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Full Length Research Paper

Evaluating of Production Functions for Simulation Rapeseed Yield in Deficit Irrigations with Monthly Intervals

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With a rapid irrigation growth, the amount of irrigation water needed for food production is putting a burden on limited water resources in the developing countries. In order to optimize water consumption for crops in these regions, we must have appropriate production functions. This study was conducted in Esmaeil Abad region of Qazvin plain near Tehran with deficit irrigation at various growth stages of rapeseed crop for two years. Maximum of observed grain yield for a maximum evapotranspiration of 820 mm was 2750 kg/ha. Various production functions similar to, Doorenbos, Minimum, Average, Raes and Tafteh were applied in order to calculate grain and oil yield response factor (K_y) for each month by first year data. After calibration, the acceptable production functions were validated by second year data. The results showed that the Tafteh et al. (2013) function with 10% NRMSE for grain yield and 8% NRMSE for oil yield in monthly interval has lowest error. Therefore this method for estimating yield in deficit irrigation for rapeseed in Qazvin Plain was recommended. The value of grain yield response factors for initial, plant development, middle and finally growth were respectively, equal to 0.35, 0.63, 0.75 ,0.52 and the value of grain yield response factors for initial, plant development, middle and finally growth were respectively, equal to 0.5, 0.8, 0.91 and 0.7. The results showed that oil yield response factors is more than grain yield response factors in each stage of rapeseed growth and the value of oil yield are much more sensitive to value of water especially in full pod formation stage. Therefore among applied treatments in this study, T_9treatment without any tension in full pod formation stage is recommended.

Keywords: Production Function, Yield response factor (K_y), Deficit irrigation, Rapeseed.

INTRODUCTION

The agricultural sector is consuming roughly 90% of annual water consumption in Iran. annual rainfall in Iran is 230 mm which is below world average and irrigation water efficiency is quite low (35%).

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Increasing water consumption due to a rapid increase of population and a very high competition from other sectors using waters, is forcing the agricultural sector to become a more efficient water use and as result the management of this to become a national priority (Smith, 2000). At the present time, a key research issue in Iran is water shortage in agriculture that requires a keen attention from all involved disciplines. It is possible to focus on six very important methods for example: Increasing soil water storage before cultivation, Decrease water consumption by plants without any negative effects, to decrease evaporation from soil surface, to employ optimization models for water consumption, improving crop water tolerance to water stress and irrigation at sensitive growth periods (Debaeke and Aboudrare, 2004).

In order to reduce expensive and time consuming field experiments, it is possible to use simulation models with sufficient accuracy to predict crop yield in different water deficit situations. Generally these models require accurate calibration and validation procedures that required a lot of field data and other information which is often not available expect in research stations. Therefore using these types of models under practical conditions cannot be very use full. (Raes et al., 2006).Some of these elaborate models includes: Robertson et al., 2001; Batchelor et al., 2002; Stockle et al., 2003; Wang et al., 2003; Ziaei and Sepaskhah, 2003; Yang et al., 2004;Tafteh and sepaskhah, 2012b and Mubeen et al.,2013.For practical and management cases we need models that requires less extensive data as above models while can easily provide yield accurate results based on crop growth stages either on monthly basis or shorter periods. The models with appropriate calibration and validation procedure can be used by managers facing periodical water shortages for the cropping pattern in their area of interests. These models can be very useful in areas short of data for all crops. It is also possible to use these models in water distribution management and optimizing the cropping patterns. These relatively simple models with a minimum of input data can provide yield output with acceptable accuracies.

In this study, models similar to, Doorenbos and Kassam (1979), Allen (1994), Raes (2004) and Tafteh et al. (2013)were employed to find out which one is performing better. These models using yield response coefficient, (K_y) that is an important parameter. On the other hand management of water distribution in Qazvin plain is monthly. Therefore monthly yield response factor and monthly interval was applied for all models. rapeseed was investigated in this study, where required data regarding K_y is lacking. In the first, models are calibrated by first year data, after that the models are evaluated by second year data. Considering the importance of rapeseed in edible oil production, water saving as a result of deficit irrigation is considerable with regard to acute water shortage in Iran. In conclusion the present study was mainly focused on the production functions with monthly interval in estimating rapeseed yield in various deficit irrigation practices.

METHOD AND MATERIALS

Experimental site

This study was conducted on a 1000 square meter land in Esmaeil Abad Research Station in Qazvin province. Peculiarities of station is 49º, 52' N and 36º 15' E with an elevation of 1285 m. The irrigation water used was neither saline nor sodium problems. The Fertilizer applied were200 kg/ha of pure Nitrogen in the urea form and 50 kg/haphosphate with form of tripl. The planting was 100 plants per square meter. Randomized complete block design was conducted with 13 treatments and 3 replicates. After land preparation plots were formed with an area of24 square meters (6 by 4 m). The averages of soil physical and chemical properties of experimental site are shown in tables 1 and 2respectively.Zarfam improved rapeseed was planted in rows. All of phosphate and 30% of nitrogen fertilizer were applied and were mixed with the soil at plowing time. The remaining nitrogen fertilizer was applied in spring at the time of stem elongation. Deficit irrigation was practiced during germination, initial growth, stem elongation, flowering, full pod formation and finally ripening stages as follow:

