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Evaluation and modification of model for the prediction of wheat yield at Iran region

Fayaz Aghayari Aralloye Bozorg[1]*, Fereydon kaveh[2], Mansour Parehkar[3] and Mohammad Manshouri[2]

[1]Water Sciences and Engineering, Science and Research Branch, Islamic Azad University (IAU), Tehran, Iran.
[2]Department of Water Sciences and Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran. [3]Faculty member, Research Institute for Water Scarcity and Drought in Agriculture and Natural Resources (RIWSD), Tehran, Iran.

In this study, the mentioned model was evaluated and modified for simulation of winter wheat (*Sabalan cul.*) under irrigated and rainfed conditions in Maragheh area (Eastern Azarbayejan province) of Iran for three consecutive crop years (1999 - 2000 to 2001 - 2002). The simulated and measured grain yields were compared. Results show that the model was simulated satisfactory for the grain yield under irrigated condition, but the model was not able to simulate the grain yield under rainfed condition. The simulated grain yield was less than observed values under rainfed condition and it sounded that soil water content in this condition was simulated lower. Therefore, the coefficient of soil readily available water was changed from 0.65 to 0.90 for rainfed grain yield simulation. The model was able to predict more available water for plant transpiration using this scheme. The modified model properly simulated the grain yield under rainfed condition. Furthermore, it was found that this model was not able to simulate the grain yield for crop year (2001 - 2002) with high rainfall during the growing season in spring and summer due to plant disease infection. The amount of this rainfall was more than 140 mm and the model was modified for this parameter. Therefore, the modified model for excess rain was able to simulate the grain yield of Sabalan winter wheat under irrigated and rainfed conditions in the Maragheh area even for years with high rainfall during the growing season in spring and summer. Finally, the modified model was validated by data obtained for Alamoot cultivar and the results indicated that there was no significant differences at 5% level between measured and predicted grain yield.

Key words: Crop modeling, grain yield simulation, winter wheat cultivar.

INTRODUCTION

Crop growth and yield as influenced by various environmental parameters have been modeled. Crop yield depends on interaction between soil, water, plant and atmosphere as a continuum system. Simulation of plant growth stages and consequently forecasting the crop yield permits better planting and more efficient management of crop production processes (Farshi et al., 1987; Pang and Letey, 1998; Zand-Parsa, 2001; Ziaei, 1999). Among different models for wheat growth and yield simulation, CERES-Wheat is used by many farm decision managers (Tsuji et al., 1994). The original CERES

model was developed for maize as described by Jones and Kiniry (1986) and later modified by Ritchie and Ottor (1985) for wheat.

Wheat growth in arid and semi-arid regions is closely related to the availability of irrigation water for irrigated wheat and rainfall for dryland wheat. Therefore, simulation of the effects of water on wheat yield can assist in irrigation scheduling and as well as to determine the impact of low rainfall amounts on wheat yield. There are many possible applications of growth and water balance model to ameliorate water management (Hoogenboom, 2000; Horie et al., 1992). Different models were presented for yield production of wheat. Sepaskhah et al., (2006) developed a model for the yield of Wheat, maize and sugarbeet under water and salt Stresses.

In this study, a model was modified for the estimation of

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*Corresponding author. E-mail: aghayari_ir@yahoo.com. Tel: +98-21-44819137.

rainfed and irrigated winter wheat yields in Maragheh area, Eastern Azarbayejan province, Islamic Republic of Iran. The model was first presented by Cordery and Graham (1989) and later modified by Ziaei and Sepaskhah (2003). The model consists of a water balance and a crop yield submodel. The water balance submodel predicts the available soil water during the growing season and the crop yield submodel provides simulation of the yield based on the predicted available soil water.

MODEL DESCRIPTION

The model which is described in this manuscript consists of a main program and nine subroutines. The subroutines are: constant values, water balance, sowing date determination, evaporation calculation, Phenological clock, evapotranspiration calculation, stress determination, crop yield estimation and statistical parameters.

