SIMULATION OF QUINOA (CHENOPODIUM QUINOA WILLD.) RESPONSE TO SOIL SALINITY USING THE SALTMED MODEL

L'EFFET DE LA SALINITÉ DU SOL SUR LA CROISSANCE DU QUINOA GRÂCE AU MODELE SALTMED

Fatemeh Razzaghi[1], Finn Plauborg[2], Seyed Hamid Ahmadi[3], Sven-Erik Jacobsen[4], Mathias N. Andersen[5], Ragab Ragab[6]

ABSTRACT

Quinoa (Chenopodium quinoa Willd.) is a crop with high tolerance to salinity and drought and its response to varying soil moisture and salinity levels was studied in a field lysimeter experiment. Quinoa (cv. Titicaca) was irrigated with different concentrations of saline water (0, 10, 20, 30 and 40 dSm^{-1}) from flowering stage for 18 days (FI_0, FI_{10}, FI_{20}, FI_{30} and FI_{40}) and then irrigation continued with tap water. Measured yield, soil water content (SWC) and soil water electrical conductivity (EC_w) under the various saline conditions were compared with simulated yield, SWC and EC_w with the water management model SALTMED. The model calibration was carried out for the unstressed crop (FI_0), while the other treatments (FI_{10}, FI_{20}, FI_{30} and FI_{40}) were used for model validation. The results showed that the model has the ability to simulate seed yield and total dry matter (seed yield + straw yield) even for stressed plants under field condition. In addition, the model simulated reasonably well the SWC and the EC_w of the root zone.

Key words: *Salt tolerance, Chenopodium quinoa Willd, lysimeter, SALTMED, Denmark.*

1 Faculty of Agricultural Sciences, Department of Agroecology and Environment, Blichers Allé 20, DK-8830 Tjele, Denmark, Fatemeh.Razzaghi@agrsci.dk
2 Aarhus University, Faculty of Agricultural Sciences, Department of Agroecology and Environment, Blichers Allé 20, DK-8830 Tjele, Denmark, Finn.Plauborg@agrsci.dk
3 Irrigation Department, Faculty of Agriculture, Shiraz University, Shiraz, Iran, seyedhamid.ahmadi@gmail.com
4 University of Copenhagen, Faculty of Life Sciences, Department of Agricultural Sciences, Højbakkegaard Allé 13, DK-2630 Taastrup, Denmark, seja@life.ku.dk
5 Aarhus University, Faculty of Agricultural Sciences, Department of Agroecology and Environment, Blichers Allé 20, DK-8830 Tjele, Denmark, MathiasN.Andersen@agrsci.dk
6 Centre for Ecology and Hydrology, CEH, UK, Rag@ceh.ac.uk

RESUME ET CONCLUSIONS

La quantité d'eau nécessaire pour la production agricole augmente due à la perpétuelle croissance de la population mondiale. Les agriculteurs doivent parfois utiliser l'eau de mauvaise qualité, qui présente une forte salinité, à cause du manque de précipitation ou d'une forte évapotranspiration.

L'utilisation d'eau saline pour l'irrigation a un effet négatif sur la fertilité des sols et réduit la productivité. Dans ces situations, il est essentiel de sélectionner les cultures pouvant tolérer les conditions salines et ayant des rendements acceptables. Suivant différentes techniques d'irrigation et conditions pédologiques, les modèles permettent à la détermination des besoins en eau des cultures, à la planification de l'irrigation, à la prévision de la production de biomasse, ainsi qu'à la salinisation du sol. L'objectif de cette étude était d'utiliser le modèle SALTMED comme outil de prévision des rendements, de la teneur en eau du sol (SWC), et de la conductivité électrique de l'eau du sol (EC_w) dans le cas d'une production de quinoa au champ.

