Journal of Agrometeorology 11 (2): 7-12 (Dec. 2009)

Irrigation -yield response factor of winter wheat for different growth phases

M. H. ALI

Agricultural Engg. Division, Bangladesh Institute of Nuclear Agriculture, P.O. Box - 04, Mymensingh 2200, Bangladesh,
Email: mha_bina@yahoo.com, hossain.ali.bina@gmail.com

ABSTRACT

The yield response factor of semi-dwarf winter wheat was determined from field experimental data conducted during three consecutive years (2002-03 to 2004-05). The yield response factor (k_y) varies depending on growth phases and also among seasons. On an average, the k_y for early, vegetative, booting-heading, and flowering-soft dough stages were 0.27, 0.21, 0.25, and 0.17, respectively. According to the value of yield response factor, the most sensitive growth stages were in the order: CRI> booting-heading>maximum tillering> flowering-soft dough. For the alternate deficit strategies (deficit at tillering + flowering –soft dough; deficit at CRI + booting-heading stages), the k_y values were 0.77 and 0.61, respectively. For the whole growing period, the k_y values were 1.58, 0.43, 2.29, and 0.61 for deficit at early, vegetative, booting-heading, and flowering-soft dough stages, respectively. The sensitivity index (lembda i, of Jensen model) for early, vegetative, booting-heading, and flowering-soft dough phases were 0.35, 0.22, 0.31, and 0.14, respectively. A more sensitive growth stage has a higher value of lambda i, and therefore water supply is more important at early and booting-heading phases.

Key words: Wheat, yield response factor, sensitivity index

Dwindling water resources and necessity for increased food production stress the need to shift our objective from potential crop yields to optimum yields with maximum water use efficiency. The extent to which the optimum yields of crops can be realised depends on how well irrigation schedules are planned in time and quantity considering the period and amount of water shortage, to meet the crop water needs. When crops are exposed to water deficit (drought or stress) at different times, the climatically determined stress will vary. Yield reduction caused by deficit irrigation depends on both the severity and timing of the water deficits (Orgez *et al*., 1992). By analyzing plant's reaction to water deficit depending on when it occurs during the life cycle one can define the conditions for maximum water use efficiency.

Doorenbos and Kassem (1979) developed a method for practical application in the field which permits quantification of crop yield response to water under both adequate and limited water supplies. This method provides a quantitative relationship between relative yield decrease and relative evapotranspiration deficit. Asadi *et al.* (2003) found yield response factor (k_y) of 1.08 for the total growth period, and the k_y values were 0.45, 0.56, 1.1, and 0.48 for tillering, stem elongation, vegetative + booting and flowering, and caryopsis development stage, respectively. Orta *et al.* (2002) estimated yield response of winter wheat to water deficit (0 –100 % soil water replenishment) in western Turkey. They found k_y for whole growing period of 0.79, 0.74, and 0.56 for cultivar Saraybosna, MV-17, and both Flamura and Kate-A-1, respectively. In fine sandy and sandy loam soil of Beijing, China, Wang *et al.* (1999) found k_y value of 0.40, 0.69, 0.90, 0.44, and 0.25 for winter afterward, winter afterward to booting, booting to flowering, flowering to milking, and milking to ripening period, respectively. Mogensen *et al.* (1985) studied drought sensitivity and yield response factor of spring wheat grown in lysimeter at Copenhegen, Denmark. For drought during tillering-shooting, shooting-booting, booting-heading, flowering, and grain formation, the k_y values were 3.0, 1.5, 0.90, 0.57 and 0.32, respectively. Based on the relative ET during the entire growing period the k_y values for the five stages were 2.85, 2.45, 3.36, 1.28, and 0.98, respectively.

From the above research findings, it is revealed that the response factor varies from place to place(weather and soil), cultivar to cultivar, season to season, and also for individual growth stage to whole growing season. So it is necessary to determine location specific (and also for cultivar specific) response factor for better management of water.

