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The application for fertilizer–yield relationships of the ET–yield response factor equation

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Abstract: Many attempts have been made to understand the plant response to water using plant growth models. The effects of fertilizer on crop yield are greater than those of water. Therefore, some models that have been developed for the evaluation of water–yield relationships can also be used for fertilizer–yield relationships. The purpose of this study was to develop an equation to use in fertilizer applications similar to one used to evaluate crop production under adequate and deficit water supply regimes. The equation can be rewritten for the fertilizer consumed by plants instead of the evapotranspiration (ET). Sample applications showed that the resulting ET–yield response factor equation can be used successfully in the evaluation of fertilizer–yield relationships. Thus, the yield loss per unit of fertilizer deficiency can be determined more precisely by the equation.

Key words: Yield–response factor, fertilization, relative yield decrease, fertilizer uptake

1. Introduction

The upper limit of yield is set by soil fertility, climatic conditions, management practices, and genetic potential of the crop. Where all of these are optimal throughout the growing season, yield reaches its maximum value. Any significant decrease in soil water storage has an impact on water availability for a crop and, subsequently, on actual yield and actual evapotranspiration (Moutonnet, 2000). The extent to which this limit can be reached will always depend on how adequately the water supply meets the biological needs of water in crop production. Therefore, the optimum use of water in crop production can only be attained when the planning, design, and operation of the water supply and distribution systems are geared toward meeting the needs in quantity and time, including the periods of water shortages. The relationships among crop, climate, water, and soil are complex and many biological, physiological, physical, and chemical processes are involved (Kassam and Smith, 2001).

While soil moisture depletion to the point of wilting reduces the vegetative growth of almost every plant species, most crops have critical growth periods during which moisture stress is especially damaging. This critical growth period often coincides with a crop's reproductive stage. With this knowledge, irrigation managers can conserve water during appropriate growth periods and apply water when it is most critical for yield or crop quality (Bauder et al., 2006). Crop water production functions describe the relationship of crop yield (Y) response to varying levels of water input and can be useful for different water management applications. A nonlinear crop response may occur when excessive water application or increased irrigation frequency results in increased ET without a corresponding increase for yield (Liu, 2002).

The effect of deficit irrigation on crop yield can be compiled from irrigation studies conducted on the different levels of irrigation. If the results of crop yield for different water levels are shown on a graph (yield values versus water applied), it can be seen that yield will not increase after a certain level of irrigation. The curve of the graph goes first as a linear move forward, and then follows a steady course. This linear part will reveal the impact of water shortage, i.e. reduction of yield under water stress (Wu, 1988). The relationship between crop yield and irrigation water can be determined when both crop water requirements and crop water deficits, on the one hand, and maximum and actual crop yield on the other, can be quantified. Water deficits and the resulting water stress on the plant have an effect on crop evapotranspiration and crop yield. Water stress in the plant can be quantified by the rate of actual evapotranspiration (ET_a) in relation to maximum evapotranspiration (ET_m). When crop water requirements are fully met then $ET_a = ET_m$; when water supply is insufficient, $ET_a < ET_m$. For most crops and climates, ET_m and ET_a can be estimated. When the full crop water requirements are not met, water stress in plants

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can develop to a point where crop growth and yield are affected. The manner in which water deficit affects crop growth and yield varies according to the crop species and growth period (Kassam and Smith, 2001).

Nutrient transition into plant roots can only be ensured through the help of water. If these substances do not dissolve in water, they cannot play a role in the nutrient uptake and growth of plants. There is an important relationship between the uptake of the plant nutrients and the amount of water available in the root area. Nutrient uptake is directly dependent on the amount of water in the root zone. Roots grow better in moist soil, and nutrient uptake is higher in moist soil than in dry soil. Thus, crop roots under adequate water conditions grow better due to an increase in nutrient uptake. Furthermore, fertilizers must be transported via water. It is not possible to consider fertilizer and irrigation water applications separately. Therefore, the effects of fertilizer together with the water on the crop yield can be determined by crop–water production functions. It is important to determine the amount of water for optimum fertilizer uptake by plants for each application. Water and fertilizer are the most important inputs in crop production. Therefore, they must be used effectively for optimum crop production. This requires detailed knowledge of the effects of fertilizer and water on plant growth and yield under different growth conditions. The aim of this study was to reveal the applicability of the ET–yield response factor equation for fertilizer–yield relationships.

