Black Sea Journal of Engineering and Science
doi: 10.34248/bsengineering.1181263

Open Access Journal
e-ISSN: 2619 – 8991

Research Article
Volume 6 - Issue 2: 53-59 / April 2023

SIMULATING THE YIELD RESPONSES OF SUGAR BEET TO DIFFERENT CLIMATE CHANGE SCENARIOS BY LINTUL-MULTICROP MODEL

Ali Kaan YETİK[1]*, Tefide KIZILDENİZ[1], Zeynep ÜNAL[1]

[1]Niğde Ömer Halisdemir University, Faculty of Agricultural Sciences and Technologies, Department of Biosystem Engineering, 51240, Niğde, Türkiye

Abstract: Sugar beet is an essential crop for the sugar industry that have a very crucial role in agro-industry of Türkiye and Konya ranks first in terms of total sugar beet production and harvested area. The predictions, that the world's human population will reach 9 billion by the end of the current century and that demand for food will increase, are forcing farmers for the decision to search for new areas for agriculture or choose the crops that will be most productive in already cultivated lands. The aim of this study was to apply the LINTUL-MULTICROP Model for investigating the adaptation of sugar beet for the current climatic conditions and for climate change scenarios to show the response of sugar beet to an increase level of carbon dioxide and temperature. Four different scenarios were compared to check the effects of the climate change on sugar beet farming in the semi-arid Konya Region as followings: i) scenario (a) is the current climate conditions; ii) scenario (b) is the average temperatures increased 2 °C, iii) scenario (c) is 200 ppm increasing atmospheric CO_2; iv) scenario (d) new optimum sowing and harvest dates in sugar beet farming and increased temperatures and atmospheric CO_2 amount were simulated together. The optimum sowing and harvesting dates of sugar beet were moved 13 days back for sowing, and 8 days forward for harvesting. The highest yield was estimated under conditions of 2 °C and 200 ppm increased atmosphere temperature and CO_2 levels with new sowing and harvest dates. The yields under irrigated conditions varied between 74.4 t ha^{-1} and 111.2 t ha^{-1}. The irrigation water requirements of sugar beet were ranged from 618.8 mm to 688.5 mm for different scenarios. In conclusion, the cultivation of sugar beet tends to alter in semi-arid Konya environment.

Keywords: Crop modelling, Yield estimation, Climate change, Sugar beet

***Corresponding author:** Niğde Ömer Halisdemir University, Faculty of Agricultural Sciences and Technologies, Department of Biosystem Engineering, 51240, Niğde, Türkiye
E mail: alikaanyetik@ohu.edu.tr (A. K. YETİK)
Ali Kaan YETİK https://orcid.org/0000-0003-1372-8407
Tefide KIZILDENİZ https://orcid.org/0000-0002-5627-1307
Zeynep ÜNAL https://orcid.org/0000-0002-9954-1151

Received: September 28, 2022
Accepted: November 29, 2022
Published: April 01, 2023

Cite as: Yetik AK, Kızıldeniz T, Ünal Z. 2023. Simulating the yield responses of sugar beet to different climate change scenarios by LINTUL-MULTICROP model. BSJ Eng Sci, 6(2): 53-59.

1. Introduction

The predictions, that the world's human population will reach 9 billion by the end of the current century and that demand for food will increase (Godfray et al., 2010), are forcing farmers for the decision to search for new areas for agriculture or choose the crops that will be most productive in already cultivated lands (Licker et al., 2010). Both cases will increase the yield, but water scarcity and climate change are another issue that farmers have to deal with, necessitating these decisions to be taken more strategically (Howden et al., 2007). Reliable local scale representation of crop growth and yields by the imitation of atmosphere-soil-vegetation interactions in managed area is essential for the correct design and implementation of these strategies (García-León et al., 2020). Crop modeling is a useful tool that helps to understand how nature responses to given inputs based on physiological knowledge of plant processes (Akhavizadegan et al., 2021). Crop models can be applied for research understanding, integration of knowledge across disciplines, site-specific experimentation, yield analysis, yield forecasting, climate change projections, scoping best management practices, breeding and commercialization of a new cultivars (Boote et al., 2013). Depending upon the purpose of usage of crop models, they are classified as Empirical models, Mechanistic models, Static and dynamic models, Deterministic models, Stochastic models, Simulation models and Optimizing models (Oteng-Darko et al., 2013).