Wheat is a prominent cereal crop that can be a substitute of Boro rice in Bangladesh in a water- limited environment. Therefore, information was sought to quantify the effect of water deficit on wheat yield (yield response factor or sensitivity factor), that could be used for appropriate water management practice to minimize yield losses under conditions of water deficits.

MATERIALS AND METHODS

Study site and experimental

The field experiments were conducted during 2002-03 to 2004-05 growing seasons at the experimental farm of Bangladesh Institute of Nuclear Agriculture (BINA), Ishurdi, Bangladesh (latitude 24 ⁰ 06′ N, longitude 89⁰ 01′ E, and 34 m above mean sea level). The soil was a calcareous brown floodplain silt loam developed from Ganges river alluvium and classified as calcareous fluvisol according to FAO/UNESCO classification (FAO, 1971). The texture is silty loam. The soil is alkaline pH (8.5), medium in organic matter (1.8 %), and with basic infiltration rate of 4.8 mm/hr. The upper and lower limits of available water were 0.45 and 0.19 m^3/m^3, respectively.

The local climate is humid and sub-tropic with summer dominant rainfall (yearly average rainfall of 1572 mm, concentrated over the months of May to September). The wheat-growing period, November to March, is characterized by dry winter. The depth to aquifer (semi-confined) from ground-surface is about 10.98 m. The piezometric surface of the water-table (measured in observation well) during the start of the experiment was 2.07 m from the ground level, declined gradually and reached to 4.60 m during maturity of the crop.

The wheat cultivar was ‘Shatabdi’ (*Triticum aestivum*), a semi-dwarf variety. It is 120-130 days cereal crop and suits the prevailing climate of winter season (Nov. – March). The phenological cycle was divided into four phases which are considered to be the most relevant from the point of view of their response to irrigation, i.e. phase-1: germination to crown-root initiation (CRI); phase -2: jointing to shooting (maximum tillering); phase -3: booting to heading; and phase-4: flowering to soft dough. Irrigation treatments were scheduled covering full deficit, no deficit at all, single deficit at different phases, and alternate deficits. Details of irrigation treatments along with Feekes scale for the growth phases are given in Table 1.

Water deficit was created by withholding irrigation at different growth phases. Irrigation amount at a particular stage was equal to 80 % of the amount required to fill upto field capacity (F.C.) to the effective root zone depth (the depth within which 80 % of the roots are concentrated). The experimental design was randomized complete block (RCB), with 4 (four) replications of the block. Each elementary plot was 3 m x 2.75 m, and was separated from adjacent plots within the replicates by 0.5 m. The crop was harvested manually. Seed yield was adjusted to 12 % moisture.

Yield response model

The yield model mostly used is the one proposed by Stewart and Hagan (1973):

$$Y = Y_m - Y_m . k_y . ETD / ET_m \quad \text{……………………..(1)}$$

In which Y = crop yield; Y_m = maximum crop yield under the same condition of soil texure, fertility, etc.; k_y = yield response factor; ETD = cumulative evapotranspiration deficit during the growth period, calculated as:

$$ETD = ET_m - ET_a \quad \text{…………………… (2)}$$

In which: ET_m = maximum evapotranspiration; ET_a = actual evapotranspiration.

The model is simple and practical and can be used when the sensitivity to moisture stress is the same during the whole growing period. For the case that the sensitivity differs significantly among growth periods, Stewart *et al.*(1977) proposed a model that takes into account the effect of moisture stress during successive phenological stages. Stewart used a different coefficient for each stage, according to:

$$y/y_m = \prod_{n=1}^{m} [1-k_{y(n)}(1-ET/ET_m)_n] \quad \text{…………(3)}$$

where n is generic growth stage, and m is the number of growth stage considered, and k_y is the crop or yield response factor. Stewarts formula is based on the theory that, considering all other factors of production at their optimum level, it is the water scarcity factor (estimated as the ratio of actual to maximum evapo-transpiration, ET/ET_m) that limit the final yield.