2. Materials and methods

2.1. Definition of the ET–yield response factor (Ky_{ET})

To evaluate the effect of plant water stress on yield decrease through the quantification of relative evapotranspiration (ET_a/ET_m), an analysis of research results shows that it is possible to determine relative yield losses if information is available on actual yield (Y_a) in relation to maximum yield (Y_m) under different water supply regimes. In order to quantify the effect of water stress, it is necessary to derive the relationship between relative yield decrease and relative evapotranspiration deficit given by the empirically derived yield response factor (Ky) (Kassam and Smith, 2001). This situation is shown in Eq. (1), developed by Stewart et al. (1977) and Doorenbos and Kassam (1979):

$$[1 - Y_a/Y_m)] = Ky_{ET}\,[1 - (ET_a/ET_m)], \qquad (1)$$

where Y_a = actual yield, Y_m = maximum yield, Ky_{ET} = evapotranspiration (ET) – yield response factor, ET_a = actual evapotranspiration, ET_m = maximum evapotranspiration, $(1 - Y_a/Y_m)$ = relative yield decrease, and $(1 - ET_a/ET_m)$ = relative evapotranspiration deficit.

An example of the implementation of this equation is given in Figure 1 (Ertek et al., 2006). It indicates that a 0.60 unit yield loss will be caused by a deficiency of 1 unit of water for the whole growing season. Furthermore, Ky values for the initial, flowering, and ripening periods are 0.81, 0.61, and 0.52, respectively. If the amount of fertilizer consumed by any plant is determined, a similar graph can be drawn for fertilizer uptake. It is clear that the yield loss per unit of fertilizer decrease can be determined. Thus, this study was designed to develop an equation to use in fertilizer applications using the yield–response factor of Eq. (1) to be used to evaluate crop production under adequate and deficit water supply regimes.

Furthermore, crop water use efficiency (WUE), as in Eq. (2), can also be derived from Eq. (3). Thus, WUE varies depending on crop response factor (Kirda, 2002).

$$WUE = \frac{Y_a}{ET_a} \qquad (2)$$

$$WUE = \left[Ky_{ET} - \frac{Ky_{ET} - 1}{ET_a/ET_m}\right] \times \frac{Y_m}{ET_m} \qquad (3)$$

2.2. Fertilizer–yield response factor (Ky_F)

A high yield can be achieved when the required nutrients are taken from the soil by plants. The plant yields are increased in proportion to the amount of nutrients taken from the soil. Any fertilization application program must be able to meet the nutritional requirements of the plants and allow the efficient use of irrigation water.

To achieve high efficiency in plant production, in addition to meeting the plants' water requirements, the plants' fertilizer needs must be met adequately. A study by Erdal et al. (2006) revealed that the effects of fertilizer deficiency in yield reduction are greater than those of water

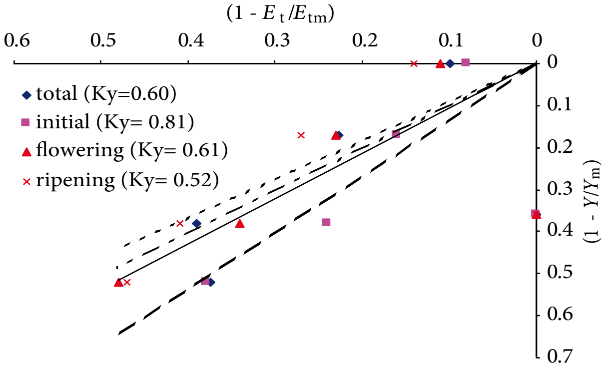

Figure 1. The relationship between relative yield decrease and relative evapotranspiration deficit of eggplant in different growth periods.

