, limited is known regarding the nutrient composition of several potato cultivars. Depending on the cultivar, potato can be a valued source of minerals, such as potassium, magnesium, and phosphorus, and dietary antioxidants. Details of nutritional level of potato post boiling and peeling of the skin prior consumption are presented in Fig. 14.5.

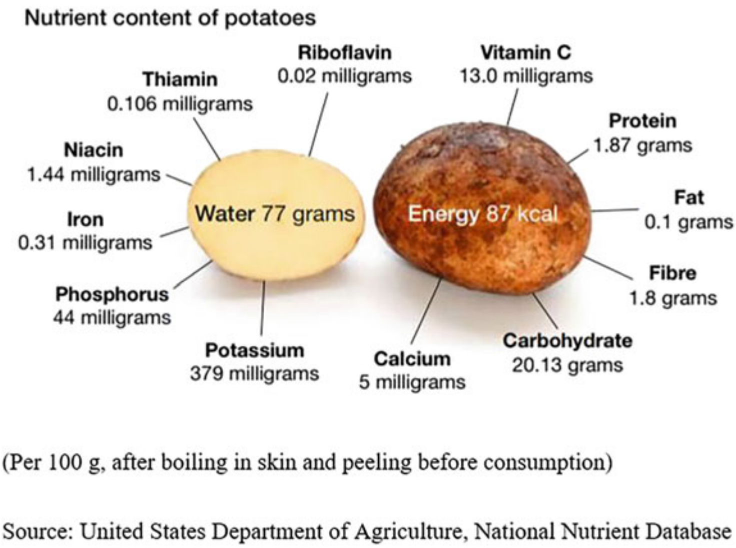

Fig. 14.5 Nutritional value of potato

14.4 Potato Production and Climate Change

Potato production can generate more economic return. This plays a significant part in food security as it can end hunger. In Pakistan, 97% increase in area under potato cultivation reported since its independence, showing how many growers are interested to sow this crop. Similarly, mean yield ha^{-1} has also been improved from 9 to 24 tonnes, and now Pakistan ranks at 20th place in the world (FAOSTAT 2017). Pakistan is self-sufficient in potato production, but due to climate change events more losses have been observed in recent years (Ahmed 2020). Climate change is now reality, and agriculture sector is one which is most vulnerable to it. Pakistan economy and its food security are largely linked with agriculture sector which is under heavy pressure due to high population, urbanization, and poor infrastructure (sowing to marketing). The climate change provides additional pressure which is difficult to sustain (Peins et al. 1996). According to the *Climate Risk Index*, Pakistan is the seventh most vulnerable country to climate change. Disease and pest pressure on potato productivity will increase because of climate change. Late blight is expected to spread to zones that have before been safe from disease. Similarly, in certain areas aphids will increase in number due to diverse seasons as it provide favorable climatic conditions. Since aphids acts as virus vectors thus causes risks in the production of seed. Currently, seed crop is grown at higher altitudes prior to seasonal occurrence of aphids for keeping it virus free. Higher production of potato in Pakistan is due to use of modern technologies and utilization of new seed varieties. However, to have sustainable yield in the context of climate change, it is necessary to have adaptation measures such as impact study analysis of climate variables on potato crop productivity and use of cultivars which can bear abiotic (high temperature and drought) and biotic stresses (late blight by *Phytophthora infestans*). The option can also be for early-maturing potatoes during short rainy seasons. Furthermore, it also requires modification in existing management practices (e.g., use of mulching, sustainable water use (drip irrigation), mixing varieties and intercropping, fertilizer rate, sowing time, access to microcredits, microinsurance, and climate information). In recent years, delay in harvesting of potato crop in Punjab was due to climate change resulting in increase in price. Similarly, cultivation in autumn beginning in September was delayed due to high temperature and rainfall variability. White and red potatoes are grown mainly in Pakistan. In Punjab, potato is mainly grown in Sahiwal, Okara, Dibalpur, Burewala, Arifwala, Kasur, Sialkot, Sheikhupura, Lahore, and Gujranwala. These areas contribute to 83% of potato production, but today these areas are under the negative impact of another climatic event called smog. Dir, Nowshera, and Mansehra from the KPK contribute to 10% production. Killa Saifullah, Kalat, and Pishin from Balochistan contribute 6%, and Hyderabad and Karachi from Sindh contribute 1% in total production of potato. In Pakistan, potatoes are grown in three seasons:. Spring (January–February (Sowing) and April–May (Harvesting)); Summer (March–May (Sowing) and August–October (Harvesting)); and Autumn (September–October (Sowing) and January–February (Harvesting)). The share of potato crop in annual production by spring, summer and autumn is 10%, 15%, and 75% respectively. Biggest shortage of potato has been seen in the start of March due to less production from spring season and poor post-harvest handling such as storage and transportation, which affects the quality of produce. Also, in spring, produce is reduced due to rapid multiplication of virus vector besides other bacterial and fungal diseases. Therefore, we need to control pests and diseases by adopting proper management practices and developing resistant varieties through modeling approaches.

