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Prediction of Soybean Yield and Water Productivity under Deficit Irrigation Using Yield-Stress Model

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ABSTRACT

Five field trials (1997-2001) were conducted at Beni Sweif governorate, Egypt to study the effect of two irrigation treatments, i.e. required amounts (the amount of soil moisture that is removed by the plants from the soil profile, plus 20% to satisfy the leaching requirement) and farmer amount (excessive) on wheat yield and water consumptive use. Furthermore, to use Yield-Stress model to simulate the depletion of readily available water from the root zone and reschedule irrigation to save irrigation water. The model predictions showed good agreement between measured and predicted values of soybean yield and water consumptive use. Results showed that rescheduling required irrigation without reducing the applied amount could increase soybean yield by an average of 1.5% over all the growing seasons. Rescheduling farmer irrigation could save an average of 17.54% of the applied amounts and could increase soybean yield by an average of 11.93% over all the growing seasons. Deducting 10 and 20% of rescheduled farmer irrigation amounts could reduced soybean yield by an average of 1.03 and 3.79%, respectively over all the growing seasons, and could save 25.79 and 34.04% of farmer irrigation water amounts, respectively. Water productivity was the highest under deducting 20% of rescheduled farmer irrigations. Therefore, to save irrigation water and to maintain low yield losses it could be recommended to irrigate soybean with the amount of rescheduled farmer irrigation less 20%.

Key words: Readily available water depletion, consumptive water use, irrigation rescheduling.

INTRODUCTION

Soybean occupies a unique position in science and agriculture, in addition of being a crop with enormous uses. Soybean is grown in almost all parts of the world for human consumption, industry and animal feed [1]. In Egypt, soybean growth period ranges usually between 100 and 120 days and requires 325-436 mm of irrigation water depending on the location [2]. The most important times for soybean plants to have adequate water are during pod development and seed fill [3]. These are the stages when water stress can lead to a significant decrease in yield. Stressful conditions, such as moisture deficiency could reduce soybean yield. As the soybean plant ages from R1 (beginning bloom) through R5 (seed enlargement), its ability to compensate under stressful conditions decreases and yield losses could increases [4].

Irrigation scheduling is the technique to timely and accurately apply irrigation water to a crop. [5]Jensen (1980) referred to irrigation scheduling as “a planning and decision-making activity that the farm manager or operator of an irrigated farm is involved in before and during most of the growing season”. Irrigation scheduling has been described as the primary tool to improve water use efficiency, increase crop yields, increase the availability of water resources, and provoke a positive effect on the quality of soil and groundwater [6]. Under scarce and costly water supplies, this practice is extremely needed. Water stress may reduce crop yield to some extent but it will remain economically feasible as long as the marginal benefit from reduced cost of water is equal or greater than marginal cost of reduced yield [7].

Using simulation models to predict soybean yield under different water stress conditions could be very helpful in the management of deficit irrigation applications. Soil water balance based irrigation scheduling models use soil water budgeting over the root zone. A number of computerized simulation models for crop water requirements have been developed using this approach ([8], [9] and [10]). These models have been widely accepted, but their adoption by farmers has been very slow because it needs to be run by professionals. In this context, Yield-Stress model [11] was design to predict the effect of deficit irrigation scheduling on the yield of several crops and their consumptive water use. Furthermore, the model was designed to be used by non-professionals, where the input of the model is easy to prepare and the output of the model is very descriptive of the process of readily available water depletion from root zone after the application of each individual irrigation. Thus, the user can easily determine at which irrigation he could apply deficit irrigation. Basically, the Yield-Stress model assumes that there is a linear relationship between available water and yield, where reduction in available water limits evapotranspiration and consequently reduced yield. This assumption is supported by the work of several researchers ([12], [13], [14] and [15]). Yield-Stress model was tested for several crops and under different soil types. The model was used in irrigation optimization for sunflower grown under saline conditions [16]. The model was also used to predict maize yield grown under water stress [17]. Furthermore, the model was validated under skipping the last irrigation for barley then the model was exploited in irrigation management [18]. Similarly, the model was validated under deficit irrigation for sesame yield [19]. The model was successfully used to predict soybean yield under deficit irrigation application [20]. Moreover, the model was used in irrigation management for wheat [21] and was also used for wheat grown under saline conditions [22].