deficit. Therefore, the above-described Eq. (1) can also be used to estimate yield losses per unit of fertilizer deficit, and new studies on this issue can be done. As a result, the ET–yield response factor equation that was applied for water can also be applied for fertilizer as a fertilizer–yield response factor equation. To evaluate the effect of fertilizer deficit on yield reduction through the quantification of relative fertilizer (F_{upa}/F_{upm}), it is possible to determine relative yield losses through relative yield reduction (Y_a/Y_m) under different fertilizer applications. Such equations can be used to derive the relationship between relative yield decrease and relative fertilizer uptake deficiency given by the empirically derived fertilizer–yield response factor (Ky_F). Thus, Eq. (1) can be rewritten as Eq. (4) for fertilizer:

$$[1-(Y_a/Y_m)] = Ky_F[1-(F_{upa}/F_{upm})], \qquad (4)$$

where F_{upa} = the actual fertilizer amount used by plants (kg ha^{-1}), F_{upm} = the maximum fertilizer amount used by plants (kg ha^{-1}), Ky_F = the fertilizer–yield response factor, and $[1 - (F_{upa} / F_{upm})]$ = the relative fertilizer deficit.

The fertilizer–yield response factor (Ky_F) gives an indication of whether the crop is tolerant to fertilizer deficiency. A response factor of greater than unity indicates that the expected relative yield decrease for a given fertilizer uptake deficit is proportionately greater than the relative decrease in fertilizer uptake by the plants. In other words, Ky_F is a ratio value used to estimate the amount of decline in plant yield versus per unit decrease of fertilizer. It is required to determine F_{upa} for the implementation of the equation. It can be also used as a symbol of specific applied fertilizer instead of F for the equations. As an example for nitrogen (N), the N_{upa} determination process was described by Erdal et al. (2006). To calculate N uptake by plants, both fruit and vegetative biomass were dried at 65 °C to a constant weight. Following that, the N uptake was calculated by multiplying the N concentration (%) by the weight of the oven-dried matter (Scholberg et al., 2000) [Eq. (5)]:

$$N_{up} = DM \times N_C, \qquad (5)$$

where N_{up} = the N uptake (kg ha^{-1}) by plants (plant nitrogen consumption), DM = the oven-dried matter (kg ha^{-1}), and N_C = the N concentration (%).

The N concentration is determined using the Kjeldahl N method [Eq. (6)] (Kacar and İnal, 2008):

$$\%N = [(VH_2SO_4 - VCH_2SO_4) \times 1.4007 \times N\,H_2SO_4] / W, \qquad (6)$$

where VH_2SO_4 = mL standard H_2SO_4 pipetted into a titrating flask as a sample, $N\,H_2SO_4$ = the normality of H_2SO_4 solution used for titration, VCH_2SO_4 = mL standard H_2SO_4 pipetted into titrating flask as a control sample, 1.4007 = milliequivalent weight of nitrogen × 100, and W = sample weight in grams.

This equation can also be used to determine the effects of different fertilizer applications on yield in different growing stages besides determining Ky_F for the whole growing season. Thus, the effect of fertilizer deficit on yield in any plant growth stage can be determined. If the amount of any fertilizer consumed by the plants is determined, the equations described above can also be applied for specific fertilizers. Thus, using the Ky obtained for the different fertilizers, a new fertilization program can be created. Furthermore, as the response to water deficit in a specific region can be locally determined, a similar situation is also valid for fertilizer deficit. As a result, the fertilizer use efficiency can be written as in Eq. (7), similar to the water use efficiency equations shown in Eqs. (2) and (3):

$$FUE = (Y_a/F_{upa}) \times 100, \qquad (7)$$

where FUE = the fertilizer use efficiency (t kg^{-1}) and Y_a = actual yield (t ha^{-1}).

FUE represents the yield obtained per unit weight of fertilizer consumed by the plants (assuming no water stress). Alternatively, the equation for crop FUE can be derived from Eq. (8) as follows.

$$FUE = \frac{Y_a}{F_{upa}} = \left[Ky_F - \frac{Ky_F - 1}{F_{upa}/F_{upm}}\right] \times \frac{Y_m}{F_{upm}} \qquad (8)$$

As the fertilizer–yield response factor (Ky_F) increases, crop FUE decreases, which in turn implies that a benefit from deficit fertilization is unlikely. Only those crops and growth stages with a lower fertilizer–yield response factor ($Ky_F < 1.0$) can generate significant savings in fertilizer through deficit fertilization.

2.3. ET–fertilizer response factor ($K_{F\text{-}ET}$)

Especially in arid and semiarid regions, irrigation and fertilization are the most effective factors in agricultural production, but their joint impact on crop production is more important than their individual impacts. First of all, irrigation causes more fertilizer uptake by plants. However, fertilizers can be washed below the root zone by excessive watering. Therefore, controlled irrigation and fertilization is of vital importance to increase plant yield.