Determination of response factor of Stewart model

To determine yield response factor k_y, the procedure outlined by Doorenbos and Kassem (1979) was followed:

- Determination of maximum yield (Y_m) of the crop (wheat, Satabdhi) as dictated by climate, under conditions of full water requirement.
- Calculation of the maximum evapotranspiration (ET_m) that prevails when crop water requirements are fully met by the available supply.
- The effect of water deficit on the crop yield was quantified by the relationship between relative yield decrease and relative ET deficit:

$$1 - Y_a/Y_m = k_y(1 - ET_a/ET_m) \quad \text{........................ (4)}$$

or,

$$k_y(i) = \frac{1-\frac{Y_a(i)}{Y_m(i)}}{1-\frac{ET_a(i)}{ET_m(i)}} \quad \text{............................ (5)}$$

Table 1: Details of irrigation treatments along with Feekes scale corresponding to growth phases

Treatment	Irrigation at growth phase*			
	CRI	Jointing to Shooting	Booting to Heading	Flowering to soft dough
T_1	0	0	0	0
T_2	1	1	1	1
T_3	0	1	1	1
T_4	1	0	1	1
T_5	1	1	0	1
T_6	1	1	1	0
T_7	1	0	1	0
T_8	0	1	0	1
T_9**	1	1	1	1
Feekes (1 –11.4)	2 -3	5 -7	9 – 10.4	10.5 – 11.1

* '1' indicates one irrigation at this stage, and '0' indicates no irrigation (deficit).
** in addition to irrigation at each stage, irrigation was given when total available moisture within the root zone dropped below 50 %.

For detail calculation procedure, readers are advised to refer to Doorenbos and Kassem (1979). Doorenbos and Kassem (1979) reported k_y values for several crops, for individual growth stages and also for the total growing season. Seasonal k_y is based on the effect of water deficit for the total growing season, while growth stage k_y is based on water deficit for individual growth stage.

In our study water stress was imposed over single growth stage (each of 4 stages considered) and also spread over more than one growth stage, therefore, both seasonal and growth stage based k_y were determined.

Determination of sensitivity index of Jensen model

According to Jensen (1968), the effect of water deficit during certain growth stages on grain yield is:

$$\frac{Y}{Y_m} = \prod_{i=1}^{n} \left(\frac{ET_i}{ET_m}\right)^{\lambda_i} \qquad \text{.................. (6)}$$

where, Y is grain yield (t/ha), Y_m the maximum yield from the plot without water stress during the growing season, ET_i the actual evapotranspiration (mm) during the growing season stage i, ET_m the maximum evapotranspiration corresponding to Y_m, λ_i the sensitivity index of crop to water stress, and i the growth stage.

To determine sensitivity index, ë, the procedure outlined by Tsakiris (1982) was followed. The equation (6) can be written as:

$$\frac{Y}{Y_m} = \prod_{i=1}^{m} (\omega_i)^{\lambda_i} \qquad 0 < ù_i < 1 \qquad \text{........... (7)}$$

Where ù$_i$ is the relative evapotranspiration (= ET_i/ET_m).

If the evapotranspiration is suppressed only during a certain stage, say the i-th then ù$_i$ =1 for all stages except the i-th stage. Therefore equation 7 yields:

$$\frac{Y}{Y_m} = \omega_i^{\lambda_i}$$

or,

$$\log(Y_i/Y_m) = ë_i \log ù_i \qquad \text{.......................... (8)}$$

Thus by taking the logarithms of the data (i.e. Y_i/Y_m and ù$_i$) the sensitivity index for the i-th period, ë$_i$, was determined. Similarly the sensitivity index were obtained for all m stages.

RESULTS AND DISCUSSION

Yield response factor for individual growth period

The value of response factor (k_y), representing relative sensitivity to water deficit, varies depending on season (Table 2). For individual growth period, the k_y value varies from 0.44 to 0.1, depending on season and growth stage. During the season of 2002-03, the highest value was found for early stage (sowing-tillering) followed by grain formation stage. The trend was inconsistent during the season of 2003-04 and 2004-05.