Climate variability has also shown impacts on potato quality which is also affected by various factors such as maturity level of crop, preharvest conditions of crop, handling and harvest conditions, health status of crop such as biochemical changes, pests and disease incidence, and preparation and management of storage environment. Good storage practices cannot enhance the quality of crop if health is compromised during preharvest conditions. Quality of tubers is affected when immature tubers are harvested, soil conditions are very wet or dry, and weather is very warm (Pinhero et al. 2009). Certain glycol-alkaloids and secondary metabolites, i.e., α-chaconine and α-solanine, found in potato are reported to be dangerous for human health (Romanucci et al. 2018). The most common potato disease worldwide is late blight caused by a water mould, *Phytophthora infestans*, that destroys leaves, stems, and tubers. Bacterial wilt is caused by the bacterial pathogen, which leads to severe losses in tropical, subtropical, and temperate regions, while potato blackleg is also a bacterial infection, which causes tubers to rot in the ground and during storage. Viruses can cut yields by 50%, and they are disseminated in tubers. Early blight caused by bacteria results in 20–50% yield losses (Van Der Waals et al. 2001; Leiminger and Hausladen 2011). Low-water supply decreases the fresh and dry tuber yield (El-Abedin et al. 2017). Dry rot is economically affecting the potato produce under storage conditions from 6% to 25% up to 60% in some cases (Stevenson et al. 2001). Similarly, certain species of Aphids are affecting the production of potatoes (Pelletier and Michaud 1995; FAO 2016). Aphids are the main source of transfer of virus-related disease. It transfers virus from one place to another and spreads diseases on large scale. Meanwhile, long-term availability of potatoes depends upon its storage, but it is limited by sprouting of potatoes. Sprouting is the major cause of potato losses during storage. So, it is necessary to maintain endodormancy within potatoes so that sprouting will be low (Eshel and Tepel-Bamnolker 2012). High temperature has remarkable negative impact on the tuber yield, i.e., tuber fresh weighs less than 80 g. Less tuber weight is associated with reduction in total tuber yield and size. Rate of tuber bulking determines total tuber yield of potato (Mihovilovich et al. 2014). Increased temperature is favorable for temperate regions but can cause problems for tropical growing potatoes (Lizana et al. 2017). Excess fertilizer causes the rapid growth of potatoes resulting in hollow tuber formation with empty cavities. Potato psyllid is a serious pest for Solanaceae crops (Jackson et al. 2009). Due to its eating habit, this pest causes significant decrease in crop yield and quality (Munyaneza and Henne 2013). It causes spreading of bacteria which causes zebra chip in potato crop (Crosslin et al. 2010). There are several diseases which are caused by pests such as Colorado potato beetle (*Leptinotarsa decemlineata*), Potato tuber moth (*Phthorimaea operculella*), Leafminer fly (*Liriomyza huidobrensis*), and Cyst nematodes (*Globodera pallida* and *G. rostochiensis*). Therefore, modeling concepts should be applied to study impacts of abiotic (temperature and water) and biotic stresses (diseases and pest) on potato crop production.

14.5 Potato Modeling Across Globe Under Different Scenarios

The APSIM potato model was developed using plant modeling framework (PMF) (Brown et al. 2011, 2014) (Figs. 14.6 and 14.7). APSIM model, as presented in Table 14.1, simulates the development of crop through different developmental stages and uses thermal time approach. Thermal time target and the progression toward peeping can be calculated by using following equations:

$$\text{Progression} = [\text{Phenology}].\text{Thermal Time}$$

Peeping to emergence (sprouting phase)**:**

$$\text{Target} = \text{Sowing depth} \times \text{Shoot rate} + \text{Shoot Lag}$$

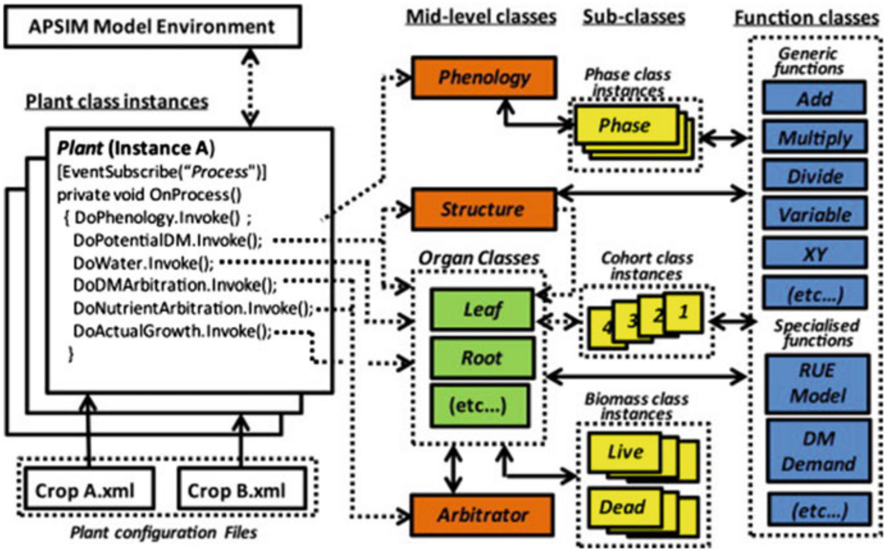

Fig. 14.6 APSIM plant basic structure (e.g., oat (left) and lucerne (right) configuration files). (Source: Brown et al. 2014 with permission from Elsevier)

$$\text{Shoot rate} = 1.35\left(\frac{\text{Degree day}}{\text{mm}}\right)$$

$$\text{Shoot lag} = 72\ (\text{Degree day})$$

$$\text{Sowing depth} = \text{in mm from manager}$$

Further detail about the growth and development of potato used by APSIM is available in the work of Brown et al. (2018).