Agricultural water management strategies are focused especially on fertilizer application and soil water conservation in dry areas. Yield decline caused by water shortage in dry areas can be compensated for to some extent through fertilization. However, the effects of fertilizers are limited due to available water (Li et al., 2004).

If enough water is absent in the root zone to dissolve the fertilizer and carry it to the upper parts of plant, a large amount of fertilizer will remain in the soil and will not be useful to the plants. The remaining portion of the fertilizer in the soil will cause environmental pollution. Therefore, the suitable amount of water needed for the plants to receive the fertilizer should be known. The yield–response factor equation can be rewritten as the ET–fertilizer response factor to determine the most appropriate water and fertilizer rate. Thus, unit decline in the fertilizer uptake by plant per unit water decrease can be calculated by following Eq. (9):

$$[1 - (F_{upa}/F_{upm})] = K_{F-ET}\,[1 - (ET_a/ET_m)] \tag{9}$$

where K_{F-ET} = the ET– fertilizer response factor.

2.4. Relationship between response factors

The following applications can be made to determine the relationships among the above-mentioned factors. If Eqs. (1) and (4) are sum-mutual, Eqs. (10) and (11) are obtained.

$$Ky_{ET}\,[1 - (ET_a/ET_m)] = Ky_F\,[1- (F_{upa}/F_{upm}) \tag{10}$$

Thus:

$$\frac{Ky_{ET}}{Ky_F} = \frac{[1 - (F_{upa}/F_{upm})]}{[1 - (ET_a/ET_m)]} \tag{11}$$

Furthermore, if Eq. (9) is applied to Eq. (11), Eq. (12) is obtained.

$$\frac{Ky_{ET}}{Ky_F} = \frac{K_{F-ET}\,(1 - ET_a/ET_m)}{(1 - ET_a/ET_m)} \tag{12}$$

If the necessary changes are made to Eq. (12), Eqs. (13) and (14) are obtained; these equations give the relationship between the response factors that were described above.

$$\frac{Ky_{ET}}{Ky_F} = K_{F-ET} \tag{13}$$

$$Ky_{ET} = Ky_F \times K_{F-ET} \tag{14}$$

Thus, the relationship of crop yield to water and fertilizer consumption can be revealed more clearly by Eq. (14).

3. Results

A sample application was carried out for a hypothetical plant (tomato) to better explain the subject. Values were created from previously conducted studies on tomato by Ertek et al. (2012) (Table). Graphs drawn using the values from the Table are shown in Figures 2–4. If the regression line on the graph is forced through the origin (0,0), then the response factor is obtained. As can be seen from Figures 2, 3, and 4, ET–yield response factor (Ky_{ET}), fertilizer–yield response factor (Ky_F), and ET–fertilizer response factor (K_{F-ET}) were determined to be 1.58, 0.79, and 1.95, respectively.

The relationships among response factors were determined using the data in the Table. If a sample calculation is done for the IR_1N_1 treatment, the following results are determined.

$[1 - (Y_a/Y_m)] = Ky_{ET}\,[1 - (ET_a/ET_m)]$; $0.74 = Ky_{ET} \times 0.40$ and $Ky_{ET} = 1.85$

$[1 - (Y_a/Y_m)] = Ky_F\,[1 - (F_{upa}/F_{upm})]$; $0.74 = Ky_F \times 0.88$ and $Ky_F = 0.84$

$[1 - (F_{upa}/F_{upm})] = K_{F-ET}\,[1 - (ET_a/ET_m)]$; $0.88 = K_{F-ET} \times 0.40$ and $K_{F-ET} = \mathbf{2.20}$

$$\frac{Ky_{ET}}{Ky_F} = K_{F\text{-}ET};\quad \frac{1.85}{0.84} = \mathbf{2.20}$$

