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Assessment of the harvest wheat yield by CROPSYST model

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Abstract. An experiment was performed to assess the wheat harvest yield using a CROPSYST model in 2008-2009 at Rashmijan zone, the northern part of Fars province, Iran. The experiment was performed in a randomized complete block design and were conducted under treat of four irrigation levels (I_1, I_2, I_3, I_4) in three replicates. Irrigation were done by a usual cycle of zone irrigation at 20% tension, 40% tension and without irrigation (dry land farming). Finally, the statistical analysis showed that, the simulation efficiency using CROPSYST model for yield, stalk and biological yield, are 0.91, 0.82 and 0.94, respectively. Notably, the investigations of yield, stalk and biologic yield showed a high correlation among yield, stalk and biologic yield (0.93, 0.95 and 0.95, respectively) which confirmed the highest accuracy of anticipated operation by using CROPSYST model. As a result, this model is evaluated as a desirable model to anticipate the harvest operation in the Marvdasht zone.

Key Words: model assessment, drought tension, yield, CROPSYST model, wheat.

Introduction. Irrigation systems management is one of the most important aspects of the agricultural practices and it needs a lot of physical, biological and economical knowledge, being determinant in crop production. During the last 30 years, the remarkable development was achieved in the plant growth models base on the improvement of the knowledge processes related to soil, plant and atmosphere. Every model of plants includes several sub models, and usually these sub models consist of various processes in soil-plant-atmosphere systems and they were used to anticipate the growth and the production of harvest. Correlatively, growth models were significantly expanded all over the world for a vast range of harvest organized research groups. The ultimate goal for the most of these research groups is to evaluate tools for assessing different ways of garden managing and agricultural production. Plant systems are complicated and constantly crops are affected by climate, soil structure, chemical factors, insects, weeds and they have even effects on each other, in the farm (allelopathy). Undoubtedly, the models which explain these manners are just the approximation of real systems which try to simulate these relationships (Addiscott & Wagener 1985; Khalil et al 2009).

Presentation and development of CROPSYST has been started from the early of 1990's and its developed motivation was created based on the vacuum observation in requirements of cultivation systems especially those which were able to perform plant alternation. It was reported that, the first sample of crop growth models in agricultural research community was attended and accessible during the 1970's (De Wit et al 1970; Arkin et al 1976) and the usages of these models in farm management or its tendency according to the application (irrigation scheduling, pest and disease control) was started at the beginning of 1980's (Wilkerson et al 1983; Swaney et al 1983; Wang et al 2006; McKinion et al 1988). Notably, models like SUCROS, which are related to De Wit school (Bouman et al 1996) and the other ones from CERES (Singh et al 2008) and CROPGRO (Boote et al 1998) family had a remarkable impact on the crop community designments.

As a matter of fact, CROPSYST was designed in a way to use EPIC power concepts (The Erosion Productivity Impact Calculator), but it consists of directed process towards the crop growth simulation and undoubtedly, it has the surrounded interaction with management and environment. This model assessment is performed by comparison of the simulation outcomes with gathered data of real world as usual. Although these assessments can be limited with several factors, and even prevent getting the model's real efficiency, the elaborative information about the initial condition for performing these comparisons is necessary; this information are not always accessible or mix with noticeable special variation under the desert condition. The model assessment, when the observed system is more complicated, becomes increasingly hard, and at this time, it needs several kinds of data to experiment the simulated various processes by this model. Furthermore, we cannot assess every model's outcome that we want, because the following measure of that is so hard or impossible. The other problem in model assessment is the selection of using quantity index in order to assess the model efficiency. This statistic index is usually based on one by one comparison (simulation against measurement) and connived the measurement errors and other innate references which are related to the field (desert) experiments. Also there are disagreements among the simulated and the measured amount of time series, and authors have oftenly claimed that, the amount were not favorably assessed and the simulation from the outcomes is an exaggeration. Recently, endeavors have been performed to conquer these problems (Donatelli et al 2002). According to Ghahraman (1999) the first academic research in the field of anticipation of agricultural harvest operation in Iran has been started 50 years ago. In the primary research, the goal was to find out the simple statistical relations among the continentals (regional) and the operation degree. Considerably, Lomas & Shashoua (1973), had an special contribution to evaluate the possibility of wheat operational anticipation from the raining period and the availability of raining in this pattern. Notably, they found out that, 52% of wheat operational variations can be explained based on annual raining measurement by using a simple linear regression according to 1972 valid data of 18 experimental places. In the research which was performed by Ghahraman the SWACROP model was used to estimate the amounts of wheat operation. Mahdavi's and Lein number M-73-18 and Turcoman and barely numbers in Karaj was evaluated. The results showed that, the Penman-Monteith equation (Penman 1948) estimated the operation more desirable, but Priestly Taylor had less result than reality.

