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Optimize Utility of Water Resources In Irrigation Projects: Linear Programming Approach

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Abstract:

Now a day's water scarcity is a crucial problem, as need of water increasing rapidly and its availability is not up to mark. Therefore it becomes necessary to develop scientific methods to utilize the water at its optimum level. The main objective of this study was to develop a separable linear programming model, considering a set of technical factors which may influence the profit of an irrigation project. The model presents an objective function that maximizes the net income and specifies the range of water availability. It is assumed that yield functions in response to water application are available for different crops and describe very well the water-yield relationships. The linear programming model was developed genetically, so that, the rational use of the available water resource could be included in an irrigation project with specific equations that were developed and applied in the irrigation project on the water-yield functions considered, cultivated land constraints, production costs and products prices.

Keywords: linear programming, net income function, simulation techniques, water demand curve.

Introduction:

To plan the water supply and distribution in an irrigation project, in relation to the production level and to the water needs, the following items must be considered: seasonal and monthly needs of water supply, crop production, crop selection, exploration models and water supply scheduling during growth period. To optimize his decision, the farmer must choose among the available production alternatives, the most efficient in the use of productive resources and the one which satisfies the previously-stated goals. In the cases where the decision is related to the allocation of scarce resources, the farmer's responsibility is to find efficient methods that can help him to make the right decision. To solve this problem, the mathematical programming models are the most recommended.

The mathematical programming quantifies an optimal way of combining scarce resources to satisfy the proposed goals, that is, they analyze the cases where the available resources must be combined in a way to maximize the profit or minimize the cost. The profit maximization in an irrigated area can be favored practicing irrigation with water deficit, also called partial irrigation.

This statement can be supported by several research scholars in the field of economics theory; they believe that when the water supply is limited, the considerations about crop and irrigated area selection must be based on crop profitability according to the effect caused when the water needs are answered by the available water supply during the crop cycle.

According to engineering, to plan irrigation with a deficit is very complex, because it is necessary to trust the production functions. The uncertainty of those functions spoils the precise production prediction as well as the most economical water level, although deficit irrigation is a concept that can be applied with great success. Many farmers who have shortage of available water resources can practice deficit irrigation aiming to maximize the profit, many times in an empirical way.

Several researchers proposed that in the case of irrigation in areas where the water availability is a limiting factor to production, the planning problems and available water resource management must be solved estimating the irrigation need of different soil/plant systems taking in account an adequate cropping pattern. The planning of an irrigation project is considered optimal, according to economical values, if the results maximize the difference between the gross income and the production costs to specific restrictions imposed to the production system. Analyzing the relation between gross income and costs, this problem can be rationally solved by a mathematical programming model.

In this study, it is assumed that the production functions are available and they represent water/production relations properly. These functions are incorporated to a separated linear programming model that considers a group of technical factors which have influence upon profitability of an irrigation project. It is necessary to equalize the model to indicate the rational use of water resource in an irrigation project.

Model Development:

The objective function was specified as the net income maximization resulted from several crops subjected to the restrictions of water availability and cropping area. The gross income by area unit was determined as being proportional to the production, while the costs were taken from a fixed component (production costs not associated to the irrigation depth) and a variable component dependent of the seasonal irrigation depth. The gross income was expressed as shown below:

$$IB = \sum_{i=1}^{n} Pi\, Xi\, Yi(W) \qquad \ldots(1)$$

where,

IB = gross income obtained by n crops in an X area;

Pi - sale price of the crop product i,

Yi (W) = crop production I in function of the irrigation depth, in kg.ha*1;

Xi = cropped and irrigated area with crop **i**, in ha; and i - an integer pertaining to the crop (1, 2,..., **n**).

