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FOOD SCIENCE & TECHNOLOGY | RESEARCH ARTICLE

Simulation of water management for fodder beet to reduce yield losses under late season drought

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Abstract: The objectives of this study were to calibrate CropSyst model for fodder beet grown under full and late season drought and to use the simulation results to analyze the relationship between irrigation amount and yield, as well as in water management to reduce yield losses under full and late season drought. For this reason, two field experiments were implemented at El-Serw Agricultural Research Station in Demiatte governorate, during 2011/12 and 2012/13 growing seasons. Two irrigation treatments were studied: full irrigation and late season drought. The model was calibrated using the data obtained from the two seasons. Results indicated that the reduction in fodder beet yield under late season drought was 11 and 12% in 2011/12 and 2012/13 growing seasons, respectively. Calibration of CropSyst revealed that the percentage of difference between measured and predicted values were low in both growing seasons. The results also indicated that changing irrigation schedule after examining water stress index under full and late season drought led to increase in fodder beet yield, as well as water and land productivity. Thus, CropSyst model can give insight into when to apply irrigation water to minimize yield losses under late season drought.

Subjects: Environment & Agriculture; Food Science & Technology; Physical Sciences

Keywords: full irrigation; crop modeling; late season drought; fodder beet; water saving; CropSyst

1. Introduction

Fodder beet (*Beta vulgaris* L.) is one of the promising winter forage crop in Egypt, especially under limited water and nutrients levels. All parts of fodder beet plant (foliage and roots) are used in

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PUBLIC INTEREST STATEMENT

Fodder beet is an important fodder crop that can be grown under adverse conditions, such as water and salinity stresses. It can substitute clover (the main forage crop in Egypt), as it requires less irrigation water. Under prevailing water scarcity conditions in Egypt, fodder beet can play an important role to reduce fodder crops production–consumption gap in Egypt.

animal feeding, whether directly or processed as silage (Sakr, Awad, Seadh, & Abido, 2014). The advantage of cultivating fodder beet is that it produces high economic yield in marginal lands (Abdallah & Yassen, 2008). Thus, its cultivation may help in overcoming the problem of feed shortage in Egypt during summer season. Several studies were carried out to determine the effect of water stress on growth and yield of fodder beet. Several studies indicated that extending irrigation interval to be 21 and 28 days significantly reduced foliage fresh and dry weights/plant and root length, whereas root diameter were not significantly affected by irrigation augmentation (Abdallah & Yassen, 2008). Furthermore, irrigation fodder beet every 28 days reduced foliage dry weight/plant, root volume, roots fresh and dry weights, crude protein, total carbohydrate, and potassium in roots, whereas crude fiber in roots of fodder beet increased (Ahmed, 2010). Furthermore, application of 100% of crop evapotranspiration (ETc) to fodder beet led to significant increases in all growth and yield characters. Whereas, water use efficiency of fodder beet plants increased significantly by decreasing the irrigation level to 50% of Etc(Kassab, Orabi, & AboEllil, 2012). El-Sarag, 2013 reported that irrigating fodder beet plants with 100% soil field capacity gave the highest fresh and dry foliage and root yields. Furthermore, irrigation when soil field capacity reached 75% produced economic forage yields. Moreover, Mahmoodi, Maralian, & Aghabarti, 2008noticed that when the available soil water content was at 70% of field capacity, maximum root yield, and quality were observed. The minimum root yield was observed at 90% of field capacity.

Crop simulation models are the dynamic simulation of crop growth by numerical integration of constituent processes with the aid of computers (Matthews, Stephens, Hess, Mason, & Graves, 2000). An example of these models is CropSyst (Stöckle, Donatelli, & Nelson, 2003; Stockle, Martin, & Campbell, 1994). CropSyst is a process-based simulation model. It uses the same approach to simulate the growth and development of potentially all herbaceous crops. To reach this aim, simplifications have been introduced to describe some processes (e.g. monolayer canopy, constant specific leaf area absence of daily assimilates partitioning). This makes CropSyst easier to be calibrated and a reduced set of crop parameters is needed. For example, the calculation of daily crop growth, expressed as biomass increase per unit area, is based on a minimum of four limiting factors, namely light, temperature, water, and nitrogen. Pala, Stockle, and Harris, (1996) suggested that adjustments of some of these parameters, accounting for cultivar-specific differences, are desirable whenever suitable experimental information is available. Thus, CropSyst can be considered a management-oriented model. CropSyst model was applied on some crops in Egypt, e.g. wheat (Abdrabbo, Ouda, & Noreldin, 2013; Khalil, Farag, El Afandi, & Ouda, 2009; Ouda, Taha, & Ibrahim, 2014; Taha, 2012). The model was applied for wheat grown in salt affected soil (Noreldin, Ouda, & AbouElenein, 2013). The model was also validated for maize yield (Ouda, Khalil, & Yousef, 2009), barley (Ouda, Khalil, et al., 2010a), and cotton (Ouda, Noreldin, AbouElenein, & Abd El-Baky, 2013).