Recent advances in statistical computing have led to the emergence of more complex models that require large amounts of data and limit their practical use, especially considering the difficulty of obtaining local data. According to studies in the literature, the general belief is that the most efficient models do not have to incorporate every plant development phase. For the time being, Simple mechanistic models continue to be valuable for answering particular concerns, especially when there is insufficient data to run more complicated models (Cabral et al., 2017). The main point of mechanistic models is to explain what is happening in the system and how it is happening. This can be done by repeating the same calculation for selected crop and selected model, feeding with different parameter values and understanding crop responsiveness to growth circumstances and assessing their outputs in a variety of scenarios (Manschadi et al., 2021).

LINTUL (Light Interception and Utilization) is one of the mechanistic models, published by Spitters (Spitters, 1989) and Spitters and Schapendonk (Spitters and Schapendonk, 1990), which computes dry matter accumulation using solar radiation interception and radiation use efficiency values. A first crop specific version LINTUL-POTATO (Haverkort and Kooman, 1997) included potato specific parameters and late was adopted to various crops. In the previous studies Gimplinger and Kaul (2012) to amaranth, Adiele et al. (2021) to cassava, Kothari et al. (2022) to soybean and Viver (2022) adopted the model successfully to the banana plant.

The crop model parameters that affect crop growth rate and yield in most cases are location or variety specific (Iizumi et al., 2014). To maximize production, the farmer should select the crop that is well suited to local climatic conditions. After the parameter values that affect crop growth rate are inserted in model to find the most suitable conditions a parameter calibration (i.e., change of sowing date, irrigation regime) need to be done. Calibration processes is done by running a crop model multiple times in iterative way to find optimum values for each parameter's effect on crop model outputs (Akhavizadegan et al., 2021).

Apart from whether the product can adapt to the current climatic conditions, there is a need to know what the yield will be in case of a change in climatic conditions in the coming years. So, climate change impacts on shifting planting seasons and water availability that might cause yield reduction should be investigated to feed policy makers with reliable data in interested regions. Therefore, in this study the LINTUL-MULTICROP Model was used to investigate the adaptation of sugar beet crop for the current climatic conditions and for climate change scenarios to show response of sugar beet to an increase level of carbon dioxide and temperature.

2. Materials and Methods

2.1. Model Explanation

The first versions of the LINTUL-MULTICROP Model programmed in Fortran was transcribed into MS-Excel by Linus Franke, the University of Bloemfontein in South Africa. Haverkort et al. (2013) and Franke et al. (2013) carried out the first scientific research using this model. The model requires three main data sets as input: climate, crop and soil data. The first of these inputs is climatic data including minimum and maximum temperature averages (°C), precipitation (mm), solar radiation (MJ m^{-2} day^{-1}) and monthly evapotranspiration values (mm). The second input crop dataset includes the dates of sowing and harvest (day), planting and effective rooting depth (cm), dry matter concentration (%), harvest index (%), sprout growth rate (Extension of the below ground sprout per day-degree, mm/degree day), effective temperature sum between emergence and 100% ground cover (GC) (0-100% GC, degree day), radiation use efficiency (RUE, g MJ^{-1}), minimum and maximum temperature for the photosynthesis and optimal photosynthesis (°C). Finally, for the soil input the model has a default option for 9 different soil types with different bulk densities, water capacities, wilting points and available water contents and the user can easily select from among the different variations. The LINTUL-MULTICROP Model has several outputs. The model can recommend adaptation strategies to climate change by determining the growing period (days), days between planting and emergence, between emergence and 100% GC and between 100% GC and harvest. The irrigation water requirements can be calculated by the model with the data of precipitation and ETP. On the other hand, the model can estimate the yield under irrigated and non-irrigated conditions (t ha^{-1}).

