Yield of sugar beet with drip irrigation, with Penman's equation and AquaCrop model

Rendimiento de remolacha azucarera bajo riego por goteo con ecuación de Penman y modelo AquaCrop

Rendimento de beterraba com irrigação por gotejamento, com equação de Penman e modelo AquaCrop

Jorge Pinna Cabrejos[1*]
Kevin Rivas Quevedo[2]

Rev. Fac. Agron. (LUZ). 2024, 41(2): e244115
ISSN 2477-9407
DOI: https://doi.org/10.47280/RevFacAgron(LUZ).v41.n2.05

Crop production

Associate editor: Dr. Jorge Vilchez-Perozo
University of Zulia, Faculty of Agronomy
Bolivarian Republic of Venezuela

[1]Universidad Privada Antenor Orrego, Facultad de Ciencias Agrarias, Escuela de Ingeniería Agrónoma, Av. América Sur 3145, Urb. Monserrate, Trujillo, Perú.
[2]Egresado de la Universidad Privada Antenor Orrego, Facultad de Ciencias Agrarias, Escuela de Ingeniería Agrónoma, Av. América Sur 3145, Urb. Monserrate, Trujillo, Perú.

Received: 28-03-2024
Accepted: 15-04-2024
Published: 25-04-2024

Keywords:
Sandy
Aridity
Spacings
Evapotranspiration
Temperature

Abstract

It is necessary to estimate sugar beet yield, because studies with this crop demonstrated than in Peruvian coastal zone, could be a profitable crop. The objective of the present experiment was to know if dry matter yield of sugar beet is related with Penman's equation, or FAO's AquaCrop model. Experiment was made in a sandy soil, non-salty, calcareous, very poor in organic matter, with drip irrigation in Peruvian northern coast. Four treatments: two, three, four and five plant rows per irrigation drip line, in a completely random design, with four replications were utilized. Calculated fresh matter weighs with AquaCrop were between 15.5 and 24.5 $Mg.ha^{-1}$, very much lesser to real ones (between 67.5 and 103.9 $Mg.ha^{-1}$) hence Aqua Crop model is not effective to estimate yield of sugar beet. It is possible to estimate yield of sugar beet, with Penman's formula, which varied between 11.40 and 27.96 $Mg.ha^{-1}$ dry weight, and the real one was between 13.4 and 21.5 $Mg.ha^{-1}$, with a "Root Mean Square Error" (RMSE) of 3.73.

*Corresponding author:jorge.pinnacabrejos@gmail.com

Resumen

Es necesario estimar el rendimiento de la remolacha azucarera, ya que los estudios con dicho cultivo han demostrado en la costa del Perú que puede ser rentable. El objetivo del presente experimento fue conocer si el rendimiento de materia seca de la remolacha azucarera se relaciona con la ecuación de Penman o con el modelo AquaCrop de la FAO. El experimento se efectuó en un suelo arenoso, no salino, calcáreo, muy pobre en materia orgánica, con riego por goteo, en la costa norte del Perú. Se establecieron cuatro tratamientos: dos, tres, cuatro y cinco líneas de plantas por lateral de riego en un diseño de bloques completos al azar, con cuatro repeticiones. Los pesos frescos calculados con el modelo AquaCrop variaron entre 15,5 y 24,5 $Mg.ha^{-1}$ y son muy inferiores a los reales (entre 67,5 y 103,9 $Mg.ha^{-1}$) por lo que no es adecuado para estimar el rendimiento de la remolacha azucarera. Mientras que sí es posible estimar el rendimiento de la remolacha azucarera con la ecuación de Penman, el que varió entre 11,40 y 27,96 $Mg.ha^{-1}$ de peso seco, y el real estuvo entre 13,4 y 21,5 $Mg.ha^{-1}$, con un "Error Cuadrático Medio" (RMSE) de 3,73.

Palabras clave: arenoso, aridez, distanciamientos, evapotranspiración, temperatura.

Resumo

É necessário estimar o rendimento da beterraba sacarina, já que os estudos com essa cultura demonstraram na costa do Peru que pode ser rentável. O objetivo da presente experiência era saber se o rendimento de matéria seca da beterraba se relaciona com a equação de Penman ou com o modelo AquaCrop da FAO. A experiência foi realizada em solo arenoso, não salino, calcário, muito pobre em matéria orgânica com irrigação por gotejamento, na costa norte do Peru. Foram estabelecidos quatro tratamentos: dois, três, quatro e cinco linhas de plantas de irrigação por lateral de Riego em um projeto de blocos completos aleatórios, com quatro repetições. Os pesos frescos calculados com o modelo AquaCrop variaram entre 15.5 e 24.5 $Mg.ha^{-1}$ e são muito inferiores aos reais (entre 67.5 e 103.9 $Mg.ha^{-1}$) pelo que não é adequado para estimar o rendimento da beterraba sacarina. Enquanto que é possível estimar o rendimento da beterraba com a equação de Penman, que variou entre 11.40 e 27.96 $Mg.ha^{-1}$ de peso seco, e o real esteve entre 13.4 e 21.5 $Mg.ha^{-1}$, com um "Erro Quadrático Médio" (RMSE) de 3.73.

