DESIGNING A SUPPLEMENTAL IRRIGATION SYSTEM

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ABSTRACT

In the dry season when the rainfall contribution to crop water requirement is not significant, the amount of land to be irrigated for maximum profit with a limited supply of water, can be easily calculated. However, in the rainy season when rainfall contributes a significant amount of the crop water requirement, the amount of land which can be irrigated by a supplemental irrigation system varies due to spatial variability of rainfall. In designing a supplemental irrigation system the long term variability of rainfall as well as economical parameters should be taken into account.

This paper describes a methodology for designing a supplemental irrigation system and for calculating the optimum amount of land which should be irrigated with a limited supply of water. The optimum amount of land to be irrigated is calculated for one station in El Salvador using crop yield models, long-term climatological data and economical parameters.

Since the day to day climatological data are not often available in many countries, the paper describes how a climatological data-base together with a weather generating model can be used to design a supplemental irrigation system.

INTRODUCTION

A dry season followed by a rainy season is typical of the climatic conditions in Latin America. During the dry season, water is often limited and only part of the land is cultivated. The amount of land to be irrigated with limited water in the dry season can be calculated using the continuity equation as follows:

$$A = \frac{Q*EI*T}{ET} \qquad (1)$$

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in which:
A= area to be irrigated for maximum yield
Q= available flow rate
EI= irrigation efficiency, %
T= Duration of irrigation during the peak use period
ET= peak crop consumptive use

The area calculated by equation 1 will result in maximum yield per unit area under the available resources. The maximum yield per unit area does not necessarily result in maximum benefit. Hargreaves and Samani(1984) discussed the parameters which affect the optimum area to be irrigated with limited water supply. Using production parameters from California, Hargreaves and Samani(1984) concluded that irrigating for maximum yield per unit area will result in maximum profit under the following conditions:

1- Land is limited and water is abundant.
2- Crop value and yields are high.
3- Rainfall makes little contribution to the crop water supply.
4- The irrigation costs are low.

Hargreaves and Samani(1984) concluded that under current economical conditions when rainfall makes little contribution to crop water requirement, irrigating for maximum yield normally results in maximum economical return. Using their common sense, Farmers who are faced with limited water supply and little rainfall often choose to irrigate for maximum yield and limit the area under cultivation. However, during the rainy season which follows the dry season, farmers have the opportunity to increase their benefit by spreading their limited irrigation water on more land.

This paper describes how crop yield models and economical parameters can be used to calculate the optimum amount of land which should be irrigated when rainfall contributes a significant amount of the crop water requirement.

CROP YIELD MODELS

Various crop growth simulation models have been developed for use with daily climatic data. Models designed for use with daily weather values include the Hanks(1974) PLANTGRO model; CERES-MAIZE, Jones and Kiniry(1986) and other CERES crop models(PNUTGRO, SOYGRO and CERES-WHEAT, IBSNAT publications, (1989). The use of predictive models

to evaluate plant yield as a function of soil water status has been reviewed by Hanks and Hill(1980) and by Vaux and Pruitt(1983). Hanks(1974) PLANTGRO model has proven applicable for
reasonable estimation of seasonal crop yield, as affected by differential water application(irrigation and rainfall). Hanks et al.(1977) validated the PLANTGRO model under several field conditions and concluded that this approach was a good tool to

simulate the effect of actual water application on Corn crop. There are two versions of the PLANTGRO model available. The first version relates the relative yield to relative transpiration as follows:

$$Y/Yp = T/Tp \qquad (2)$$

where Yp is potential yield when transpiration is equal to potential transpiration Tp; Tp is defined as transpiration when soil water availability does not limit transpiration, and T is the actual transpiration. Equation (2) is recommended for dry matter prediction. In the second version of the PLANTGRO model which is recommended for grain prediction, the growing season is divided into several stages, according to the approach presented by Jensen(1968) as follows:

$$Y/Yp = (T1/Tp1)^{L1} * (T2/Tp2)^{L2} \ldots\ldots\ldots \qquad (3)$$

Where L is stage weighing factor. In a personal communication with the senior author, Hanks(1987) recounted the second version of his model stating that the spatial variability of stage weighing factors(L) is so significant that the second version of the model does not provide any improvement over the first version and that until a suitable approach for evaluating the complicated process of stage stress on final grain yield is found we might as well use the first version for both grain and dry matter prediction.