FI: Full Irrigation (100%FI), T_1:Deficit irrigation in stem elongation (0%FI) and flowering (35%FI),T_2: Deficit irrigation in flowering (35%FI) and finally ripening (0%FI),T_3: Deficit irrigation in flowering(35%FI), full pod formation (10%FI) and finally ripening (0%FI),T_4: Deficit irrigation just in flowering (35%FI),T_5: Deficit irrigation in full pod formation (0%FI) and finally ripening (0%FI),T_6: Deficit irrigation in flowering (70%FI), full pod formation (0%FI) and finally ripening (0%FI),T_7: Deficit irrigation in full pod formation (70%FI) and finally ripening (70%FI),T_8: Deficit irrigation in initial growth (50%FI), flowering (70%FI), full pod formation (0%FI) and finally ripening (0%FI),T_9: Deficit irrigation in germination (70%FI), initial growth (60%FI) and flowering (60%FI),T_{10}: Deficit irrigation in germination (70%FI), initial growth (60%FI), flowering (60%FI), full pod formation (75%FI) and finally ripening (0%FI),T_{11}: Deficit irrigation in germination (70% FI), initial growth (60%FI), flowering (60%FI), full pod formation (10%FI) and finally ripening (0%FI),T_{12}: Deficit irrigation in germination (70%FI), initial growth (60%FI), flowering (60% FI) and finally ripening (80%FI).These treatments for better explain are shown in table 3.

Monthly evapotranspiration and some local weather information in 1th and 2th year are presented in table number 4 and 5 respectively. Duncan test was used to check significant difference between treatments. Also this test was applied for important of averaged plant characteristics for each years, and the results are shown in tables 6 and 7.

Table 1. physical properties of soil for two years

Depth	Clay	Silt	Sand	ρb	FC	PWP
cm	%	%	%	g cm^{-3}	cm^3 cm^{-3}	cm^3 cm^{-3}
0-25	51	34	15	1.44	0.21	0.11
25-50	35	50	15	1.42	0.2	0.1
50-75	47	38	15	1.47	0.23	0.12
75-100	39	54	7	1.53	0.23	0.12
100-125	37	54	9	1.55	0.23	0.13
125-150	39	42	19	1.6	0.24	0.13

Table 2. The average of some chemical properties of the experimental soil for two years

Depth cm	pH -	EC dS/m	Nitrate meq/l	Potassium meq/l	Phosphor meq/l	Calcium meq/l	Sodium meq/l	Magnesium meq/l
0-50	7.3	0.86	0.7	5.7	0.25	1.8	0.27	0.48
50-100	7.5	1.1	1.2	6.1	0.32	2.1	0.31	0.52

Table 3. The percentage of deficit irrigation (%) was applied for treatments in each month.

growth stage	germination	initial growth			stem elongation		flowering and first pod formation	full pod formation	finally ripening
	Month								
treatment	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**
T_1	100%	100%	-	-	-	0%	35%	100%	100%
T_2	100%	100%	-	-	-	100%	35%	100%	0%
T_3	100%	100%	-	-	-	100%	35%	10%	0%
T_4	100%	100%	-	-	-	100%	35%	100%	100%
T_5	100%	100%	-	-	-	100%	100%	0%	0%
T_6	100%	100%	-	-	-	100%	70%	0%	0%
T_7	100%	100%	-	-	-	100%	100%	70%	70%
T_8	100%	50%	-	-	-	100%	70%	0%	0%
T_9	70%	60%	-	-	-	100%	60%	100%	100%
T_{10}	70%	60%	-	-	-	100%	60%	75%	0%
T_{11}	70%	60%	-	-	-	100%	60%	10%	0%
T_{12}	70%	60%	-	-	-	100%	60%	100%	80%
FI	100%	100%	-	-	-	100%	100%	100%	100%

Measurement methodologies

Net irrigation is calculated in various soil depths increments of the root zone i.e. 25, 75,100 and 125 cm according to the following equation:

$$d_n = \sum_{i=1}^{n} (\theta_{fci} - \theta_i)\Delta_z \qquad (1)$$

Where d_n is the net water requirement depth (m), $\theta_{fci}$is field capacity and θ_i is soil moisture inilayer at and before irrigation, respectively (m3 m-3), Δ_z is the depth of layer (m) and n is the number of layers. Root growth was calculated as follows (Borg and Grimes, 1986):

$$Z_r = R_{DM}\left[0.5 + 0.5\,\mathrm{SIN}\left(\frac{3.03 D_{AS}}{D_{TM}} - 1.47\right)\right] \quad (2)$$

Which z_r is the root zone of plant in D_{AS} days after planting,R_{DM} is maximum root zone after final developing growth stag and D_{tm} is the number of days required to reachR_{DM}.Sepaskhah and Tafteh, (2012) reported $R_{DM}$is 1m for rapeseed and D_{tm} is 200 days. The rapeseed evapotranspiration for each treatment was calculated from Jensen (1973)as:

$$ET = I + P - D \pm \left(\sum_{i=1}^{n} (\Delta\theta)_i \Delta S_i\right) \qquad (3)$$

where ET is evapotranspiration, I is depth of water irrigation (mm), P is the precipitation (mm), D is depth of water deep percolation from root zone (mm), n is the

Table 4. Monthly and total rapeseed evapotranspiration (mm) in each treatments on first year.