Palavras-chave: arenoso, aridez, espaçamentos, evapotranspiração, temperatura.

Introduction

In the Peruvian coast (Valdivia *et al*., 2001) developed experiments with sugar beet (*Beta vulgaris* L. subsp. vulgaris var. altissima Döll) in highly saline soils that do not allow another crop, and Reynoso *et al*., (2001) mentioned that in saline soils it can be employed as a profitable crop by producing 90 $Mg.ha^{-1}$ of roots. In France it produces a lot of sugar per hectare/year (around 13.7 $Mg.ha^{-1}$ of sugar) (Heno *et al*., 2018), and it is one of the most profitable crops for ethanol extraction (Zicari *et al*., 2019). In Peru, it already produced similar amounts of sugar (Reynoso *et al*., 2001). It is required to expand the knowledge of *B. vulgaris* L. to move to the next stage, as an industrial crop, so it is necessary to estimate its yield being precision agriculture the most appropriate method, and for this purpose it is required that the indices obtained through satellite methods are validated with field data. To validate the yield obtained, the water consumption by the same can be used with the AquaCrop "model" of FAO (2012), or with the Penman equation (1971). It is necessary to indicate that the Penman equation (1971) calculates crop yield with the water consumed, and should not be confused with the Penman-Monteith formula that calculates crop evapotranspiration (FAO, 2006) with meteorological data.

The AquaCrop model is effective when working with irrigated sugar beet, it predicts yield, biomass, water productivity (Araji *et al*., 2019), tuberous root yield (Bitri and Grazhdani, 2015), being a good model in general (Sanchez-Sastre *et al*., 2020). But it is not so good when there is water stress due to excess or lack of moisture (Stricevic *et al*., 2011; Alishiri *et al*., 2014; Malik *et al*., 2017; Garcia-Vila *et al*., 2019) or lack of nitrogen (Alishiri *et al*., 2014).

Crop yield, mathematically expressed with an equation (Penman, 1971), depends on its water utilization (evapotranspiration), if there are no phytosanitary or water deficit problems. This equation, with some adaptations, has been successfully used in pastures by Fitzgerald *et al*. (2005; 2008), and in sugarcane by Pinna *et al*. (1983), who indicate that the solar radiation fixation efficiency (ε) varies with the different cultivars in various parts of the world between 1.15 % and 4.14 %, and found a value of 1.75 % for the Peruvian coast in the cultivar H32-8560. For this last crop and two other cultivars Burgos (1984) shows values of 1.5 % and 3.9 %; and also 1.9 % for sugar beet. The efficiency (ε) varies according to the type of crop; Penman (1971) indicates a value of 0.9 % for grass and 1.4 % for potato.

Researchers also use a similar, more specific concept, which is the Solar Radiation Utilization Efficiency (RUE) that relates biomass production to the Photosynthetically Active Radiation (PAR) intercepted by a crop (Mariscal *et al*., 2000) expressed in grams of dry matter per Mega Joule of photosynthetically active radiation (g $DM.MJ\ PAR^{-1}$) (Hoffmann and Kenter, 2018) (Hoffmann and Kenter, 2018).

Both concepts were used by Monteith (1977) who showed the same value for barley, potato, apple, and sugar beet crops: 1.4 $g.MJ^{-1}$ equivalent to an efficiency (ε) of 2.4 %. Hoffmann and Kluge-Severin (2010) indicated an RUE of 1.2 $g.MJ^{-1}$ for sugar beet. RUE varies with cultivars, with irrigation, with seeding density and whether they are C3 or C4 plants, in many crops and in different countries (Hatfield *et al*., 2019; Rong *et al*., 2021); also, with regions (countries), with nitrogen application, with crop management (Rong *et al*., 2021) and with tillage type (Hatfield *et al*., 2019).

In potato, whose RUE is the same as that of sugar beet according to Monteith (1977), it is higher than in other C3 crops and even higher than in some C4 crops, being 3.5-3.7 $g.MJ^{-1}$ in England, 3.9 in Scotland, 3.2-3.8 in Japan and 2.9-3.0 in Denmark (Lizana *et al*., 2021) higher than those indicated by Monteith (1977) for potato and sugar beet in England. Lizana *et al*. (2021) report a value of 5.9 for potato in the central coast of Peru and indicate that RUE varies with genotypes, nitrogen deficiency and the presence of nematodes. The objective of the experiment was to determine whether the dry matter yield of sugar beet irrigated by drip irrigation is related to the Penman equation (1971) or to the AquaCrop model of FAO (2012).