Based on the authors experience no yield model can always predict the final yield with 100 percent accuracy. Nevertheless, Until better crop yield models are developed ,the existing models are good tools for decision making in agricultural management. In describing the methodology for designing a supplemental irrigation system in this paper, the PLANTGRO model was used. The methodology is not limited to PLANTGRO model and any other model can be used for this purpose.

PROCEDURE

In order to describe the methodology for designing a supplemental irrigation system, a station in El Salvador was selected. This site was used since this is an area with shallow soil and erratic rainfall with long history of yield loss due to insufficient rainfall. The irrigation systems are limited and only part of the land can be cultivated during the dry season. The farmers depend mainly on rainy season crop production for survival. Before using the PLANTGRO model for decision making regarding the design of a supplemental irrigation system in the area, it was decided to test the model predictions against measured yield values in the area. Measured Corn grain yield values and other agronomical parameters were available from James and Stutler(1982) for San Andres station in El Salvador. The PLANTGRO model was used to predict the yield under the above climatological conditions. Figure 1 shows the measured and predicted relative yield values. While the model prediction for more than fifty percent relative yield was reasonably good, the model overestimated the low yield values. A close examination of the data reported by James and Stutler(1982) showed that these were the treatments which were heavily fertilized and subjected to water stress. This type of overestimation therefore can be expected from the PLANTGRO model since it does not take into account the stress caused by fertilizer. The positive aspect of the model prediction was that it closely predicted the values at higher than 50% relative yield which is the range for economical production of corn in the area for both rainfed and irrigated conditions.

Figure 2, shows the year to year variability of corn yields for a station in El Salvador under rainfed agriculture. The variability is caused by spatial variability of rainfall and the shallow soil conditions. The risk of losing a large portion of the crop due to draught is high. Irrigation can reduce the yield variability. However, there is not enough water to irrigate all the land. If we assume that at the station shown in figure 2 there is enough water to irrigate only ten percent of the land during the dry season, how much land can be irrigated during the rainy season?. This question can be answered by examining the alternatives using the PLANTGRO model and economical parameters. If a pump is producing enough water to irrigate only 10 percent of the land during the dry season, the same pump can be used to irrigate 20%, 30%, 40% ... or 100% of the land during the rainy season simply by increasing the irrigation interval or decreasing the depth of applied water proportionally. To do this extra irrigation equipment at additional cost needs to be purchased. The PLANTGRO model together with long-term climatological data and soil parameters are used to generate a series of yield values from each of these alternatives. The net benefit from each alternative is then calculated by subtracting the total income from the cost of production. Figure 3, shows the calculated long-term average net benefit using 13 years of climatological data and other local economical parameters (irrigation cost, price of yield etc.). As is shown in figure 3, the average income has increased by $15 per hectare by stretching the water to 50% of the land. Based on the analysis shown in figure 3 irrigating 50% of the land would be the optimum if the objective is to increase the long-term average income. However, when dealing with low income farmers, it might be desirable to try to increase the minimum income during the worst year instead of increasing the average benefit. Figure 4 shows the optimum amount of land(20%) to be irrigated to maximize the minimum farmer's income during the worst year.

The optimum amount of land to be irrigated also depends on the extra cost of irrigation system. Figure 5 shows the effect of irrigation cost on optimum percent of irrigable land. As is shown in figure 5, as the cost of irrigation increases, the optimum percent of irrrigable land approaches that of the dry season.

WEATHER GENERATING MODEL

In the above analysis, the actual measured climatological data was used to calculate the optimum amount of irrigable land during the rainy season. In many cases the long-term day to day climatological data are very difficult to obtain. In this case the alternative would be to use a weather generating model to simulate the long term climatological data using a data base. One such model was described by Samani et al(1987). The WMAKER model described by Samani et al(1987) can be used together with the data base which is now available for Latin America, Africa and part of Asia, to generate the long-term climatological values. Figure 6 compares the optimum irrigable area calculated using WMAKER generated climatic values and measured climatic values. The result obtained from using WMAKER is reasonably close to the result obtained from measured climatic data.

