Economic optimization of wheat production under deficit irrigation in the Zayanderoud Region, Isfahan

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Abstract
Water is indispensable in agriculture. Water shortage, along with low irrigation efficiencies in Iran, as a semi-arid country, justifies research in deficit irrigation. In the current study, the economic of deficit irrigation of wheat in Zayanderoud region, Isfahan was examined. The aim and the general expressions were used to derive a set of specific expressions for a particular case study involving a quadratic production function and a cubic cost function. The method was used to find out the crop water requirements. Required water was employed to evaluate the effects of over irrigation (dry/land). Economic data for each farm were collected through interviews with farmers using two steps cluster sampling in the 2000-2001 years. The information were collected from the farmers facing limitation in land and water as well, and the irrigation was full. This investigation clearly demonstrates that maximam profit achieved naturally by full irrigation and the next preference would be limitation in water rather than the land. The findings of the study show that deficit irrigation will be more profitable than full irrigation in semi-arid regions, and the estimate of optimum water use as an exact prescription for amount of water to apply is recommended.

Key words: Deficit irrigation, Production function, Cost function

Introduction
Under some circumstances, maximum attainable income for an irrigated field may be achieved by deficit irrigation, the deliberate under-irrigation of the crop. Design or manage irrigation for deficit irrigation, the analyst must rely upon crop production function that relate water use to crop yields. It is important to know precisely what level of water use will maximize profit. Deficit irrigation is a concept that can be usefully applied. Many farms are, deliberately under-irrigating some field to increase net income. This paper leads to estimates of the profit-maximizing level of the range of water use within which deficit irrigation is more profitable than full irrigation (English, 1981).

The increase in applied water is associated with higher irrigation frequencies, greater evaporation may occur with relatively little increase in yield (Hanks, 1974; Hanks and Hill, 1980). The irrigation system will be become less efficient as water use approaches full irrigation. This decline in efficiency is largely associated with variability in applied water, crop characteristics, and soil characteristics (English et al., 1986). The expressions are completely general in the sense that they can be used with any crop production function and cost function that the analyst chooses.

Farm operations are often constrained by a shortage of irrigation water. When that is the case, the water saved by deficit irrigation of one piece of land might be used to irrigate additional land, thus increasing farm income. The potential increase in farm income is an opportunity cost of the water. Where water supplies are limited, opportunity costs may be the amount of land under irrigation is constrained by a limited water supply, the economic returns to water will be maximized the depth of water applied and increasing the area of land.
under irrigation until the marginal profit per hectare multiplied by the number of hectares irrigated just equals the total profit per Hectare (English and Orlob, 1978)

The economics of deficit irrigation are examined. The concepts developed in the heuristic discussion are developed into a set of rigorous mathematical expressions for determination of optimum water use under deficit irrigation. These expressions can also be used to estimate the water use within which deficit irrigation would be more profitable than full irrigation (English, 1990).

The effect of irrigation intensity on the net revenue of cotton and potato in two separate regions in the northeastern part of Iran was investigated by Ghahremani and Sepasckhah (1994). They came to the conclusion that the optimum level of water deficit in Esfarayen was 20 percent for potato and cotton and, in Esfarayen and Daregaz it was 25 percent and 9 percent respectively. With this amount of reserved water, it is possible to increase yield crop up to 25, 10 and 15 percent respectively.

The findings of the study also showed that if the ratio of benefit of cost (B/C) for each irrigation treatment was smaller than 1.5, those types of potato and cotton would not be recommended for Esfarayen and Daregaz.

A research done by Hargreaves and Samani (1984) showed that the system of irrigation had a meaningful effect on yield product. They also mentioned that the relation between crop and water used can be divided into two parts. The first part relates to deficit irrigation and the second relates to over-irrigation. If full irrigation used, the production function curve will be linear up to 50 percent.

Solomon (1985) believes that plant production function differences should be taken into account, and the amount of water used by the plant during its growth should be investigated.

Keith (2003) proved the efficient irrigation management for any crop based on the crop's yield threshold, the soil's allowable soil moisture depletion percentage or a predetermined soil moisture level as in a vineyard deficit irrigation program. The results of Keith's study show that the efficient use of water resources through good management has a great effect on crops yield.

Pascual et al. (2004) said that regulated deficit irrigation treatment improved water-use efficiency because about 30 percent less irrigation water was applied in the regulated deficit irrigation in the control treatment. They concluded that high-cropping almonds can be successfully grown in semiarid regions.