Materials and methods

Study site

The work was developed with data from an experiment with drip irrigation already published (Rivas and Pinna, 2021), at the Fundo Agroindustrial UPAO, northern coast of Peru (8°12'10.22.22" S, 78°58'10.95" W) in a sandy soil. The Peruvian coast is classified as a hyperarid region (UNESCO, 1977), subtropical desert (Tosi, 1960). This climate has not varied much over time (SENAMHI, 2020). The experiment was conducted in winter, with minimum temperatures higher than those found in other latitudes, in other tropical countries; and maximum temperatures well below those found in those places due to the special characteristics of the climate, which lead to almost zero precipitation (table 1).

Crop management

An initial irrigation was carried out to reach a field capacity humidity at a depth of 1 m. A wet "blanket" was obtained at depth without differentiated bulbs. Direct sowing was carried out, one seed per stroke, in a cone 5 cm deep and 3 cm in diameter drilled in the soil, which was filled with a 1/1 mixture of river sand and worm humus, where the seed was placed. Cooper cultivar sugar beet monogerm seed was used. Because sugar beet has a germination percentage of about 80 % and because germination was not uniform in all the plots, it was reseeded at 22 and 29 days and transplanted at 46 days.

Irrigation was done from 1.20 hours to 2 hours daily until 50 days after planting (dap), to replenish the moisture lost by evapotranspiration, and to maintain the moisture at field capacity, the first time based on the formula that calculates the sheet to be applied, with the field capacity, moisture content, bulk density, root depth; later "adjusted" with observations of soil pits. From day 51 onwards, daily irrigation was started based on the actual Kc (crop coefficient, coverage, measured in the field, with a tape measure, leaf area, leaf area, "green", over total area) multiplied by Eo (tank evaporation), that is, with the evapotranspiration of the crop, which is equal to Eo multiplied by Kc. The soil was maintained at field capacity, since the water lost by evapotranspiration was replaced daily. An application efficiency of 100 % was considered.

The reference evapotranspiration (ETo) was not used, but the evapotranspiration calculated with Kc and Eo, since in the experimental area (and in the entire Peruvian coast) the wind speed is low and the relative humidity high (Table 1), so this evapotranspiration is a better indicator than the reference evapotranspiration (FAO, 2006). Actual (measured) and variable Kc were taken for each treatment. A class "A" evaporimeter tank was used, which is used to irrigate an area of about 150 ha. At 14 dap, fertilization was started using weekly fertigation (total dose 150 N - 80 P_2O_5 - 200 K_2O) following a template prepared according to the needs of the crop during the various physiological stages; and was harvested at 170 dap.

Treatments and data analysis

A randomized complete block design with four treatments and four replications, was used: T1, two lines of plants located every 11 cm, per lateral (line) of irrigation, (hoses, with drippers every 40 cm, and an expense (Q) of 1.5 $L.h^{-1}$ each); T2, three lines per lateral every 17 cm; T3, four lines every 22 cm; T4, five lines every 28 cm. Plant spacings were 0.11 m, 0.17 m, 0.22 m and 0.28 m between plants, with 2, 3, 4 and 5 lines of plants per lateral, respectively, and 1.80 m between laterals. Plant density was similar, i.e., around 100,000 plants per hectare (101,010 $plants.ha^{-1}$ between 11 cm, 98,039 between 17 cm, 101,010 between 22 cm and 99,206 between 28 cm). The 100 m long furrow was divided into 4 treatments of 25 m length each. Having more rows meant more irrigation because the Kc measured was higher, and higher yields were obtained, which widened the range of data, improving the comparison of the two methodologies.

Regression analysis was performed as a measure of the "fit" of the relationship between measured and calculated data, by means of the coefficient of determination. The agreement between the models and the observed data was performed with the "Mean Squared Error" (RMSE), considering that the lower the value, the better the agreement, and when the RMSE is normalized, less than 10 % is excellent, 10 to 20 % good, 20 to 30 % regular, and more than 30 % bad; and the agreement index "d" which is excellent when it is one (1) and very bad close to zero (0) (Garcia-Vila *et al*., 2019).

Yield evaluation

Root dry matter, is 24 % of root fresh weights (Reynoso *et al*., 2001; Valdivia *et al*., 2022), that of leaves plus crowns, is 14 % of fresh weight (Valdivia *et al*., 2022). For the total yield, both fresh and dry matter, fibrous roots were not considered, because at harvest they are only 3 % of the total biomass (Vamerali *et al*., 2009).