In 6 years survey on wheat, Pannkuk et al (1997) evaluated the accuracy of CROPSYST model at Polman University in Washington province, USA. The statistical structure (mean and standard deviation) simulations and observed data were the same. Root Mean Square Error (RMSE) fluctuated from 7 to 14% for grain operation and from 5 to 9% for evaporation and transpiration. Wilmot Agreement Index fluctuated from 0.92 to 0.97, and similar production functions resulted from simulation and observed data. According to this calibration, they stated that the CROPSYST model is a desirable model for analysis of directorial efficiency operation in order to save water in wheat cultivation. Bellocchi et al (2002) in the research by the title of *CROPSYST model usage in the dry land (Deim) corn cultivation*, under different management choices, the CROPSYST model was evaluated to simulate the produced matter of biologic corn and the amount of nitrogen absorption by the plant in reflecting to the various ploughing ways, manure and earth covers in the center of Italy. The simulated results by this model were compared to the observed results. The Average Modeling Efficiency was equal to 96%. Stockle et al (1994, 1997), Pala et al (1996) and Tingem et al (2007) examined the efficiency of the simulate the produced matter of biologic corn and the wheat, corn, sorghum and soy grain, operation of the CROPSYST model in reaction to the water and nitrogen. Experiments consisted of expanded area of non-irrigation to complete irrigation and the fewer amounts to the abundant amount of soil's nitrogen. In these assessments the distinct efficiency were consisted of RMSE index and Wilmot Agreement Index. The goal of this research was the assessment of harvest operation anticipation by usage of a CROPSYST model in Marvdasht plain, one of the strategic regions of wheat production in Iran.

CROPSYST model description. CROPSYST model is a simulated model for crop growth system in the form of usage in several years. It presents several plants with daily step as an absorbency tool to study the climate, soil effect, and the management over the efficiency, production cultivation systems and environment. The focus of this model is on the presentation of favorable users' environment; prepare the relation with GIS software, aerology generator and other useful programs. CROPSYST is simulated the balance sheet of soil-water, plant nitrogen balance sheet, plants penology, adumbral growth and the root, production of biologic material, harvest operation, production and remain decay, soil erosion by water and saltiness. These processes are affected by climate, soil specification, plant features, and the directorial choices of cultivation system which includes crop alternation and rotation, cultivation election, irrigation, nitrogen fertilizer, saltiness of irrigation water and soil, plow operation and the remain management.

Water balance sheet. In this model water balance sheet includes: raining, irrigation, surface stream, crop interceptive, and water bathetic penetration, redistribution of water in soil profile, water penetration, plant transpiration and evaporation. Water redistribution in soil can be simulated by the simple cascade way or solving the Richard soil flow equation (Campbell 1985; Ross & Bristow 1990). CROPSYST offers two options in order to account the reference plant (ET_0) transpiration and evaporation: which consist of Penman-Monteith (Monteith 1965) and Priestley & Taylor (1972) models. Use of Penman-Monteith method is done according to the suggested way of FAO (Allen et al 1998). This option needs daily amount of minimum and maximum temperature, solarization, minimum and maximum temperature comparative humidity and wind speed. The Priestley and Taylor model just needs the temperature and solarization data, but the user should enter the fixed accurate amount of Priestley-Taylor. Potential evaporation and transportation (ETc) is resulted from multiplying ET_0 with plant coefficient (K_C). The plant cover on the earth determines the division of plant potential transpiration and soil potential evaporation. The real plant transpiration and the soil evaporation depend on the existence of water in profile of soil (Stockle & Jara 1998; Jara & Stockle 1999).