**Materials and Methods**

A general relationship exists between irrigation water use and crop yield. When a small amount of water is applied it will be almost completely used by the crop. At higher levels of applied water, reflecting various water losses that develop as water use approaches full irrigation. If the increase in applied water is associated with higher irrigation frequencies, greater evaporation may occur with relatively little increase in yields.

It is possible to derive a set of equations to estimate the values of the aforementioned variables. Such equation would be useful for analysis of optimum water use for alternatives of system design and operation.

The profit to be realized from irrigation will be determined by the amount of water applied. Assume that we are concerned with only one crop like wheat, and that fixed amount of land and water have been allocated for production of that crop.

The irrigated area may also be a function of water use:
A= \frac{\text{w.t}}{w} \quad (1)

Where: A=total area of wheat crop to be irrigated(ha)
\text{w.t}: total available water supply( m^3 )
\text{w}: water applied per unit of land ( m^3 /ha )

The level of water use which maximize yields\(w_m\) can be determined by taking the derivative of the yield function:

\[ \frac{\partial y(w)}{\partial w} = 0 \quad (2) \]

Where: \(y(w)\) = yield per unit of land, expressed as a function of \(w\)(kg/ha)

The value of \(w\) that satisfies Eq. 2 will be \(w_m\).

We determine the level of water use that will maximize net income when land is limiting, we begin by taking the partial \(I_f: (w) = A.i_1 (w)\) with respect to \(w\). The net income per hectare is a function of applied water.

\[ \frac{\partial I_f (w)}{\partial w} = A \frac{\partial i_1 (w)}{\partial w} + i_1 \frac{\partial A}{\partial w} \quad (3) \]

Where: \(I_f (w)\) = net farm income from all irrigation land($/ha)
\(i_1 (w)\) = net income per unit of land under irrigation($/ha)

When land is limiting, A is presumed constant.

The optimum level of water use(\(w_i\)) will be defined by the equation:

\[ \frac{\partial i_1 (w)}{\partial w} = 0 \quad (4) \]

When water is limiting, A is a function of \(w\), as was noted and optimum water use(\(w_w\)) can be determined:

\[ \frac{\partial i (w)}{\partial w} = P_c \frac{\partial y(w)}{\partial w} - \frac{\partial C(w)}{\partial w} \quad (5) \]

\[ \frac{\partial A}{\partial w} = \frac{w_i}{w^2} \quad (6) \]

The equation for optimum water use are, then:

\[ P_c \frac{\partial y(w)}{\partial w} = \frac{\partial C(w)}{\partial w} \quad (7) \]

Let: \(P_c\)=crop price of wheat($/ha)
\(C(w)\)=production costs per unit of land, expressed as a function of \(w\)($/ha)

When land is limiting, and :
The net income per hectare is a function of applied water.

\[ i_{l}(w) = p_{c}y(w) - c(w) \]  

(9)

By substituting \( w_{m} \) into Eq. 9:

\[ i_{l}(w_{m}) = p_{c}y(w) - c(w) \]  

(10)

When water is limiting, solving Eqs. 7 and 8 for \( w \) will yield the optimal values of applied water, \( w_{l} \) and \( w_{w} \).

Eq. 7 is where the marginal cost of production equals the value of the marginal product.

The optimum water use will occur at the point where the MC=VMP are equal (\( w_{l} \)) when land is the limiting factor.

It will be necessary to first develop specific models of yield and cost \( y(w) \) and \( C(w) \), then substitute those models into the general equations and solve for the various values of \( w \). The yield function can be represented:

\[ y(w) = a_{1} + b_{2}w + C_{1}w \]  

(11)

The cost function might reasonably be represented:

\[ C(w) = a_{2} + b_{2} + C_{2}w_{2} \]  

(12)

Where the coefficients \( a_{2} \) and \( b_{2} \) are fixed costs and variable costs of production, the various levels of water used is of interest to the analyst \((W_{l}, W_{w}, W_{m}, W_{el}, W_{em})\) can be derived by substituting Eqs. 9 and 10 into the general equations derived earlier. The five levels of water use are shown in the index.

The data shows water use and yield for 120 fields of wheat on various farms that were monitored as part of that study in 2001.

**Results**

A study of irrigation in the Zayanderoud Region was carried out by the researchers. The analytical framework developed in this paper was used to study optimum irrigation. The farm applied 398 mm of water to the field, realizing a yield of 5180 kg of wheat/ha. Full irrigation would have required 408 mm of water to the field.

The yield curve is closely approximated by the following regression equation for water use.

\[ \text{y(w)} = a_{1} + b_{2}w + C_{1}w \]  

(11)
\begin{align*}
y(w) &= 1900 + 25.3w - 0.027w^2 \\
R^2 &= 0.98
\end{align*}

Where \( y(w) \) = yield, in kg/ha and \( w \) = depth of water applied, in millimeters equivalent depth or \( m^3*10 \) per hectare.