Water balance sub-model (WATBAL)

WATBAL was developed for appropriate estimation of important parameters such as partitioning of available energy between evaporation and transpiration. Division of rainfall among surface depression storage, runoff and infiltration, is conducted in this part of model.

The root zone is divided into two layers. The first layer is 10 cm of soil depth. The depth of second layer is related to root depth and can get to 120 cm from the soil surface. Evaporation can only remove water from the first layer. Transpiration and deep perco-lation are ways in which water can be depleted from the second layer. The water balance equation is the basis of WATBAL. The potential evaporation and transpiration are dependent on pan evaporation and leaf area index (LAI). The following equations are calibrated form of equations that were used by Cordery and Graham (1989) based on the work of Tanner and Jury (1976):

$$Epot = Epan * \exp(-0.55 LAI) \tag{1}$$

$$Tpot = Epan (1 - \exp(-0.55 LAI)) \tag{2}$$

where Epan is daily pan evaporation (mm), LAI is leaf area index (decimal), and Epot and Tpot are potential evaporation and transpiration (mm), respectively. LAI is calculated as the product of leaf area ratio (LAR, ha leaf kg^{-1}) and above ground green biomass (GDM, kg ha^{-1}). Since GDM in the beginning of growing season is nearly 0, LAI during the first month of growing season can get to a minimum of 0.1. LAR, according to Cordery and Graham (1989) can be estimated by accumulative pan evaporation since sowing. Equations (3) and (4) are used for calculating the LAR prior to and after anthesis, respectively:

$$LAR = [\min (220, 238.0 - 0.846 \times EOS + 0.0009 \times EOS^2)] \tag{3}$$

$$LAR = [\max (35, 120.0 - 0.11 \times EOS)] \tag{4}$$

where EOS is accumulative pan evaporation since sowing (mm).

The actual evapotranspiration is related to the availability of soil water in root zone. Before vegetation initiation, all the available energy is devoted to evaporation from surface depression and then from the first layer of soil. Evaporation can deplete soil moisture content of the first layer to 2 vol. %. After vegetation initiation, the available energy is partitioned between evaporation and transpiration.

Actual evapotranspiration

The actual transpiration depends on location of available water in root zone and root activity. It is assumed that transpiration occurs at potential rate when available water is more than a specific fraction of holding capacity of soil layers. Otherwise, the actual transpiration (AT) decreases linearly to zero when the soil water content (SWL) is reduced to permanent wilting point (PWP). The lower limit of available water above which actual and potential transpiration are the same, changes according to weather conditions. Actual transpiration rate is calculated according to following equations:

$$HCL_i = FC_i - PWP_i \tag{5}$$

where HCL_i, FC_i and PWP_i are water holding capacity, field capacity and permanent wilting point of layer i, respectively.

$$HCL = \sum_{i=1}^{n} HCL_i, \quad n = 2 \tag{6}$$

$$ASW_i = SWL_i - PWP_i \tag{7}$$

where ASW_i and SWL_i are the plant available water content and soil water content of layer i, respectively.

$$ASW = \sum_{i=1}^{n} ASW_i, \quad n = 2 \tag{8}$$

$$AT = Tpot \quad if \quad ASW \geq (1 - MAD)HCL \tag{9}$$

$$AT = \left(\frac{Tpot}{1 - MAD} \right) \left(\frac{ASW}{HCL} \right) \quad if \quad ASW < (1 - MAD)HCL \tag{10}$$

$$FMAD = 0.65 \tag{11}$$

$$MAD = 0.7 \times FMAD \quad if \quad Epan \geq 10 \text{ mm per day} \tag{12}$$

$$MAD = 1.3 \times FMAD \quad if \quad Epan < 3.6 \text{ mm per day} \tag{13}$$

$$MAD = FMAD \quad if \quad 3.6 \leq Epan \leq 10 \text{ mm per day} \tag{14}$$

where MAD is the maximum allowed deficit, and FMAD is a constant. Other terms were defined previously.