The Penman equation (1971):

$$Y/Et = 39\varepsilon \quad \text{Mg.ha}^{-1}\text{.cm}^{-1} \qquad (1)$$

where Et is the accumulated transpiration in cm, Y is the total dry matter production in $Mg.ha^{-1}$ and (ε) is the solar radiation fixation efficiency (efficiency of conversion of radiation received on the crop surface, into dry matter -converted into energy units-), we worked with three efficiencies (ε) indicated for sugar beet in the literature: 1.9 % (Burgos, 1984), 2.4 % (Monteith, 1977) and 3.77 % (Hoffmann and Kenter, 2018), in the latter case, with Monteith's (1977) ratio

Table 1. Meteorological data. Monthly average from June 2 to November 18, 2017.

Month	Maximum temperature	Minimum temperature	Mean temperature	Relative humidity	Rainfall	Wind speed
	ºC	ºC	ºC	%	mm	$km.h^{-1}$
Jun	22.4	16.6	19.5	84.9	0.00	5.4
Jul	21.7	16.1	18.9	84.8	0.01	5.1
Aug	19.9	15.4	17.6	84.4	0.05	5.1
Sep	19.5	14.7	17.1	89.2	0.04	5.4
Oct	19.8	14.6	17.2	89.4	0.02	4.6
Nov	23.0	16.6	19.8	75.0	0.06	5.8

(Rivas y Pinna, 2021).

between RUE and (ε) (1.4 g.MJ^{-1}, is equivalent to an efficiency (ε) of 2.4 %). Efficiency (ε) data are not available for Peru.

Data for AquaCrop

For AquaCrop, the data in 1able 1 were used, when available, and when not, with the default data of the program, which according to Sanchez-Sastre *et al*. (2020) are well calibrated, which imply small changes in the default data and in the estimates of yields (FAO, 2012). Temperatures were worked by month. All requested variables were entered into the model, at the required frequencies, and are the same for all treatments, except Kc and irrigation.

Results and discussion

Table 2 shows the water used and the Kc employed per tens (ten days) for AquaCrop (water was applied differentially, daily, for each treatment according to its Kc in equal amounts to each replicate). As Kc was measured, in the first tens of the crop, when the leaf area was very small, Kc were also extremely low. Root yields are shown in table 3.

Yields estimated with AquaCrop increase with drip line when fresh weight as with the real ones, but not in dry weight (table 4) (weight which is important for estimates with Penman (1971) as with the RUE) since the harvest index (HI) shown by the model as a result after its execution, for dry weights: 84 %, 83.8 %, 81 %, and 70.2 % for two, three, four, and five rows, decreases with the number of rows instead of increasing, or being the same, despite the data being the same for all treatments except Kc and irrigation. Between the estimated and measured yield in fresh weight, the RMSE shows a low agreement, and when normalized, it is very low, the "d" index shows an extremely low one; and it has a moderately good fit since the regression between the actual fresh weight with the one calculated with AquaCrop is: Y=0.2363X+1.2773 (R^2 0.7843). The estimated fresh weights are much lower than the actual ones, by almost four times, which is in agreement with other crops (Sherzod *et al*., 2023) and explains the low agreement.

Table 2. Water applied in the experiment (mm).

Treatments	Te	I		II		III		IV		V		VI	
	Dt	2-11 jun		12-21 jun		22 jun-1 jul		2-11 jul		12-21 jul		22-31 jul	
		Kc	mm.d^{-1}	Kc	mm.d^{-1}	Kc	mm.d^{-1}	Kc	mm.d^{-1}	Kc	mm.d^{-1}	Kc	mm.d^{-1}
Two rows		0.002	0.04	0.06	2.477	0.16	5.23	0.20	1.55	0.20	4.90	0.34	7.95
Three rows		0.004	0.08	0.07	3.059	0.20	6.72	0.25	5.90	0.39	9.56	0.52	13.46
Four rows		0.005	0.10	0.07	2.848	0.18	6.09	0.23	5.34	0.46	11.28	0.64	15.49
Five rows		0.007	0.15	0.01	0.372	0.27	7.28	0.28	6.43	0.71	17.40	0.88	22.74
Treataments	Te	VII		VIII		IX		X		XI		XII	
	Dt	1-10 aug		11-20 aug		21-30 aug		31 aug-9 sep		10-19 sep		20-29 sep	
		Kc	mm.d^{-1}	Kc	mm.d^{-1}	Kc	mm.d^{-1}	Kc	mm.d^{-1}	Kc	mm.d^{-1}	Kc	mm.d^{-1}
Two rows		0.34	9.63	0.34	10.54	0.34	9.61	0.34	13.26	0.34	12.58	0.34	8.16
Three rows		0.52	13.59	0.52	16.12	0.52	13.75	0.52	20.28	0.52	19.24	0.52	12.48
Four rows		0.64	16.23	0.64	19.84	0.64	16.51	0.64	24.96	0.64	23.04	0.64	15.36
Five rows		0.88	21.51	0.88	27.28	0.88	22.03	0.88	34.32	0.88	32.56	0.88	21.12
Treatments	Te	XIII		XIV		XV		XVI		XVII		Total	
	Dt	30 sep-9 oct		10-19 oct		20-29 oct		30 oct-8 nov		9-17 nov			
		Kc	mm.d^{-1}	Kc	mm.d^{-1}	Kc	mm.d^{-1}	Kc	mm.d^{-1}	Kc	mm.d^{-1}	mm	
Two rows		0.34	17.75	0.34	11.22	0.34	15.98	0.34	13.78	0.27	9.06	153.79	
Three rows		0.52	23.16	0.52	17.16	0.52	24.44	0.52	21.16	0.42	13.86	234.20	
Four rows		0.64	26.78	0.64	21.12	0.64	30.08	0.64	25.96	0.51	17.37	278.39	
Five rows		0.88	34.00	0.88	29.04	0.88	41.36	0.88	35.80	0.71	23.91	377.31	