The SUBSTOR-potato model is a cropping system model of decision support systems for agrotechnology transfer (Jones et al. 2003; Hoogenboom et al. 2019). Ritchie et al. (1995) provide a detailed description of SUBSTOR-potato model. This model can be requested from DSSAT portal (www. DSSAT.net). Relative temperature function for tuber initiation (RTFFTI) in SUBSTOR-potato model uses following equations:

$$\text{RTFFTI} = 0; (\text{Tempearture} \le 4)$$

$$\text{RTFFTI} = 1 - \left(\frac{1}{36}\right)(10 - \text{Temperature})^2; (\text{Temperature} > 4 \text{ and Temperature} \le 10)$$

$$\text{RTFFTI} = 1; (\text{Temperature} > 10 \text{ and Temperature} \le 10)$$

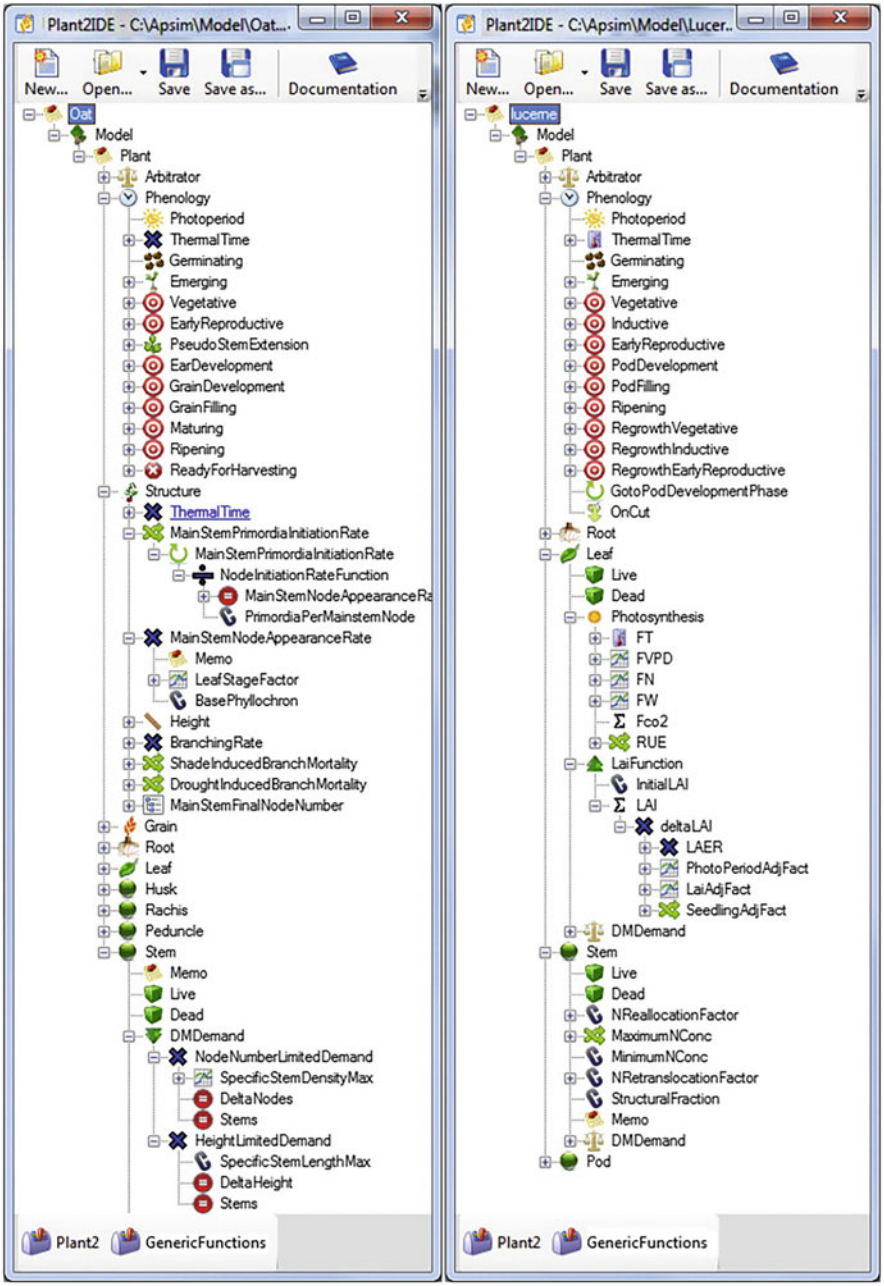

Fig. 14.7 Plant modeling framework of APSIM. (Source: Brown et al. 2014 with permission from Elsevier)

Table 14.1 List of stages and phases used in the simulation of crop phenological development

Phase number	Phase name	Initial stage	Initial stage
1	Dormant	Planting	Peeping
2	Sprouting	Peeping	Emergence
3	Vegetative	Emergence	Tuber initiation
4	Early tuber	Tuber initiation	Final leaf
5	Late tuber	Final leaf	Full senescence
6	Senesced	Full senescence	Maturity
7	Maturity	Maturity	Eternity

Source: APSRU, APSIM; Brown et al. (2018)

$$\text{RTFFTI} = 1; (\text{Temperature} > 10 \text{ and Temperature} \leq \text{Critical temperature})$$

$$\text{RTFFTI} = 1 - \left(\frac{1}{64}\right)(\text{Temperature} - \text{Critical Temperature})^2;$$
$$(\text{Temperature} > \text{Critical Temperature and Temperature} \leq \text{Critical Temperature} + 8)$$

Relative day length function for tuber initiation (RDLFFTI) can be modeled by using following equation:

$$\text{RDLFFTI} = (1 - \text{P2}) + 0.00694 \times \text{P2} \times (24 - \text{PHPER})^2$$

RDLFFTI is function of day length in hours (PHPER) and sensitivity to day length (P2). RDLFFTI = 1 when photoperiod is less than 12 h.