Biological material production. Figure 1 reveals the calculation method for the daily aggregation of biologic material by CROPSYST. The main core of this calculation is to determine the growth of biological material without any tension (potential), according to the plant potential transpiration and interceptive PAR (photosynthetically active radiation) by the plant. Then this potential growth is corrected by the water and nitrogen limitations to calculate the real daily biologic materials. From the common method which is used in leaves in the carbon and steam exchange, the conservative relationship between the plant transpiration and biologic material is created. Therefore the potential biological material production can be calculated daily as follows (Tanner & Sinclair 1983).

$$B_{PT} = \frac{K_{BT} T_P}{VPD} \qquad (1)$$

Where,

B_{PT}: the biological material production depends on the plant potential transpiration ($Kgm^{-2}day^{-1}$),

T_P: the potential plant transpiration ($Kgm^{-2}day^{-1}$),

VPD: medium shortage of atmosphere steam pressure at daylight [Kilopascals (kPa)]

K_{BT}: coefficient of biological material transpiration (Tanner & Sinclair 1983; Loomis & Connors 1992).

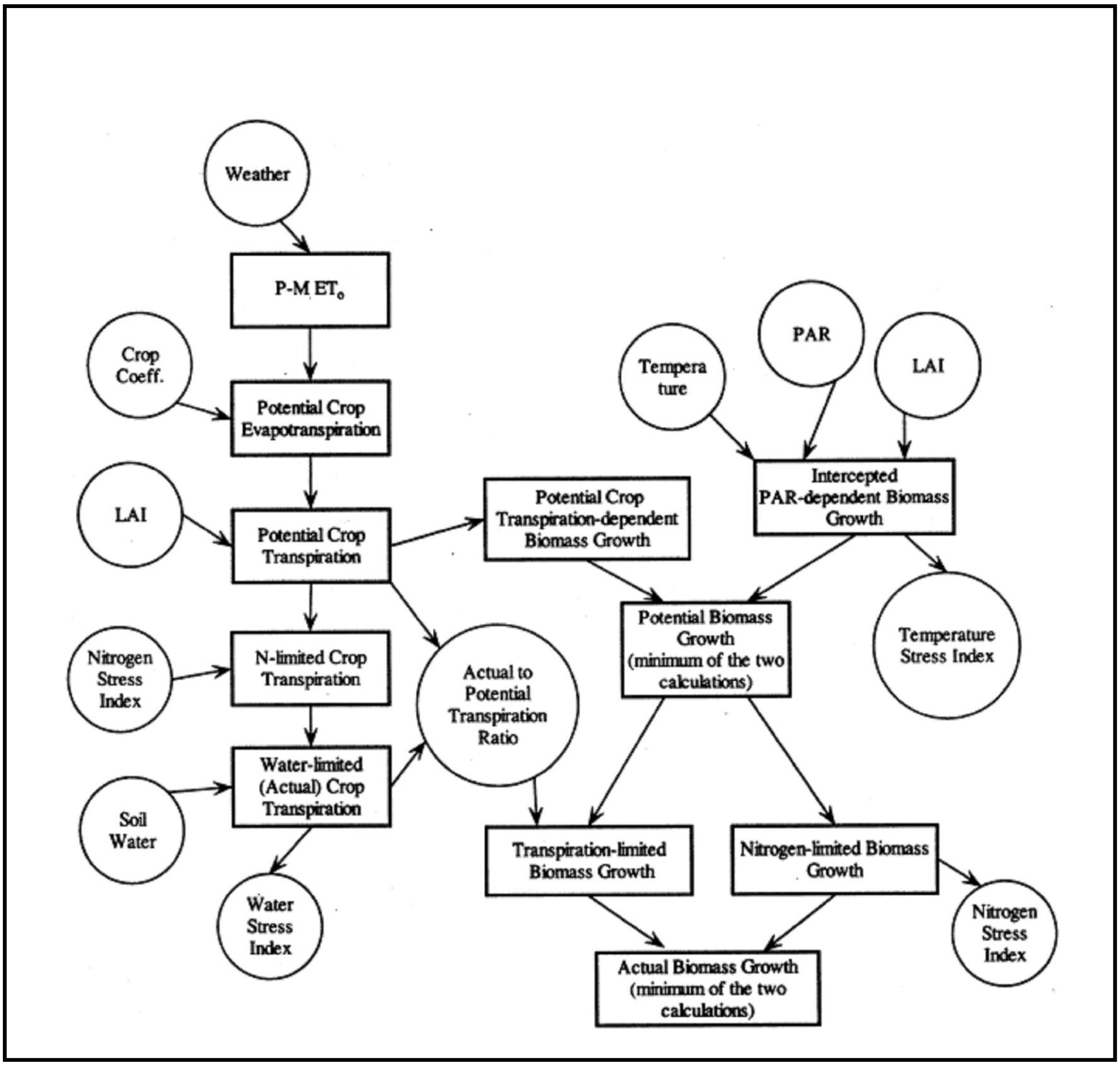

Figure 1. The growth calculation chart of biological material by CROPSYST model.

Tanner & Sinclair relation (1983) in shortage of low steam pressure, become unstable. In fact this relation anticipates the growth unlimitedly in shortage of steam pressure near the zero value. To solve this problem, the second estimation of biologic material production, without any tension is calculated as the follows (Monteith 1965).

$$B_{IPAR} = eIPAR \quad (2)$$

In which,
B_{IPAR}: Biologic material production dependant to PAR interceptive ($Kgm^{-2}day^{-1}$)
e: solarization consumption efficiency ($KgMJ^{-1}$)
IPAR: The daily amount of photosynthesis active radiation which is intercepted by the plant ($MJm^{-2}day^{-1}$) (Kiniry et al 1989).