Te = Tens; Dt = Dates; Kc = crop coefficient; mm.d^{-1} = millimeters per tens.

Table 3. Average yield of the four treatments.

Treatments	Yield Mg.ha^{-1}					
	Roots		Leaves plus Crowns		Total	
	Fresh	Dry	Fresh	Dry	Fresh	Dry
Two rows	39.9	9.6	27.6	3.9	67.5	13.4
Three rows	51.0	12.2	29.2	4.1	80.2	16.3
Four rows	58.6	14.1	25.9	3.6	84.4	17.7
Five rows	69.5	16.7	34.5	4.8	103.9	21.5

Table 4. Estimated yields and their agreement with Penman and AquaCrop methods.

Treatments	Yield Mg.ha-1				
	Penman			AquaCrop	
	Dry ε(1.90 %)	Dry ε(2.40 %)	Dry ε(3.77 %)	Fresh	Dry
Two rows	11.40	14.39	22.61	15.50	13.04
Three rows	17.34	21.90	34.41	21.00	17.60
Four rows	20.63	26.06	40.93	23.50	19.04
Five rows	27.96	35.32	55.48	24.50	17.18
RMSE	3.73	8.57	22.95	63.69	2.38
RMSE Normalized (%)	21.67	49.71	133.19	75.82	13.68
d	0.83	0.54	0.21	0.04	0.74

RMSE = root mean square error; d = concordance index

The dry weights calculated with AquaCrop are similar to the real ones, have a good agreement according to the RMSE, and according to the normalized one, good. They have a high "d" index, but with a very low fit because they do not follow the same trend, especially in the five-row data (R^2 = 0.3905) (figure 1). The contradiction in AquaCrop between fresh and dry weights indicates that this model is not ideal for estimating sugar beet yields, because the crop itself is very important in the calculations it develops, such as, for example, the harvest index (HI), which cannot be adjusted or modified, because it is a result of the model itself. It also depends on the absence of stress of any kind, whether due to the presence of weeds, pests or diseases (Pinheiro *et al*., 2024). When there is water stress in sugar beet, the results are very variable (Stricevic *et al*., 2011; Alishiri *et al*., 2014; Malik *et al*., 2017; Garcia-Vila *et al*., 2019), also due to lack of nitrogen (Alishiri *et al*., 2014); in this study, the stress that occurred was due to nematode attack, which produced deficiencies in the assimilation of water and nutrients (Shakeel *et al*., 2022).

The coefficient of determination (R^2) between actual dry weight and calculated fresh yield, surprisingly, is better than dry versus dry (figure 1) and fresh versus fresh, with AquaCrop, despite the fact that the default data used are the same in dry weight, fresh and treatments, which reinforces the idea that it is not an adequate model to estimate beet yield.

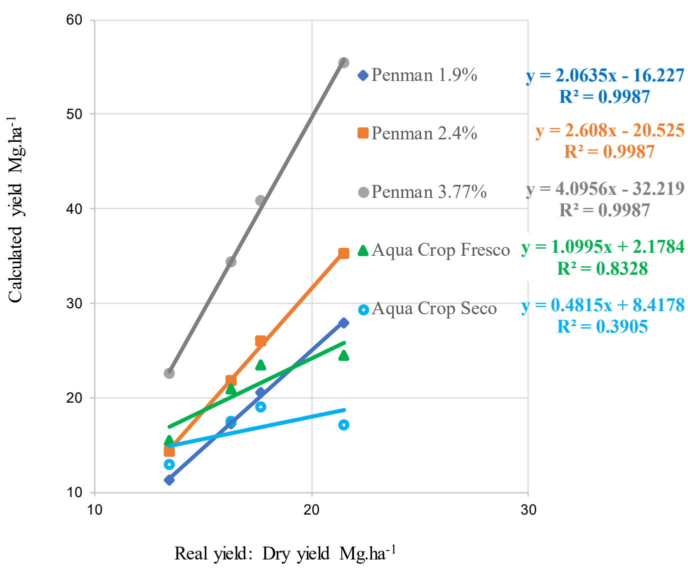

Figure 1. Regressions between actual dry weights and calculated yields.