Thus, the objectives of this paper were (i) to calibrate CropSyst model for fodder beet grown under full and late season drought; (ii) to use simulation results to analyze the relationship between irrigation amount and yield; (iii) to use simulation results in water management, in order to minimize yield losses under full and late season drought.

2. Methodology

2.1. Field experiments

Two field experiments were carried out at the experimental research station in El-Serw, Demiatte governorate (latitude 31.25, longitude31.48 and elevation 50 m), Agricultural Research Center during 2011/12 and 2012/13 growing seasons to simulate the effect of late season drought and water management on fodder beet yield. The preceding summer crop was rice over growing seasons. The used experimental design was randomized complete blocks with three replications. Each experimental basic unit included 10 ridges, each of 60 cm apart and 7.0 m length, comprising an area of 42 m^2 (1/100 fed). The experimental field was prepared and then divided into the experimental units. Calcium superphosphate at 360 kg/ha (15.5% P_2O_5) was applied during soil preparation. Sowing took place on 5th and 6th November in the first and second seasons, respectively. Fodder beet was hand sown 3–5 seeds/hill using dry sowing method on one side of the ridge in hills 25 cm apart. Plants were thinned at 30 days after sowing (DAS) to obtain one plant/hill (67,200 plants/ha). Nitrogen in forms of ammonium nitrate (33.5% N) was applied at the rate of 240 kg N/ha in two equal doses, the first was applied after thinning (30 DAS) and the second was conducted before the third irrigation (60 DAS). The common agricultural practices for growing fodder beet according to the recommendations of the Egyptian Ministry of Agriculture (Fodder beet bulletin 2012 (in Arabic) were followed, except factors under study. Two irrigation treatments were studied: full irrigation (composed of seven irrigations) and late season drought (resulted from withholding last irrigation, i.e. 6 irrigations). Table 1 shows the amount of water applied in each irrigation and total amounts under both treatments in the two growing seasons.

Figure (1(a) and (b)) showed the amount of rain fall during the two growing seasons.

Physical and chemical properties of the soil in the experimental site are shown in Table 2.

Furthermore, soil water constants were measured and are shown in Table 3.

Table 1. Measured applied irrigation water at each irrigation treatments in both growing seasons

Amount of applied water for full irrigation (m^3/ha)			
Irrigation date	**2011/12growing season**	**Irrigation date**	**2012/13growing season**
05/11/2011	1,400	06/11/2012	1,400
11/12/2011	700	11/12/2012	700
12/01/2012	800	17/01/2013	800
12/02/2012	1,100	12/02/2013	1,100
14/03/2012	800	18/03/2013	900
05/04/2012	1,000	07/04/2013	1,000
20/04/2012	1,000	27/04/2013	1,100
Harvest	22/05/2012	29/04/2013	
Amount of applied water under late season drought (m^3/ha)			
Irrigation date	2011/12 growing season	Irrigation date	2012/13 growing season
05/11/2011	1,400	06/11/2012	1,400
11/12/2011	700	11/12/2012	700
12/01/2012	800	17/01/2013	800 8,000
12/02/2012	1,100	12/02/2013	1,100
14/03/2012	800	18/03/2013	900
05/04/2012	1,000	07/04/2013	1,000
Harvest	22/05/2012	29/04/2013	