Biomass accumulation after tuber initiation and partitioning could be calculated by using following equations:

$$\text{PCARB} = \text{RUE} \times \frac{\text{PAR}}{\text{Plants}} (1 - \text{Exp}(-0.55 \times \text{LAI})) \times \text{PCO}_2$$

Here

PCARB = function of RUE (g MJ^{-1})
PAR = photosynthetically active radiation (PAR, MJ m^{-2})
LAI = leaf area index (dimensionless)

Maximum tuber growth (TIND), sink strength (DTII), and carbon demand of tubers after tuber initiation (DEVEFF) are calculated by following equations:

$$\text{Maximum tuber growth (TIND)} = \text{DTII}_{\text{average}} \left(\frac{1}{\text{NFAC}}\right) \text{DEVEFF}; \text{NFAC} > 1$$

$$\text{Maximum tuber growth (TIND)} = \text{DTII}_{\text{average}} \times \text{DEVEFF}; \text{NFAC} > 1$$

$$\text{Maximum tuber growth (TIND)} = \text{RTFFTI}; \text{if no stress}$$

$$\text{Maximum tuber growth (TIND)} = \text{RTFFTI} + 0.5 \times (1 - \min(\text{SWFAC}, \text{NSTRES}, 1))$$

$$\text{DEVEFF} = \min((\text{XSTAGE} - 2) \times 10 \times \text{PD}, 1)$$

$$\text{XSTAGE} = 2.0 + (\text{CUMRTFVINE})/100$$

Here

DTIIavg = three-day moving average of daily values of sink strength (DTII)
DEVEFF = carbon demand of tubers after tuber initiation
XSTAGE = Progression through each phenological stage as a function of the cumulative leaf thermal time (CUMRTFVINE)
PD = index that suppresses tuber growth (PD = 0 or 1)
NFAC = nitrogen deficiency factor (NFAC)

SUBSTOR model simulates potential tuber growth (PTUBGR, g plant^{-1} day^{-1}) as a function of potential tuber growth rate (G3), relative temperature factor for root growth (RTFSOIL), and plant density.

$$\text{PTUBGR} = \text{G3} \times \text{PCO}_2 \times \frac{\text{RTFSOIL}}{\text{Plants}}$$

$$\text{GROTUB (Actual tuber growth)} = \text{PTUBGR} \times \min(\text{TURFAC}, \text{AGEFAC}, 1) \times \text{TIND}$$

$$\text{PLAG (Actual leaf expansion)} = \text{G2} \times \frac{\text{RTFVINE}}{\text{Plants}} \times \min(\text{TURFAC}, \text{AGEFAC}, 1)$$

$$\text{Leaf growth (GROLF)} = \frac{\text{Actual leaf expansion (PLAG)}}{\text{Leaf weight ratio (LALWR)}}$$

$$\text{Stem growth (GROSTM)} = \text{GROLF} \times 0.75$$

$$\text{Root growth (GRORT)} = (\text{GROLF} + \text{GROSTM}) \times 0.2$$

SUBSTOR-potato model converts tuber dry weight to tuber fresh weight assuming dry matter contents of 20%. Performance of the SUBSTOR-potato model across contrasting growing conditions was conducted by Raymundo et al. (2017). CropSyst VB–Simpotato model was used for the evaluation of potato production system in Pacific Northwest of the USA by Alva et al. (2004). This model is used to predict fate and transport of N under different nitrogen and water management options. The Simpotato model was presented by Hodges et al. (1992) using standards of IBSNAT (International Benchmarks Sites Network for Agrotechnology Transfer) project. LINTUL-POTATO-DSS is another important robust model (Haverkort et al. 2015).

STICS model was calibrated and evaluated by Morissette et al. (2016) to determine the cultivar-specific critical N concentration dilution curves and to quantify gain in model performance with cultivar-specific N concentration curves rather than a generic curve. Nitrate leaching was evaluated by Jégo et al. (2008) using STICS crop models in the field of potato and sugar beet crop. This model firstly evaluated using field data and then analyzed the impacts of different practices on nitrate leaching. Results showed that excessive irrigation in potato field resulted in higher nitrate leaching compared to sugarbeet as it has high N uptake capacity. Virtual experiments further suggested that N fertilization should be adjusted based on (1) season (2) crop in field (3) irrigation water, and (4) other factors precisely needed for potato crops.

Precision agriculture technologies, soil maps, and meteorological stations provide minimum data set, but optimal nutrients requirements are possible by the use of multilevel modeling as proposed by Parent et al. (2017). Mitscherlich equation was used to elaborate a multilevel N fertilizer response model for potato. According to Mitscherlich equation, rate of yield response reduces as soil nutrient level along with nutrient addition increases. Following equation is proposed by Rajsic and Weersink (2008):

$$\text{Yield} = \text{Asymptote} \times \left(1 - e^{-\text{Rate} \times (\text{Environment} + \text{Dose})}\right)$$

Here yield = crop production per unit area and dose = fertilizer amount per unit area.