With Penman's (1971) equation, only dry weights are calculated, which increase with rows per lateral table 4) as well as the real ones (table 3), since the applied water increased with rows because its Kc also increased. Except with the ε of 1.9 % the calculated yields are much higher than the actuals. The RMSE between the real data and that calculated with the ε of 1.9 % is good, the normalized one is regular and the high "d" index, very good (table 4); the coefficient of determination, very good (R^2= 0.9987) (figure 1). The coefficients of determination, between real dry weights and those calculated with Penman (1971) are the same for all efficiencies, which is normal since it is the change of a single variable in all cases ("common factor") which is the coefficient ε.

The results show that it is possible to estimate sugar beet yields with Penman (1971). The results with ε of 2.4 % and 3.77 % indicate that it would be possible to work in the future with the figure of 1.9 %, which is not exact, since there is a distorting factor which is the attack of nematodes. In this sense Hatfield (2014) affirms that, in corn and soybean there are differences in RUE in different years and with different tillage methods in the soil. Lizana *et al*. (2021) indicate that, in potato, nitrogen deficiency reduces photosynthesis and RUE, as does stress caused by nematodes. Therefore, although Penman (1971) is useful for estimating sugar beet yields, it is necessary to carry out experiments to find the ε for each cultivar, taking into account that the production factors must be found at the optimum, avoiding nutrient, water, or phytosanitary stresses.

Conclusions

With AquaCrop, the calculated fresh weights are much lower than the real ones. The calculated dry weights are similar to the actual weights, although they do not follow the same trend, especially in the five-row treatment. AquaCrop is not suitable for estimating sugar beet yields. It is necessary to calibrate the model with respect to the crop itself, especially the harvest index (HI).

It is possible to estimate beet yields with the Penman (1971) equation. It is necessary to carry out experiments to find the solar radiation fixation efficiency (ε) with Penman (1971) for each cultivar, considering good agronomic management to prevent any stress event.

Acknowledgments

To Prof. André Théwis and Mr. Dick Vermoote for making the arrangements for the donation of the seed by Sesvanderhave, a company to whom thanks are also due.

Literature cited

Alishiri, R., Paknejad, F. & Aghayari, F. (2014). Simulation of sugarbeet growth under diferent water regimes and nitrogen levels by aqua crop. *International Journal of Biosciences*, *4*(1), 1-9. https://www.researchgate.net/publication/342079161_Simulation_of_sugarbeet_growth_under_different_water_regimes_and_nitrogen_levels_by_aqua_crop

Araji, H.A., Wayayok,A., Khayamin, S., The, C.B.S., Abdullah, A.F., Amiri, E. & Bavani, A.M. (2019). Calibration of the Aquacrop model to simulate Sugar Beet production and water productivity under different treatments. *Applied engineering in agriculture, 35*(2), 211–219. http://christopherteh.com/publications/resources/NRES12946.pdf

Bitri, M. & Grazhadani, S. (2015). Validation of Aqua Crop model in the simulation of sugar beet production under different water regimes in southeastern Albania. *International Journal of Engineering Science and Innovative Technology, 4*(6), 171-181. www.ijesit.com/Volume%204/Issue%206/IJESIT201506_20.pdf

Burgos, J.J. (1984). El clima en la producción de alimentos en América Latina. Sesión ordinaria de 8 de agosto de 1984. *Academia Nacional de Agronomía y Veterinaria*, *38*(5), 4-34. https://core.ac.uk/download/pdf/296354711.pdf

FAO. Organización de las Naciones Unidas para la Alimentación y la Agricultura. (2006). Evapotranspiración del cultivo. Guías para la determinación de los requerimientos de agua de los cultivos. *In estudio FAO Riego y Drenaje 56. R.G. Allen, L.S. Pereira, D. Raes, M. Smith (Eds).* Food and Agriculture Organization of the United Nations. Rome. 298p. https://www.fao.org/3/x0490s/x0490s00.htm

FAO. Organización de las Naciones Unidas para la Alimentación y la Agricultura. (2012). Crop Yield Response to Water. *In FAO Irrigation and Drainage Paper 66. P. Steduto, T. C. Hsiao, E. Fereres, D. Raes (Eds).* Food and Agriculture Organization of the United Nations. Rome. 500p. https://www.fao.org/3/i2800e/i2800e00.htm

Fitzgerald, J.B., Brereton, A.J. & Holden, N.M. (2005). Assessment of regional variation in climate on the management of dairy cow systems in Ireland using a simulation model. *Grass and Forages Science*, *60*, 283-296. https://doi.org/10.1111/j.1365-2494.2005.00479.x