Ritchie (1972) presented a relationship for calculating the evaporation from a bare soil after rainfall. He related the water loss from a bare soil to the square root of time. Ritchie (1985) used this equation in a similar manner to model the water balance for wheat growth model. Cordery and Graham (1989) estimated the actual evaporation by following the procedure of Ritchie (1972). http://www.sciencedirect.com/science/article/B6T3X-47836H9-2/2/f4bcc47438d46251fce5331004132c2eZiaei and Sepaskhah (2003) used a similar equation and obtained satisfactory results. Therefore, actual evaporation is calculated based on potential evaporation and the number of days from the last rainfall or irrigation as follows:

$$Eact = Epot \times t^{-0.5} \tag{15}$$

where Eact is the actual evaporation, Epot the potential evaporation, and t is the number of days after wetting the soil.

Soil water movement

Water holding capacity of soil layers and surface depression storage are site dependent parameters. These values can be used as fitting parameters. During the time of precipitation, surface storage and soil layers act as a simple cascade. That is, when the surface store gets filled, the major part of precipitation infiltrates to the first layer and a small proportion runs off. The amount of runoff depends on runoff coefficient, which is the ratio of runoff to rainfall. This coefficient is dependent on the local conditions and may be varied between 0 and 1. When the soil water content of the first layer reaches its field capacity, the excess water percolates to the second layer. On the rare occasions when all soil storages become filled, any subsequent precipitation percolates to the deep layers. The soil water content of second layer can fluctuate between permanent wilting point and field capacity limits.

The amount of water, which is removed from soil layers, is also related to root activity in the root zone. Therefore, following equations, which are modified forms of Greacen and Hignett (1976) equations are used for downward extension of root:

$$DR(Inc) = 9 \times \frac{1}{5} EO^{0.5} \qquad \text{(for dry soil condition)} \qquad (16)$$

$$DR(Inc) = 9 \times \frac{1}{5} EO^{0.5} \qquad \text{(for wet soil condition)} \qquad (17)$$

where EO is the 5-day pan evaporation, which is calculated by summing the previous 5 days of data, and DR (Inc) is the daily root extension.

Crop yield sub-model (CROPY)

This model was developed to estimate grain yield on the basis of WATBAL sub-model. Here, it is assumed that the yield is only affected by the availability of water and energy. Other parameters are ignored. The phonologic development of crop is simulated in three periods, pre-anthesis, anthesis and post-anthesis. Timing of each period as shown in Table 2 is dependent on accumulated pan evaporation since sowing. The model calculates the daily increment of dry matter as product of actual transpiration and transpiration efficiency, that is:

DM (Inc) =TE×AT

$$(18)$$

where DM (Inc) is the dry matter increment (kg ha^{-1}), TE is the transpiration efficiency (kg ha^{-1} mm), and AT is the actual transpiration (mm). The following equation is used for computing transpiration efficiency as a function of daily pan evaporation, E is in mm (Cordery and Graham, 1989):

TE=102−13E+0.53E^2 $\qquad\qquad$ (19)

The above ground green biomass (GDM) is given by:

GDM=0.8DM−SEN $\qquad\qquad\qquad$ (20)

where SEN is the loss of biomass due to senescence and DM is accumulated dry matter. SEN changes during the growing season. The following equations are used depending on the growth stages

SEN=0 (between germination and stem extension) $\qquad$ (21)

SEN=0.0003×GDM (between stem extension and booting) (22)

SEN=0.0008×GDM (between booting and anthesis) $\qquad$ (23)

$$SEN = K \left(\frac{TEO}{MT - ANT} \right) \qquad \text{(at post-anthesis)} \qquad (24)$$

where in Equation (24), TEO is the accumulated pan evaporation from the beginning of post-anthesis period, ANT and MT are defined as the accumulated pan evaporation for anthesis and maturity since sowing,

respectively and K is a calibration coefficient.