SUMMARY AND CONCLUSIONS

The optimum amount of land to be irrigated for maximum benefit under a limited water supply was calculated for a station in El Salvador. PLANTGRO model was used to calculate the long-term yield values for each alternative. The long-term yield values together with local economical parameters were then used to calculate the net benefit. It was shown that the optimum amount of land to be irrigated in the rainy season with a limited water supply is a dynamic parameter which depends on spatial variability of rainfall, soil parameters, economical parameters and management objectives.

When the long-term climatological data are not available, a weather generating model can be used together with a data base to generate the climatological information. Even though the present crop yield models leave more to be desired, they can be used as a tool to project the optimum amount of land that can be irrigated in the rainy season. The crop yield models, the weather generating models and some common sense combined with local farmers experience can lead to better water management practices.

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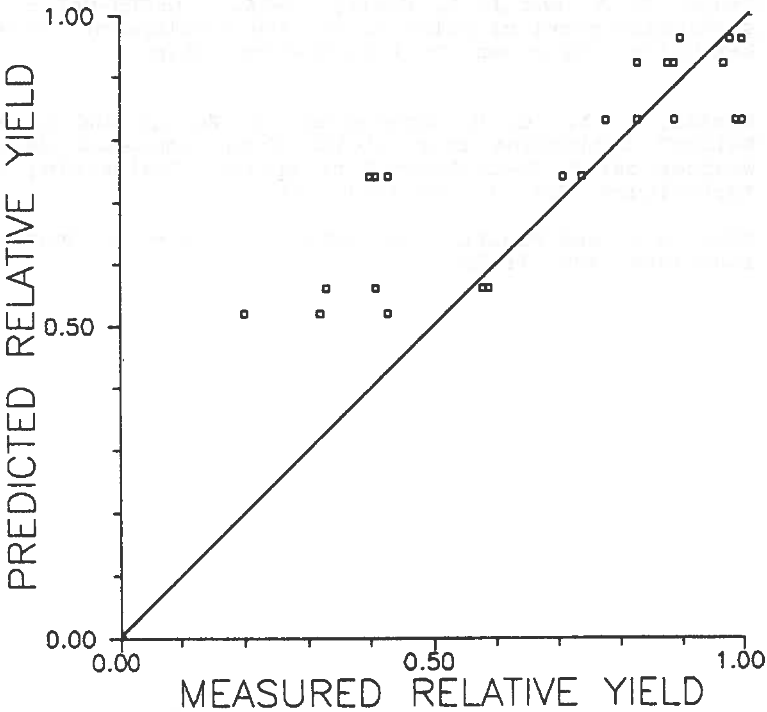

Figure 1- Comparison of measured and predicted relative yield for San Andres, El Salvador.

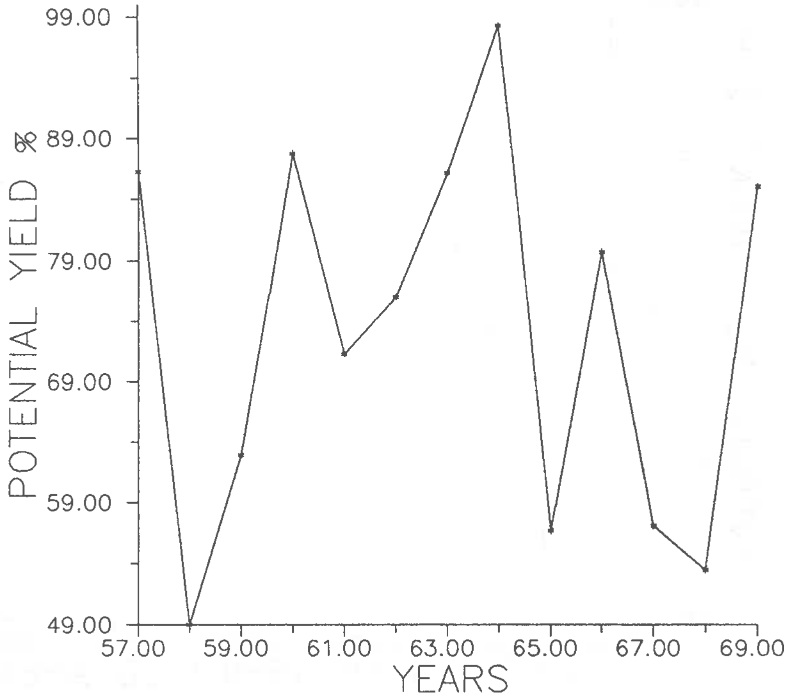

Figure 2- Year to year variability of corn grain yield simulated by PLANTGRO model for La Union, El Salvador.