Les effets de la salinité et du manque d'eau sur le quinoa (Chenopodium quinoa Willd., cv. Titicaca) ont été étudiés dans les lysimètres au champ. Le quinoa a été irrigué avec les solutions salines de différentes conductivités électriques (0, 10, 20, 30 and 40 dSm^{-1}) à partir de la floraison et pendant 18 jours (FI_0, FI_{10}, FI_{20}, FI_{30} and FI_{40}), puis l'eau a été utilisée pour l'irrigation. Nous avons utilisé la version récente de SALTMED 2010 (version 3.06.00) développée par Ragab Ragab (http://www.swup-med.dk/SALTMED.aspx). SALTMED peut simuler la croissance, la production de biomasse, les rendements, la teneur en eau du sol et la conductivité électrique à différents profondeurs et à différentes distances de la source d'irrigation. Nous avons comparé les données simulées aux données mesurées. Le modèle a été calibré en utilisant les données mesurées pour la modalité FI_0 et validé en utilisant les données mesurées pour les autres modalités (FI_{10}, FI_{20}, FI_{30} and FI_{40}).

Les résultats montrent une concordance acceptable entre les prévisions et les mesures de teneur en eau et de conductivité électrique pour les zones racinaires (0-40 et 0-60 cm de profondeur). Les rendements en tiges et graines calculés par le modèle sont très proches des rendements mesurés pour les modalités où les plantes sont irriguées avec des solutions salines (les rendements de matière sèche et de graines pour FI_{20} étaient de 5.16 Mg ha^{-1} et 1.50 Mg ha^{-1}, alors que les rendements mesurés étaient de 5.08 Mg ha^{-1} et 1.47 Mg ha^{-1} pour ces deux paramètres).

En conclusion, SALTMED peut être utilisé pour prévoir les rendements en tige et en graines de plantes subissant un stress hydrique ou salin. De plus, les prévisions de teneur en eau et de conductivité électrique pour la zone racinaire sont satisfaisantes.

Mots clés : *Tolérance à la salinité, Chenopodium quinoa Willd, lysimètre, SALTMED, Danemark.*

1. INTRODUCTION

Quinoa (*Chenopodium quinoa* Willd.) is a facultative halophyte known to tolerate abiotic stresses such as drought (Jacobsen et al., 2009) and salinity (Hariadi et al., 2011). Little is known about quinoa crop characteristics and its modelling. Therefore, studies on quinoa not only will enrich the literature with more information but also supply models with quantified crop parameters. The SALTMED model (Ragab, 2002 and Ragab et al. 2005 a&b) has been developed to predict crop water uptake, temporal soil moisture regimes, salinity distribution, crop growth and seed yield under saline conditions for different irrigation systems, crops and soil types.

The objective of this study was to use SALTMED model as a tool to simulate the seed yield, dry matter, soil water content and soil water salinity of field-grown quinoa (cv. Titicaca). The modelling activity included calibration of crop and soil parameters and a validation step using independent data leading to a SALTMED model, which may be used to predict quinoa production under saline and fresh water conditions.

2. MATERIALS AND METHODS

A field lysimeter experiment was carried out, at the Faculty of Agricultural Sciences, Aarhus University, Denmark. A total of 20 concrete drainable lysimeters (2.7 m long, 1.6 m wide and 1.4 m deep) filled with coarse sandy soil were used in this study. A Danish bred cultivar of quinoa (cv. Titicaca) was sown on 24 April 2009 at a depth of 2.5 cm with an inter- and intra-row spacing of 24 cm and 5 cm, respectively.

All lysimeters were irrigated daily with 2 mm of tap water after sowing until germination (May 3rd 2009) and thereafter irrigation was performed with drip irrigation to 95% of field capacity (FC). Full irrigation (FI; 95% of FC) combined with five salinity levels (0, 10, 20, 30 and 40 dS m^{-1}) of irrigation water were applied from 55 DAE (days after emergence). At initiation of flowering (DAE 55), irrigation was switched to saline water in all lysimeters (except for 0 salinity treatment; FI_0) and continued for 18 days. Thereafter from 73 DAE the irrigation was continued by applying tap water. The total of five treatments was distributed in randomized complete block design with four replications. Total dry matter (straw yield + seed yield) and seed yield of all treatments were determined at the end of the growing period.

The soil water content (SWC) was monitored manually by using time domain reflectrometry (TDR) based on the Tektronix cable tester (e.g. Plauborg et al., 2005). The TDR rods (in pairs) were installed vertically to measure the volumetric water content at different depths (0-20, 0-40, 0-60, 0-80 cm) in all treatments. The soil water content after imposing salinity was measured gravimetrically by collecting the soil samples from 0-60 cm of at 10 cm intervals. The EC of soil water (EC_w, dSm^{-1}) was calculated by measuring gravimetric water content and electrical conductivity of soil samples.