As a result these data express the remarkable variations, and the conclusions from these methods used by CROPSYST have always been important due the experiment's amount to be selected without any plant tension and to be selected from that which is performed in the environment with low shortage of pressure steam.

Although the e parameter include common thermal diet effects during the experiments, but thermal limitation in growth primary steps would not be calculated so as a result it is possible to estimate the biologic material production more than reality during the growth primary steps in low temperature, especially about the winter plants or those that are cultivated in the beginning of spring. A temperature limitation factor is put in CROPSYST to correct e amount during the growth primary steps. That is assumed that this factor is from 0 to 1 and with weather temperature fluctuation it is linearly increased from the base temperature to one optimize degree development (growth) for growth primary steps.

Along every simulation day, the potential biologic material production for that day (B_P) is taken as a minimum B_{PT} and B_{IPAR}. This amount is used as a base for calculating the biologic material growth in water and nitrogen limitation condition (daily real biologic material production).

In order to determine the water limitations, the effect of nitrogen inefficiency on plant transpiration should be estimated. This effect will be calculated by increasing the adumbral resistance (Van Keulen & Seligman 1987). For every simulation day, maximum (N_{max}), critical (N_{Crit}), and minimum (N_{min}) of plant nitrogen density will be calculated. N_{max} is the possible maximum density of N, N_{Crit} is the plant critical density ($KgKg^{-1}$) in less than which the biologic material production decreases and N_{min} is the minimum plant nitrogen density ($KgKg^{-1}$) in which the biologic material growth will be stopped. The amounts of N_{max}, N_{Crit}, N_{min} have fluctuations during the growth seasons as an aggregated subordinate of biologic material, following the arrefication growth method (Greenwood et al 1990). More details about this discussion are presented by (Stockle et al 1997).