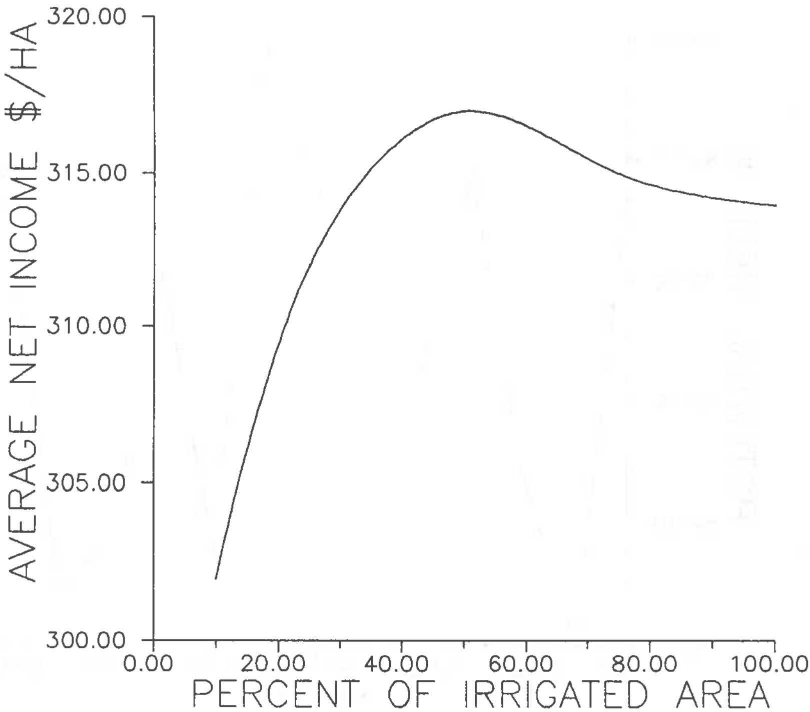

Figure 3- LOng-term average net income versus percent of irrigated area during the rainy season(La union, E. S.).

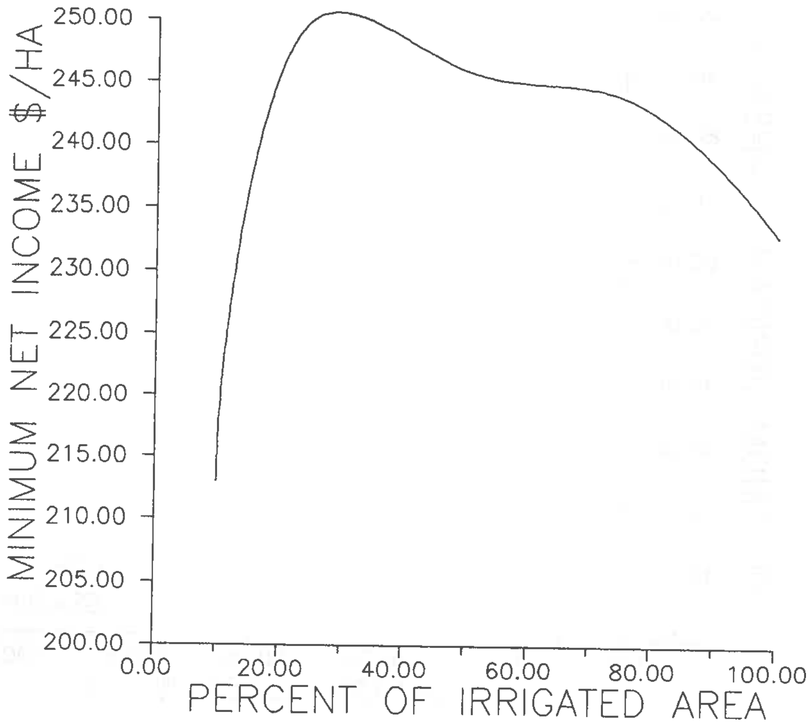

Figure 4- Long-term minimum net benefit versus percent of irrigated area during the rainy season(La union, E.S.)