Grain number is related to the total dry matter at anthesis. For this propose, the relationship that was applied by Cordery and Graham (1989) has been adopted as:

GN=min (−910+2.15DMA, 3480+1.01DMA) $\qquad$ (25)

where GN is the grain number per square meter (m^{-2}) and DMA is the total dry matter at anthesis (kg ha^{-1}).

After anthesis, dry matter and LAI in sequence, gradually decreases as a result of senescence. In this period, all the net

assimilate production is allocated to grain growth. A proportion of the dry matter at anthesis is set aside in the plant as a source for post-anthesis grain development. Grain growth is related to available energy, actual transpiration and crop dry matter at anthesis. The process of grain growth is given by the following equations in an abbreviated form. These equations are modified forms of the equations that were used by Cordery and Graham (1989). They are used in order as presented:

$$GR1 = 0.3 \times GSIZE \times 2^{(0.47E-2.38)} \qquad\qquad (26)$$

$$GR2 = GR\max \times 1.5^{(0.47E-2.38)} \qquad\qquad (27)$$

$$GR = \min(GR1, GR2) \qquad\qquad (28)$$

$$(29)$$

$$GRX = \frac{1}{100}(GR \times GN) \qquad\qquad (30)$$

$$RES = RESTOT \times \frac{1}{144}E$$

$$RESTOT = 0.1 \times DMA \qquad\qquad (31)$$

$$TLGI = DM(Inc) = AT \times TE \qquad\qquad (32)$$

$$GR\max = 0.7 \qquad\qquad (33)$$

$$GYINC = \min(GRX, TLGI + RES) \qquad\qquad (34)$$

$$GR = GYINC \times \frac{100}{} \qquad\qquad (35)$$

Table 1. Irrigation depth (mm) in different irrigation treatments during the growing seasons during 1999-2002 years.

Irrigation no.	Date	Number of days from sowing	Irrigation treatment numbers			
			1	2	3	4
1	14 October 1999	0	0	36	36	36
2	20 May 2000	219	0	24	48	72
3	4 June 2000	234	0	24	48	72
4	14 October 2000	9	0	40	40	40
5	24 April 2001	201	0	24	48	72
6	15 May 2001	222	0	24	48	72
7	29 May 2001	236	0	24	48	72
8	14 October 2001	5	0	40	40	40
9	22 May 2002	225	0	24	48	72
10	7 June 2002	241	0	24	48	72

Table 2. Phonological calendar of wheat (Sabalan cul.) during the first crop year (1999 - 2000) in study area.

Phonological stage	Date	Days from sowing	Cumulative pan evaporation since sowing (mm)
Planting	14 October 1999	0	0
Emergence	29 October 1999	15	60
Tillering	27 March 2000	165	250
Stem extension	4 May 2000	203	450
Booting	12 May 2000	211	500
Heading	20 May 2000	219	569
Effective cover	3 June 2000	233	690
Ripening	18 June 2000	248	850
maturity	28 July 2000	288	1360

$$GSIZE = GSIZE + GR \qquad (36)$$

where GR1 and GR2 are the potential growth rate (mg per day), GRX is the potential grain yield (kg ha^{-1}), RES is the contribution of pre-anthesis biomass to grain yield (kg ha^{-1}), RESTOT is the total available pre-anthesis biomass for grain (kg ha^{-1}), TLGI is the net biomass increment (kg ha^{-1}), GRmax is the maximum grain growth rate (mg per day), GYINC is the grain yield increment (kg ha^{-1}), GR is the grain mass increment (mg per day), and GSIZE is the grain mass (mg).

The calculations in Equations (26) – (36) are repeated in post-anthesis period at a daily time intervals. Finally, the grain yield is calculated by the following equation:

$$GY = GN \times \frac{1}{100\,GSIZE} \qquad (37)$$

where GY is the grain yield (kg ha^{-1}), GN is the grain number (m^{-2}), and GSIZE is the grain mass (mg).