Mitscherlich parameters have been shown in Fig. 14.8. Application of different models and strategies on the potato crop improvements have been presented in Table 14.2.

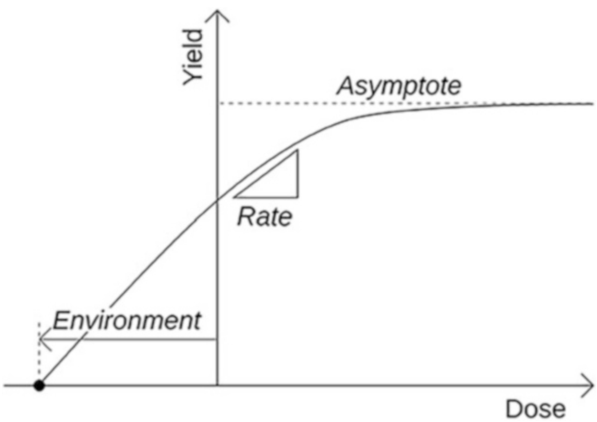

Fig. 14.8 Mitscherlich parameters. (Source: Parent et al. 2017)

Table 14.2 Model applications in tube research

S. No	Model applications	References
1.	Application of APSIM-potato model	Tang et al. (2020)
2.	DSSAT model to manage nitrogen in potato rotations with cover crops	Geisseler and Wilson (2020)
3.	Soil and climate data aggregation on potato yield and irrigation water requirement using APSIM	Ojeda et al. (2020)
4.	SUBSTOR-potato model to design deficit irrigation strategies	Montoya et al. (2020)
5.	Quantification of the canopy cover dynamics in potato	Khan et al. (2019)
6.	Agronomic options for better potato production	Tang et al. (2019)
7.	Mulching-induced variations in tuber productivity and NUE in potato in China	Wang et al. (2019)
8.	Deficit irrigation strategies using MOPECO model	Martínez-Romero et al. (2019)
9.	Protection of potatoes from adverse weather conditions through appropriate mitigation strategies and by the use of cropping system model (CSM)-SUBSTOR-potato	Woli and Hoogenboom (2018)
10.	Optimizing N fertilizer levels besides time of application in potatoes under seepage irrigation	Rens et al. (2018)
11.	FAO dual Kc approach to assess potato transpiration	Paredes et al. (2018)
12.	Application of CropSyst model to simulate potato crop	Montoya et al. (2018)
13.	Change in potato phenology	Tryjanowski et al. (2017)
14.	AquaCrop to simulate potato yield	Razzaghi et al. (2017)
15.	AquaCrop model application for irrigation management in potato	Montoya et al. (2016)
16.	Irrigation scheduling using AquaCrop	Linker et al. (2016)
17.	Root system architecture and abiotic stress tolerance	Khan et al. (2016)
18.	Breeding strategies of table potato	Eriksson et al. (2016)
19.	Effect of high temperature on potato	Rykaczewska (2015)
20.	Benefits of controlled release urea on potato	Gao et al. (2015)
21.	Multivariate analysis between potato and treatments	Šrek et al. (2010)
22.	Yield response of potato to nitrogen	Shillito et al. (2009)
23.	Modeling tuber crops	Singh et al. (1998)
24.	Climate change and potato production	Rosenzweig et al. (1996)
25.	Temperature effect on potato growth and carbohydrate metabolism	Lafta and Lorenzen (1995)
26.	Virtual potato crop modeling	Raymundo et al. (2014)

References

Ahmed M (2020) Introduction to modern climate change. Andrew E. Dessler: Cambridge University Press, 2011, 252 pp, ISBN-10: 0521173159. Sci Total Environ 734:139397. https://doi.org/10.1016/j.scitotenv.2020.139397

Alva A, Marcos J, Stockle C, Reddy V, Timlin D (2004) CropSyst VB–Simpotato, a crop simulation model for potato-based cropping systems: II. Evaluation of nitrogen dynamics. In: Proceedings of the 4th International Crop Science Congress, Brisbane, Australia, 2004

Brown HE, Huth N, Holzworth D (2011) A potato model build using the APSIM Plant. NET framework, pp 961–967

Brown HE, Huth NI, Holzworth DP, Teixeira EI, Zyskowski RF, Hargreaves JNG, Moot DJ (2014) Plant modelling framework: software for building and running crop models on the APSIM platform. Environ Model Softw 62:385–398. https://doi.org/10.1016/j.envsoft.2014.09.005

Brown H, Huth N, Holzworth D (2018) 1 The APSIM Potato Model. http://apsimdev.apsim.info/ApsimxFiles/Potato4403.pdf

Costa LD, Vedove GD, Gianquinto G, Giovanardi R, Peressotti A (1997) Yield, water use efficiency and nitrogen uptake in potato: influence of drought stress. Potato Res 40:19–34

Crosslin JM, Munyaneza JE, Brown JK, Liefting LW (2010) A history in the making: Potato Zebra chip disease associated with a new Psyllid-borne Bacterium – a tale of striped potatoes. APSnet Features. https://doi.org/10.1094/APSnet-Feature-2010-0110

Dalla Costa L, Delle Vedove G, Gianquinto G, Giovanardi R, Peressotti A (1997) Yield, water use efficiency and nitrogen uptake in potato: influence of drought stress. Potato Res 40:19–34