2.2. Study Site

The study was carried out for the Konya Province (37°41' 29'' N, 33°14' 39'' E; altitude 1016 m), located in Central Anatolia, Türkiye (Figure 1). The Konya Province is a part of the Konya Plain (the second largest plain in Türkiye after the Çukurova Plain) which supplies 17% of the total agricultural lands of Türkiye. Sugar beet is an essential crop in Konya Plain and the sugar industry has a very crucial role in agro-industry of Türkiye (Zengin et al., 2003). Konya is the leading city in terms of total sugar beet production and harvested area in Türkiye with 5 725 947 tons and 89 179 ha, respectively (TURKSTAT, 2022). Therefore, Konya was selected as study area of this work for simulating sugar beet production for Türkiye.

Figure 1. The location of study area.

A semi-arid climate prevails in the region and the average climate data from 1929 to 2020 and the monthly crop evapotranspiration data (ETP) are given in Table 1 (TSMS, 2022).

2.3. Plant Material

Sugar beet, which is well adapted to the ecological conditions of the region and has an economically critical role in the region, was used as plant material. The input crop data of LINTUL-MULTICROP model obtained from various literatures was examine and given in Table 2.

2.4. Climate Change Scenarios

Four different scenarios were created to compare effects of the climate change on sugar beet farming in the semi-arid Konya Region (Table 3).

Table 1. The long-term annual climate data of Konya Province (1929-2021)

Months	Avg. min. temperature (°C)	Avg. max. temperature (°C)	Avg. mean temperature (°C)	Avg. precipitation (mm)	Radiation (MJ m^{-2} day^{-1})	ETP (mm)
January	-4.2	4.6	-0.2	38.1	8.3	41.3
February	-3.3	7.0	1.5	28.5	10.8	54.0
March	-0.2	11.8	5.6	29.3	16.6	82.8
April	4.3	17.5	11.1	32.0	19.6	98.1
May	8.6	22.4	15.9	43.1	24.1	120.5
June	12.6	26.7	20.1	53.1	26.0	129.8
July	15.9	30.2	23.5	7.5	25.6	127.9
August	15.6	30.2	23.3	6.4	22.6	113.0
September	11.0	26.0	18.8	13.5	18.5	92.3
October	5.9	20.0	12.8	29.5	13.4	66.9
November	0.8	13.0	6.5	32.2	9.7	48.3
December	-2.3	6.6	1.7	43.2	7.7	38.5
Average	5.4	18.0	11.7	29.7	16.9	84.4

Table 2. Input parameters for the model

Parameters		Values	References
Sowing date (days)		15/04	Petkeviciene, 2009
Planting depth (cm)		3	Acar, 2015
Harvest date (days)		28/09	Yetik and Candoğan, 2022
Effective rooting depth (cm)		120	Jégo et al., 2008
Dry matter concentration (%)		24	Starke and Hoffman, 2014
Harvest index (%)		70	Mamyandi, et al., 2012
Sprout growth rate (mm degree day^{-1})		0.3	Durr and Boiffin, 1995
0-100% GC (degree day)		885	Noor and Khan, 2015
RUE (g MJ^{-1})		0.92	Kamali et al., 2022
Temperature for the photosynthesis (°C)	Minimum	4	Terry, 1968
	Maximum	25	
Temperature for the optimum photosynthesis (°C)	Minimum	13.4	
	Maximum	38	

Table 3. The climate change scenarios created for the study

Scenario	Explanation
a	Current conditions
b	Current mean temperatures 2 °C
c	Current CO_2 +200 ppm
d	2 °C, +200 ppm, new sowing, harvest dates

The first scenario (a) was simulated by the current climate conditions for the Konya Province with the aim of comparison, the second scenario (b) was run by the future expectation in which the average temperatures were increased by 2 °C degrees and the third scenario (c) was increasing of atmospheric CO_2 with 200 ppm added to current 410 ppm which is another estimation for the future and causes the increasing radiation use efficiency of crops, and finally in the fourth scenario (d) new optimum sowing and harvest dates in sugar beet farming and increased temperatures and atmospheric CO_2 amount were simulated together.