Fitzgerald, J.B., Brereton, A.J. & Holden, N.M. (2008). Simulation of the influence of poor soil drainage on grass-based dairy production systems in Ireland. *Grass and Forages Science, 63*, 380-389. https://doi.org/10.1111/j.1365-2494.2008.00637.x

Garcia-Vila, M., Morillo-Velarde, R. & Fereres, E. (2019). Modeling sugar beet responses to irrigation with Aqua Crop for optimizing water Allocation. *Water*, *11*(9), 1918. https://doi.org/10.3390/w11091918

Hatfield, J.L. (2014). Radiation use efficiency. Evaluation of cropping and management systems. *Agronomy Journal*, *106*(5), 1820-1827. https://doi.org/10.2134/agronj2013.0310

Hatfield, J.L. & Dold, C. (2019). Photosynthesis in the solar corridor systems. *In The Solar Corridor System. Implementation and Impacts. Deichman, C.L., Kremer, R.J. (Eds.)*. Academic Press. pp. 1- 33. https://doi.org/10.1016/B978-0-12-814792-4.00001-2

Heno, S., Viou, L. & Khan, M. (2018). Sugar beet production in France. *Sugar Tech*, *20*, 392-395. https://doi.org/10.1007/s12355-017-0575-x.

Hoffmann, C.M. & Kenter, C. (2018). Yield potential of sugar beet – have we hit the ceiling? *Front. Plant Science*, *9*,289. https://doi.org/10.3389/fpls.2018.00289

Hoffmann, C.M. & Kluge-Severin, S. (2010). Light absorption and radiation use efficiency of autumn and spring sown sugar beets. *Field Crop Research*, *119*, 238-244. http://dx.doi.org/10.1016/j.fcr.2010.07.014

Lizana, X.C., Sandaña, P., Behn, A., Ávila-Valdés, A., Ramírez, D.A., Soratto, R.P. & Campos, H. (2021). Chapter 18 – Potato. *In Crop Physiology Case Histories for Major Crops. Sadras, V.O., Calderini, D.F. (Eds.).* Academic Press. pp. 550-587. https://dokumen.pub/qdownload/crop-physiology-case-histories-for-major-crops-0128191945-9780128191941.html

Malik, A., Shakir, A.S., Ajmal, M., Jamal, M. & Ali, T. (2017). Assessment of Aqua Crop model in simulating sugar beet canopy cover, biomass and root yield under different irrigation and field management practices in semi-arid regions of Pakistan. *Water Resources Management*, *31*(13), 4275-4292. http://link.springer.com/10.1007/s11269-017-1745-z

Mariscal, M.J., Orgaz, F. & Villalobos, F.J. (2000). Radiation-use efficiency and dry matter partitioning of a young olive (*Olea europeae*) orchard. *Tree Physiology*, *20*, 65-72. https://doi.org/10.1093/treephys/20.1.65

Monteith, J.L. (1977). Climate and the efficiency of crop production in Britain. *Philosophical Transactions of the Royal Society of London. B. Biological Sciences, 281*, 277-294. https://doi.org/10.1098/rstb.1977.0140

Penman, H. L. (1971). Water as a Factor in Productivity. *In Potential Crop Production, P. F. Wareing & J. P. Cooper (Eds.)*, Heinemann, London, pp. 89-99. https://scholar.google.com/scholar_lookup?&title=Water%20as%20a%20factor%20in%20productivity&pages=89-99&publication_year=1971&author=Penman%2CHL https://www.amazon.com/Potential-Crop-Production-P-F-Wareing/dp/0435629905

Pinheiro, A.G., Alves, G.P., Alves de Souza, C.A., Araújo Júnior, G.N., Jardim, A.M., de Morais, J.E., de Souza, L.S., Lopes, D.C., Neto, A.J., Montenegro, A.A., Gomes, J.E. & da Silva, T.G. (2024). Calibration and validation of the AquaCrop model for production arrangements of forage cactus and grass in a semi-arid environment. *Ecological Modelling*, *488*, 110606. 10.1016/j.ecolmodel.2023.110606

Pinna C., J., Valdivia V., S. & Tello A., H. (1983). Yield estimation of sugarcane from evapotranspiration data. *Proceedings of the International Society of Sugar Cane Technologists*, *18*, 485-506. https://www.researchgate.net/publication/311949613_PLANT_PHYSIOLOGY_YIELD_ESTIMATION_OF_SUGAR_CANE_FROM_EVAPOTRANSPIRATION_DATA

Reynoso C., J., Valdivia V., S., Larsen C. E. & Pinna C., J. (2001). Comparativo de cultivares de remolacha azucarera en suelos salinos. *Arnaldoa*, *8*(1), 93 - 100. https://www.researchgate.net/publication/311949805_Comparativo_de_cultivares_de_remolacha_azucarera_en_suelos_salinos