Davies A, Jenkins T, Pike A, Shaq J, Carson I, Pollock CJ, Parry MI (1996) Modelling the predicted geographic and economic response of UK cropping systems to climate change scenarios: the case of potatoes. Asp Appl Biol 45:63–69

El-Abedin TKZ, Mattar MA, Alazba AA, Al-Ghobari HM (2017) Comparative effects of two water-saving irrigation techniques on soil water status, yield, and water use efficiency in potato. Sci Hortic 225:525–532

Eriksson D, Carlson-Nilsson U, Ortíz R, Andreasson E (2016) Overview and breeding strategies of table potato production in Sweden and the Fennoscandian region. Potato Res 59(3):279–294. https://doi.org/10.1007/s11540-016-9328-6

Eshel D, Tepel-Bamnolker P (2012) Can loss of apical dominance in potato tuber serve as a marker of physiological age? Plant Signal Behav 7:1158–1162

FAO (2017). http://faostat.fao.org/. Accessed in Jan 2017

Food and Agriculture Organization of the United Nations (FAO), World crop production statistics (2016). http://www.faostat.fao.org. Accessed 10th Sept 2016

Gao X, Li C, Zhang M, Wang R, Chen B (2015) Controlled release urea improved the nitrogen use efficiency, yield and quality of potato (Solanum tuberosum L.) on silt loamy soil. Field Crop Res 181:60–68. https://doi.org/10.1016/j.fcr.2015.07.009

Geisseler D, Wilson R (2020) Nitrogen in potato rotations with cover crops: field trial and simulations using DSSAT. Agron JAccepted Author Manuscript. https://doi.org/10.1002/agj2.20177

Hack H, Gall H, Klemke Th., Klose R, Meier U, Stauss R, Witzenberger A (2001) The BBCH scale for phonological growth stages of potato (*Solanum tuberosum* L.). In: Meier U (ed) Growth stages of mono and dicotyledonous Plants, BBCH Monograph, Federal Biological Research Centre for Agriculture and Forestry

Haverkort AJ, Franke AC, Steyn JM, Pronk AA, Caldiz DO, Kooman PL (2015) A robust potato model: LINTUL-POTATO-DSS. Potato Res 58(4):313–327. https://doi.org/10.1007/s11540-015-9303-7

Hijmans RJ (2003) The effect of climate change on global potato production. Am J Pot Res 80:271–279. https://doi.org/10.1007/BF02855363

Hodges T, Johnson S, Johnson B (1992) SIMPOTATO: a highly modular program structure for an IBSNAT style crop simulation. Agron J 84:911–915

Hoogenboom G, Porter CH, Shelia V, Boote KJ, Singh U, White JW, Hunt LA, Ogoshi R, Lizaso JI, Koo J, Asseng S, Singels A, Moreno LP, Jones JW (2019) Decision support system for agrotechnology transfer (DSSAT) version 4.7.5 (www.dssat.net). DSSAT Foundation, Gainesville, FL

Jackson BC, Goolsby J, Wyzykowski A, Vitovsky N, Bextine B (2009) Analysis of genetic relationships between potato psyllid (Bactericera cockerelli) populations in the United States, Mexico and Guatemala using ITS2 and Inter Simple Sequence Repeat (ISSR) data. Subtrop Plant Sci 61:1–5

Jégo G, Martínez M, Antigüedad I, Launay M, Sanchez-Pérez JM, Justes E (2008) Evaluation of the impact of various agricultural practices on nitrate leaching under the root zone of potato and sugar beet using the STICS soil–crop model. Sci Total Environ 394(2):207–221. https://doi.org/10.1016/j.scitotenv.2008.01.021

Jones JW, Hoogenboom G, Porter CH, Boote KJ, Batchelor WD, Hunt LA, Wilkens PW, Singh U, Gijsman AJ, Ritchie JT (2003) The DSSAT cropping system model. Eur J Agron 18 (3–4):235–265. https://doi.org/10.1016/S1161-0301(02)00107-7

Khan MA, Gemenet DC, Villordon A (2016) Root system architecture and abiotic stress tolerance: current knowledge in root and tuber crops. Front Plant Sci 7(1584). https://doi.org/10.3389/fpls.2016.01584

Khan MS, Struik PC, van der Putten PEL, Jansen HJ, van Eck HJ, van Eeuwijk FA, Yin X (2019) A model-based approach to analyse genetic variation in potato using standard cultivars and a segregating population. I. Canopy cover dynamics. Field Crop Res 242:107581. https://doi.org/10.1016/j.fcr.2019.107581

Kooman PL, Haverkort AJ (1995) Modelling development and growth of the potato crop influenced by temperature and daylength: LINTUL-POTATO. In: Haverkort AJ, MacKerron DKL (eds) Potato ecology and modelling of crops under conditions limiting growth: proceedings of the second international potato modeling conference, held in Wageningen 17–19 May, 1994. Springer Netherlands, Dordrecht, pp 41–59. https://doi.org/10.1007/978-94-011-0051-9_3

Kooman PL, Fahem M, Tegera P, Haverkort AJ (1996a) Effects of climate on different potato genotypes 2. Dry matter allocation and duration of the growth cycle. Eur J Agron 5:207–217

Kooman PL, Fahem M, Tegera P, Haverkort AJ (1996b) Effects of climate on different potato genotypes 1. Radiation interception, total and tuber dry matter production. Eur J Agron 5:193–205