The objectives of this research were: (i) to validate of Yield-Stress model for soybean grown under required irrigation and farmer irrigation treatments, (ii) to use the model in irrigation management to save water (iii) To use the model to predict the effect of deducting 10 and 20% of total irrigation on soybean yield.

MATERIALS AND METHODS

Field trials

The aim of this study was to study the effect of two irrigation treatments, i.e. required amounts (the amount of soil moisture that is removed by the plants from the soil profile, plus 20% to satisfy the leaching requirement) and farmer amount (excessive) on wheat yield and water consumptive use. Furthermore, to use Yield-Stress model to simulate the depletion of readily available water from the root zone and reschedule irrigation for both irrigation treatments to save irrigation water. Data of soybean yield and consumptive water use were available from a trial carried out at Beni Sweif governorate (Middle Egypt) for five growing seasons, i.e. from 1997 to 2001. These data were obtained from a project called "Soil and Water Resources Management" of the Agricultural Research Center, Egypt in collaboration with ICARDA. Soil fertility analysis was done before planting and revealed that N content was 88 ppm, P content was 12.2 ppm and K content was 1050 ppm. Furthermore, sand % was 13.2, silt % was 36.6, clay % was 50.2, pH was 7.4 and EC was 0.48 dS/m. The recommended doses of NPK were applied at the three sites. Soybean seeds were planed in the 3rd week of May in all the five growing seasons. Irrigation was applied according to governmental enforced irrigation intervals. Applied irrigation water was measured through discharge from a calibrated portable pump. The soil water content was determined before irrigation to calculate the required amount of applied irrigation water to reach field capacity. Two irrigation treatments were used: required irrigation amount and farmer irrigation amount. The required irrigation amount treatment was the amount of soil moisture that is removed from the soil profile, plus 20% to satisfy the leaching requirement. The farmer irrigation amount was the amount that the farmer applied, which is normally higher than the required amount. Consumptive water use was calculated before each irrigation using the following equation [23] (Israelsen and Hansen, 1962).

$$CWU = (\Theta_2 - \Theta_1) * BD * ERZ$$

Where: CWU=the amount of consumptive use (cm); Θ_2=soil water percentage after irrigation; Θ_1 = soil water percentage before the following irrigation; BD=bulk density in g/cm^3; ERZ= effective root zone. Harvest occurred on the 1st week of September for all growing seasons. Table (1) shows season length and seasonal weather parameters for the studied growing seasons.

Table 1. Season length and seasonal weather parameters for soybean planted at Beni Sweif site

Season	Season length (days)	Mean temperature (°C)	Relative humidity (%)	Wind speed (m/sec)	Solar radiation (Mj/m²/day)
1997	106	27.0	53	1.4	25.6
1998	101	28.6	56	1.4	25.8
1999	111	30.1	59	1.4	25.6
2000	100	31.0	58	1.4	25.8
2001	104	32.7	58	1.4	25.7

Yield-Stress Model Description

The Yield-Stress model uses a daily time step. The model requires two types of input data. Input data by the user and input data file. The model asks the user to input planting and harvesting date, crop partitioning coefficient and harvest index. The model also asks the user to input soil characteristics i.e. clay, silt, sand, organic matter, and $CaCo_3$ percentages. The other input data source is a file represent the whole growing season, starts with sowing month and date, and ends with harvesting month and date. The file contains maximum, minimum and mean temperature, relative humidity, solar radiation, wind speed, FAO's crop coefficient and the date and the amount of each individual irrigation. The model has two main components: soil water balance calculation routine and crop yield calculation routine. The model determine soil water balance by calculating readily available water at the root zone using equations described in FAO publication Nº56 [24]. Reference evapotranspiration (ETo) is calculated using Penman-Monteith equation [24]. Crop evapotranspiration (ET_{crop}) is calculated by multiplying ETo by crop coefficient. The model calculates root zone depletion by accumulating ET_{crop} and compares it with readily available water on a daily basis. If root zone depletion is higher than readily available water, the model calculates a water stress coefficient (ks) and uses it to calculate ET_{crop} adjusted [24].