Considering water as the unique variable factor, to the technical unity the production cost was represented:

$$CP_i = C_i + C_w W_i \qquad \ldots(2)$$

or, to the economical unity:

$$CP = \sum_{i=1}^{n} C_i X_i + \sum_{i=1}^{n} C_w W_i X_i \qquad \ldots(3)$$

where,

CP - production cost of the farm;

Cw = irrigated water cost;

Wi = seasonal irrigation depth, applied to the culture i, in mm; and

Ci = crop production costs of crop i, not directly related to the irrigation depth.

The objective function of the economical unity was formulated as shown below:

$$\text{Max } Z = \sum_{i=1}^{n} P_i Y_i\,(W) X_i - \sum_{i=1}^{n} C_i X_i - \sum_{i=1}^{n} C_w X_i W_i \qquad \ldots(4)$$

where,

Z = net income of the farm resulting from **n** crops with irrigation depth **Wi**,

The restrictions to what the objective function is subjected to are generally expressed as shown below:

$$\sum_{i=1}^{n} W_i X_i \leq V_a \quad \ldots (5)$$

$$\sum_{i=1}^{n} a_{ij} X_i \leq A_j, \text{ for } j = 1,2,\ldots,j \quad \ldots (6)$$

$$X_i \geq 0 \quad \ldots (7)$$

where,

Va - annual volume of available water, in mm.ha;

aij = amount of input **j**, by unit of area necessary to crops; and

Aj = maximum availability of input **j**.

This model is a problem of non linear programming because the objective function has a non linear function [**Yi(W)**]. This function can be linearised through the part-linearization technique and the model treated as a problem of separated linear programming.

The model of separated linear programming is developed approaching the non linear functions of crop answers for piecewise linear functions, enabling the "simplex method" to find the solution. The answer function is divided in **k** linear segments, where **k** is an integer (**k**= 1,2, ., **s**).

If two reference points are considered: (**Yi0, Wi0**) representing the maximum productivity and the corresponding irrigation depth and (**Yis, Wis**) representing the minimum productivity and the corresponding irrigation depth, a reduction in the irrigation depth of the crop i from **Wi0** to **Wi1** (**DWi1**) implies a productivity reduction from **Yi0** to **Yi1** (**DYi1**); a reduction from **Wi1** to **Wi2** (**DWi2**) results in **Yi1** to **Yi2** (**Yi2**) and this way successively. Generally, a reduction in the irrigation depth from **Wi k-1** to **Wik** (**DWik**) results in a productivity reduction from Y**i k-1** to Yik (**DYik**).

The region between **Yi0** and **Yis** is the rational zone for resource allocation. It starts from a point where the average product/unit of resource is maximum and ends at the point where the maximum product is attained. The irrigation depth most be selected somewhere between s and zero, where marginal water productivity is equal to its price.

The model represented by the equations (4), (5), (6) and (7) will be modified here taking into account the linear answer functions by parts to n crops. Considering that all crops are irrigated with a depth to obtain maximum productivity (**Wi0**) to an **X** area, the following gross income function can be obtained:

$$IB_0 = \sum_{i=1}^{n} X_{i0} Y_{i0} P_i \quad \ldots (8)$$

where $\mathbf{IB_0}$ is the gross income obtained with n irrigated crops with depth $\mathbf{W_0}$, in US$.

The reduction of the irrigation depth from $\mathbf{Wi_0}$ to **Wi1** (D**Wi1**) implies in the reduction of the gross income of the crop i from **IBi0** to **IBi1** (D**IBi1**). In the same way, a depth reduction from **Wi1** to **Wi2** (D**Wi2**) results in the reduction of the gross income from **IBi1** to **IBi2** (D**IBi2**), and so on.