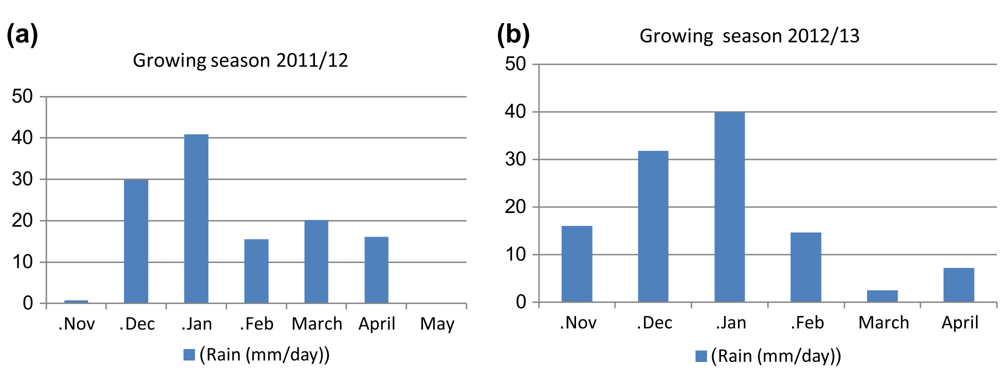

Figure 1. Rain fall during the growing seasons of (a) 2011/12 and (b) 2012/13.

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Table 2. Physical and chemical properties of the experimental sites at an average of soil depth 0–60 cm during 2011/12 and 2012/13 growing seasons

Properties Seasons	Sand%	Silt %	Clay %	$CaCo_3$%	EC ds/m	pH %	Total N(%)	OM%
2011/2012	11.79	22.26	65.95	1.34	7.7	8	0.84	0.86
2012/2013	12.23	21.67	66.1	1.41	7.75	8.01	0.95	0.75

Table 3. Soil field capacity, wilting point, available water, and bulk density at different soil depth (cm) of the experimental sites as the averages of both seasons

Soil depth (cm)	Field capacity (% mass)	Wilting point (% mass)	Available water (% mass)	Bulk density (g/cm³)
0–15	48.43	26.31	22.12	1.11
15–30	45.58	24.77	20.21	1.2
30–45	46.99	25.53	21.46	1.23
45–60	42.86	23.29	19.57	1.11
Average	45.96	24.97	20.84	1.16

Harvest was done on 22/5/2012 and 29/4/2013, where all plants that produced from the five inner ridges of each plot were harvested and cleaned. Roots and foliage were separated and weighted in kilograms, then converted to tons to estimate root yields. For the simulation purposes, we only measured roots weight.

2.2. CropSyst model calibration

The model was calibrated using the data obtained from the two seasons. Input files required by CropSyst model for fodder beet crop were prepared and used to run the model. One management file represents each irrigation treatment. The date of each phenological stage was used to calculate growing degree days for that stage. Fodder beet fresh roots weight yield were used for model calibration. The values of the crop input parameters were either taken from the CropSyst manual (Stockle & Nelson, 1994) or set to the values observed in the experiments. The calibration consisted of adjustments of fodder beet input parameters to reflect reasonable simulations. These adjustments were around values that were either typical for the crop species or known from previous experiences with the model. These parameters were: aboveground biomass-transpiration coefficient (kPa kg/m³) and light to aboveground biomass conversion (g/MJ). The imbedded values of these parameters in the database of the model were adjusted to reflect a reasonable simulation. To test the goodness of fit between the measured and predicted data, the percentage of difference between measured and predicted values for values of fodder beet roots yield in each growing season was calculated. Furthermore, root mean square error (RMSE) was calculated (Jamieson et al., 1998), which describes the average difference between measured and predicted values. In addition, Willmott index of agreement (*d*) was calculated and it takes a value between 0.0–1.0 with value of 1.0 meaning a perfect fit (Willmott, 1981).

2.3. Simulation of water management

Under each treatment in both seasons, water stress index was simulated by CropSyst model. As indicated in the CropSyst manual, stress index is determined as one minus the ratio of actual to overall potential biomass growth for each day of the growing season. Potential growth is defined as the growth calculated from potential transpiration and actual transpiration. Actual biomass growth is obtained after growth limitations have been applied. Water stress index range from 0 to 1, where 0 is no stress and 1 is maximum stress. Irrigation rescheduling was done to reduce water stress index under both treatments and the model was used to simulate the effect of the adjustment in irrigation schedule for both irrigation treatments. Reduction of fodder beet yield losses under late season drought was done by simulating the effect of adding an irrigation amount representing 50% of the last irrigation in the full irrigation treatment in both growing seasons. The applied irrigation amount for the last irrigation was 500 and 550 m^3/ha in the 1st and 2nd growing seasons, respectively.

