Description of the Deficit Irrigation Economics Model

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General Comment

This spreadsheet is a model that is described in detail in: Trout, T.J. and D.T. Manning. 2019. An economic and biophysical model of deficit irrigation. Agron. J. 111:1–12. doi:10.2134/agronj2019.03.0209

General Instructions

This spreadsheet progressively presents a biophysical and economic model of deficit irrigation with water leasing. Parameters are input into the yellow highlighted cells of each worksheet. Parameters from previous worksheets are copied to following worksheets. Relationships are graphed. Final output is the net income (NI) for a given set of biophysical and economic parameters.

WPF Model - Water Production Function and Water Productivity (3 input parameters)

The normalized Water Production Function (WPF) model is based on normalizing both the yield and ETc relative to the maximum Yield (Yp) and maximum (potential) ETc (ETp). The normalized WPF is modelled as a 2nd degree polynomial: YR = A + Bx + Cx2 where x = the relative ET. The coefficients of the normalized WPF are derived based on a relative ET value, x2, for which the projected yield is YR2, and the degree of curvilinearity, represented by the coefficient of the squared term (C). A common scenario is YR2 = 0 at x = x0. The C coefficient can vary from 0, which produces a linear WPF, to negative values that produce concave downward WPFs. With these assumptions, the remaining polynomial coefficients (A and B) are derived, and the WPF is plotted (Fig (a)). Three WPFs can be compared with the right side graph.

Through algebraic manipulation of the normalized WPF, the water productivity (WP = Y/ET) and the marginal WPF (derivative of WPF)are derived and shown on graphs (b) and (c). The relative ET value is determined that gives the maximum WP, and the minimum relative ET that produces WP>1 (the lower end of the range for which WP>1). These points are shown on the WPF graph. For deficit irrigation to be potentially beneficial, the marginal WPF should be less than or equal to 1 at x = 1 (C > (1-B)/2).

IrrReq - Irrigation Requirement and Marketable CU (11 Input Parameters)

The Irrigation Requirement is based on ET being met by the sum of three sources of water: Irrigation Supply (IS), Seasonal Precipitation (R), and use from Soil Water Storage (S). Each source has an associated "effectiveness" or use efficiency, or that portion of the water source that is used for ETc. The three efficiencies, Ei, Er, and Es, vary with the relative ET and thus can be derived as a function of x. All three efficiencies are assumed to be 1 (100%) at low ET (large deficit), and decrease to a minimum value at full ET (x=1). The relative decrease is assumed to be concave or linear and is modeled as a second degree polynomial. The amount of effective rainfall and water from storage is then calculated along with the irrigation supply required to meet the target ET.

Precipitaton Efficiency, Er: User inputs an assumed precipitation efficiency at full ET, Er1; the relative ET value, xr, below which Er = 1; and a quadratic coefficient, G, that defines the curvilinearity of the relationship between these two points. The other two polynomial coefficients are calculated. The quadratic coefficient, G, will be <=0, with 0 providing a linear relationship. Er values must be limited to <= 1.0.

Storage Efficiency, Es: Model assumes the storage efficiency at full ET, Es1, is 0 (no net use of soil water storage over the season; same storage at the beginning and end of the season). User inputs the relative ET value, xs, below which all of the available soil water storage is used (Es = 1) and a quadratic coefficient, K, that defines the curvilinearity of the relationship between these two points. The other two polynomial coefficients are calculated. The quadratic coefficient, K, will be <=0, with 0 providing a linear relationship. Es values must be limited to <= 1.0.

Irrigation Efficiency, Ei: User inputs an assumed irrigation efficiency at full ET, Ei1; the relative ET, xi, below which Ei = 1; and a quadratic coefficient, N, that defines the curvilinearity of the relationship. The other two polynomial coefficients are calculated. The quadratic coefficient, N, will be <=0, with 0 providing a linear relationship.   Ei values must be limited to <= 1.0.

Irrigation Requirement, IR, and Supply, IS: User inputs a seasonal precipitation amount, R; a total soil water storage at the beginning of the season, S; and a seasonal potential ET, ETp. The irrigation requirement is calculated as the ET (ETp*x) minus the effective seasonal precipitation, Re (R*Er(x)) and minus the effective storage, Se (S*Es(x)), all of which are functions of the relative ET. The required irrigation supply is then IR/Ei. These are plotted vs. x.