The price of wheat was considered in the analysis: 0.2 $/kg. Production costs for the field were determined from interviews with the farm owner-operator.

The resulting cost function was:

\begin{align*}
C(w) &= 1152930 + 915w - 0.486w^2
\end{align*}

Where: \( c(w) \) = total production cost in dollars per hectare.

Let:

a. fixed costs = 1117530
b. variable costs = 459.6w
c. price of water \( m^3/ha = 120*10w \)
d. cost of irrigation = 50*10w
e. others costs \( 18*y_1(w) = 18(1900 + 25.3w - 0.027w^2) \)

The values of \( w_m, w_f, w_w, w_{el}, \) and \( w_{ew} \) were determined for crop price using Eqs. 11-17.

The approach involves determination of five levels of water use:

(1) the level at which yield is maximized \( (w_m) \)
(2) the deficit levels at which the net income would just equal the income at full irrigation, either when land is limited or when water is limited \( (w_{el} \) or \( w_{ew} \))
(3) the deficit at which returns to land are maximized \( (w_f) \)
(4) the deficit at which returns to water are maximized \( (w_w) \). By determining these five levels of irrigation, the analyst can gain a useful perspective on the returns associated with deficit irrigation.

**Discussion**

An analytical framework for dealing with deficit irrigation has been presented. Table 1 summarizes the results of the analyses. (Refer to Table 1.)

When available land is limited the optimum use strategy will be that which maximizes net returns to land. The range within deficit irrigation would be more profitable than full irrigation begins at 260 mm or 63 percent of full irrigation.

In the water limiting situation, the profitable deficit begins at 68 percent of full irrigation. The decision-maker can regard the estimate of optimum water use as an exact prescription for amount of water to apply.

Completely general equations for calculating optimum levels of water use were derived analytically (Eq. 4, 7, 8, 9, 10). These equations can be combined with any yield and cost functions to derive the five relevant levels of water use. As an illustration, specific yield and cost function were derived based on a quadratic production function and cost function. The resulting equation for \( w_m, w_f, w_w, w_{el}, \) and \( w_{ew} \) (Eq. 13-19) provide a simple algorithm for
analysis of optimum irrigation with use. The required inputs are the coefficients in Eqs. 11 and 12 and the price of the crop.

While the optimum irrigation levels can be estimated, they can not be known precisely. However, within the range between \( w_m \) and \( w_{el} \), or \( w_{ew} \) deficit irrigation will be more profitable, than full irrigation.

The optimal levels of water use \( (w_i \) and \( w_w) \) were found to be relatively low, and the profitable deficit range (the range between \( w_m \) and \( w_{el}, w_{ew} \)) was rather wide, suggesting that the decision to under-irrigate in these particular circumstances was potentially profitable and reasonably safe.

References:
**Table Legend**

**Table 1. Case study Summary**

<table>
<thead>
<tr>
<th>Irrigation Strategy</th>
<th>Water use (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$w_m$</td>
<td>408</td>
</tr>
<tr>
<td>$w_{el}$</td>
<td>260</td>
</tr>
<tr>
<td>$w_{ew}$</td>
<td>277</td>
</tr>
<tr>
<td>$w_l$</td>
<td>320</td>
</tr>
<tr>
<td>$w_w$</td>
<td>310</td>
</tr>
</tbody>
</table>

Derived from the research results.

**Index**

The five levels of water use:

\[
\begin{align*}
    w_m &= \frac{b_1}{2c_1} \\
    w_{el} &= \frac{b_2 - p_c b_1 + z_1}{2p_c c_1} \\
    w_{ew} &= \frac{-z_2 + \left[ z_2 - 4p_c c_1 (p_c a_1 - a_2) \right]^{\frac{1}{2}}}{2p_c c_1} \\
    w_l &= \frac{b_2 - p_c b_1}{2p_c c_1} \\
    w_w &= \frac{\left[ (p_c a_1 - a_2) \right]^{\frac{1}{2}}}{2p_c c_1}
\end{align*}
\]

Where:

\[
\begin{align*}
    z_1 &= \left[ \left( p_c b_1 - b_2 \right)^2 - 4p_c c_1 \left( \frac{p_c b_1^2}{4c_1} - \frac{b_2 b_2}{2c_1} \right) \right]^{\frac{1}{2}} \\
    z_2 &= \frac{p_c b_1^2 - 4a_2 c_1 + 4p_c a_1 c_1}{2b_1}
\end{align*}
\]