2.1 Model description

In this study, the recent version of SALTMED 2010 (version 3.06.00) developed by Ragab Ragab (http://www.swup-med.dk/SALTMED.aspx) was used for simulation of yield, soil water content and salinity. The SALTMED 2010 has the ability to simulate crop growth, biomass production, yield, soil water content and soil water salinity at different depths and different distance from the irrigation source. A full description of this model is provided in (http://www.swup-med.dk/SALTMED.aspx).

The model was run with the data from the field study of quinoa. The calibration of the model was carried out for the FI_0 treatment by fine tuning some of the crop and hydraulic parameters. Other treatments (FI_{10}, FI_{20}, FI_{30} and FI_{40}) were used for model validation.

2.2 Statistical analysis

Mean bias error (MBE), mean absolute error (MAE), root mean square error (RMSE) and relative error (RE) were used to compare the measured and simulated soil water content, EC_w, dry matter and seed yield.

$$MBE = \frac{1}{n}\sum_{i=1}^{n}(S_i - O_i) \quad (1)$$

$$MAE = \frac{1}{n}\sum_{i=1}^{n}(|S_i - O_i|) \quad (2)$$

$$RMSE = \left(\frac{\sum_{i=1}^{n}(S_i - O_i)^2}{n}\right)^{0.5} \quad (3)$$

$$RE = \frac{O - S}{O} \times 100 \quad (4)$$

where S is the simulated value, O is the observed value and n is total number of measured values.

3. RESULTS AND DISCUSSION

3.1 Calibration

The variation in observed and simulated SWC during the crop growth period is shown in Fig. 1. The model-simulated SWC was found to be close to observed values at 0-40, 0-60 and 0-80 cm, while it was over estimated at 0-20 cm. Result of statistical analysis showed that the SALTMED model simulated SWC reasonably well (Table 1), especially at 0-40, 0-60 and 0-80 cm depths.

Table 1. Statistical analysis of soil water content (SWC) of FI_0 at four different depths (Analyse statistique de la teneur en eau du sol à quatre profondeurs pour la modalité FI_0)

Parameter	Depth (cm)			
	0-20	0-40	0-60	0-80
MBE	0.0976	0.0025	-0.0135	-0.0011
MAE	0.0976	0.0150	0.0182	0.0118
RMSE	0.1010	0.0173	0.0228	0.0158