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	∑	Treatment
Evapotranspiration (mm)	150	79	50	25	25	0	65	135	135	665	T_1
	150	79	50	25	25	25	65	135	0	554	T_2
	150	79	50	25	25	25	65	14	0	433	T_3
	150	79	50	25	25	25	65	135	135	689	T_4
	150	79	50	25	25	25	188	0	0	542	T_5
	150	79	50	25	25	25	135	0	0	490	T_6
	150	79	50	25	25	25	192	87	96	730	T_7
	150	35	25	25	25	25	135	0	0	421	T_8
	100	42	43	20	20	25	100	135	135	620	T_9
	100	42	43	20	20	25	100	98	0	448	T_{10}
	100	42	43	20	20	25	100	15	0	364	T_{11}
	100	42	43	20	20	25	100	135	105	590	T_{12}
Full Irrigation(mm)	150	79	50	25	25	25	188	135	135	812	**FI**
Total Rainfall(mm)	13	19	42	35	45	28	32	12	0	226	
Mean Temp. (°C)	19	12	5	4	3	7	11	16	18	-	
Relative humidity (%)	51	56	61	55	59	53	52	44	43	-	

Table 5. Monthly and total rapeseed evapotranspiration (mm) in each treatments on second year.

Month	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	∑	Treatment
Evapotranspiration (mm)	152	75	57	26	26	0	69	131	132	668	T_1
	152	75	57	26	26	25	69	131	0	561	T_2
	152	75	57	26	26	25	69	14	0	444	T_3
	152	75	57	26	26	25	69	131	132	693	T_4
	152	75	57	26	26	25	196	0	0	557	T_5
	152	75	57	26	26	25	138	0	0	499	T_6
	152	75	57	26	26	25	196	89	98	744	T_7
	152	37	28	26	26	25	138	0	0	432	T_8
	106	44	44	19	21	25	110	131	132	632	T_9
	106	44	44	19	21	25	110	100	0	469	T_{10}
	106	44	44	19	21	25	110	15	0	384	T_{11}
	106	44	44	19	21	25	110	131	108	608	T_{12}
Full Irrigation(mm)	152	75	57	26	26	25	196	131	132	820	**FI**
Total Rainfall(mm)	24	10	84	40	43	23	38	14	0	276	
Mean Temp. (°C)	22	13	7	6	4	5	12	15	21	-	
Relative humidity (%)	48	52	57	47	49	48	51	48	44	-	

number of layers, ΔS is depth of each layer (mm) and $\Delta\theta$is changing of soil water contents ($cm^3\ cm^{-3}$) between irrigations. These values are presented in tables 4, 5. In this study, Soil physics properties were assumed constant in each year. During the growing season weeding, spraying for pests and diseases were performed. Rapeseed was harvested by hand and seed's rapeseed was dried and separated from the sheath. After that 100-seed weight, seed oil content, seed protein content, grain, straw, oil and protein yields were measured for each treatment in each year. These results of first and second year are shown in table 6 and 7 respectively.

Yield production functions

The K_y values were derived by Doorenbos and Kassam (1979) for 23 crops. In rapeseed case K_y is not exist among these 23 crops, therefore monthly K_y of rapeseed for each model was calculated. According to value of evapotranspiration and the actual harvested yield in each

Table 6. The average of Plant characteristic, Deep percolation, Grain and Oil yield water use efficiency of rapeseed in different irrigation treatments for first year.

Treatment	Grain Yield (Kg ha-1)	Straw yield (Kg ha-1)	1000 – Seed weight (g)	Seed oil content (%)	Seed protein content (%)	Oil yield (Kg ha-1)	Grain Yield water use efficiency (kg m-3)	Oil Yield water use efficiency (kg m-3)	Deep percolation (mm)
T_1	1732f	3829e	4.40cd	42%ab	15%d	727e	0.26g	0.11e	228c
T_2	1822ef	4211de	3.97efg	37%cd	10%f	674ef	0.33e	0.12de	156f
T_3	1330g	2993f	3.81fg	33%e	6%h	439g	0.31ef	0.10e	95h
T_4	2027cd	4611cd	4.60bcd	45%a	18%c	912c	0.29fg	0.13cd	228c
T_5	2077cd	4154e	4.50bcd	40%bc	13%e	831d	0.38d	0.15b	161f
T_6	2110c	4642c	4.30de	35%de	8%g	739e	0.43b	0.15b	133g
T_7	2330b	5243b	4.80abc	43%ab	24%ab	1002b	0.32ef	0.14bc	250b
T_8	2007cde	4616cd	4.20def	37%cd	10%f	743e	0.48a	0.18a	109h
T_9	2420b	5324b	4.90ab	44%a	23%b	1065b	0.39cd	0.17a	200d
T_{10}	1893def	4110e	3.80fg	34%de	7%gh	644f	0.42bc	0.14bc	108h
T_{11}	1820ef	4112e	3.75g	35%de	8%g	637f	0.50a	0.17a	67i
T_{12}	2320b	5104b	4.80abc	43%ab	16%d	998b	0.39cd	0.17a	184e
FI	2750a	6316a	5.10a	43%ab	25%a	1183a	0.34e	0.15b	294a

*Means followed by the same letters in each parameter are not significantly different at 5% level of probability

treatment and maximum evapotranspiration and attainable yield in full irrigation (FI), different production functions are calibrated by first year data.