In N density the plant between the N_{max} and N_{Crit} the adumbral resistance remains without any change, but r_C in N density between N_{max} and N_{Crit} increases as follows:

$$r_C N_S = \frac{r_C}{\left[1 - \frac{N_{Crit} - N_C}{N_{Crit} - N_{\min}}\right]} \qquad (3)$$

In which,
r_C N_S: the amount of nitrogen in adumbral resistance with tension ($daym^{-1}$), whose amount is under the dominance of absolute maximum of resistance in closing aperture and
N_C: the present plant nitrogen density ($KgKg^{-1}$). Therefore the plant transpiration in limitation of N, T_N are calculated through the decrease of potential transpiration in reaction to r_C variations.

$$T_N = T_P \frac{\gamma(1 + \frac{r_C}{r_a})}{\Delta + \gamma(1 + \frac{r_C N_S}{r_a})} \qquad (4)$$

In which,
The Δ is saturation steam pressure slop, subordinate of temperature ($Kpa^{\circ}C^{-1}$)
γ: the fixed atmometer ($Kpa^{\circ}C^{-1}$) and
r_a: the aerodynamic resistance against steam transfer ($daym^{-1}$)
To get more information about last parameters refer to (Allen et al 1998).
The real plant transpiration (T_A) by capability of plant water absorbency from soil to match with T_N need (which is equal to plant potential transpiration when N is not the limitation factor), TA is calculated from the Stockle & Jara (1998) plan.
The biologic material growth in transpiration limitation (B_T) will be calculated as follows:

$$B_T = B_P \left\| \frac{T_A}{T_P} \right\| \qquad (5)$$

In which,
B_T is according to $Kgm^{-2}day^{-1}$,
B_p is the potential biologic material growth for that day ($Kgm^{-2}day^{-1}$) and

$\frac{T_A}{T_P}$ is the comparison of the real transpiration to the potential.

The calculation of biologic material growth which is limited by nitrogen (B_N) is as follows:

$$B_N = B_T\left[1-\frac{N_{Crit}-N_C}{N_{Crit}-N_{\min}}\right] \quad (6)$$

In which,

B_N ($Kgm^{-2}day^{-1}$) is according to the plant N density among N_{max} and N_{Crit}, while the biologic material growth is not affected by nitrogen.

The harvest operation. The harvest operation simulation depends on the whole aggregated biologic material in physiologic maturation (B_{PM}) and removal index of (HI).

$$Y = B_{PM}.HI \quad (7)$$

In which,

Y is the harvest operation (Kgm^{-2}) and B_{PM} is according to Kgm^{-2}.

The removal index is corrected based on without tension removal index regarding to the (water and nitrogen) tension and plant sensitivity to tension and grain filling.

This research was performed in 2008-2009 in Rashmijan zone. Marvdasht plain, is in the north of Fars province, Iran. According to the importance of wheat production in Marvdasht, the decline of Static level in that spot and drought in recent years, it is valuable to perform this research there as it is a good sample of climate and irrigation management factor's effects on wheat cultivation. The experiment field longitude was 52 and 85 eastern minutes, it's latitude is 29 and 87 northern minutes. That was 5 km far from east of Marvdasht near the Rashmijan region and its altitude from sea level was 1539 m.