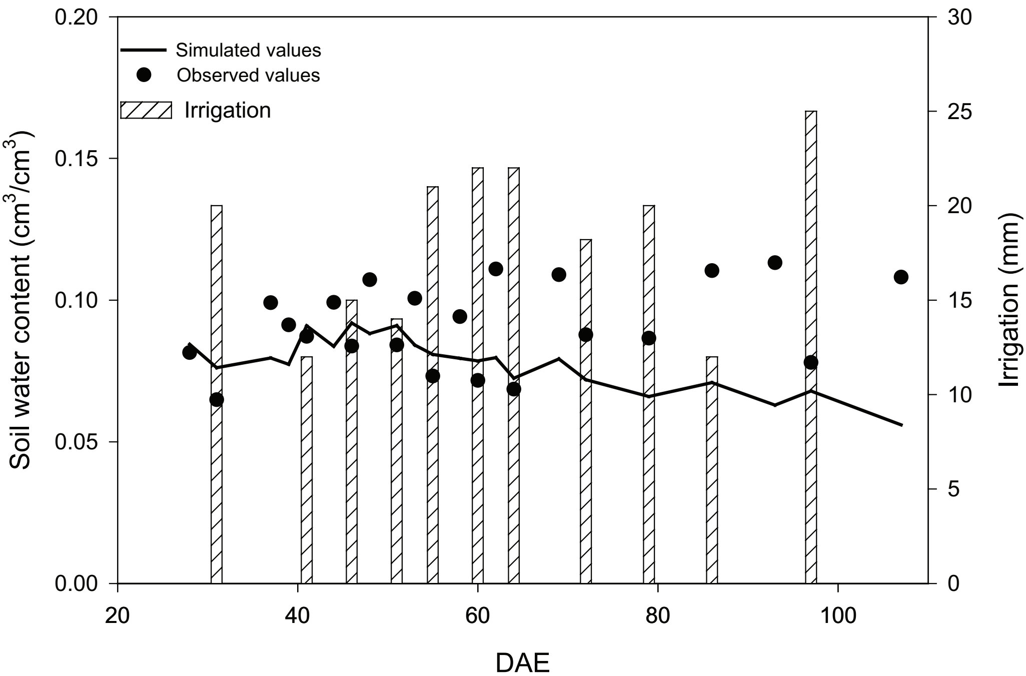

Figure 1. Observed and simulated volumetric soil water content of FI_0 at 0-60 cm depth and applied irrigation during growth period (Irrigation et teneur volumétrique en eau du sol mesurée et calculée pour la modalité FI_0 entre 0 et 60 cm de profondeur)

The observed and simulated total dry matter were very close to each other (6.06 and 6.07 Mg ha^{-1}, respectively), and the observed and simulated seed yield were almost the same (2.45 Mg ha^{-1}) as shown in Table 2.

Table 2. Observed and simulated values, and the error of total dry matter and seed yield for treatment FI_0 (Rendement de matière sèche et de graines pour la modalité FI_0 (mesures, prévisions, erreur relative)

Total dry matter			Seed yield		
Observed (Mg ha^{-1})	Simulated (Mg ha^{-1})	Relative error (%)	Observed (Mg ha^{-1})	Simulated (Mg ha^{-1})	Relative error (%)
6.06	6.07	-0.11	2.45	2.45	-0.04

3.2 Validation

Simulated and observed SWC of the 0-60 cm depth within the crop growth period are shown in Figs. 2 for FI_{20} and FI_{40}, respectively. The statistical analysis (Table 3) showed that the model simulated SWC close to observed values at 0-60 cm (Figs. 2a and b).

Table 3. Statistical analysis of soil water content (SWC) at 0-60 cm and different salinity levels (Analyse statistique de la teneur en eau du sol entre 0 et 60 cm de profondeur pour les modalités FI_{10}, FI_{20}, FI_{30} and FI_{40})

Depth (cm)	Parameter	Treatment			
		FI_{10}	FI_{20}	FI_{30}	FI_{40}
0-60	MBE	0.0066	0.0187	0.0107	0.0134
	MAE	0.0104	0.0272	0.0128	0.0152
	RMSE	0.0131	0.0424	0.0154	0.0180