To any **i** crop, the total reduction of the gross income until a **k** point will be:

$$\Delta IB_k = \sum_{i=1}^{n} \Delta IB_{ik} \quad \ldots (9)$$

Considering n crops where each one gives D**IBik**, the following can be observed:

$$\Delta IB_k = \sum_{i=1}^{n} \sum_{k=1}^{z} \Delta IB_{ik} \quad \ldots (10)$$

Assuming that there is no variation in the total area available for irrigated cropping when the irrigation depth is varied and only the productivity of the crop can vary, for **n** cultures the equation below can be drawn:

$$\Delta IB = \sum_{i=1}^{n} \sum_{k=1}^{z} X_{ik} \Delta Y_{ik} P_i \quad \ldots (11)$$

$$IB = \sum_{i=1}^{n} X_{i0} Y_{i0} P_i - \sum_{i=1}^{n} \sum_{k=1}^{z} X_{ik} \Delta Y_{ik} P_i \quad .. (12)$$

For an irrigation depth **Wi0** and area X**i0**, the crop production cost **i**, related to the irrigation depth, can be expressed as:

$$CP_{i0} = C_i X_{i0} + C_w X_{i0} W_{i0} \quad \ldots (13)$$

Therefore, for **n** crops result the

following equation:

$$\sum_{i=1}^{n} CP_{i0} = \sum_{i=1}^{n} C_i X_{i0} + \sum_{i=1}^{n} C_w X_{i0} W_{i0} \quad \dots (14)$$

The reduction of the irrigation depth from **Wi0** to **Wi1** (D**Wi1**) brings a cost reduction from **CPi0** to **CPi1** (**DCPi1**), and so on. The cost reduction comes only from the water cost. For an unit area, it can be observed:

$$\Delta CP_{i1} = C_w (W_{i0}\ W_{i1}) = C_w \Delta W_{i1} \quad \dots (15)$$

$$\Delta CP_{i2} = C_w (W_{i1} - W_{i2}) = C_w \Delta W_{i2} \quad \dots (16)$$

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$$\Delta CP_{ik} = C_w (W_{ik-1} - W_{ik}) = C_w \Delta W_{ik} \quad \dots (17)$$

For **n** crops and **k** segments in the production function, the production cost using the irrigation depth **Wk** , can be formulated as:

$$CP = \sum_{i=1}^{n} C_i X_{i0} + \sum_{i=1}^{n} C_w X_{i0} W_{i0} - \sum_{i=1}^{n} \sum_{i=1}^{z} C_w \Delta W_{ik} X_{ik} \quad \dots (18)$$

The net income obtained for **n** crops in an **X** area, irrigated with the water depth **Wk,** will be:

$$z = IB_k - CP$$

$$z = \sum_{i=1}^{n} X_{i0} Y_{i0} P_i - \sum_{i=1}^{n} \sum_{k=1}^{z} X_{ik} \Delta Y_{ik} P_i$$

$$-\left(\sum_{i=1}^{n} C_i X_{i0} + \sum_{i=1}^{n} C_w X_{i0} W_{i0} - \sum_{i=1}^{n} \sum_{i=1}^{z} C_w \Delta W_{ik} X_{ik}\right) \quad \dots (19)$$

The aim of the economical unity is to maximize the net income function (**Z**). This maximization was set up following the restrictions below.

(a) the water volume consumed in the irrigation at **k** level must not exceed the maximum volume available:

$$\sum_{i=1}^{n} X_{i0} W_{i0} - \sum_{i=1}^{n} \sum_{k=1}^{s} X_{ik} \Delta W_{ik} \le V_a \quad \dots (20)$$

$$\sum_{i=1}^{n} X_{i0} w_{i0} - \sum_{i=1}^{n} \sum_{k=1}^{s} X_{ik} \Delta w_{ik} \le V_m \quad \dots (21)$$

where,

Wik = total water depth applied during the growing season **i**, at irrigation level **k**, in nun;

wik = monthly water depth applied to the culture **i**, at irrigation level **k**, in mm;

Va = annual water volume available, in mm.ha; and

Vm = monthly water volume available, in mm.ha.

(b) cropped area restriction for crop **i**:

$$X_{i0} \le ou \ge G_i \quad \dots (22)$$

where Gi is the restricted cropped area (ha) for crop **i**.