3. Results and Discussion

The growth season length simulations of the LINTUL-MULTICROP for different scenarios are shown in Table 3. In scenario (c), if 200 ppm is added to the existing atmospheric CO_2 amount, the new RUE value is determined as 1.45 g MJ^{-1} (Werker and Jaggard, 1998). For the scenario (d), the new sowing and harvesting dates were determined with the effects of increasing temperature expectations (2 °C) on the growing period as given in Figure 2. The optimum temperature for photosynthesis (13.4 °C) was selected as a reference temperature, considering minimum and maximum extreme temperatures during the day and the dates are shifting from 15th to 2nd April for sowing and from 28th September to 6th October for harvesting, were established (as demonstrated in Figure 2).

The growing period of sugar beet cultivated in semi-arid Konya environment determined as 166 days according to model. Since sowing and harvesting dates were input of the model, the total growing period was not changed except for scenario (d), but the 2 °C temperature increase in scenario (b) provided sugar beet to reach maturity stage earlier than in the other scenarios (Table 4). In scenario (d), with the new sowing and harvest dates, the stage between 100% GC and harvest was 14 days longer than scenario (b) and 22 days longer than scenario (a) and (c) (Table 4). Previous studies stated that the adaptations including modifying sowing and harvest dates might theoretically decrease the impacts of climate change on agriculture (Mendelsohn et al., 1994; Rosenzweig and Hillel, 1998; Challinor et al., 2014; Battisti et al., 2018; Rahman et al., 2018; Pequeno et al., 2021). Jones et al. (2013), reported that early sowing may be possible in sugar beet, as a result of warmer temperatures in Europe in March, according to HadCM2 Climate Model. Richter et al. (2006) stated that the sowing date is a crucial parameter to reduce the influence of climate change on sugar beet cultivation. Alexandrov and Hoogenboom (2000) reported that modification of the sowing date can decrease the adverse impact of climate change on maize farming.

The determined yields and irrigation water requirements by the model for different scenarios are given in Table 5. The potential yields for different scenarios were varied between 87.2 t ha^{-1} and 132.3 t ha^{-1}, the yield for irrigated cultivation values varied between 74.4 t ha^{-1} and 111.2 t ha^{-1} and the yield for non-irrigated cultivation between 43.8 t ha^{-1} and 61.7 t ha^{-1}. The irrigation water requirements of scenarios (a,c), (b) and (d) were determined as 618.8, 688.5 and 758.1 mm, respectively.

When the yields of irrigated cultivation for different scenarios are examined, it is seen that under current conditions (scenario a) the yield for the irrigated cultivation was 74.4 t ha^{-1} (Table 5). Increasing temperatures and RUE values resulted as an increase on the yield of sugar beet for scenarios (b) and (c). Additionally, the new sowing and harvesting dates increased sugar beet yield in scenario (d) (49%).

In previous studies conducted under Konya conditions, the ranges of sugar beet yields were reported as 35.3-49.6 by Gezgin et al. (2001), as 52.3 – 93.1 t ha^{-1} by Zengin et al. (2009) and as 28.1-77.3 by Topak et al. (2011).

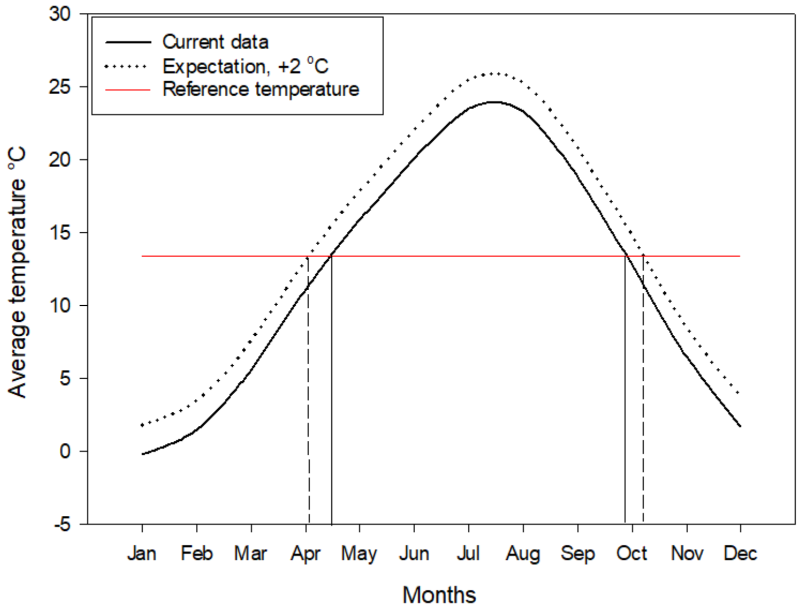

Figure 2. Determination of new dates of sowing and harvest of sugar beet in Konya.