Lafta AM, Lorenzen JH (1995) Effect of high temperature on plant growth and carbohydrate metabolism in potato. Plant Physiol 109(2):637–643. https://doi.org/10.1104/pp.109.2.637

Leiminger JH, Hausladen H (2011) Early blight control in potato using diseaseorientated threshold values. Plant Dis 96:124–130

Linker R, Ioslovich I, Sylaios G, Plauborg F, Battilani A (2016) Optimal model-based deficit irrigation scheduling using AquaCrop: a simulation study with cotton, potato and tomato. Agric Water Manag 163:236–243. https://doi.org/10.1016/j.agwat.2015.09.011

Lizana XC, Avila A, Tolaba A, Martinez JP (2017) Field responses of potato to increased temperature during tuber bulking: projection for climate change scenarios, at high-yield environments of Southern Chile. Agric For Meteorol 239:192–201

Lutaladio N, Castaidi L (2009) Potato: the hidden treasure. J Food Compos Anal 22(6)

Lutz W, Samir KC (2010) Dimensions of global population projections: what do we know about future population trends and structures? Philos Trans R Soc Lond B-Biol Sci 365 (1554):2779–2791

Martínez-Romero A, Domínguez A, Landeras G (2019) Regulated deficit irrigation strategies for different potato cultivars under continental Mediterranean-Atlantic conditions. Agric Water Manag 216:164–176. https://doi.org/10.1016/j.agwat.2019.01.030

Miglietta F, Magliulo V, Bindi M, Cerio L, Vaccari FP, Loduca V, Peressotti A (1998) Free air CO_2 enrichment of potato (Solanum tuberosum L.): development, growth and yield. Glob Chang Biol 4:163–172

Mihovilovich E, Carli C, De Mendiburu F, Hualla V, Bonierbale M (2014) Protocol for tuber bulking maturity assessment of elite and advanced potato clones. Int. Potato Center, Lima, Peru. 18–19

Montoya F, Camargo D, Ortega JF, Córcoles JI, Domínguez A (2016) Evaluation of Aquacrop model for a potato crop under different irrigation conditions. Agric Water Manag 164:267–280. https://doi.org/10.1016/j.agwat.2015.10.019

Montoya F, Camargo D, Domínguez A, Ortega JF, Córcoles JI (2018) Parametrization of Cropsyst model for the simulation of a potato crop in a Mediterranean environment. Agric Water Manag 203:297–310. https://doi.org/10.1016/j.agwat.2018.03.029

Montoya F, Camargo D, Córcoles JI, Domínguez A, Ortega JF (2020) Analysis of deficit irrigation strategies by using SUBSTOR-potato model in a semi-arid area. J Agric Sci:1–14. https://doi.org/10.1017/S002185961900090X

Morissette R, Jégo G, Bélanger G, Cambouris AN, Nyiraneza J, Zebarth BJ (2016) Simulating potato growth and nitrogen uptake in eastern Canada with the STICS model. Agron J 108 (5):1853–1868. https://doi.org/10.2134/agronj2016.02.0112

Munyaneza JE, Henne DC (2013) Chapter 4 – Leafhopper and psyllid pests of potato. In: Alyokhin A, Vincent C, Giordanengo P (eds) Insect pests of potato. Academic Press, San Diego, pp 65–102. https://doi.org/10.1016/B978-0-12-386895-4.00004-1

Ojeda JJ, Rezaei EE, Remenyi TA, Webb MA, Webber HA, Kamali B, Harris RMB, Brown JN, Kidd DB, Mohammed CL, Siebert S, Ewert F, Meinke H (2020) Effects of soil- and climate data aggregation on simulated potato yield and irrigation water requirement. Sci Total Environ 710:135589. https://doi.org/10.1016/j.scitotenv.2019.135589

Paredes P, D'Agostino D, Assif M, Todorovic M, Pereira LS (2018) Assessing potato transpiration, yield and water productivity under various water regimes and planting dates using the FAO dual Kc approach. Agric Water Manag 195(Supplement C):11–24. https://doi.org/10.1016/j.agwat.2017.09.011

Parent S-É, Leblanc MA, Parent A-C, Coulibali Z, Parent LE (2017) Site-specific multilevel modeling of potato response to nitrogen fertilization. Front Environ Sci 5(81). https://doi.org/10.3389/fenvs.2017.00081

Peins DR, Crawford JW, Grashoff C, Jefferies RA, Parter JR, Marshall B (1996) A simulation study of crop growth ahd development under climate change. Agric For Meteorol 79:271–887

Peiris DR, Crawford JW, Grashoff C, Jefferies RA, Porter JR, Marshall B (1996) A simulation study of crop growth and development under climate change. Agric For Meteorol 79 (4):271–287. https://doi.org/10.1016/0168-1923(95)02286-4

Pelletier Y, Michaud D (1995). Insect pest control on potato: genetically-based control. In: Duchesne RM, Boiteau G (eds) Potato insect pest control: development of a sustainable approach, Gouvernement du Que'bec. 69–79

Pinhero RG, Coffin R, Yada RY (2009) Post-harvest storage of potatoes. Advances in potato chemistry and technology. Academic Press (Elsevier), New York, pp 339–370

Rajsic P, Weersink A (2008) Do farmers waste fertilizer? A comparison of ex post optimal nitrogen rates and ex ante recommendations by model, site and year. Agric Syst 97(1):56–67. https://doi.org/10.1016/j.agsy.2007.12.001