The yield decreased 1.85 units with a decrease of 1 unit of water in the IR_1N_1 treatment; similarly, the yield decreased 0.84 units with a decrease of 1 unit of fertilizer. In addition, it can be said that the decrease in fertilizer uptake is 2.20 units per decrease of 1 unit of water. Similar procedures can be also performed for the other treatments. Thus, the relationships among response factors can be found separately for each treatment. If the response factor values on the graphs are substituted into the equation, we can see that it still gives the correct result. Small differences are due to rounding the numbers during the calculation and forcing them through the origin (0,0) of the regression line on the graph.

$$\frac{Ky_{ET}}{Ky_F} = K_{F-ET};\quad \frac{1.58}{0.79} = 2.0 \approx 1.95$$

Fertilizer use efficiencies were determined using the data in the Table. If a sample calculation is done for the IR_1N_1 treatment, the following results are determined. As can be seen from the Table, the highest FUE value was obtained for the $I_1IR_1N_1$ treatment. Although FUE values at the same irrigation levels decreased for the higher fertilizer application levels, WUE values increased. On the other hand, the highest WUE/FUE rates were obtained

Table. The simulated results for an experiment on a hypothetical plant*.

Treatment	I_R, mm	ET, mm	N, kg ha^{-1}	N_{up}, kg ha^{-1}	Yield, tone ha^{-1}	$1 - N_{upa}/N_{upm}$	$1 - Y_a/Y_m$	$1 - ET_a/ET_m$	WUE, t ha^{-1} mm^{-1}	FUE, kg kg^{-1}	WUE/FUE
$I_1I_{R1}N_1$	500	520	25	22	25	0.88	0.74	0.40	0.048	1.14	0.042
$I_1I_{R1}N_2$	500	535	80	55	55	0.7	0.43	0.39	0.103	1.00	0.103
$I_1I_{R1}N_3$	500	550	160	142	79	0.24	0.18	0.37	0.144	0.556	0.258
$I_1I_{R2}N_1$	650	675	25	24	26	0.87	0.73	0.22	0.039	1.080	0.036
$I_1I_{R2}N_2$	650	690	80	72	65	0.61	0.32	0.21	0.094	0.903	0.104
$I_1I_{R2}N_3$	650	700	160	160	87	0.14	0.09	0.20	0.124	0.544	0.229
$I_1I_{R3}N_1$	800	845	25	30	32	0.84	0.67	0.03	0.038	1.067	0.036
$I_1I_{R3}N_2$	800	850	80	64	65	0.66	0.32	0.02	0.076	1.016	0.075
$I_1I_{R3}N_3$	800	865	160	146	96	0.22	0	0.01	0.111	0.658	0.169
$I_2IR_1N_1$	500	540	25	16	13	0.91	0.86	0.38	0.024	0.813	0.030
$I_2I_{R1}N_2$	500	550	80	63	47	0.66	0.51	0.37	0.085	0.746	0.115
$I_2I_{R1}N_3$	500	560	160	130	65	0.3	0.32	0.36	0.116	0.500	0.232
$I_2I_{R2}N_1$	650	695	25	18	15	0.9	0.84	0.20	0.022	0.833	0.026
$I_2I_{R2}N_2$	650	705	80	79	58	0.58	0.4	0.19	0.082	0.734	0.112
$I_2I_{R2}N_3$	650	715	160	163	75	0.12	0.22	0.18	0.105	0.460	0.228
$I_2I_{R3}N_1$	800	840	25	20	19	0.89	0.8	0.03	0.023	0.950	0.024
$I_2I_{R3}N_2$	800	855	80	90	65	0.52	0.32	0.02	0.076	0.722	0.105
$I_2I_{R3}N_3$	800	870	160	186	79	0	0.18	0	0.091	0.425	0.214

*: Values in this table were inspired by previously conducted studies on tomato by Ertek et al. (2012).
IR = irrigation water, ET = plant water consumption, I1 = irrigation interval of 5 days, I2 = irrigation interval of 10 days, N = nitrogen applied, Nup = nitrogen uptake by plant.

for the highest water application level. Furthermore, the highest yields were found at the highest WUE/FUE ratios.

$$FUE = \frac{Y_a}{F_{upa}} = \left[Ky_F - \frac{Ky_F - 1}{F_{upa}/F_{upm}}\right] \times \frac{Y_m}{F_{upm}}$$

$$FUE = \frac{25}{22} = \left[0.84 - \frac{0.84 - 1}{22/186}\right] \times \frac{96}{186} = 1.14$$

4. Discussion

According to the determined response factor values, the effect on yield of the plant's water consumption (ET) is higher than that of fertilizer. Considering the ET–fertilizer response factor (K_{F-ET}) on the fertilizer uptake of irrigation water, a large effect can be observed. It can be said that irrigation water indirectly leads to an increase in yield via transporting fertilizer for the plant's needs.