The first function was investigated is Doorenbos and Kassam (1979) have presented in equation 4:

$$\frac{y_a}{y_m} = 1 - K_y\left(1 - \frac{ET_a}{ET_m}\right) \quad (4)$$

Where Y_a is the actual yield (kg/ha), Y_m is potential yield (kg/ha), K_y is sensitive coefficient of rapeseed, ET_a is actual evapotranspiration (mm) and ET_m is potential evapotranspiration of rapeseed (mm).This method was calibrated for total growth period and K_y values are calculated for grain and oil yield.

For estimating of yield reduction in deficit irrigations which was applied in several growth stages, yield production functions define as follow (Rao et al., 1988):

$$\frac{y_a}{y_m} = F\left(1 - K_{yi}\left(1 - \frac{ET_{ai}}{ET_{mi}}\right)\right) \quad (5)$$

Where Y_a is the actual yield (kg/ha), $Y_m$is potential yield, Et_{ai} is the actual evapotranspiration in period number i(mm), ET_{mi} is the potential evapotranspiration in period number i(mm), k_{yi} is the sensitive coefficient in each period, i is the number of stage, and F is type of Function. One of these functions is Minimum product loss which was proposed by Allen(1994):

$$\frac{Y_a}{Y_P} = \mathrm{Min}\left\{\frac{Y_{a1}}{Y_{P1}}, \frac{Y_{a2}}{Y_{P2}}, \ldots, \frac{Y_{ai}}{Y_{Pi}}\right\} \quad (6)$$

Where Y_a is the the actual yield (kg/ha), Y_p is potential yield, Y_{ai}/Y_{pi} are expected relative yield in stage number i. The expected relative yield for each stage is estimated by right hand terms of Equation4 for each period. This method was calibrated for monthly period for grain and oil yield.

Table 7. The average of Plant characteristic, Deep percolation, Grain and Oil yield water use efficiency of rapeseed in different irrigation treatments for second year.

Treatment	Grain Yield (Kg ha-1)	Straw yield (Kg ha-1)	1000 – Seed weight (g)	Seed oil content (%)	Seed protein content (%)	Oil yield (Kg ha-1)	Grain Yield water use efficiency (kg m-3)	Oil Yield water use efficiency (kg m-3)	Deep percolation (mm)
T_1	1750f*	3869e	4.70bc	44%ab	17%c	770f	0.26g	0.12de	216c
T_2	1880ef	4345cd	4.20d	40%de	13%e	752fg	0.34d	0.13d	145e
T_3	1320g	2970f	3.51e	35%g	8%g	462h	0.30ef	0.10e	89h
T_4	2000de	4550cd	3.98d	43%bc	16%cd	860de	0.29fg	0.12de	216c
T_5	2110cd	4220de	4.20d	42%cd	15%d	890d	0.38c	0.16bc	154e
T_6	2140cd	4708c	4.40cd	40%de	13%e	856de	0.43b	0.17ab	123f
T_7	2360b	5310b	4.80bc	45%a	24%ab	1062b	0.32def	0.14c	241b
T_8	2037de	4685c	4.00d	39%ef	12%e	793ef	0.47a	0.18a	102gh
T_9	2390b	5258b	5.00ab	46%a	23%b	1099b	0.38c	0.17ab	194d
T_{10}	1898ef	4121de	4.20d	39%ef	12%e	740fg	0.40bc	0.16bc	106g
T_{11}	1848ef	4175de	4.05d	37%fg	10%f	684g	0.48a	0.18a	66i
T_{12}	2280bc	5258b	4.90ab	44%ab	17%c	1003c	0.38c	0.17ab	181d
FI	2730a	6270a	5.20a	45%a	25%a	1229a	0.33de	0.15c	282a

*The same characters in each parameter means are not significantly different at 5% level of probability

Table 8. Monthly grain yield response factors K_y of methods

Method	RMSE	NRMSE	d	Total	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Doorenbos	277	0.136	0.80	0.92	-	-	-	-	-	-	-	-	-
Minimum	497	0.232	0.02	-	0.27	0.50	0.50	0.50	0.50	0.50	0.60	0.65	0.45
Average	246	0.133	0.75	-	0.31	0.65	0.65	0.65	0.65	0.65	0.70	0.75	0.50
Raes	215	0.121	0.77	-	0.31	0.60	0.60	0.60	0.60	0.60	0.65	0.75	0.50
Tafteh	186	0.095	0.86	-	0.35	0.60	0.60	0.60	0.60	0.60	0.63	0.75	0.52

The additive function was introduced by Stewart et al. (1977)but it was rejected by kipkorir, (2002) because this function estimate product yield unrealistic and low. Therefore in this study isn't use of additive function.