Model modification

The provided data set by Tavakoli (2002) were used in this investigation. These data were obtained from Research Center for Dryland Agriculture located in Maragheh zone, at Iran. The soil type was silty clay at the site. Soil moisture at field capacity and permanent wilting point were 38, 20 vol. %, respectively. Four irrigation treatments consisted of non-irrigation (number 1), 33% of full irrigation (number 2), 66% of full irrigation (number 3) and full irrigation (number 4) were applied. Date and amount of irrigation are presented in Table 1. Wheat cultivar Sabalan (*Triticum aestivum* L. *Sabalan cul.)* was planted on the 14, 5 and 9 October in 1999, 2000 and 2001, respectively. Table 2 depicts the time of growth stages and their corresponding cumulative pan evaporation since sowing during the first crop year (1999 - 2000). Phonological calendars for the other years (2000 - 2002) were in existence. Grain yield was measured several times during the growing season for different treatments. Daily pan evaporation and rainfall data were obtained from the near weather station.

The comparison between measured and predicted grain yieldshowed that the simulated grain yield under irrigated condition for many years were satisfactory, but it was not able to simulate the grain yield under rainfed condition. The simulated grain yield was less than observed values under rainfed condition and it sounded that soil water content in this condition was simulated lower. Thus, the model for this condition was modified (change FMAD from 0.65 to 0.9). The modified model properly simulated the grain yield under rainfed condition. Furthermore, it was found that this model was not able to simulate the grain yield for crop years with high rainfall during the growing season in spring and summer due to plant disease infection. Thus, the model modified for this condition.
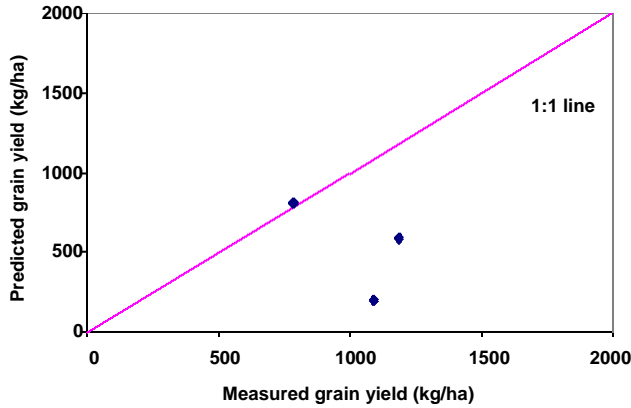
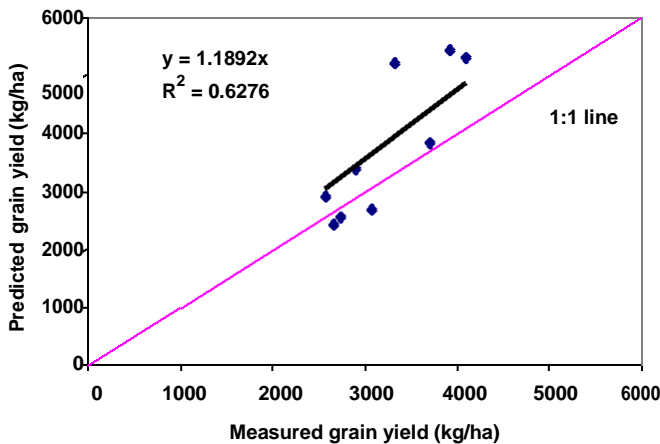**Figure 1.** Comparison between measured and predicted grain yield (rainfed treatments before modification).

Figure 2. Comparison between measured and predicted grain yield (irrigated treatments before modification).
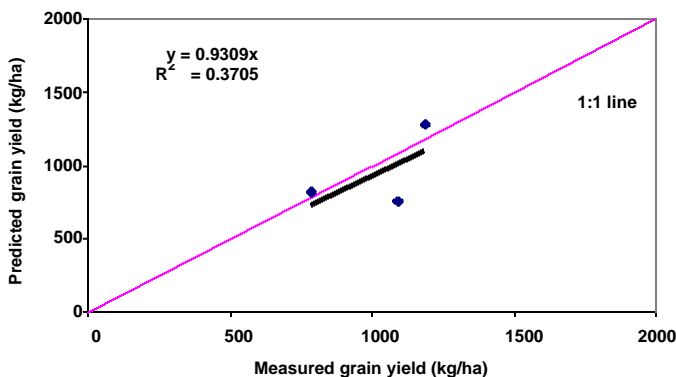

Figure 3. Comparison between measured and predicted grain yield with modified model (rainfed treatments after modification).