Considerably, the studying zone has different climate from northern and southern zones in Fars province. Its raining measure is various and low and its evaporation measure is high. Table 1 shows the continental data in 2007-2008 agriculture years. These data are taken from the nearest synoptic aerology station in Zargan city. After the field preparation (plow and turntable) in the November 16th, 2007, wheat (Chamran cultivar) was cultivated by farm machine. A quantity of 250 kg seed with 250 kg urea fertilizer were used for each hectare. The experiment was performed in randomized complete block design. The treatments included: 4 treatment with 4 irrigation levels: I_1, I_2, I_3, I_4, i.e. irrigation by usual cycle of zone, irrigation by 20% tension in cycle, irrigation by 40% tension in cycle and without irritation (dryland farming), respectively. The plot's dimension was 4x8m and the distance from each other was 1m. The irrigation resource was 120 m depth and the approximate exit of the water was recorded 15 L per every second which it led the water near the ports then led to reach to the favorite plot. Meantime at the favorite plot, Felom device W.S.C (version 4) was used to measure the enter debi of the plot for the irrigation time and the usage of water for every plot.

Different level of irrigation were conducted by adding tension or postpone the irrigation base on the common irrigation schedule in the zone which it was similar to plan treatment I_1 (control) described as: in the beginning of the agricultural season in s short time and after the cultivation of wheat seed. Notably, according to raining data the plants needed lower levels of water and the next turn was postponed to the mid of March. Thereafter the irrigation turn had been every 15 days. In Marvdasht usually the irrigation of wheat conducts by 4 to 5 turns, but in the current agricultural year, wheat harvesting was done 20 to 30 days earlier because of the hot weather and unheard drought and base of this result 4 irrigations were done in 2007 and 1 irrigation in 2008.

Table 1

The aerology parameters in (1386-1387) agricultural year

Minimum temperature	Maximum temperature	Comparative humidity	Wind speed	Sunlight hours	solarization	The source transpiration &evaporation	Raining	The plant potential transpiration & evaporation	References
°C	°C	%	m/s	hours	MJ/m²/day	mm	mm	mm	Month
-1.4	10.5	65	2.8	6.8	12.3	58.34	90.97	30.5	January
0.6	14.5	58	3.9	7.5	15.3	85.13	61.24	63.7	February
3.2	18.7	51	4.7	8.2	18.8	139.83	37.03	138	March
7.3	24	49	4.9	9	22.3	181.9	22.49	220.3	April
10.8	30.3	34	4.9	11.1	26.5	265.2	2.13	239.6	May
0.5	13.4	63	2.5	6.8	11.6	61.33	81.29	21.5	December

In case of I_2 treatment, which showed the 20% water tension on irrigation cycle, instead of every 15 days, it's turn was changed to every 18 days. In I_3 treatment, which showed 40% water tension, irrigation was used every 21 days, and in case of I_4 treatment, which was without irrigation, it was irrigated just after cultivation in 2007 and in I_2 and I_3 the last irrigation turn was omitted because it was near the harvest time. Considerably, the used water for irrigation in I_1, I_2, I_3, I_4 treatments were recorded 503, 434, 395 and 121 mm respectively, after the harvest of wheat in 22th of May 2007, equal to 11th of January 2008. Meantime, some of the plant parameters were measured in order to investigate the drought tension's effects on parameters of wheat plant such as: the tiller number per m^2, the spikelet number per m^2, the grain per ear, the total grain in m^2, 1000 kernel weight, chaff weight in m^2, plant height, flag leaf weight, ear length, grain yield and biological yield.

To measure the mentioned parameters, 1 m^2 was harvested from each plot. The number of total available tillers in 1m^2 was accounted, then 40 samples were elected accidentally from every plot's tillers and parameters of plant height and ear length were measured. Therefore the samples were dried in 100' centigerad in 24 hours and the rest parameters were measured.