Another production function is the average method which was applied by Tafteh et al. (2013),and the equation is written as follow:

$$\frac{Y_a}{Y_P} = \frac{1}{n}\sum_{i=1}^{n}\left\{\frac{Y_{a1}}{Y_{P1}}, \frac{Y_{a2}}{Y_{P2}}, \ldots, \frac{Y_{ai}}{Y_{Pi}}\right\} \quad (7)$$

Average method is calibrated for monthly period and monthly $K_y$values are calculated for grain and oil yield.

Another production function put forward by Jensen (1968) is multiplicative function which was improved by Raes (2004) in his BUDGET model as follow:

$$\frac{y_a}{y_m} = \prod_{i=1}^{M}\left(1 - K_{yi}\left(1 - \frac{ET_{a,i}}{ET_{m,i}}\right)\right)^{\frac{\Delta t_i}{L_i}} \quad (8)$$

Where M:is number of steps with length Δt_i(day), i is interval number, L_i is total length of the intervals (day), and $Et_{a,I}$ is actual evapotranspiration and $ET_{m,i}$is potential evapotranspiration in step j.k_{yi} is the sensitive coefficient at stage i. This method is used with monthly intervals. The Raes method is calibrated for monthly period and monthly K_y values are calculated for grain and oil yield.

To improve the accuracy of the equation 8, some changing in this method was applied by Tafteh et al. (2013), they has been proposed, new method as follow:

$$\frac{Y_a}{Y_m} = \prod_{i=1}^{n}\left(1 - K_{yi}\left(1 - \frac{ET_{a,j}}{ET_{m,j}}\right)\right)^{\frac{K_{yi}}{\sum_{i=1}^{n} K_{yi}}} \quad (9)$$

Where Y_a is the actual yield (Kg/ha), Y_m is the potential yield (kg/ha), $ET_{a,j}$ is the actual evapotranspiration (mm) in each period, and $ET_{m,j}$ is the potential evapotranspiration (mm)in each period, k_{yi} is the sensitive coefficient at any period, i is period number , and n is the number of intervals. The tafteh method is calibrated for monthly period and monthly K_y values are calculated for grain and oil yield. After calibration, the acceptable models were validated by second year data.

Analyses method

For statistical comparison of the values estimated by different methods, Simulation values are compared to measurement data by three statistical estimators:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - Y_i)^2} \quad (10)$$

$$NRMSE = \frac{\sqrt{\frac{1}{n}\sum_{i=1}^{n}(X_i - Y_i)^2}}{\bar{X}} \quad (11)$$

$$d = 1 - \left[\frac{\sum_{i=1}^{n}(x_i - y_i)^2}{\sum_{i=1}^{n}(|x_i - \bar{X}| + |y_i - \bar{Y}|)^2}\right] \quad (12)$$

Which in RMSE is the Root Mean square error, n is number of data, X is the Data was measured and Y is data was predicted by models, d is Agreement index, NRMSE is the Normal Root Mean square error.

Water Use Efficiency

Grain and oil water use efficiency was obtained by using the following equations:

$$WUE_{GY} = \frac{Gy}{ET} \quad (13)$$

$$WUE_{OY} = \frac{Oy}{ET} \quad (14)$$

WhereWUE_{GY} is Grain yield water use efficiency (kg m-3),WUE_{OY} is Oil yield water use efficiency (kg m-3), Gy is the Grain yield (kg ha-1), Oy is the Oil yield (kg ha-1), and ET is the evapotranspiration (m3 ha-1). The grain and oil water use efficiencies calculated by equation 13 and 14 are shown in table6 and 7 for each year.

Results

Plant characteristics

The results show that applied treatments have significant difference together (tables 6 and 7) that is accordance which reported by Shabani et al. (2013); Sepaskhah and Tafteh (2012); Shirani-rad and Sharghi (2011) and Ghobadi et al. (2006). Too the maximum evapotranspiration on first and second year were 812 and 820 mm respectively. The maximum attainable yield on first and second yearwere2750 and 2730 kg/ha respectively that is accordance which reported by Shabani et al. (2013).The values of plant characteristics on first and second year are shown in Table 6 and 7 respectively. These parameters are including: Grain, Straw and oil yield, 1000 – Seed weight, Seed and oil content, grain and oil yield water use efficiency and deep percolation. The same range of plant characteristics are reported by Shirani-rad and Sharghi (2011) Sepaskhah and tafteh (2012) and Shabani et al. (2013).The results show that maximum of grain yield among deficit irrigations on first year was 2420 kg/ha and maximum of Straw yield was 5324 kg/ha in T_9 treatment. Also maximum of oil yield was 1065 kg/ha in T_9 treatment. The maximum grain and oil yield water use efficiency was0.48 and 0.18kg/m3 respectively in T_8treatment.Oilyield water use efficiencyinT_9treatmentwas 0.17 and it don't has significant different with T_8 treatment. The maximum deep percolation was 294 mm in FI. The value of deep percolation in $T_9$was 32% lower than FI. These results show that deficit irrigations decrease deep percolation that it is accordance which reported by Tafteh and