Table 4. Growing stages of sugar beet grown in different scenarios

Scenario	A	b	c	d
Days between planting and emergence	12	10	12	12
Days between emergence and 100% GC	66	60	66	65
Days between 100% GC and harvest	88	96	88	110
Growing period (days)	166	166	166	187

Table 5. Yield and irrigation simulations of different scenarios for sugar beet crop

Scenario	a	b	c	d
Potential yield (t ha^{-1})	87.2	92.8	112.9	132.3
Yield irrigated (t ha^{-1})	74.4	78.6	90.1	111.2
Yield not irrigated (t ha^{-1})	43.8	45.3	57.1	61.7
Irrigation water requirements (mm)	618.8	688.5	618.8	758.1

Tognetti et al. (2003) reported that the root yield of sugar beet ranged from 40.2 t ha^{-1} to 78.70 t ha^{-1} under Italy conditions. These results are in parallel with the simulation results of scenario (a). Freckleton et al. (1999) and Kenter et al. (2006) reported that high temperatures tend to discourage yields of sugar beet. In our study as the model tends to adapt to the effects of climate change, it increased the amount of irrigation water. For this reason, it is thought that there is no decrease in yield despite the increase in temperature in scenario (b). The yields under a higher RUE value in scenario (c) were higher than the current conditions. Hoffman and Kenter (2018), reported that RUE is one of the most important parameters to achieve potential yield in sugar beet, and with optimum RUE, a potential yield of 24 t ha^{-1} can be reached under Germany conditions. Yagiz et al. (2020) reported a 42% increase in potential potato yield under Konya conditions with the increase of RUE. Kamali et al. (2022) determined statistically significant a linear relationship between RUE value and root yield of sugar beet. The simulation results for scenario (d) showed that adaptation to climate change for sugar beet farming in Konya can be provided by changing the sowing and harvesting dates. The yield for irrigated cultivation increased by 49% compared to current conditions. Tingem and Rivington (2009) reported a 32.1% increase in maize yield, a 17.6% increase in sorghum yield, and an almost trebled increase in ground nut yield with the effects of new sowing dates and increasing atmospheric CO_2 amount. Asseng et al. (2019) stated that higher RUE and different sowing and harvest dates provide higher yield and biomass growth in the models.

The irrigation water requirements were calculated as 618.8 mm for scenarios (a) and (c), as 688.5 mm for scenario (b) and 758.1 mm for scenario (d). The irrigation water requirements of sugar beet varied between 70 mm and 912 mm under Konya conditions (Süheri et al., 2007). Similar ranges were reported in the previous studies. Topak et al. (2011) determined the irrigation water requirements of sugar beet as between 244.2 - 977 mm under Konya climatic conditions. Köksal et al. (2011) reported a range from 65 mm to 865 mm for the irrigation water need of sugar beet in a semi-arid environment. Faberio et al. (2003) reported the irrigation water need of sugar beet as 897 mm. In previous modeling studies, Garcia-Vila et al. (2019) reported the 700 mm for the irrigation need of sugar beet by the AquaCrop Model. Stricevic et al. (2011), determined the range of irrigation water requirement of sugar beet as 586.8-767 mm with the AquaCrop Model.

4. Conclusion

Yield optimization is a very important parameter in terms of the quality and economic value of the product obtained from the agricultural sector. In recent years, the conditions in which optimum efficiency will be achieved in cultivation have changed considerably due to the changes in the precipitation regime under the impacts of climate change, the increases in the air temperature and atmospheric CO_2 amount. In this study, the response of sugar beet yield grown in Konya to different climate scenarios was investigated and optimum growing conditions were evaluated for adaptation to these scenarios. The LINTUL-MULTICROP Model calculated different sowing-harvest dates, three different yield values and irrigation water requirements. The optimum sowing and harvesting dates of sugar beet were moved 13 days back for sowing, and 8 days forward for harvesting. Three different yields were stated by the model and the highest yields were estimated for scenario d (2 °C, +200 ppm, new sowing and harvest dates). The yields under irrigated conditions varied between 74.4 t ha^{-1} and 111.2 t ha^{-1}. The irrigation water requirements of sugar beet ranged from 618.8 mm to 688.5 for different scenarios. The present findings indicated that the cultivation of sugar beet tends to alter in semi-arid Konya environment. The amount of irrigation water should be increased and the harvest and sowing dates should be changed in order to avoid loss of yield in temperature increases in the region.