Rivas Q., K. & Pinna C., J. (2021). Estudio del número de líneas de plantas, por lateral de riego, en remolacha azucarera (Beta vulgaris L. var. Altissima Döll cv. Cooper); en un suelo de textura arena regada por goteo. Pueblo Continente, 32(2), 607-612. https://www.researchgate.net/publication/360947012_Estudio_del_numero_de_lineas_de_plantas_por_lateral_de_riego_en_remolacha_azucarera_Beta_vulgaris_L_var_Altissima_Doll_cv_Cooper_en_un_suelo_de_textura_arena_regada_por_goteo

Rong, L., Gong, K., Duan, F., Li, S., Zhao,M., He, J., Zhou, W. & Yu, Q. (2021). Yield gap and resource utilization efficiency of three major food crops in the world – A review. *Journal of integrative Agriculture*, *20*(2), 349-362. https://doi.org/10.1016/S2095-3119(20)63555-9

Sanchez-Sastre, L.F., Alte da Veiga, N.M.S., Ruiz-Potosme, N.M., Hernandez-Navarro, S., Marcos-Robles, J.L., Martin-Gil, J. & Martin-Ramos, P. (2020). Sugar beet agronomic performance evolution in NW Spain in future scenarios of climate change. *Agronomy*, *10*, 91. https://uvadoc.uva.es/bitstream/handle/10324/52812/Sugar-beet-agronomic-performance.pdf?sequence=1&isAllowed=y

SENAMHI. (2020). Clima. Mapa Climático del Perú. Disponible en https://www.senamhi.gob.pe/?&p=mapa-climatico-del-peru

Shakeel, A., Khan, A.A., Bhat, A.H. & Sayed, S. (2022). Nitrogen fertilizer alleviates root-knot nematode stress in beetroot by suppressing the pathogen while modulating the antioxidant defense system and cell viability of the host. *Physiological and Molecular Plant Pathology*, *120*, 101838. https://www.sciencedirect.com/science/article/abs/pii/S0885576522000534?via%3Dihub

Sherzod, N., Nurbekov, A., Kosimov, M., Gafurova, L., Boulange, J. & Watanabe, H. (2023). Applicability of the AquaCrop model for simulating winter wheat under a semi-arid climate in Uzbekistan. *Journal of Arid Land Studies*, *33*(2), 91-104. https://www.jstage.jst.go.jp/article/jals/33/2/33_91/_article

Stricevic, R., Cosic, M., Djurovic, N., Pejic, B. & Makisivomic, L. (2011). Assessment of the FAO Aqua Crop model in the simulation of rainfed and supplementary irrigated maize, sugar beet and sunflower. *Agricultural Water Management*, *98*(10), 1615-1621. https://www.sciencedirect.com/science/article/abs/pii/S0378377411001193

Tosi, J. (1960). Zonas de vida natural en el Perú. Lima: *Ed IICA-OEA*. https://books.google.es/books?hl=es&lr=&id=PJYgAQAAIAAJ&oi=fnd&pg=PP8&dq=+Zonas+de+vida+natural+en+el+Per%C3%BA.&ots=yUhUta9oGL&sig=z-RU3WZau_ucen2vtmyblbabK_4#v=onepage&q=Zonas%20de%20vida%20natural%20en%20el%20Per%C3%BA.&f=false

UNESCO. (1977). Un nuevo mapa de la distribución mundial de las regiones áridas. *La Naturaleza y sus Recursos*, *13*(3), 2-3. https://unesdoc.unesco.org/ark:/48223/pf0000264924

Valdivia V., S., Reynoso C., J., Pinna C., J. & Larsen C., E. (2001). Efecto de las sales en la producción de la remolacha azucarera en la costa árida del Perú. *Antenor Orrego, 10*(16-17), 71 - 80. https://www.researchgate.net/publication/311950920_Efecto_de_las_sales_en_la_produccion_de_la_remolacha_azucarera_en_la_costa_arida_del_Peru

Valdivia V., S, Pinna C., J. & Valdivia S., S. (2022). Balance de fósforo en un suelo salino cultivado con remolacha azucarera (*Beta vulgaris* L. subsp. *vulgaris* var. *altissima* Döll). *Cienc. Tecnol. Agropecuaria*, *23*(3): e2614. https://revistacta.agrosavia.co/index.php/revista/article/view/2614/977

Vamerali, T., Guarise, M., Ganis, A. & Mosca, G. (2009). Effects of water and nitrogen management on fibrous root distribution and turnover in sugar beet. *European Journal of Agronomy, 31*, 69-76. http://dx.doi.org/10.1016/j.eja.2009.03.005

Zicari, S., Zhang, R. & Kaffka, S. (2019). Sugar beet. *In Z. Pan, R. Zhang, and S. Zicari (Eds.), Chapter 13, Integrated processing technologies for food and agricultural by-products* (pp. 331-351). Academic Press. https://doi.org/10.1016/C2017-0-00901-1.