Table 9. Monthly oil yield response factors K_y of methods

Method	RMSE	NRMSE	d	Total	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun
Doorenbos	111	0.137	0.85	0.98	-	-	-	-	-	-	-	-	-
Minimum	225	0.257	0.44	-	0.45	0.50	0.50	0.50	0.50	0.50	0.60	0.70	0.50
Average	98	0.124	0.80	-	0.42	0.65	0.65	0.65	0.65	0.65	0.70	0.80	0.50
Raes	85	0.103	0.83	-	0.41	0.60	0.60	0.60	0.60	0.60	0.70	0.80	0.60
Tafteh	66	0.081	0.89	-	0.5	0.7	0.7	0.7	0.7	0.70	0.80	0.90	0.70

sepaskhah, 2012a and Tafteh and sepaskhah, 2012b.Therefore T_9 is the best method among applied treatments. The minimum of grain, straw, protein and oil yield are obtained in T_3. The lowest Grain yield water use efficiency was obtained in $T_1$and the lowest Oil water use efficiency was obtained in T_3. Therefore T_1 and $T_3$are not suitable methods for deficit irrigations of rapeseed. Also performance of T_9 was acceptable and performance of T_1 and T_3 was not acceptable on second year.

Calibration of production functions

Base on measured date on first year and different methods which are used in this study, the yield response factors of rapeseed are calculated. The grain and oil yield response factors in each month are shown in table 8 and 9 respectively. These results showed that type of production function influence on yield response factors. In Doorenbos method, the grain yield response factor was obtained equal to 0.92 and the oil yield response factor was obtained equal to 0.98 for total growth stage. This method has 14% normal root mean square error (NRMSE) in estimated grain and oil yield. In Minimum method, minimum of grain yield response factor was obtained equal to 0.27 in germination stage and maximum of grain yield response factor was obtained equal to 0.65 in full pod formation stage. Minimum of oil yield response factor was obtained equal to 0.45 in germination stage and maximum of oil yield response factor was obtained equal to 0.7 in full pod formation stage. The value of yield response factors in Minimum method is less than other methods. This method has 23% and 26% NRMSE in estimated grain and oil yield respectively. The results showed that this method is weaker than Doorenbos method. Therefore Minimum method is not suitable to estimate grain and oil yield of rapeseed. In Average method minimum of grain yield response factor was obtained equal to 0.31 in germination stage and maximum of grain yield response factor was obtained equal to 0.75 in full pod formation stage. Minimum of oil yield response factor was obtained equal to 0.42 in germination stage and maximum of oil yield response factor was obtained equal to 0.8 in full pod formation stage. This method has 13% and 12% NRMSE in estimated grain and oil yield respectively. This result shows that this method is better than Doorenbos method. Therefore Average method is acceptable to estimate grain and oil yield of rapeseed. In Raes method minimum of grain yield response factor was obtained equal to 0.31 in germination stage and maximum of grain yield response factor was obtained equal to 0.75 in full pod formation stage. Minimum of oil yield response factor was obtained equal to 0.41 in germination stage and maximum of oil yield response factor was obtained equal to 0.8 in full pod formation stage. This method has 12% and 10% NRMSE in estimated grain and oil yield respectively. This result showed that this method is better than Average method. Therefore Raes method is acceptable to estimate grain and oil yield of rapeseed with monthly intervals. In Tafteh method, minimum of grain yield response factor was obtained equal to 0.35 in germination stage and maximum of grain yield response factor was obtained equal to 0.75 in full pod formation stage. Minimum of oil yield response factor was obtained equal to 0.5 in germination stage and maximum of oil yield response factor was obtained equal to 0.9 in full pod formation stage. This method has 10% and 8% NRMSE in estimated grain and oil yield respectively. This result shows that Tafteh method is better than Raes method. Therefore Tafteh method is acceptable to estimate grain and oil yield of rapeseed. These results show that rapeseed plant has minimum sensitivity in germination stage and maximum sensitivity in full pod formation stage. Therefore deficit irrigation is not applied on full pod formation stage. For this reason,$T_9$is best treatment for deficit irrigation among applied treatments. In all of methods oil yield response factor is more than grain yield response factor that it is accordance which reported by Shabani et al. (2013).Tafteh and Raes methods could estimate better compared to other methods that it is accordance which reported by Raes et al. (2006) and Tafteh et al. (2013).These results showed that Average, Raes and Tafteh methods are acceptable compare to Doorenbos method. Therefore these methods with values of grain yield response factors (tables 8) and oil yield response factors (tables 9) are recommended.