RESULTS AND DISCUSSION

Estimation of grain yield is the main objective of crop

yield modeling. The simulated grain yield versus observed grain yield for rainfed and irrigated treatmentare shown in Figures 1 and 2, respectively. Figure 1 indicates that the model is not capable for grain yield prediction under rainfed condition. The simulated grain yield was less than observed values under rainfed condition and it sounded that soil water content in this condition was simulated lower.

Therefore, the coefficient of soil readily available water (FMAD) was changed from 0.65 - 0.90 for rainfed grain yield simulation. The model was able to predict more available water for plant transpiration using this scheme. The results of modified model under rainfed condition were indicated in Figure 3. It was indicated that simulated grain yield under rainfed condition was sort of acceptable. The results in Figure 2 indicated that the simulated grain yield under irrigated condition during the 1999 - 2000 and 2000 - 2001 crop years is satisfactory, but it was not acceptable to simulate the grain yield during the 2001 - 2002 crop years.

According to the investigation carried out, the yield was decreased because of the increase in the amount of rain and probably pest, thereby, causing plant dieses. Wheat rust was reported in Maragheh zone on that year. The rainfall values during the 1999 -2000, 2000 - 2001 and 2001 - 2002 crop years in spring and summer were 110, 122, and 183 mm, respectively. The amount of this rainfall was more than 140 mm. A regression equation was created between ratio summation of irrigation and rainfall in spring and summer to rainfall in spring and summer and ratio observed grain yield values to predicted grain yield values for the modification of the model. Therefore, following equation created for the modification of the model:

$$Y = 0.282X + 0.208, \ R^2 = 0.922 \qquad (38)$$

where Y is the ratio observed grain yield values to predicted grain yield values (modification coefficient), X is ratio summation of irrigation and rainfall in spring and summer to rainfall in spring and summer, and R^2 is regression coefficient.

The modified model for high rainfall condition was run and the obtained results were shown in Figure 4. It showed that the ability of modified model for prediction grain yield has been improved under irrigated condition. Plant dieses and pest are not considered in the model. Therefore, the model was just edited for the event, which occurred in 2001 - 2002.

It can be said, the edition is only applicable for Maragheh zone or similar regions. Figure 5 show the comparison between measured and predicted grain yield under rainfed and irrigated condition. The results showed the ability of the modified model in providing reasonable estimate of rainfed and irrigated winter wheat yield. Also, the results indicated that there was no significant differences at 5% level between measured and predicted grain yield.
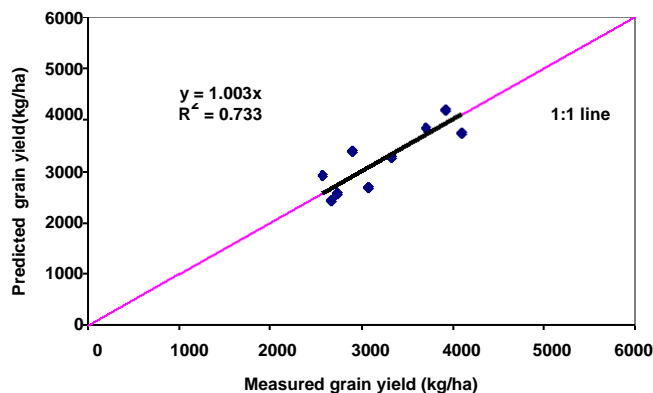
Figure 4. Comparison between measured and predicted grain yield with modified model (irrigated treatments after modification).
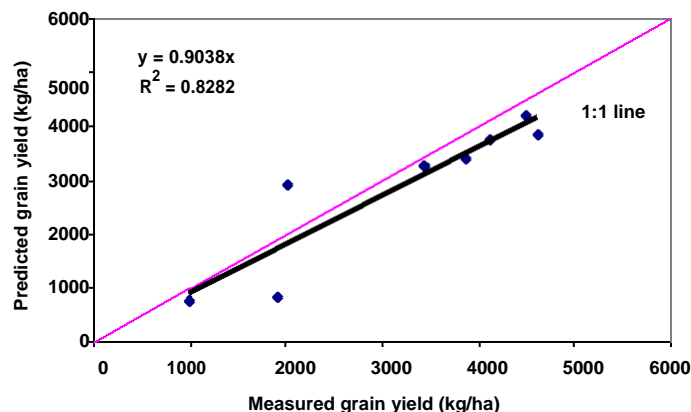