Author Contributions

The percentage of the author(s) contributions is present below. All authors reviewed and approved final version of the manuscript.

	A.K.Y.	T.K.	Z.Ü.
C		50	50
D		50	50
S		100	
DCP	50	50	
DAI	100		
L	100		
W	40	30	30
CR		50	50
SR	100		

C=Concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

References

Acar M. 2015. Şeker pancarının seyreltmeli ve blok ekim uygulamalarının sıra üzeri bitki dağılımı ile kalite özelliklerine etkisi. PhD thesis, Selçuk University, Institute of Science, Konya, Türkiye, pp: 54.

Adiele JG, Schut AGT, Beuken RPM, Ezui KS, Pypers P, Ano AO, Giller KE. 2021. A recalibrated and tested LINTUL-Cassava simulation model provides insight into the high yield potential of cassava under rainfed conditions. Eur J Agron, 124: 126242.

Akhavizadegan FJ, Ansarifar LW, Huber I, Archontoulis SV. 2021. A time-dependent parameter estimation framework for crop modeling. Sci Rep, 11(1): 1-15.

Alexandrov VA, Hoogenboom G. 2000. The impact of climate variability and change on crop yield in Bulgaria. Agric For Meteorol, 104(4): 315-327.

Asseng S, Martre P, Maiorano A, Rötter RP, O'Leary GJ, Fitzgerald GJ, Ewert F. 2019. Climate change impact and adaptation for wheat protein. Glob Chang Biol, 25(1): 155-173.

Battisti R, Sentelhas PC, Parker PS, Nendel C, Gil MDS, Farias JR, Basso CJ. 2018. Assessment of crop-management strategies to improve soybean resilience to climate change in Southern Brazil. Crop Pasture Sci, 69(2): 154-162.

Boote KJ, Jones JW, White JW, Asseng S, Lizaso JI. 2013. Putting mechanisms into crop production models. Plant Cell Environ, 36(9): 1658-1672.

Cabral JS, Valente L, Hartig F. 2017. Mechanistic simulation models in macroecology and biogeography: state-of-art and prospects. Ecography, 40(2): 267-280.

Challinor AJ, Watson J, Lobell DB, Howden SM, Smith DR, Chhetri N. 2014. A meta-analysis of crop yield under climate change and adaptation. Nat Clim Chang, 4(4): 287-291.

Durr C, Boiffin J. 1995. Sugarbeet seedling growth from germination to first leaf stage. J Agric Sci, 124(3): 427-435.

Faberio C, Santa Olalla M, Lopez R, Dominguez A. 2003. Production and quality of sugar beet (Beta vulgaris L.) cultivated under controlled deficit irrigation condition in semiarid-climate. Agric Water Manag, 62: 215-227.

Franke AC, Haverkort AJ, Steyn JM. 2013. Climate change and potato production in contrasting south African agro-ecosystems 2. Assessing risks and opportunities of adaptation strategies. Potato Res, 56(1): 51-66.

Freckleton RP, Watkinson AR, Webb DJ, Thomas TH. 1999. Yield of sugar beet in relation to weather and nutrients. Agric For Meteorol, 93(1): 39-51.

García-León D, López-Lozano R, Toreti A, Zampieri M. 2020. Local-scale cereal yield forecasting in Italy: Lessons from different statistical models and spatial aggregations. Agron J, 10(6): 806.

Garcia-Vila M, Morillo-Velarde R, Fereres E. 2019. Modeling sugar beet responses to irrigation with AquaCrop for optimizing water allocation. Water, 11(9): 1918.