Production Function: The relative yield, YR, is plotted as a function of actual crop ETc, IR, and IS. This demonstrates the effect of precipitation, soil water storage, and irrigation efficiency on the crop production function. Note that the IR and IS production function intercepts are positive if R + S is larger than ETp*x0, and their slopes are less than that of the ET WPF.

Three Marketable ET values for a historically fully irrigated field are calculated and shown on the figure with 3 different assumptions. Historic CU is calculated as historic ET minus effective precipitation under fully irrigated conditions. Method 1 assumes precipitation use efficiency does not change with relative ET, and no net use of water from soil water storage. Method 2 assumes precipitation use efficiency does increase with declining ET and no net use of water from soil water storage. Method 3 assumes precipitation use efficiency does increase with declining ET and net water use from soil water storage increases with declining ET.

EconModel: Net Income Economic Model based on leasing of saved ET (7 input parameters)

The economic model applies yield income, water lease income, costs of production, and water costs to the WPF and irrigation requirement models to calculate the net income with leasing based on reduction in consumptive use (Eq. 15). Potential yield, the historic consumptive use, and costs and prices are input into row 6. The upper portion of the worksheet calculates the various physical parameters for a given relative ET (input into cell C9) based on biophysical coefficients from column L and these cost/prices. Er, Es, and Ei are limited to <= 1.0, and Y and IR are limited to >= 0. Cell D6 calculates a Wc value based on historic full irrigation and the parameters. Note that default biophysical parameters are copied from the previous spreadsheets, but can also be input into column L.

The middle portion of the worksheet calculates the net income for a range of relative ET values and the parameters input above and plots the results. The maximum net income and xop (determined numerically to +-0.01) is also plotted.

The lower table calculates NI for a range of relative ET values based on the approximate model (Eq. 15b) and calculates xop' and maximum NI based on the approximate solution (App 2 in the Agron J paper). An initial Ei is input into cell A73 (default value 0.75). Ei is then adjusted to the actual Ei at xop', and xop' is recalculated for two iterations. The approximate solution is shown on the graph above. The approximate NI model with Ei at xop' is graphed along with the exact model to show the bias in the approximate model. The graph shows that the approximate solution over-estimates xop due to the bias in the approximate model.

EconModel II: Net Income Economic Model based on leasing of Irrigation Supply (7 input parameters)

This model is the same as the above model except leasing is based on saved irrigation water supply, IS (Eq. 16). Potential yield, the historic irrigation water use, and costs and prices are input into row 6. The upper portion of the worksheet calculates the various physical parameters for a given relative ET (input into cell C9) based on biophysical coefficients from column L and these cost/prices. Er, Es, and Ei are limited to <= 1.0, and Y and IR are limited to >= 0. Cell D6 calculates a Ws value based on historic full irrigation and the parameters. Note that default biophysical parameters are copied from the previous spreadsheets, but can also be input into column L.

The middle portion of the worksheet calculates the net income for a range of relative ET values and the parameters input above and plots the results. The maximum net income and xop (determined numerically to +-0.01) is also plotted. Note that, for the same parameters, NI for model II will be higher than for the model based on IR because the amount of leasable water is increased. In areas where leasing of water supply is allowed, the lease price, Pw, will generally be lower than where only the CU portion of the water supply can be leased. There is no approximate optimum relative ET for this condition.

PriceSens: Analysis of price effect on optimum relative ET and maximum net income (1 input parameter)

The EconAnal worksheet compares the optimum relative ET and maximum NI for a range of crop and lease prices based on the approximate solution. Crop price (Py) is input into cell G7. All other parameters and coefficients are copied from the EconModel worksheet. xop' and NIM are calculated and graphed for a range of lease prices (Pw). Irrigation efficiency, Ei, is iterated once. Effects of crop and lease prices can be compared. Because these results are based on the approximate solution, they will slightly overestimate xop and underestimate NIM.

The lower section is an example of graphing xop' and NIM for 3 crop prices. Values are calculated in the upper section and values copied to this section for plotting.