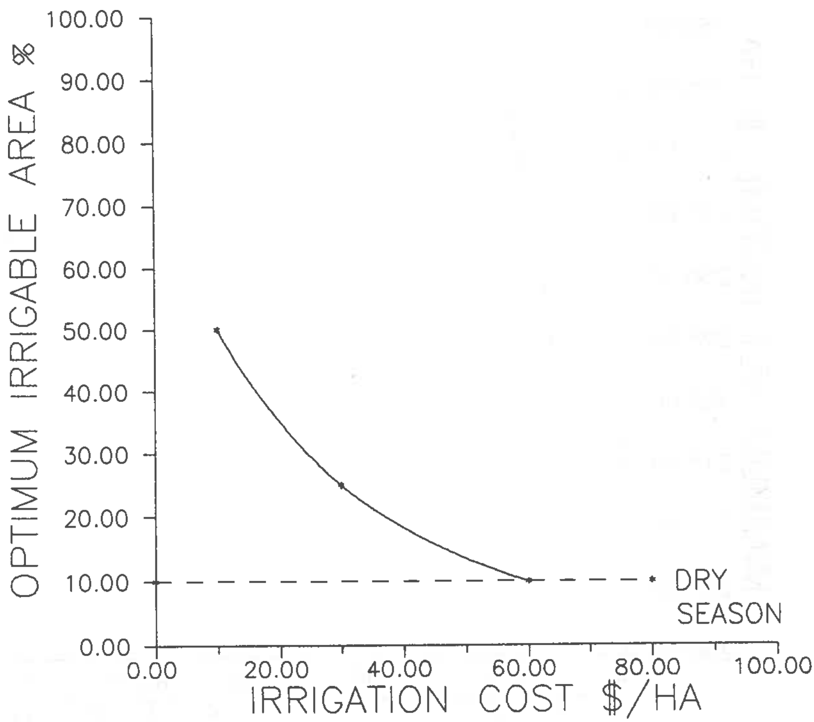

Figure 5-Effect of irrigation cost on optimum irrigable area (La union, E.S.).

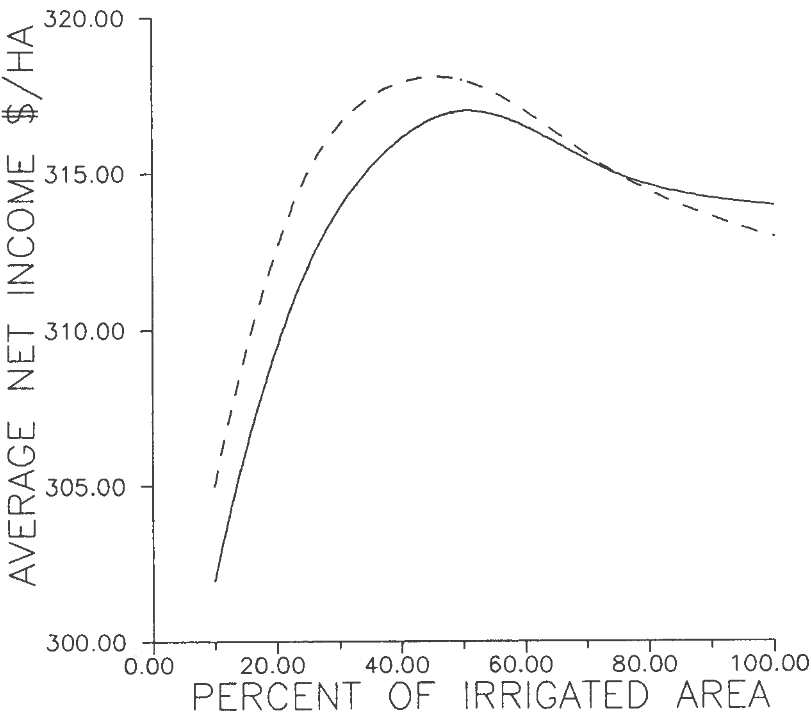

Figure 6- Long-term average net income versus percent of irrigated area using measured climatological data(solid curve) and WMAKER generated data(Dashed curve).