Furthermore, to test the efficiency of using the suggested water management, crop water productivity (kg/m^3) and land productivity (kg/m^2) were calculated. Both measurements are quantitative terms used to define the relationship between crop produced with the amount of applied irrigation water or unit of land involved in crop production. They are useful indicators for quantifying the impact of irrigation scheduling decisions, with regard to water management (FAO, 2003).

3. Results and discussion

3.1. Fodder beet yield and irrigation amounts

The reduction in the yield as a result of deficit late season drought (skipping the last irrigation) was 11 and 12% in 2011/12 and 2012/13 growing seasons, respectively (Table 4). Furthermore, the saving in applied water in the two seasons was 15 and 16%, respectively.

This result implied that the last irrigation was contributed by 11 and 12% of final fodder beet fresh yield. Although high percentage of applied water was saved, the yield losses will represent high economic loss for farmers and could prevent them from adopting this practice. However, as a result of the projected water scarcity, a more rational use of irrigation water should be adopted and late season drought principles should be accepted with a certain level of reduction in yield level (Hamdy, Sardo, & Ghanem, 2005). Therefore, modeling yield reduction under late season drought should be recommended. Furthermore, there is a need to improve water management to reduce yield losses. Using CropSyst model for this matter is very useful as indicated by (Ouda, Noreldin, & Abdelhamid, 2015).

3.2. CropSyst calibration

The percentage of difference between measured and predicted value of fodder beet yield were low in both growing seasons (Table 5). It ranged between 0.2-–0.6% for fodder beet yield. RMSE was 0.005 and 0.99 ton/ha for fodder beet yield, respectively.

CropSyst model is characterized by its ability to be accurately calibrated, as it was highlighted by several publications (Benli, Pala, Stockle, & Oweis, 2007; Khalil et al., 2009; Ouda, Sayed, et al., 2010b; Singh, Tripathy, & Chopra, 2008).

3.3. Water stress index

The model was used to simulate water stress index to determine the daily efficiency of applied water to fulfill the needs of the growing plants. Figure 2(a) shows that the applied water in the 1st growing season was not enough, even under full irrigation, and low water stress existed from 101 to 108 days after planting, where water stress index (WSI) was 0.25. Furthermore, water stress existed from 156 to 180 days after planting and reached 0.33 and 0.39. In the 2nd growing season, WSI was higher 108 days after planting (0.34) and was lower during the end of the growing season (WSI < 0.3) (Figure 2(b)).

Table 4. Percentage of reduction (PR%) in fodder beet fresh yield (ton/ha) and irrigation amount (m^3/ha) as result of treatments

Treatments	2011/2012 growing season				2012/2013 growing season			
	Yield	PR (%)	Irrigation	PR (%)	Yield	PR (%)	Irrigation	PR (%)
Full irrigation	75	–	6,800	–	85	–	7,000	–
Late season drought	67	11	5,800	15	75	12	5,900	16

Table 5. Measured versus predicted fodder beet yield in both growing seasons

Treatments	2011/12 growing season			2012/13 growing season		
	Measured	Predicted	PD%	Measured	Predicted	PD%
Full irrigation	74.6	74.2	0.6	84.5	84.1	0.4
Deficit irrigation	66.7	66.5	0.2	74.5	74.3	0.3
RMSE (*d*)	0.005 (0.99)			0.005 (0.99)		

Note: PD% = percentage of different between measured and predicted, *RMSE* = root mean square error; *d* = Willmott index of agreement.

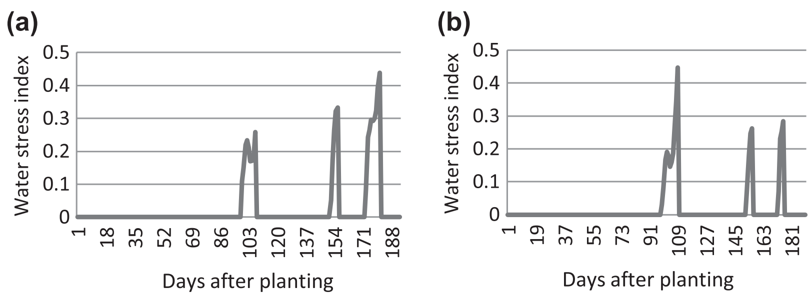

Figure 2. Simulated water stress index for fodder beet grown under full irrigation in the 2011/12 (a) and 2012/13 (b) growing seasons.