Figure 6. Comparison between measured and predicted grain yield with modified model (Alamoot cultivar treatments).
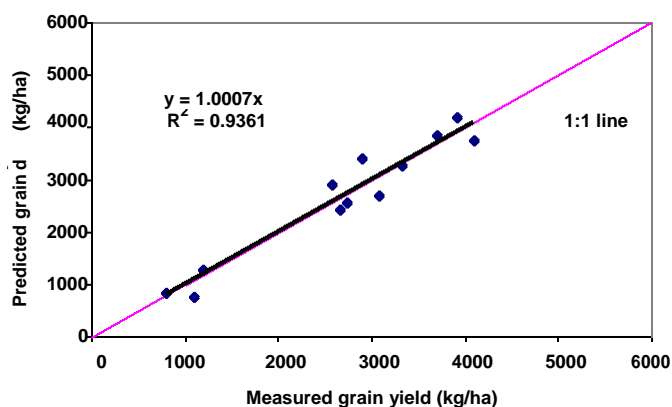

Figure 5. Comparison between measured and predicted grain yield with modified model (rainfed and irrigated treatments).

Model validation

The other set of data obtained by Tavakoli (2002) were used to verify the model. The data were provided by an experiment in which wheat cultivar Alamoot was planted in Maragheh area during 2000 - 2002 years. The conditions of climate and irrigation treatments in Alamoot cultivar and Sabalan cultivar were the same. The simulated grain yield versus the observed grain yield is shown in Figure 6. The results showed the ability of model to provide reasonable estimate of winter wheat yield. Also, the results indicated that there was no significant differences at 5% level between measured and predicted grain yield. As a result, the modified model can be used for forecasting winter wheat yield in the study area.

Conclusions

The model under irrigated condition indicates a good agreement for crop years with normal rainfall during the growing season, but it was not able to simulate the grain yield for crop years with high rainfall during the growing season in spring and summer due to plant disease infection. The rainfall values during the 1999 - 2000, 2000 - 2001 and 2001- 2002 crop years in spring and summer were 110, 122, and 183 mm, respectively. The amount of this rainfall was more than 140 mm and the model was modified for this parameter. Furthermore, whit comparison between measured and predicted grain yield under rainfed condition indicates that the results is not satisfactory. Therefore, the coefficient of soil readily available water (FMAD) was changed from 0.65 - 0.90 for rainfed grain yield simulation. The results indicated that simulated grain yield under rainfed condition were sort of acceptable. Finally, the modified model properly simulated the grain yield under irrigated and rainfed conditions. Most of the applied equations in this model had been developed in other regions of the world that might have reduced the precision of the estimations for the study area. The improvement of the applied equations (e.g. (3), (4), (16), (17), (19) and (25)) could increase the accuracy of the model. The inputs of the model are very simple and available from many weather stations. This property simplifies the investigation of the effects of irrigation on grain yield. For instance, the best time and amount of supplementary irrigation can be estimated by using the model. In general, the model can improve the precision of the farm irrigation management.

ACKNOWLEDGEMENT

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