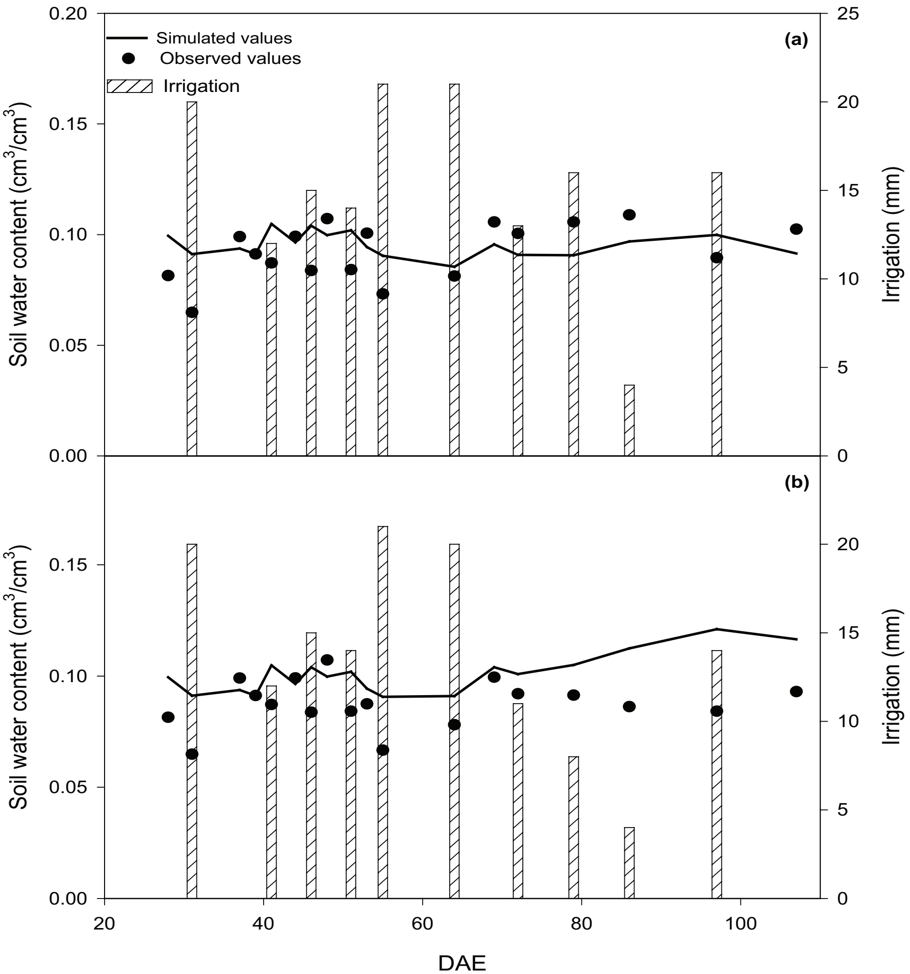

Figure 2. Variation in simulated and measured soil water content and irrigation applied to (a) FI_{20} and (b) FI_{40} during the growth period (Irrigation et teneur volumétrique en eau du sol mesurée et calculée pour les modalités FI_{20} (a) et FI_{40} (b) pendant la période de croissance)

Figure 3 shows the variation in simulated and observed EC_w of FI_{20} for two depths (40-50 cm and 50-60 cm). The results showed that the simulated EC_w followed the same pattern as observed values; however it was initially lower than the observed values in the depth 50-60 cm. The high R^2 value of the linear relationship between the simulated and observed EC confirms the ability of the model to well predict EC_w (Fig. 4).

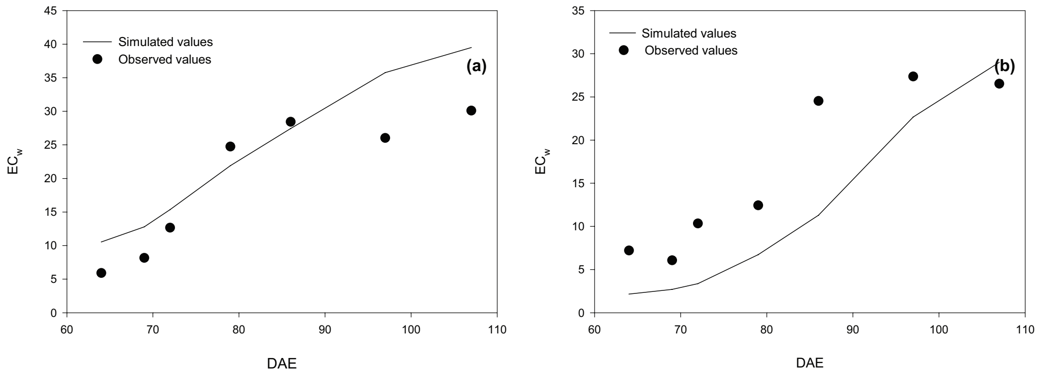

Figure 3. Variation in simulated and observed ECw of soil water at (a) 40-50 cm and (b) 50-60 cm depth in FI_{20} treatment after imposing the saline solution (Variations de la teneur en eau et de la conductivité électrique mesurées et calculées à deux profondeurs (a : 40-50 cm et b : 50-60 cm) pour la modalité FI_{20} après l'application de la solution saline)