Regarding deficit irrigation, where only the last irrigation was skipped, WSI reached 0.50 during the end of both growing season (Figure 3(a and b)). Thus, the reduction in fodder beet yield by 11 and 12% (Table 4) was not only attributed to deducting the last irrigation, but also to water stress during both growing seasons.

Thus, using simulation results to analyze the relationship between applied irrigation amount and the resulted yield allowed us to detect the presence of water stress during the growing seasons of fodder beet.

3.4. Water management for fodder beet

To overcome the effect of water stress on fodder beet yield under full irrigation, new irrigation schedule was developed, where the fourth irrigation dated 12/2/2012 Table (1) was executed in 5/2/2012, one week earlier to overcome water stress occurred early in the vegetative stage of growth. Similar procedure was done in the second growing season. Table 6 indicated that fodder beet yield was increased under both irrigation treatments when the new irrigation schedule was used to run CropSyst model. In the 1st growing season, fodder beet yield was increased by 2% under full irrigation in both growing seasons. Furthermore, it was increased by 1 and 0.6% in the 1st and 2nd seasons, respectively, under deficit irrigation. Although these increase percentages under late season drought are low, it is still good under late season drought.

Figure 4 illustrates the comparison between WSI under measured irrigation schedule and the new irrigation schedule in the 1st growing season. Figure 4(b) indicates that WSI was lower in values compared to the measured irrigation schedule shown in Figure 4(a). Furthermore, the duration of water stress was reduced under the new schedule.

Table 6. Effect of the new irrigation schedule on fodder beet yield (ton/ha) in the 2011/2012 and 2012/2013 growing seasons

Treatments	1st growing season			2nd growing season		
	Measured	Predicted	PD%	Measured	Predicted	PD%
Full irrigation	74.2	76.0	+2	84.1	85.4	+2
Late season drought	66.5	67.0	+1	74.3	74.7	+0.6

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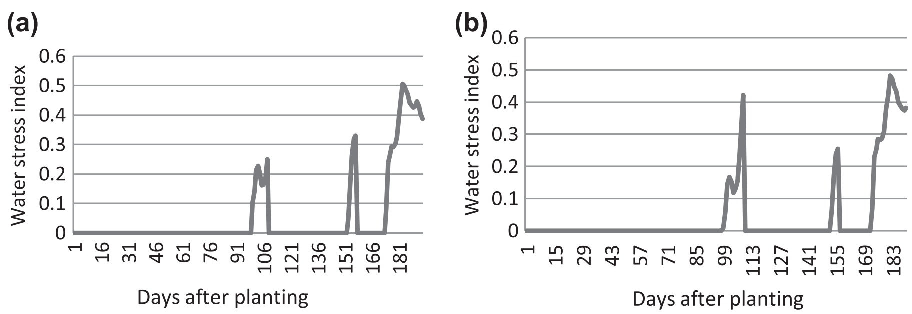

Figure 3. Simulated water stress index for fodder beet grown under late season drought in the 2011/12 (a) and 2012/13 (b) growing seasons.

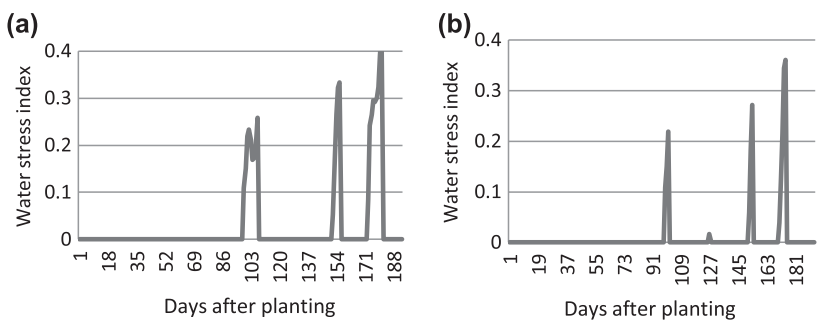

Figure 4. Comparison between water stress index for fodder beet grown under full irrigation treatment (a) and new schedule (b) in the 2011/2012 growing season.

Similar trend was observed in the 2nd growing season, where WSI was lower in values and duration under the new schedule, compared to the measured irrigation schedule in Figure 5.