The assessment of anticipated operation was done according to the comparisons between the features of anticipated data and observed data. The operation of anticipated wheat harvest using CROPSYST model for I_1, I_2, I_3 and I_4 treatments were statistically compared with observed wheat harvest operation. To assess the anticipated operations we used Mean Error (ME) and Relative Error (RE), Root Mean Square Error (RMSE), Coefficient of Variation (Cv) and Efficiency (EF). These parameters are described as follows (Panda et al 2003):

$$ME = \frac{1}{N}\sum_{i=1}^{N}\left(C_{Si} - C_{oi}\right) \qquad (8)$$

$$RE = \frac{ME}{C_o} = \frac{\frac{1}{N}\sum_{i=1}^{N}\left(C_{Si} - C_{oi}\right)}{\frac{1}{N}\sum_{i=1}^{N}\left(C_{oi}\right)} \qquad (9)$$

$$RMSE = \left[\frac{1}{N}\sum_{i=1}^{N}\left(C_{Si} - C_{oi}\right)^2\right]^{0.5} \qquad (10)$$

$$Cv = \frac{RMSE}{C_o} = \frac{\left[\frac{1}{N}\sum_{i=1}^{N}\left(C_{Si} - C_{oi}\right)^2\right]^{0.5}}{\frac{1}{N}\sum_{i=1}^{N}\left(C_{oi}\right)} \qquad (11)$$

$$EF = \left[\frac{\frac{1}{N}\sum_{i=1}^{N}\left(C_{Si} - C_{oi}\right)^2}{\frac{1}{N}\sum_{i=1}^{N}\left(C_{oi} - C_o\right)^2}\right] \qquad (12)$$

Results and Discussion. The statistical analysis results from Table 3 showed that, the simulated efficiency by CROPSYST model for grain, chaff and biological yield which is equal to 0.91, 0.82, and 0.94, respectively.

The amount of ME, RE, RMSE, Cv and simulation random (EF) showed the high accuracy of simulation by CROPSYST model. Stockle et al (1994, 1997) reported about the grain of wheat operation simulation and its comparison with the observed data in Yota province, USA. By using CROPSYST, RMSE, RMSECv models the amounts of 0.44 and 0.108 were respectively recorded for 4.1 tons observed grain operation in hectare against 4.26 tones simulated grain operation in hectare. The experiment I_2 treatment with 4.53 tones in hectare observed grain operation is put in the same limitation. The anticipated grain operation for this treatment is equal to 4.43 tones in hectare. The RMSE and CV amount which were getting in this experiment for wheat grain operation were respectively equal to 0.15 and 0.52. Pala et al (1996), in north of Syria, in other research for wheat kind (Cham 1) by using the CROPSYST model, while the amount of RMSE and Cv was respectively equaled to 0.55 and 0.25 and for wheat (Hourami kind) these amounts were recorded 0.56 and 0.32 for observed wheat grain operation 2.18 and 1.75 tones in hectare against the simulated operation wich were recorded 2.41 and 2.08 tones in hectare.

Figs 2-4 show the comparison of observed and anticipated biological, chaff and grain operation variation in I_1, I_2, I_3 and I_4 treatments. The figure investigations expose high correlation among biological, chaff and grain operation which are 0.93, 0.95 and 0.95 respectively; that is the confirmation of high accuracy in anticipation operation by the CROPSYST model.

Table 2

The comparison between grain yield, chaff and biological anticipation and the amounts which were observed by CROPSYST model

Wheat biologic operation (tone in hectare)		Wheat chaff operation (tone in hectare)		Wheat grain operation (tone in hectare)		Reference
observed	anticipated	observed	anticipated	observed	anticipated	treatments
12.04	10.39	6.51	5.48	5.54	4.9	I_1
9.29	9.7	4.76	5.26	4.53	4.43	I_2
6.21	7.57	3.46	4.06	2.75	3.51	I_3
2.09	3.48	1.15	2.22	0.95	1.25	I_4

Table 3

Statistic grain yield analysis, chaff and biological anticipated, by cropsyst model

EF	Cv	RMSE	RE	ME	Plant parameters
0.91	0. 15	0.52	0.023	0.081	wheat grain operation
0.82	0.21	0.83	0.072	0.28	wheat chaff operation
0.94	0.17	1.29	0.05	0.37	wheat biological operation