(c) total planted area restricted to each month:

$$\sum_{i=1}^{m} X_{i0} \le S_m, \quad for\ m = 1,2,\dots,12 \quad \dots (23)$$

where **Sm** is the total area available (ha) for the cropping in the month m.

(d) the irrigated area with **Wik** depth must not exceed the irrigated area with the depth for the maximum production:

$$X_{ik} - X_{i0} \le 0,\ for\ i = 1,2,\dots,n \quad \dots (24)$$

(e) non-negativity:

$$X_{i0} \ge 0 \quad and \quad X_{ik} \ge 0 \quad \dots (25)$$

Application Consideration of the Model:

The model was applied to any Irrigation Project, especially in the area where water availability is less and demand of water for irrigation purpose is more. The necessary coefficients to the model were obtained by simulation techniques. The aim was to obtain an optimal pattern of irrigated crops compatible with the area exploration characteristics in such a way to maximize the net income of the project. The constraints were highlighted concerning the availability of water, soil and market. The model was developed genetically using linear programming problem and optimum solution to water, seeding season, production costs without the water cost and the product price obtained.

The farmers' water demand curve was obtained according to a methodology based in several hypotheses with limitations. Initially, it was established that when the water availability is small, the irrigation project users will implement first the crops with greater incomes. As the water availability increases, crops with lower incomes will be used. So, the obtained demand curve assumes that the water and others resources usage is done efficiently. However, the technological level among the users is variable, so, with the same water volume, different farmers will have different net incomes.

Another limitation of the model concerns the uncertainty to which the farmer is subjected. The objective function considered herein admits a given structure of income and costs. Either the incomes or the costs are subjected to variations; hence it is not possible to guarantee a fixed price of the products and inputs. One solution for these problems would be to include in the model probability elements in order to consider risk factors.

Conclusion:

The main approaches for these models can be derived in two groups, according to the treatment given to the source of uncertainty. In the first group, the only uncertainty source is related to the net income per unit of each production alternative. In this case, the primary uncertainty source (marginal net income, prices and costs) are coupled to one single risk component, expressed in the objective function of the models. In the second group, are the approaches that include in the mathematical models the randomness of the technical coefficient of the restrictions, and levels of available resource. This approach is generically called stochastic programming. In any case, the modeling is very complex, requiring time series of information which, usually, are not available.

Concerning the labour problem, also considered of influence in case studies, effects on the shadow price can be expected. The lowers the labor power availability, due to difficulties in hiring or to the small number of family numbers, the lower will be the price which the farmer could be willing to pay for water use. This is due to the fact that having low labor power, cultivated area could be decreased and consequently, the net income of this land parcel implying in a lower availability of resources for water payment. It remain to the known if the charged price is based on investment and operational costs, or if there is some type of subsidy to the taxes charged to the user of the service.

References:

Dantzig, G. B., (1983): linear programming and Extensions (Princeton University press).

Dykstra, D.P., (1983): Mathematical programming for Natural Resources Management (New York: McGraw hill).

Hargreaves, G.H.; Samani, Z.A. (1984): Economics considerations on deficit irrigation, Journal of the Irrigation and Drainage Engineering, v.l 10, n.4, p.343-258.

Hart, W.E.; Norum, D.I.; Peri, G., (1980): Optimal seasonal irrigation application analysis." Journal of the Irrigation and Drainage Division, v.l06, n.3, p.221-235.

Kumar, R.; Khepar, S.D., (1980): Decision models for optimal cropping patterns in irrigations based on crop water production functions, Agriculture Water Management, v.3, n.l, p.65-76, 1980.

Mannocchi, F.; Mecarelli, P., (1994): Optimization analysis of deficit irrigation systems, Journal of the Irrigation and Drainage Engineering, v.l20, n.3, p.484-503.

Taha, H., (2009): Operations Research: an Introduction, 7th Edition, Prentice-Hall International, Singapore.