Dry matter production is calculated using solar energy level as the limiting factor [25]. This method converts total solar radiation to micro-Einstein. Then, it assumed that 82% of the visible light was intercepted by chloroplasts with maximum quantum efficiency equals to 10% (10 photons reduces one CO_2 molecule). Furthermore, the method subtracts 33%

of gross photosynthesis as respiration cost to calculate net photosynthesis, which is converted from µmoles/cm^2 to g/m^2 dry matter produced per day. Using data resulted from previous experiments done in Egypt from 1999 to 2004 growing seasons, a soybean biomass partitioning coefficient was developed to be multiplied by the pervious amount of produced dry matter to calculate the daily amount of biomass that is produced by soybean plants. The model predicts seed yield through multiplying the amount of produced biomass by harvest index. Under water stress conditions, where the predicted readily available water is lower than predicted ET_{crop}, the value of the predicted yield will be reduced in relation to the reduction in the daily water consumption.

Methodology

For the field trials, the model was run for the above mentioned growing seasons using the required irrigation amounts and the applied irrigation amounts by the farmers. Soybean yield and consumptive water use were predicted. To test the accuracy of the model, percent difference between measured and predicted values for each case was calculated, in addition to root mean squared error (RMSE) and Willmott index of agreement [26]. Furthermore, regression analysis was done to test the strength of the relationship between measured and predicted yield and consumptive water use.

In an attempt to either increase yield without increasing the applied required irrigation application or increase yield and save irrigation water under farmer irrigation application, the predicted depletion of the readily available water from root zone was examined and a new irrigation schedule was proposed to efficiently use irrigation water. New input data files were developed for each case and soybean yield was predicted. Moreover, soybean yield was predicted after deducting 10 and 20% of modified farmer irrigation amount. Finally, water productivity was calculated for required irrigation amount, modified required irrigation, required irrigation amount, farmer irrigation amount, modified farmer irrigation amount, modified farmer irrigation amount less 10% and modified farmer irrigation amount less 20%.

RESULTS AND DISCUSSION

Field trials

The amounts of applied irrigation water and its corresponding yield values are shown in Table (2). Soybean yields were significantly differed (one sided t-test, $P < 0.05$) under the application of either required or farmer irrigation amounts. Regarding to required irrigation amount, the highest irrigation amount produced low soybean yield in 1997 growing season. On the other hand, in 2001 growing season, the amount of applied irrigation was the lowest and produced high yield, compared with the other growing seasons (Table 2). Furthermore, the farmer's irrigation amounts were higher than the required irrigation amounts by 15.00-24.81% and produced less yield than the required irrigation amounts by 1.67-16.78%.

Table 2. Irrigation amounts of applied water and corresponded soybean yield values

Growing season	Required irrigation		Farmer irrigation		% increase in irrigation amount by farmers	% decrease in farmers yield
	Irrigation (m^3/ha)	Yield (ton/ha)	Irrigation (m^3/ha)	Yield (ton/ha)		
1997	5100	1.43	6000	1.19	15.00	16.78
1998	4178	1.20	5489	1.18	23.88	1.67
1999	4558	1.82	5432	1.59	16.09	12.64
2000	4216	1.73	5607	1.69	24.81	2.31
2001	3901	1.73	5083	1.54	23.25	10.98

YIELD-STRESS MODEL EVALUATION

Soybean yield prediction under the application of required irrigation amount

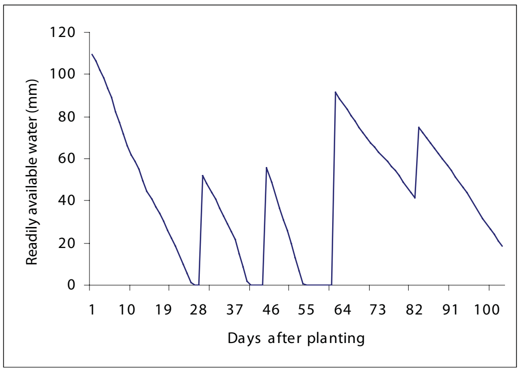
Results in Table (3) showed the good agreement between measured and predicted values of soybean yield and consumptive water use under the application of required irrigation amounts. Percent difference between measured and predicted yield was less than 1% over all the growing seasons. Regression analysis between measured and predicted soybean yield had a significant linear relationship ($P < 0.001$), with equation $y = -0.0318 + 1.0226 x$ ($R^2 = 0.9993$). Furthermore, percent difference between measured and predicted values of consumptive water use was between 1.62-2.97%. RMSE was 0.0079 ton/ha and 0.1085 cm for yield and consumptive water use, respectively. Whereas, Willmott index of agreement was 0.9997 for both yield and consumptive water use (Table 3). A significant linear relationship ($P < 0.001$), with equation $y = -2.4027 + 1.0919 x$ ($R^2 = 0.9990$) was found between measured and predicted values of consumptive water use.