Andersen and Aremu (1991) found year to year variation of yield response factor (about 60-100% variation). For winter wheat, Doorenbos and Kassam (1979) reported k_y values of 0.2, 0.6, and 0.5 for the vegetative, flowering,

Table 2: The yield response factors (k_y) at various growth stages. Calculated for water deficits during individual growth periods and for the total growth period.

Treatment	Growth stages	K_y for individual growth stages			K_y for total growth period		
		02-03	03-04	04-05	02-03	03-04	04-05
T_3	Sowing – tillering	0.44	0.12	0.24	1.14	0.40	3.22
T_4	Tillering – booting	0.23	0.10	0.35	0.65	0.11	0.55
T_5	Booting – heading	0.24	0.19	0.32	0.41	0.16	6.30
T_6	Flowering-soft dough	0.41	0.10	0.04	1.39	0.20	0.25
T_7					0.49	0.16	1.67
T_8					1.01	0.22	0.61

and grain formation period, respectively. For spring wheat, Mogensen *et al.*(1985) found maximum k_y value of 3.0 for drought during tillering and jointing, and minimum of 0.32 for grain formation stage. In contrast, Islam *et al.*(2002) found k_y values of 0.18 and 0.45 for the vegetative and yield formation stages, respectively. FuJun *et al.*(1999) found the highest k_y value for booting to flowering (k_y =0.90), followed winter afterward to booting (k_y = 0.40). Asadi *et al.*(2003) found maximum k_y for vegetative growth + booting and flowering stages. Zhang *et al.*(1999) found more sensitive stage of wheat (in terms of k_y) for water stress from stem elongation to heading and from heading to milking.

Compared to the yield response factors reported by Doorenbos and Kassam (1979), the yield response factor for booting-flowering and grain formation stages in the present investigation are low. These may be due to the combined effect of cultivar and climate factors. Here, the early stage showed maximum value on an average. This is supported by the yield data of treatment T_{10}, in which single irrigation at early stage was provided (Table 3). Doorenbos and Kassam (1979) reported only one value for whole vegetative period (sowing to prior flower), but not separated the early stage (or may have common irrigation at early stage). The minimum value for yield formation stage corroborated with the findings of Mogensen *et al.*(1985).

For whole growing period

The values of the response factor calculated for the entire growing period also showed yearly variations and inconsistent trend (Table 2). During the season of 2002-03, the maximum value was obtained for deficit at grain formation stage. During 2003-04, the early stage showed the maximum value followed by grain formation. Doorenbos and Kassam (1979) reported a k_y value of 1.0 for water deficit occurring equally over the entire growing period. Mogensen *et al.*(1985) found maximum value of 3.36 for drought during booting–heading and minimum of 0.98 for drought during grain formation of spring wheat.

Sensitivity index of Jensen model

Drought sensitivity index of Jensen yield model (lambda i, $ë_i$), were influenced by timing of water deficit (Table 4). The index also showed year to year variations. In general, the ë values were larger at early stage, became smaller at tillering-booting stage, and then became larger at heading –flowering stage, and again smaller at grain formation stage. Since the $ë_i$ values are exponential coefficient, a $ë_i$ with a relatively larger positive magnitude suggests that yield may be particularly sensitive to water stress or deficit during that specific growth period.

The sensitivity index was lower (about one-third) during the growing season of 2003-04 compared to those of 2002-03 and 2004-05. The reason of such low sensitivity may be due to the fact that during 2003-04, the experiment was set up in another position of the same field (due to crop rotation problem) in which huge organic residues added organic matter to the soil that may results in healthy soil condition for vigor crop growth & also may influence moisture release properties of soil, and consequently less sensitive to moisture deficit. In addition, the atmospheric water demand (in terms of reference crop evapotranspiration, ET_0) from booting to ripening stage during 2003-04 was lower than that of 2004-05 (**Fig.1.**) which facilitates stress adaptation to the crop.