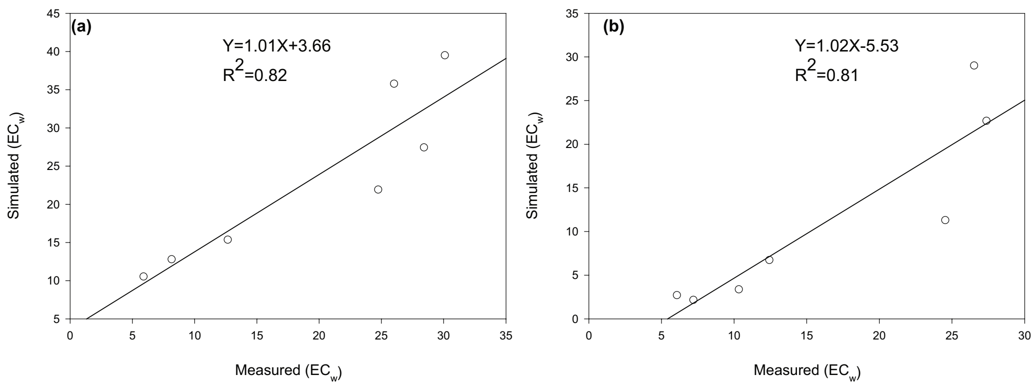

Figure 4. Linear relationship between the observed and simulated ECw of soil water of FI_{20} treatment at (a) 40-50cm and (b) 50-60cm depth (Conductivité électrique de l'eau du sol mesurée et calculée pour la modalité FI_{20} à deux profondeurs (a : 40-50 cm et b : 50-60 cm))

The simulated dry matter and seed yield of FI_{20} were 5.16 Mg ha^{-1} and 1.50 Mg ha^{-1}, while the observed values were 5.08 Mg ha^{-1} and 1.47 Mg ha^{-1}, respectively. In addition the simulated dry matter and seed yield of FI_{10}, FI_{30} and FI_{40} were also in agreement with the observed values (Table 4).

Table 4. Observed, simulated and the per cent relative error of total dry matter and seed yield at harvest for different salinity levels (Rendement de matière sèche et de graines pour les modalités FI_{10}, FI_{20}, FI_{30} and FI_{40} (mesures, prévisions, erreur relative))

Treatment	Total dry matter			Seed yield		
	Observed ($Mg\ ha^{-1}$)	Simulated ($Mg\ ha^{-1}$)	Relative error (%)	Observed ($Mg\ ha^{-1}$)	Simulated ($Mg\ ha^{-1}$)	Relative error (%)
FI10	5.88	5.90	-0.37	1.99	2.01	-0.84
FI20	5.08	5.16	-1.57	1.47	1.50	-1.95
FI30	5.87	5.84	0.47	1.77	1.75	0.97
FI40	5.66	5.60	1.05	1.66	1.62	2.16

4. CONCLUSIONS

In our field experiments with quinoa, the use of saline waters for irrigation caused a moderate reduction in seed yield and dry matter. The results showed that there was a good agreement between observed and simulated seed yield and dry matter. Therefore, we can conclude that the SALTMED model has the ability to simulate seed yield and dry matter of quinoa irrigated with saline and fresh water. In addition the SALTMED model was able to simulate the water content and EC_w of the root zone reasonably well.

REFERENCES

Hariadi, Y., Marandon, K., Tian, Y., Jacobsen, S-E., Shabala, S., 2011. Ionic and osmotic relations in quinoa (*Chenopodium quinoa* Willd.) plants grown at various salinity levels. Journal of Experimental Botany 62, 185–193.

http://www.swup-med.dk/SALTMED.aspx

Jacobsen, S-E., Liu, F., Jensen, C.R., 2009. Does root-sourced ABA play a role for regulation of stomata under drought in quinoa (*Chenopodium quinoa* Willd.). Scientia Horticulturae 122, 281–287.

Ragab, R., 2002. A holistic generic integrated approach for irrigation, crop and field management: the SALTMED model. Environmental Modelling & Software. 17, 345-361.

Ragab, R., Malash, N., Abdel Gawad, G., Arslan, A., Ghaibeh, A., 2005a. A holistic generic integrated approach for irrigation, crop and field management: 1. The SALTMED model and its application using field data from Egypt and Syria. International Journal of Agricultural Water Management 78, 67-88.

Ragab, R., Malash, N., Abdel Gawad, G., Arslan, A., Ghaibeh, A., 2005b. A holistic generic integrated approach for irrigation, crop and field management: 2. The SALTMED model validation using field data of five growing seasons from Egypt and Syria. International Journal of Agricultural Water Management 78, 89-107.

Plauborg, F., Iversen, B.V., Lærke, P.E., 2005. In Situ Comparison of three Dielectric Soil Moisture Sensors in Drip Irrigated Sandy Soils. Vadose Zone Journal 4, 1037-1047.