Table 3. Measured versus predicted soybean yield and consumptive water use under applying the required irrigation amounts

Growing season	Yield (ton/ha)			CWU (cm)		
	Measured	Predicted	% difference	Measured	predicted	% difference
1997	1.43	1.42	0.70	34.02	33.47	1.62
1998	1.20	1.21	0.83	34.17	33.40	2.25
1999	1.82	1.81	0.55	39.36	38.19	2.97
2000	1.73	1.72	0.58	36.76	35.84	2.50
2001	1.73	1.73	0.00	40.29	39.15	2.83
RMSE	0.0079			0.1085		
Willmott index	0.9997			0.9997		

Figure (1) illustrated the depletion of readily available water from root zone under the application of required irrigation amounts in 2001 growing season. The growing season of 2001 was graphed because soybean plants received the lowest irrigation amount, compared with the other growing seasons. Figure (1) indicated that there are five hills in that graph, each top of these hills represent irrigation day and the amount of readily available water at root zone. The graph also showed that all the readily available water at root zone was depleted after the 1st, the 2nd and the 3rd irrigations, where water stress prevailed for 13 days. Furthermore, there was a plenty of readily available water at root zone after the 4th, and the 5th irrigations.

Figure 1. Readily available water depletion from root zone for soybean grown under the application of required irrigation amount in 2001 growing season.



Soybean yield prediction under the application of farmer irrigation amount

The difference between measured and predicted soybean yield under the application of farmer irrigation amount was less than 1% over all the five growing seasons (Table 4). Regarding to consumptive water use, percent difference between measured and predicted values was between 2.18-3.79%. Results in Table (4) also indicated that RMSE was 0.0085 ton/ha and 0.2364 cm for yield and consumptive water use, respectively. Whereas, Willmott index of agreement was 0.9994 and 0.9995 for yield and consumptive water use, respectively (Table 4). and between measured and predicted consumptive water use, with equation y = 2.1086 + 0.9761 x (R^2 = 0.9949). Regression analysis between measured and predicted soybean yield had a significant linear relationship ($P < 0.001$), with equation -0.0248 + 1.0215 x (R^2 = 0.9990).

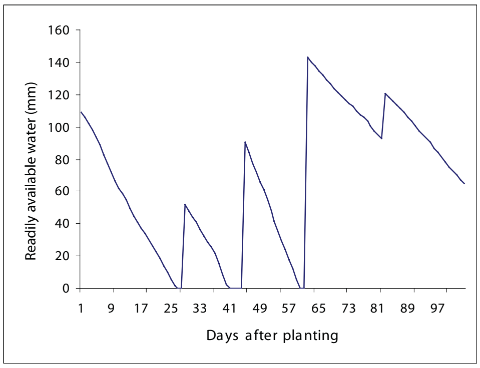
Table 4. Measured versus predicted soybean yield and consumptive water use under applying farmer irrigation amounts

Growing season	Yield (ton/ha)			CWU (cm)		
	Measured	Predicted	% difference	Measured	predicted	% difference
1997	1.19	1.20	0.84	35.57	34.29	3.60
1998	1.18	1.17	0.85	35.68	34.52	3.25
1999	1.59	1.58	0.63	40.10	38.58	3.79
2000	1.69	1.68	0.59	38.90	37.68	3.14
2001	1.54	1.53	0.65	42.17	41.25	2.18
RMSE	0.0085			0.2364		
Willmot index	0.9994			0.9995		

CWU= consumptive water use

Figure (2) showed that under farmer irrigation amount, all the readily available water at root zone was depleted after the 1st, the 2nd and the 3rd irrigations, where water stress prevailed for 6 days. Whereas, after the 4th, and the 5th irrigations, a plenty of readily available water at root zone was exist.

Figure 2. Readily available water depletion from root zone for soybean grown under the application of farmer irrigation amount in 2001 growing season.