For early and grain formation stages, the $ë_i$ were nearly the same during 2002-03 and 2004-05; in contrast the $ë_i$ for tillering-booting and booting-flowering stages during 2002-03 were about half to that of 2004-05. Similar to that of yield response factor (k_y), the sensitivity index (ë) was found relatively consistent for the early stage and booting-heading stage.

Zhang and Oweis (1999) found highest value of sensitivity of durum wheat for stem elongation - booting and lowest for maturity. YanJun and ZiZhen (2004) derived the sensitivity index (ë) from two years field experiment and

Table 3: Grain yield under different treatments

Treatments	Seed yield (t ha^{-1})			
	2002-03	2003-04	2004-05	Average
T1	1.995	2.071	1.574	1.880
T2	3.711	3.978	3.404	3.698
T3	3.153	3.721	3.144	3.339
T4	3.474	3.872	3.169	3.505
T5	3.661	3.859	3.168	3.563
T6	3.466	3.846	3.395	3.569
T7	3.306	3.739	3.141	3.395
T8	2.977	3.618	2.994	3.196
T9	3.920	4.017	3.480	3.806
T10	-	3.281	2.779	3.030

Table 4: Sensitivity index (ë, of Jensen model) of wheat yield to water deficit at various growth stages.

Growth stages	λ – during different years		
	02-03	03-04	04-05
Sowing – tillering	0.41	0.17	0.47
Tillering – booting	0.21	0.07	0.39
Booting – heading	0.33	0.08	0.54
Flowering - Soft dough	0.24	0.08	0.09

concluded that heading was the most critical stage for irrigation. Bala *et al.*(1988) found (from lysimeter experimental data) a ë- value of 0.2 for water stress at tillering, booting-heading, and flowering stages.

The results indicate that wheat grown in the prevailing climate is most sensitive to water deficit during early and booting-heading stages.

CONCLUSIONS

The results based on yield response factor k_y showed that the order of sensitive growth stages to water deficit were sowing to tillering (k_y = 0.27), booting to flowering (k_y = 0.25), tillering to booting (k_y = 0.21), and flowering to soft dough (k_y = 0.17).

Sensitivity index lambda i ($ë_i$, of Jensen model) for early, vegetative, booting-heading, and flowering-soft dough phases were found 0.35, 0.22, 0.31, and 0.14, respectively. A more sensitive growth stage has a higher value of lambda i, and therefore water supply is more important at early and booting-heading phases.

REFERENCES

Andersen, M.N. and J.A. Aremu. (1991). Drought sensitivity, root development and osmotic adjustment in field grown peas. *Irri. Sci.,* 12: 45-51.

Asadi, H., M.R. Neishaboori, and H. Siadat. (2003). Evaluating the wheat response factor to water (k_y) in different growth stages in Karaj. *Iranian J. Agril. Sci.*, 34(3): 579-586.

Bala, B.K., M.A. Satter, M.A. Halim and M.S.U. Talukdar. (1988). Simulation of crop-irrigation systems. *Agril. Systems*, 27: 51-65.

Doorenbos, J. and A. H. Kassam. (1979). Yield response to water. FAO Irrigation and Drainage Paper No. 33, FAO Rome.

FAO .(1971). Soil survey project of Bangladesh. Soil Resources Technical Report 3 of FAO, Rome, *p*. 211.

FuJun, W., Q. Mengwen, W. Huaguo and Z. Changjiu. (1999). The response of winter wheat to water stress and nitrogen fertilizer use efficiency. *In*: Yield Response to Deficit Irrigation, Kirda, C. (Edit.), Kluwer's Publishers, U.K., pp. 39-48.

Islam, M.S., K.C. roy and M.A. Hossain. (2002). Determination of yield response factors of wheat for Joydebpur region of Bangladesh. *In*: Proc., 2nd Annual Paper Meet, Agril. Engg. Division. The Institution of Engineers, Bangladesh, *pp*. 1-8.