3.5. Use of water management to reduce yield losses under late season drought

Reduction in fodder beet fresh yield losses under late season drought was achieved by simulating the effect of an added irrigation amount equal to 50% of the final irrigation used in the full irrigation treatment. Results in Table 7 showed that increase in fodder beet yield by 4 and 2% in the 1st and 2nd growing seasons, respectively, as a result of changing irrigation schedule under late season drought treatment. This result indicates that irrigation management can reduce yield losses under late season drought.

3.6. Water and land productivity for fodder beet

Table 8 shows that the new schedule under full irrigation attained the lowest water productivity value in the 1st growing season. Furthermore, this value was similar to the value obtained when late season drought plus 500 m^3/ha was applied. Similar trend was observed in the 2nd growing season. The highest water productivity in both growing season was obtained when late season drought with new schedule was used, i.e. 11.6 and 12.8 kg/m^3, in the 1st and 2nd growing season, respectively, Table 8. Regarding to land productivity, the highest value was obtained from application of full irrigation with the new irrigation schedule in both growing seasons, i.e. 7.6 and 8.5 kg/m^2, in the 1st and 2nd growing seasons, respectively (Table 8). Thus, land and water productivity can be enhanced by improving water management under application of either full or deficit irrigation.

Table 7. Percentage of increase in fodder beet yield as a result of changing irrigation schedule under late season drought

Treatments	Measured yield (ton/ha)	Predicted yield (ton/ha)	Percentage of increase (%)
1st growing season	66.5	69.0	+4
2nd growing season	74.3	75.6	+2

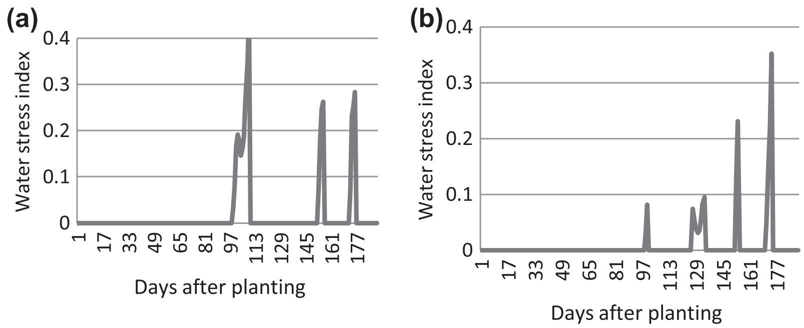

Figure 5. Comparison between water stress index for fodder beet grown under full irrigation treatment (a) and the new schedule (b) in the 2012/13 growing season.

Table 8. Water and land productivity for fodder beet under different irrigation treatments

Treatments	Yield (ton/ha)	Irrigation (m^3/ha)	Water productivity (kg/m^3)	Land productivity (kg/m^2)
2011/12 growing season				
Full irrigation	74.2	6,800	11.0	7.5
Full irrigation new schedule	76.0	6,800	11.2	7.6
Late season drought	66.5	5,800	11.5	6.7
Late season drought new schedule	67.0	5,800	11.6	6.7
Late season drought+ 500 m^3/ha	69.0	6,300	11.0	6.9
2012/13 growing season				
Full irrigation	84.1	7,000	12.1	8.5
Full irrigation new schedule	85.4	7,000	12.2	8.5
Late season drought	74.3	5,900	12.7	7.5
Late season drought new schedule	74.7	5,900	12.8	7.5
Late season drought+ 550 m^3/ha	75.6	6,400	12.0	7.6

4. Conclusion

Modeling has become a major research tool in agriculture for resource management, which could help in extending findings and conclusions to conditions not tested in the field. Our results show that CropSyst model offers good representations of crop growth and its interaction with applied irrigation. It can present an excellent tool in management of water utilization. Water management to obtain yield values close to the potential value under full and late season drought is a valid practice for water conservation.

Our results indicate that changing irrigation schedule after examining water stress index under full and late season drought resulted in an increase in fodder beet yield, water productivity, and land productivity. Thus, CropSyst model can give us insight as to when to reduce irrigation water without significant reduction in yield.

This study indicates that it is possible to utilize the CropSyst model in managing crop production by optimally reducing irrigation and reducing cost of production.

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Competing Interests
The authors declare no competing interest.

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