As shown in Figure 4, the decrease in fertilizer uptake is 1.95 units for a decrease of 1 unit of water. Thus, a water deficit will cause a decrease in crop yield by reducing fertilizer uptake (Figure 2). The usefulness of the nutrients being added to the soil through different fertilizers, reaching the plant's root zone, turning into convenient forms for the plant, and being assimilated by the plant is related to the available soil water. More specifically, water and fertilizer are 2 complementary factors. They cannot fully be useful for plants without being appropriately combined. When water is a limiting factor, plant development cannot reach the desired level through fertilizer applications. If there is available adequate water in the plant root zone, the yield increase by fertilization is more pronounced.

Considering the agricultural inputs such as water, fertilizers, chemicals, or machinery, research studies revealed that fertilizer alone is responsible for increasing crop yield by up to 50%. Therefore, the lack of proper nutrients in the root zone of plants is also an important issue to consider for crop production. The nutrient content of plants is directly related to the amounts of available nutrients in the growth environment of the plants. In addition, the amount of water required to convey fertilizer in the soil to the tissues and organs of the plant must also be known. The conducted studies revealed that the lowest level of fertilizer uptake by plants comes from inadequately watered soil (Eryuce and Kilic, 2001).

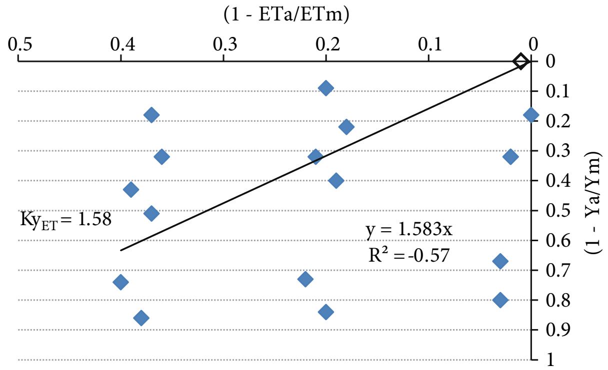

Figure 2. The relationship between a decrease in relative yield (Y) and relative evapotranspiration (ET) deficit for a hypothetical plant.

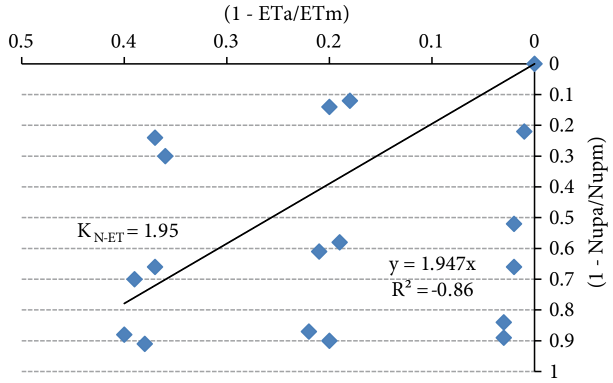

Figure 4. The relationship between a decrease in relative fertilizer (N) and relative evapotranspiration (ET) deficit for a hypothetical plant.

As can be seen from the Table, crop yield in the treatments applied with the same amount water increased depending on the level of fertilizer applied per unit of water. FUE values decreased due to the increase of fertilizer uptake (N_{up}) by plant. As a result, the most appropriate water and fertilizer levels required to achieve optimum yield rate can be determined by the choices between the highest WUE and FUE values at the lowest or highest WUE/FUE ratios. The highest yields were obtained at the highest WUE/FUE ratios. Therefore, the WUE and FUE values should be taken into account together in evaluation of similar studies.