The above situation assumed that applying farmer irrigation amounts reduced soybean yield compared with required irrigation amounts in all the studied growing seasons. However, these farm trials provide only a limited evaluation of the model, and as data from more treatments in different locations and years become available, the model should be further tested. However, for the purposes of this study we felt that the model worked sufficiently well to warrant the exploration of other irrigation scheduling schemes.

USING YIELD-STRESS MODEL IN IRRIGATION RESCHEDULING

Soybean yield prediction under required irrigation rescheduling

The predicted depletion of readily available water during each growing season was examined and a new irrigation schedule was proposed under required irrigation. Results in Table (5) implied that soybean yield could be increase using the same irrigation amount, if irrigation was reschedule. The highest soybean yield increase occurred in 2001 growing season (2.89%). Furthermore, consumptive water use was also increase and the difference between measured and predicted values were between 0.38-2.05%.

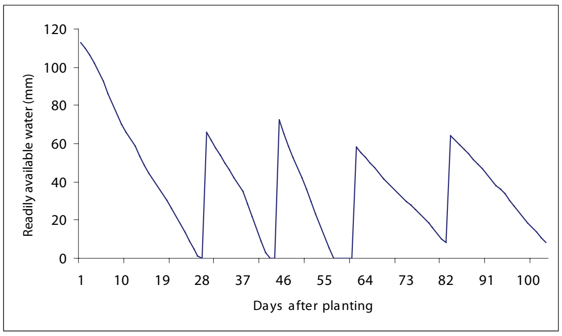
Table 5. Measured versus predicted soybean yield and consumptive water use under required irrigation rescheduling.

Growing season	Yield (ton/ha)			CWU (cm)		
	Measured	Predicted	% difference	Measured	predicted	% difference
1997	1.43	1.42	-0.70	34.02	33.47	1.62
1998	1.20	1.23	+2.50	34.67	33.96	2.05
1999	1.82	1.83	+0.55	39.36	38.69	1.70
2000	1.73	1.77	+2.31	37.26	37.12	0.38
2001	1.73	1.78	+2.89	40.29	40.11	0.45

CWU= consumptive water use

Figure (3) showed that after rescheduling irrigation in 2001 growing season, all the readily available water at root zone was depleted after the 1st, the 2nd, and the 3rd irrigations, where the number of water stressed days was reduced from 13 days to 8 days and yield was increased by 2.89%.

Figure 3. Readily available water depletion from root zone for soybean grown under the application of modified required irrigation amount in 2001 growing season.



Soybean yield prediction under farmer irrigation rescheduling

Under farmer irrigation amount, the predicted depletion of readily available water during each growing season was examined and a new irrigation schedule was proposed to save irrigation water. The highest percentage of saved irrigation water could be obtain in 1997 growing season (23.33%), which concise with the highest percent of yield increase (19.33%). Whereas, the lowest percentage of saved irrigation water (13.24%) could be obtained in 2001 growing season. The lowest percent of yield increase was obtained in 1998 growing season (4.24%). Present difference between actual and predicted consumptive water use was between 2.42-3.98%.

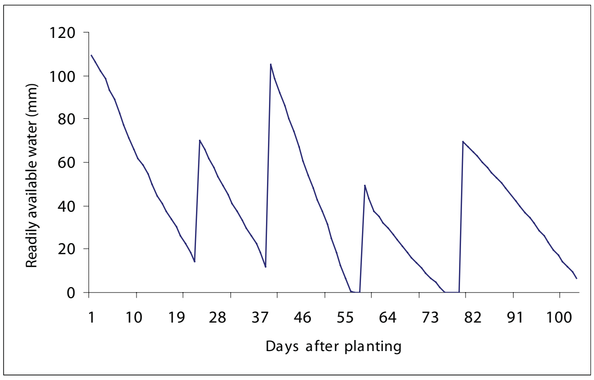
Table 6. Measured versus predicted soybean yield and consumptive water use under farmer irrigation rescheduling.