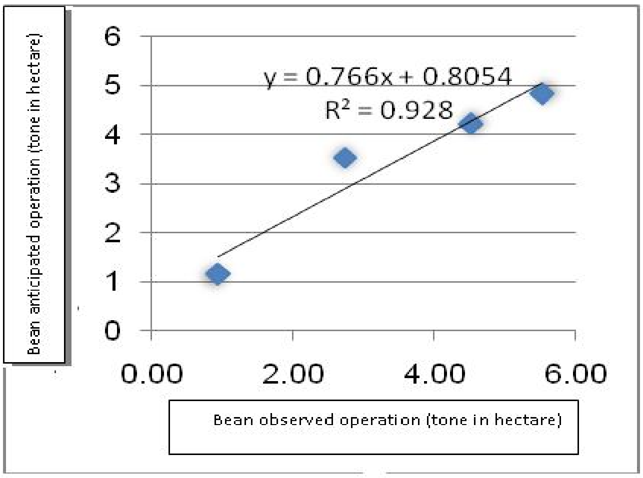

Figure 2. Variation of grain anticipated operation against the observed one.

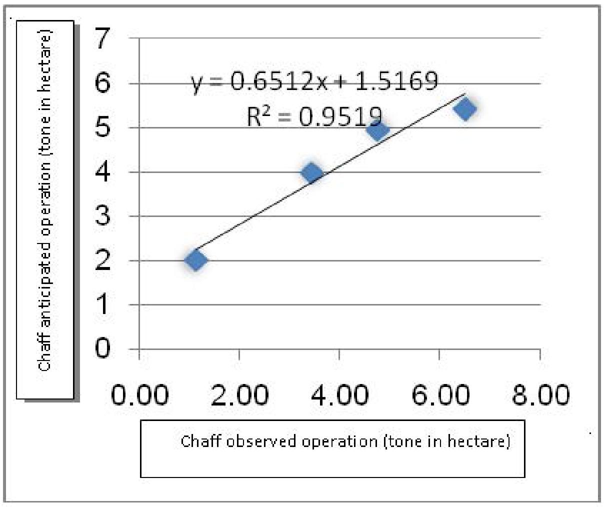

Figure 3. Variation of chaff anticipated operation against the observed one.

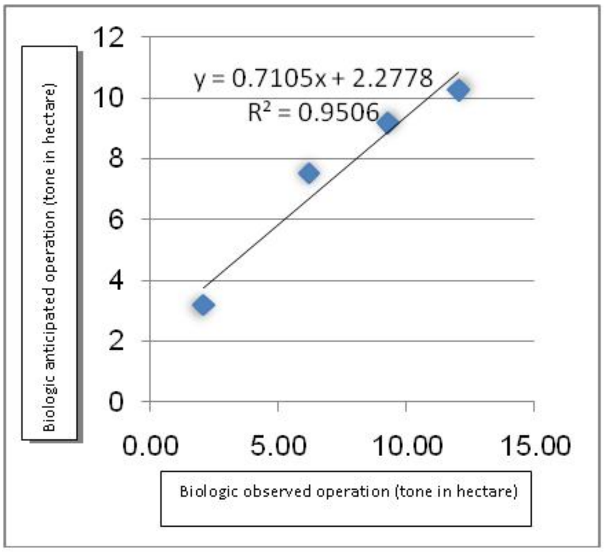

Figure 4. Variation of anticipated biologic operation against the observed one.

Conclusions. The result of statistic analysis shows that CROPSYST model is efficient and accurate in anticipation of harvest operation. Since the tested treatments in this experiment had several amounts of water for irrigation, and the result of this matter has several harvest operation limitation, the CROPSYST model is evaluated in the vast range. This model evaluation showed it is desirable to anticipate the harvest operation in Marvdasht climate. It was obvious that the correctness and accuracy of entered data had a remarkable effect on conformity of observed and anticipated amounts.

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