In the study conducted on the effects on tomato yield of different water and fertilizer levels by Erdal et al. (2006), fertilizer level was increased while keeping water level constant, and a yield increase was observed. When both the water and fertilizer levels increased, crop yield increased linearly depending on water and fertilizer levels. However, after a certain level of applied water, crop yield was unfavorably affected. Compared with the fertilizer treatments, irrigation in the unfertilized treatments had very little effect on yield. For this reason, it is useful to know the mutual effects of irrigation and fertilization on cultivated crop yields. The mutual effects of ET–yield response factor (Ky_{ET}), fertilizer–yield response factor (Ky_F), and ET–fertilizer response factor (K_{FET}) could be determined by using the above-mentioned equations. Thus, the mutual effects of the response factors can be determined by comparing them with each other.

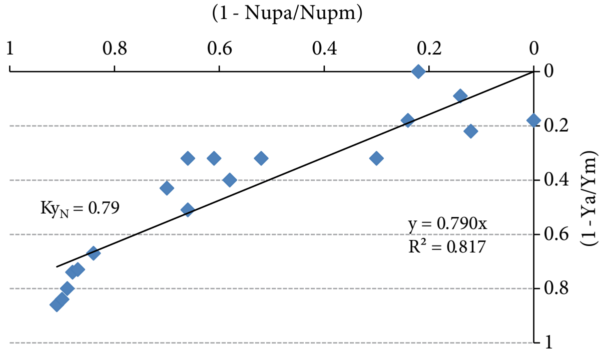

Figure 3. The relationship between a decrease in relative yield (Y) and relative fertilizer (nitrogen, N) deficit for a hypothetical plant.

According to the results of a study conducted on the effects on crop fresh yield and dry matter partitioning of grain amaranth at different water levels (100%, field capacity; 75%; and 50%) and fertilizer levels (100%, 90 kg ha^{-1}; 75%; and 50%) by Ejieji and Adeniran (2010), the highest and the lowest yields were obtained from treatments with the water content kept at field capacity and 100% fertilizer application and with plots with 50% of the moisture content of field capacity and 50% of the fertilizer treatment, respectively. The study showed that the yield and growth of amaranth was greatly affected by moisture and the level of fertilizer stress. Both the water and fertilizer applications had significant effects on both fresh and dry matter productions, but the effect of the water was more pronounced on the crop than that of the fertilizer. Furthermore, water, fertilizer, and their interaction significantly affected dry matter partitioning.

In a study conducted by Cooper et al. (1987) on the effects of fertilizer on barley production related to soil water dynamics and crop water use in different soil types, the fertilizer applications resulted in large increases in WUE. A field experiment was conducted to study the coupling effect of water and fertilizers on spring wheat yield in a semiarid area by Li et al. (2000). A regression model shows that water was the most important factor affecting spring wheat yield. N was the most sensitive factor, water was the second, and P was the third. The effects of N, P, and water on yield were statistically significant and met the law of diminishing returns. Properly increasing P fertilizer when there is a lack of water could strengthen the drought resistance of spring wheat. In a study related to different levels of total water applied (high water, 400 mm; moderate water, 300 mm; and low water, 100 mm) and different fertilizer levels (high fertilizer, 372 kg ha^{-1}; moderate fertilizer, 248 kg ha^{-1}; low fertilizer, 124 kg ha^{-1}; and without fertilizer application) conducted by Li et al. (2004), WUE was the highest under high water with high fertilization, while grain yield was consistently the highest. This indicates that plentiful water with high fertilizer was the most efficient method in the experiment.

As a result of the present study, economic analysis related to product losses for 1 unit decrease in water or fertilizer can be conducted using the ET–yield response factor and fertilizer–yield response factor values that are determined for plants grown in a region. Thus, the most appropriate irrigation and fertilization programs can be implemented. In addition, the plant's optimum fertilizer and water needs can be understood through the determination of the ET–fertilizer response factor and an excessive use of fertilizer and water can be prevented. Furthermore, growers will have prior knowledge related to yield losses due to water and fertilizer deficits. Sample applications in the study show that the ET–yield response factor equation can be used successfully in the evaluation of fertilizer–yield relationships. Furthermore, the study may help provide guidelines for deficit fertilizer and water applications and determine the optimum fertilizer level for plants in different growth stages through the estimation of expected relative yield decrease. Thus, results may help control irrigation and fertilization in agricultural water management, especially in semiarid regions. In addition, the yield loss per unit of fertilizer deficiency in studies with constant water level and different fertilizer levels can be determined more precisely using the fertilizer–yield response factor equation.

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