Growing season	Yield (ton/ha)			% of saved irrigation water	CWU (cm)		
	Measured	Predicted	% increase		Measured	predicted	% reduction
1997	1.19	1.42	19.33	23.33	35.57	34.39	3.32
1998	1.18	1.23	4.24	16.65	35.68	34.26	3.98
1999	1.59	1.83	15.09	15.65	40 .10	38.69	3.52
2000	1.69	1.77	4.73	18.85	38.90	37.42	3.80
2001	1.54	1.79	16.23	13.24	42.17	41.15	2.42

CWU= consumptive water use

Figure (4) showed that after rescheduling farmer irrigation (modified farmer irrigation) in 2001 growing season, the readily available water at root zone was depleted after the 4th, and the 5th irrigations, where the number of water stressed days was reduced from 7 days to 5 days.

Figure 4. Readily available water depletion from root zone for soybean grown under the application of modified farmer irrigation amount in 2001 growing season.



USING YIELD-STRESS MODEL TO PREDICT SOYBEAN YIELD UNDER DEFICIT IRRIGATION

Soybeans yield prediction under 10% deficit irrigation

Results in Table (7) showed that a relatively large amount of farmer irrigation water could be saved. Deducting 10% of the amount of modified farmer irrigation slightly reduced soybean yield, except for 2001 growing season, where yield reduction was 2.79% (Table 7).

Table 7. Measured versus predicted soybean yield under 10% deficit irrigation of modified farmer irrigation

Growing season	Predicted yield (ton/ha) under			% of saved water from farmer irrigation amount
	Rescheduling Irrigation	Deducting 10%	% difference	
1997	1.42	1.41	0.70	31.00
1998	1.23	1.23	0.00	24.98
1999	1.83	1.81	1.09	24.08
2000	1.77	1.76	0.56	26.97
2001	1.79	1.74	2.79	21.92
Average	1.64	1.59	1.03	25.79

Soybeans yield predictions under 20% deficit irrigation

Yield losses could be increased under deducting 20% of the amount of modified farmer irrigation (Table 8). Under this situation, yield reduction was low, except for 2001 growing season, where it was 9.5%.

Table 8. Measured versus predicted soybean yield under 20% deficit irrigation

Growing season	Predicted yield (ton/ha) under			% of saved water from farmer irrigation amount
	Rescheduling Irrigation	Deducting 20%	% difference	
1997	1.42	1.40	1.41	38.67
1998	1.23	1.22	0.81	33.32
1999	1.83	1.76	3.83	32.52
2000	1.77	1.71	3.39	35.08
2001	1.79	1.62	9.50	30.59
Average	1.61	1.54	3.79	34.04

WATER PRODUCTIVITY CALCULATION

Water productivity was higher under required irrigation amount, compared with farmer irrigation amount (Table 9). Furthermore, water productivity under required irrigation amount was similar to the values under modified required irrigation amount, except for 2000 and 2001 growing seasons, where the values under modified required irrigation amount was higher. The highest water productivity was obtained under applying modified farmer irrigation amount less 20% over all the growing seasons (Table 9).

Table 9: Water productivity under the application of different irrigation amounts

	Water productivity (kg/m3) under the application of					
	Required irrigation	**Farmer irrigation**	**Modified required irrigation**	**Modified farmer irrigation**	**Modified farmer irrigation less 10%**	**Modified farmer irrigation less 20%**
1997	0.28	0.20	0.28	0.31	0.34	0.38
1998	0.29	0.21	0.29	0.27	0.30	0.33
1999	0.40	0.29	0.40	0.40	0.44	0.48
2000	0.41	0.30	0.42	0.39	0.43	0.47
2001	0.44	0.30	0.46	0.41	0.44	0.46

DISCUSSION AND CONCLUSION

Egyptian agriculture suffers from the wasteful use of irrigation water by farmers. Convincing farmers to reduce the amount of applied irrigation water is difficult unless they observe high yield resulted from using less irrigation water. Results from Table (2) showed that applying farmer's irrigation amount resulted in lower yield, compared with the resulted yield from required irrigation amounts. This could be attributed to oxygen deficiency in root zone and/or nutrients leach from root zone. Therefore, it could be safely assumed that there is a potential to save irrigation water.