Gezgin S, Hamurcu M, Apaydin M. 2001. Effect of boron application on the yield and quality of sugar beet. Turk J Agric Forest, 25(2): 89-95.

Gimplinger DM, Kaul HP. 2012. Calibration and validation of the crop growth model LINTUL for grain amaranth (Amaranthus sp.). J Appl Bot Food Qual, 82(2): 183-192.

Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Toulmin C. 2010. Food security: the challenge of feeding 9 billion people. Science, 327(5967): 812-818.

Haverkort AJ, Franke AC, Engelbrecht FA, Steyn JM. 2013. Climate change and potato production in contrasting south African agro-ecosystems 1. Effects on land and water use efficiencies. Potato Res, 56(1): 31-50.

Haverkort AJ, Kooman PL. 1997. The use of modeling growth and development in ideotyping of potato under conditions defining, limiting and reducing yields. Euphytica, 94: 191-200.

Hoffmann CM, Kenter C. 2018. Yield potential of sugar beet–have we hit the ceiling? Front Plant Sci, 9: 289.

Howden SM, Soussana JF, Tubiello FN, Chhetri N, Dunlop M, Meinke H. 2007. Adapting agriculture to climate change. Proc Natl Acad Sci, 104(50): 19691-19696.

Iizumi T, Luo JJ, Challinor AJ, Sakurai G, Yokozawa M, Sakuma H, Yamagata T. 2014. Impacts of El Niño Southern Oscillation on the global yields of major crops. Nat Commun, 5(1): 3712.

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(2-3): 207-221.

Jones PD, Lister DH, Jaggard KW, Pidgeon JD. 2003. Future climate impact on the productivity of sugar beet (Beta vulgaris L.) in Europe. Clim Change, 58(1): 93-108.

Kamali HR, Zand-Parsa S, Zare M, Sapaskhah AR, Kamgar-Haghighi AA. 2022. Development of a simulation model for sugar beet growth under water and nitrogen deficiency. Irrig Sci, 40(3): 337-358.

Kenter C, Hoffmann CM, Märländer B. 2006. Effects of weather variables on sugar beet yield development (Beta vulgaris L.). Eur J Agron, 24(1): 62-69.

Köksal ES, Güngör Y, Yildirim YE. 2011. Spectral reflectance characteristics of sugar beet under different levels of irrigation water and relationships between growth parameters and spectral indexes. Irrig Drain, 60: 187-195.

Kothari K, Battisti R, Boote KJ, Archontoulis SV, Confalone A, Constantin J, Salmerón M. 2022. Are soybean models ready for climate change food impact assessments? Eur J Agron, 135: 126482.

Licker R, Johnston M, Foley JA, Barford C, Kucharik CJ, Monfreda C, Ramankutty N. 2010. Mind the gap: how do climate and agricultural management explain the 'yield gap'of croplands around the world? Glob Ecol Biogeogr, 19(6): 769-782.

Mamyandi MM, Pirzad A, Zardoshti MR. 2012. Effect of Nano-iron spraying at varying growth stage of sugar beet (Beta vulgaris L.) on the size of different plant parts. Intern J Agric Crop Sci, 4(12): 740-745.

Manschadi AM, Eitzinger J, Breisch M, Fuchs W, Neubauer T, Soltani A. 2021. Full parameterisation matters for the best performance of crop models: inter-comparison of a simple and a detailed maize model. Int J Plant Prod, 15(1): 61-78.

Mendelsohn R, Nordhaus WD, Shaw D. 1994. The impact of global warming on agriculture: A Ricardian analysis. American Econ Rev, 1: 753-771.

Noor A, Khan MR. 2015. Efficacy and safety of mixing azoxystrobin and starter fertilizers for controlling Rhizoctonia solani in sugar beet. Phytoparasit, 43(1): 51-55.

Oteng-Darko P, Yeboah S, Addy SNT, Amponsah S, Danquah ETO. 2013. Crop modeling: A tool for agricultural research–A review. J Agric Res Dev, 2(1): 001-006

Petkeviciene B. 2009. The effects of climate factors on sugar beet early sowing timing. Agron Res, 7: 436-443.