Raymundo R, Kleinwechter U, Asseng S (2014). Virtual potato crop modeling A comparison of genetic coefficients of the DSSAT-SUBSTOR potato model with breeding goals for developing countries. Zenodo. https://doi.org/10.5281/zenodo.7687

Raymundo R, Asseng S, Prassad R, Kleinwechter U, Concha J, Condori B, Bowen W, Wolf J, Olesen JE, Dong Q, Zotarelli L, Gastelo M, Alva A, Travasso M, Quiroz R, Arora V, Graham W, Porter C (2017) Performance of the SUBSTOR-potato model across contrasting growing conditions. Field Crop Res 202:57–76. https://doi.org/10.1016/j.fcr.2016.04.012

Razzaghi F, Zhou Z, Andersen MN, Plauborg F (2017) Simulation of potato yield in temperate condition by the AquaCrop model. Agric Water Manag 191:113–123. https://doi.org/10.1016/j.agwat.2017.06.008

Rens LR, Zotarelli L, Rowland DL, Morgan KT (2018) Optimizing nitrogen fertilizer rates and time of application for potatoes under seepage irrigation. Field Crop Res 215:49–58. https://doi.org/10.1016/j.fcr.2017.10.004

Ritchie J, Griffin TS, Johnson BS (1995) SUBSTOR: functional model of potato growth, development and yield. In: Modelling and parameterization of the soil-plant-atmosphere system: a comparison of potato growth models, pp 401–435

Romanucci V, Di Fabio G, Di Marino C, Davinelli S, Scapagnini G, Zarrelli A (2018) Evaluation of new strategies to reduce the total content of α-solanine and α-chaconine in potatoes. Phytochem Lett 23:116–119

Rosenzweig C, Phillips J, Goldberg R, Carroll J, Hodges T (1996) Potential impacts of climate change on citrus and potato production in the US. Agric Syst 52(4):455–479. https://doi.org/10.1016/0308-521X(95)00059-E

Rykaczewska K (2015) The effect of high temperature occurring in subsequent stages of plant development on potato yield and tuber physiological defects. Am J Potato Res 92(3):339–349. https://doi.org/10.1007/s12230-015-9436-x

Singh U, Matthews RB, Griffin TS, Ritchie JT, Hunt LA, Goenaga R (1998) Modeling growth and development of root and tuber crops. In: Tsuji G, Hoogenboom G, Thornton P (eds) Understanding options for agricultural production, vol 7. Systems approaches for sustainable agricultural development. Springer, Dordrecht, pp 129–156. https://doi.org/10.1007/978-94-017-3624-4_7

Shillito RM, Timlin DJ, Fleisher D, Reddy VR, Quebedeaux B (2009) Yield response of potato to spatially patterned nitrogen application. Agric Ecosyst Environ 129(1):107–116. https://doi.org/10.1016/j.agee.2008.07.010

Šrek P, Hejcman M, Kunzová E (2010) Multivariate analysis of relationship between potato (Solanum tuberosum L.) yield, amount of applied elements, their concentrations in tubers and uptake in a long-term fertilizer experiment. Field Crop Res 118(2):183–193. https://doi.org/10.1016/j.fcr.2010.05.009

Stevenson WR, Loria R, Franc GD, Weingartner DP (2001) Compendium of potato diseases, 2nd edn. The American Phytopathological Society, St. Paul

Tang J, Xiao D, Bai H, Wang B, Liu DL, Feng P, Zhang Y, Zhang J (2020) Potential benefits of potato yield at two sites of agro-pastoral ecotone in North China under future climate change. Int J Plant Prod. https://doi.org/10.1007/s42106-020-00092-7

Tang J, Wang J, Fang Q, Dayananda B, Yu Q, Zhao P, Yin H, Pan X (2019) Identifying agronomic options for better potato production and conserving water resources in the agro-pastoral ecotone in North China. Agric For Meteorol 272-273:91–101. https://doi.org/10.1016/j.agrformet.2019.04.001

Tryjanowski P, Sparks TH, Blecharczyk A, Małecka-Jankowiak I, Switek S, Sawinska Z (2017) Changing phenology of potato and of the treatment for its major pest (Colorado potato beetle) – a long-term analysis. Am J Potato Res. https://doi.org/10.1007/s12230-017-9611-3

Van Der Waals JE, Korsten L, Aveling TAS (2001) A review of early blight of potato. Afr Plant Prot 7:91–102

van Oort PAJ, Timmermans BGH, van Swaaij ACPM (2012) Why farmers' sowing dates hardly change when temperature rises. Eur J Agron 40:102–111. https://doi.org/10.1016/j.eja.2012.02.005

Wahid A, Gelani S, Ashraf M, Foolad MR (2007) Heat tolerance in plants: an overview. Environ Exp Bot 61(3):199–223. https://doi.org/10.1016/j.envexpbot.2007.05.011

Wang L, Coulter JA, Palta JA, Xie J, Luo Z, Li L, Carberry P, Li Q, Deng X (2019) Mulching-induced changes in tuber yield and nitrogen use efficiency in potato in China: a meta-analysis. Agronomy 9(12):793

Woli P, Hoogenboom G (2018) Simulating weather effects on potato yield, nitrate leaching, and profit margin in the US Pacific Northwest. Agric Water Manag 201:177–187. https://doi.org/10.1016/j.agwat.2018.01.023