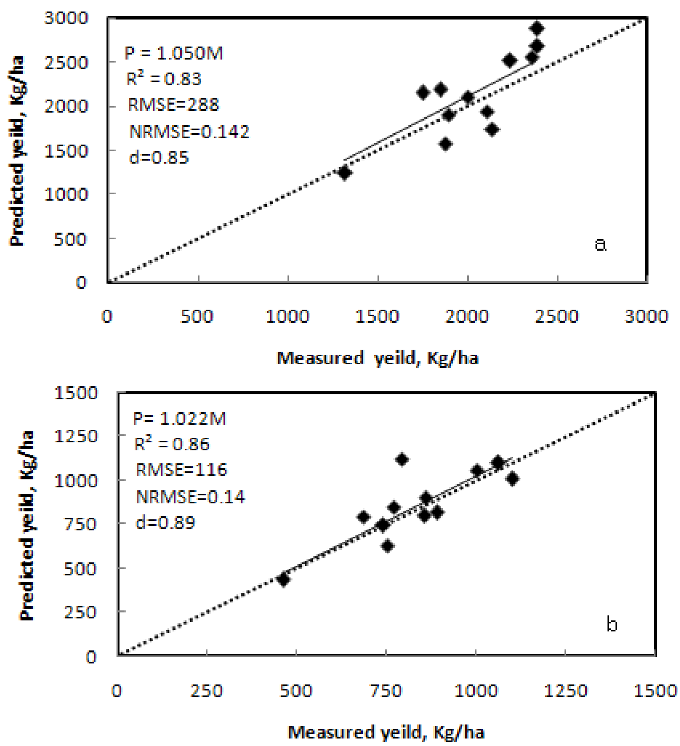

Figure1. Relationship between values of measured and predicted a) grain and b)oil yield of rapeseed by Doorenbos method.

DISCUSSION

Validation of production functions

Calibration results showed that average, Raes and Tafteh methods were acceptable. For validation of these methods, the measured values on second year were applied. These methods with values of grain yield response factors (tables 8) and oil yield response factors (tables9) are used to estimate grain and oil yield of rapeseed in different deficit irrigations. The measured and estimated grain yield by Doorenbos method are shown in Figure 1.a and the measured and estimated oil yield are shown in Figure 1.b. Estimated yield are compared to measured yield by the values of RMSE, NRMSE and d which are shown in figures 1a and 1b.These results showed that Doorenbos method has 14% NRMSE in estimated yield and it has not sufficient accuracy. Therefore this method with total yield response factor is not suggested to estimate yield in multi-stage water stress. Second function is Average method. The measured and estimated grain yield by Average method are shown in Figure 2.a and the measured and estimated oil yield are shown in Figure 2.b. Estimated yield are compared to measured yield by the values of RMSE, NRMSE and d which are shown in figures 2a and 2b.These results showed that Average method has 14% and 13% NRMSE in estimated grain and oil yield respectively. It has not sufficient accuracy. Therefore this method with monthly yield response factor is not suggested to estimate yield in multi-stage water stress. Next function is Raes method. The measured and estimated grain yield by Raes method are shown in Figure 3a and the measured and estimated oil yield are shown in Figure 3.b. Estimated yield are compared to measured yield by the values of RMSE, NRMSE and d which are shown in figures 3a and 3b.These results showed that Raes method has 12% and 10% NRMSE in estimated grain and oil yield respectively. This method with monthly yield response factor can estimate yield better than average method inmulti-stage water stress. Therefore this method is acceptable. The last method is Tafteh method. The measured and estimated grain yield by Tafteh method are shown in Figure 4.a and the measured and estimated oil yield are shown in Figure 4.b. Estimated yield are compared to measured yield by the values of RMSE, NRMSE and d which are shown in figures 4a and 4b.These results show that Tafteh method has 10% and 8% NRMSE in estimated grain and oil yield respectively. It has lowest errorin comparison with other methods. This method with monthly yield response factor can estimate yield better than other methods in multi-stage water stress. Therefore this method is the most appropriate method among the applied methods in this study. Tafteh method can clearly increase the accuracy of estimate that is accordance which reported by Tafteh et al. (2013).So this method is recommended to estimate grain and oil yield in deficit irrigations. This method with

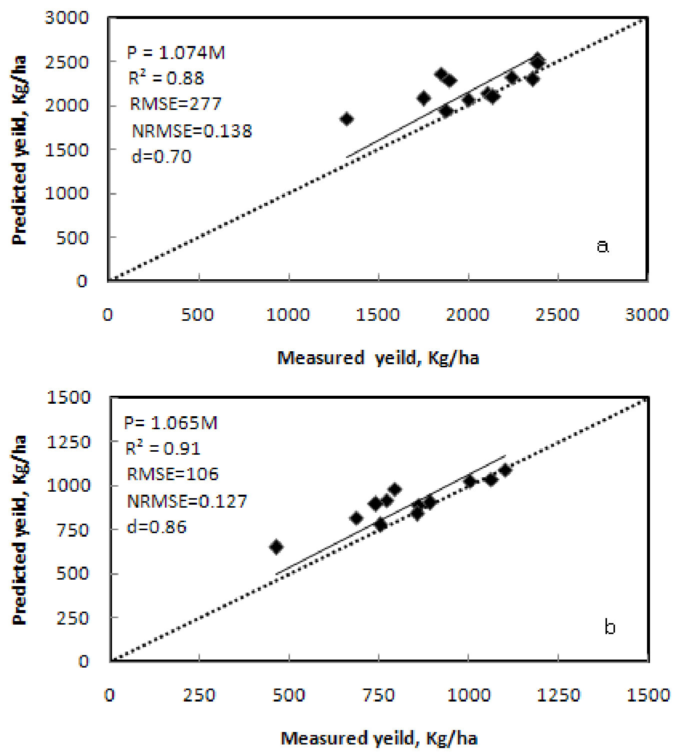

Figure 2. Relationship between values of measured and predicted a) grain and b)oil yield of rapeseed by Average method.