Prequeno DN, Hernandez-Ochoa IM, Reynolds M, Sonder K, MoleroMilan A, Robertson RD, Asseng S. 2021. Climate impact and adaptation to heat and drought stress of regional and global wheat production. Environ Res, 16(5): 054070.

Rahman MH, Ahmad A, Wang X, Wajid A, Nasim W, Hussain M, Hoogenboom G. 2018. Multi-model projections of future climate and climate change impacts uncertainty assessment for cotton production in Pakistan. Agric For Meteorol, 253: 94-113.

Richter GM, Qi A, Semenov MA, Jaggard KW. 2006. Modelling the variability of UK sugar beet yields under climate change and husbandry adaptations. Soil Use Manag, 22(1): 39-47.

Rosenzweig C, Hillel D. 1998. Climate change and the global harvest: potential impacts of the greenhouse effect on agriculture. Oxford University Press, Oxford, UK, 1st ed., pp: 336.

Spitters CJ, Schapendonk AH. 1990. Evaluation of breeding strategies for drought tolerance in potato by means of crop growth simulation. Gen Aspects of Plant Min Nut, 2: 151-161.

Spitters CJT. 1989. Crop Growth Models: Their usefulness and limitations. Acta Hortic, 267: 349-368.

Starke P, Hoffmann C. 2014. Yield parameters of Beta beets as a basis to estimate the biogas yield. Sug Ind, 2: 169-176.

Stricevic R, Cosic M, Djurovic N, Pejic B, Maksimovic L. 2011. Assessment of the FAO AquaCrop model in the simulation of rainfed and supplementally irrigated maize, sugar beet and sunflower. Agric Water Manag, 98(10): 1615-1621.

Süheri S, Topak R, Yavuz D. 2007. Farkli sulama programlarinin şeker pancari verimine ve su kullanim randimanina etkisi. Selcuk J Agric Food Sci, 21(43): 37-45.

Terry N. 1968. Developmental physiology of sugar beet: i. the influence of light and temperature on growth. J Exp Bot, 19(4): 795-811.

Tingem M, Rivington M. 2009. Adaptation for crop agriculture to climate change in Cameroon: turning on the heat. Mitig Adapt Strateg Glob Chang, 14(2): 153-168.

Tognetti R, Palladino M, Minnocci A, Delfine S, Alvino A. 2003. The response of sugar beet to drip and low-pressure sprinkler irrigation in southern Italy. Agri Water Manage, 60(2): 135-155.

Topak R, Süheri S, Acar B. 2011. Effect of different drip irrigation regimes on sugar beet (Beta vulgaris L.) yield, quality and water use efficiency in Middle Anatolian, Turkey. Irrig Sci, 29(1): 79-89.

TSMS. 2021. Turkish State Meteorological Service, climate data of long term period. URL: https://mgm.gov.tr (access date: August 2, 2022).

TURKSTAT. 2022. Turkish Statistical Institute. URL: https://tuikweb.tuik.gov.tr/ (access date: August 2, 2022).

Viver IA. 2022. Translation and evaluation of the LINTUL2-Banana crop growth model in R. MSc Thesis, Wagenigen University & Research, Wagenigen, Nederland.

Werker AR, Jaggard KW. 1998. Dependence of sugar beet yield on light interception and evapotranspiration. Agric For Meteorol, 89(3-4): 229-240.

Yagiz AK, Cakici M, Aydogan N, Omezli S, Yerlikaya BA, Ayten S, Haverkort AJ. 2020. Exploration of climate change effects on shifting potato seasons, yields and water use employing NASA and national long-term weather data. Potato Res, 63(4): 565-577.

Yetik AK, Candoğan BN. 2022. Optimisation of irrigation strategy in sugar beet farming based on yield, quality and water productivity. Plant Soil Environ, 68: 358-365.

Zengin M, Gökmen F, Yazici MA, Gezgin S. 2009. Effects of potassium, magnesium, and sulphur containing fertilizers on yield and quality of sugar beets (Beta vulgaris L.). Turkish J Agric Forest, 33(5): 495-502.

Zengin M, Uyanöz R, Çetin Ü. 2003. A study on the soil tare of sugar beet in Konya. Selcuk J Agric Sci, 17: 53-55.