Jensen, M. E. (1968). Water consumption by agricultural plants. In: Kozlowski (edit.), Water deficit and plant growth, vol.2, Academic press, New York, pp. 1-22.

Mogensen, V.O., H.E. Jensen and M.A. Rab. (1985). Grain yield, yield components, drought sensitivity and water use efficiency of spring wheat subjected to water stress at various growth stages. *Irrig. Sci.,* 6: 131-140.

Orgez, F., L. Mateos and E. Fereres. (1992). Season length and cultivar determine the optimum ET deficit in cotton. *Agron. J.* 84: 700 – 706.

Orta, A.H., Erdem, T., Sehirali, S., Erdem, Y. , Baser, I. and Yorgancilar, O., (2002). Water - yield relation and water-use efficiency of winter wheat in Western Turkey. *Cereal Res. Commun.*30(3-4), 364-374.

Stewart, J. I., and Hagan, E. M., (1973). Functions to predict effects of crop water deficit. *J. Irrig. Drain. Div., ASCE*, 99(IR4), 429-439.

Stewart, J. I., R. M. Hagen, W. O. Pruitt, R. J. Hanks, R. E. Denilson, W. T. Franklin and E. B. Jackson. (1977) . Optimizing crop production through control of water, salinity levels. Utah Water Research Lab. PRWG 151, Logan, Utah, 191 pp.

Tsakiris, G. P. (1982). A method for applying crop sensitivity

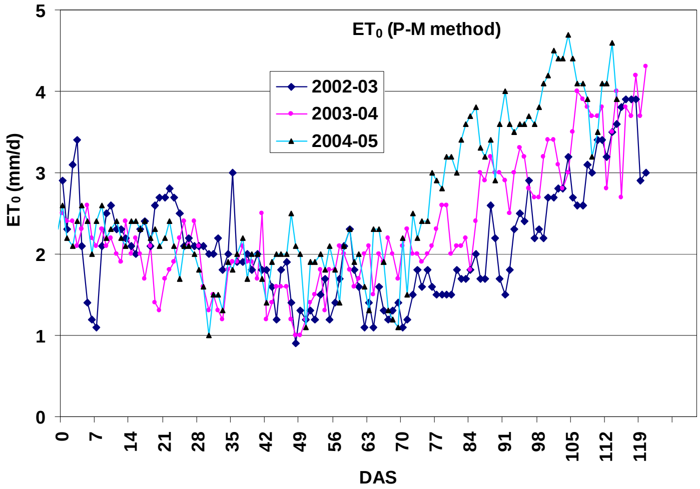

Fig. 1: Pattern of reference evapotranspiration ($ET_{0,}$ Penman-Monteith method) during the growing season

factor in irrigation scheduling. *Agric. Water Manag*, 5: 335 – 343.

Wang, F., MengWen, Q., HuaGuo, W., ChangJiu, Z., Wang, F.J., Qi, M.W., Wang, H.G. and Zhou, C.J. (1999). The response of winter wheat to water stress and nitrogen fertilizer use efficiency. *In*: Kirda, C., Moutonnet, P., Hera, C., Nielsen, D. R.(Edit). Crop yield response to deficit irrigation, Kluwer Academic Publishers, *p.* 39-48.

YanJun, D. and L. ZiZhen. (2004). Water deficit sensitivity analysis for winter wheat under limited irrigation. *Acta Botanica Boreall Occidentalia Sinica,* 24(3): 412-417.

Zhang, H. and T. Oweis. (1999) . Water-yield relations and optimal irrigation scheduling of wheat in the Mediterranean region. Agril. *Water Manage.*, 38: 195-211.

Zhang, H., X. Wang, M. You and C. Liu. (1999). Water-yield relations and water-use efficiency of winter wheat in the North China Plain. *Irri. Sci.,* 19(1): 37-45.

Received : December 2007; Accepted : November 2008