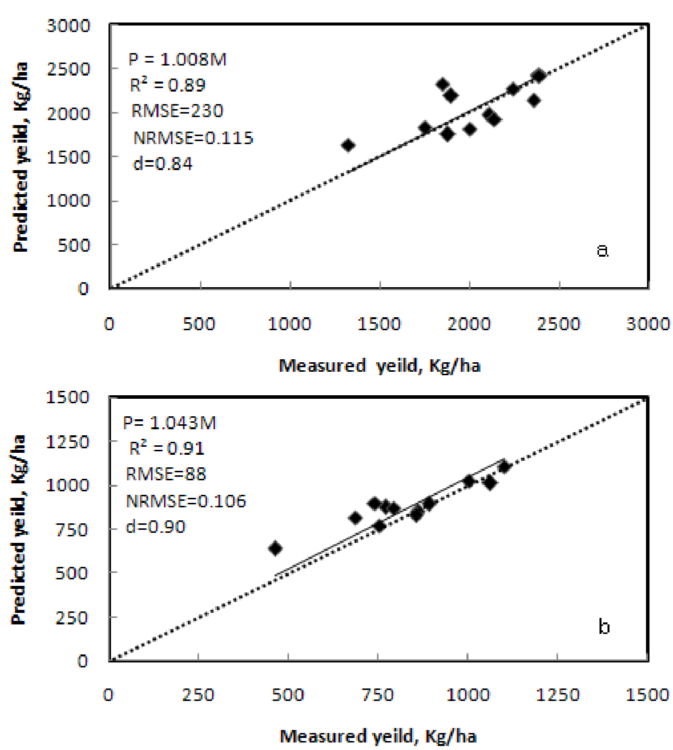

Figure 3. Relationship between values of measured and predicted a) grain and b)oil yield of rapeseed by Raesmethod.

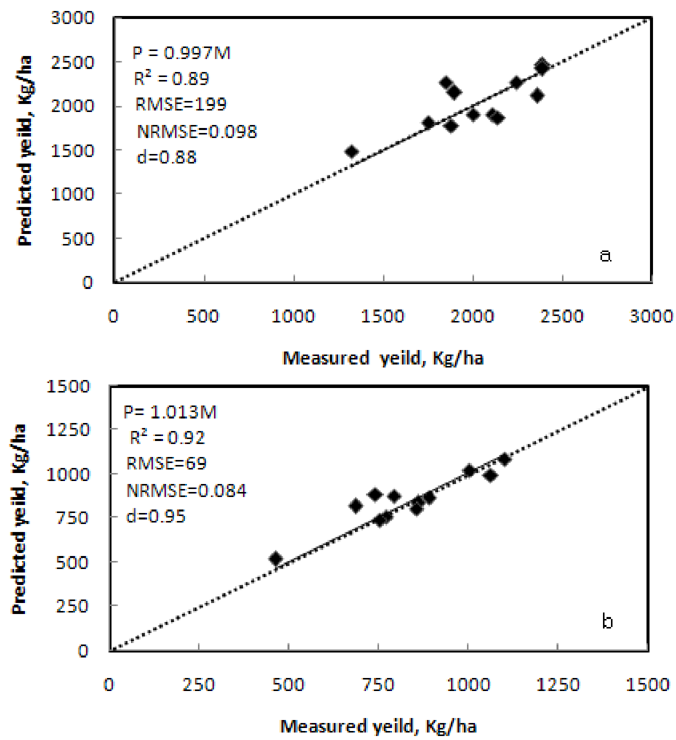

Figure 4. Relationship between values of measured and predicted a) grain and b) oil yield of rapeseed by Tafteh method.

value of grain yield response factors for first stage, second stage, third stage and final stage of rapeseed growth respectively equal to 0.35, 0.6, 0.75 and 0.52 and value of oil yield response factors respectively equal to 0.5, 0.7, 0.9 and 0.7 are recommended. This result showed that oil yield response factors are more than grain yield response factors in each stage of rapeseed growth. Therefore oil yield are much more sensitive to value of evapotranspiration especially in full pod formation stage.

CONCLUSIONS

Among aforesaid methods, the Tafteh method estimate better than the other methods and it is proposed as a suitable method to estimate grain and oil yield in deficit irrigations with multi-stage water stress. Also, this method with value of grain yield response factors for first stage, second stage, third stage and final stage of rapeseed growth respectively equal to 0.35, 0.6, 0.75 and 0.52 and value of oil yield response factors for first stage, second stage, third stage and final stage of rapeseed growth respectively equal to 0.5, 0.7, 0.9 and 0.7 are recommended. This result showed that oil yield response factors is more than grain yield response factors in each stage of rapeseed growth and the value of oil yield are much more sensitive to value of water especially in full pod formation stage. Therefore among applied treatments in this study, T_9treatment with 630 mm evapotranspiration and without any tension in full pod formation stage is recommended. T_9treatment can reduce deep percolation to 32% of full irrigation. Also this method increases value of oil yield water use efficiency from 0.15in FI to 0.17 in T_9.

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