Yield-Stress model predicted values for soybean yield and consumptive water use was close to the measured values under the two irrigation treatments, i.e. farmer irrigation and required irrigation (Table 3 and 4). CROPGRO-Soybean model predicted soybean seed yield with a percent difference about 4.26% [27]. Whereas, RZWQM model simulated soybean seed yield by a 0.7% overestimation [28]. Furthermore, CROPGRO-Soybean model predicted consumptive water use of soybean with a percent difference about 5.30% [27]. Whereas, RZWQM model simulated soybean consumptive water use by a 4.00% overestimation [28]. Therefore, it could be also absolutely assumed that Yield-Stress model can predict soybean yield and water consumptive use in high degree of accuracy.

Examining the depletion of readily available water at root zone showed the variation of the amount of each individual irrigation, where it is sometimes completely depleted before the occurrence of the following irrigation. Other times, the amount of applied each individual irrigation was larger than what the growing plants need and a considerable amount of water was lost to ground water (Fig 1 and 2). This situation is common for either farmer irrigation or required irrigation amounts. Therefore, using the model in irrigation rescheduling helped in saving irrigation water. Furthermore, the potential soybean yield could be increased under rescheduling irrigation. Using the model to reschedule required irrigation leaded to an increase in the yield between 0.55-2.89% using the same amount of applied required irrigation (Table 5). This situation occurred as a result of the lessening in the number of water stress days after rescheduling required irrigation (Fig 3), which positively reflected on final yield (Table 5). Modifying the amount of farmer irrigation to save irrigation water and to reduce the number of stress days also resulted in yield increase. The amount of saved irrigation water was between 13.24-23.33% and yield was increased by 4.24-19.33% (Table 6). Similar results were obtained when the model was used predict wheat yield under farmer irrigation rescheduling [21].

Deducting 10 and 20% of modified farmer irrigation amounts could reduced soybean yield by an average of 1.03 and 3.79%, respectively over all the growing seasons, and save 25.79 and 34.04% of farmer irrigation water amount, respectively over all the growing seasons (Table 7 and 8). Water productivity was the highest under deducting 20% of modified farmer irrigations (Table 9).

A comparison was made between soybean yield resulted from required irrigation amount, modified farmer irrigation amount and modified farmer irrigation amount less the deducted percentage to determine which amount produced the highest yield (Table 10). Under modified farmer irrigation the amount of applied irrigation water was increased by a certain percentage than the amount of required irrigation water, except for 1997 growing season, where irrigation amount was reduced by 9.80% and the yield was reduced by only 0.70%. Thus, the amount of modified farmer irrigation water was increased by 9.51, 0.53, 7.92, and 13.05% for 1998, 1999, 2000, and 2001 growing seasons, respectively compared with required irrigation amounts. Furthermore, soybean yield was increased by 2.50, 0.55, 2.31, and 3.47%, respectively compared with required irrigation amount (Table 10). However, under deducting 10% of the amount of modified farmer irrigation, a different percent of irrigation water was saved every growing season, except for 2001 growing season, where irrigation was increased by 1.74%. The corresponding yield values varied between a little bit decrease and increase. Under deducting 20% of the amount of modified farmer irrigation, the percent of saved irrigation water increased over all the growing seasons and yield losses slightly increased, except for 1998 growing season, where yield was higher than the yield resulted from required irrigation by 1.67% (Table 10). Therefore, it could be concluded that to save irrigation water and to maintain low yield losses it could be recommended to irrigate soybean with the amount of modified farmer irrigation less 20%.

Table 10. Percent difference in yield and irrigation amounts between required irrigation amount, modified farmer irrigation amount, and modified farmer irrigation amount less 10 and 20%.

Growing Season	% difference between required irrigation and modified farmer irrigation		% difference between required irrigation and modified farmer irrigation less 10%		% difference between required irrigation and modified farmer irrigation less 20%	
	Irrigation amounts (m3/ha)	Yield (ton/ha)	Irrigation amounts (m3/ha)	Yield (ton/ha)	Irrigation amounts (m3/ha)	Yield (ton/ha)
1997	-9.80	-0.70	-18.82	-1.40	-27.84	-2.10
1998	+9.51	+2.50	-1.44	+2.50	-12.39	+1.67
1999	+0.53	+0.55	-9.53	-0.55	-19.58	-3.30
2000	+7.92	+2.31	-2.87	+1.73	-13.66	-1.16
2001	+13.05	+3.47	+1.74	+0.58	-9.56	-6.36

(-) indicates a decrease in irrigation amount and yield;

(+) indicates an increase in irrigation amount and yield.

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