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EPIC-JORDAN: A CROP SIMULATION MODEL USED FOR ANALYZING AGRICULTURAL PRODUCTION IN THE MAFRAQ AREA OF JORDAN

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INTRODUCTION

Recent advances in crop growth modelling make it possible to predict crop yields under a wider variety of conditions than could ever be feasibly tested in experiments and field trials. Models that can predict yields that will be realized under a wide range of moisture conditions are particularly useful for comparing alternative crops and practices for rainfed crop production in areas with marginal and highly variable rainfall. Field trials would need to be carried out for several years before it would be possible to determine how a new crop variety or farming practice would perform over the entire range of weather conditions that may occur in any year.

Modelling also can be useful in predicting long-run consequences of cropping systems and practices without the necessity of continuing experiments or observing changes over a number of years. One recently developed crop growth model, The Erosion Productivity Impact Calculator (EPIC), adds the capability to trace out long-run changes in productivity that will results from the cumulative effects of erosion and deterioration in soil qualities.

This document reports the adaptation of the EPIC model for use in long-run yield predictions in rainfed barley cropping areas of Jordan. Rainfed barley areas are generally in the zone that receives annual rainfall averaging from 200 millimeters (mm) to 350 mm; but rainfall varies widely from year to year.

Studies of agricultural alternatives in the rainfed area of Jordan can benefit greatly from ability of crop growth models to predict outcomes over a wide range of

weather conditions and to trace out long-run consequences of alternative cropping systems.

Study Area

Jordan is a relatively small and mostly semi-arid country. Only 790,000 hectares of land have a combination of soils and climate suitable for rainfed agricultural production, and irrigated land is also limited. Jordan's agriculture is able to supply less than 30 percent of the food demands of its 3 million people. Still agriculture is an important component of the Jordanian economy as it contributes approximately 12 percent of the gross domestic product and provides employment for 14 percent of the work force (el-Hurani). There is a need to sustain and, if possible, increase agricultural productivity.

Our study focuses on rainfed agriculture in the zone which receives annual rainfall averaging 200-350 mm. This zone occupies about 560,000 hectares throughout Jordan and contains approximately 70 percent of Jordan's cultivated land. A traditional form of agriculture is practiced in the area with a minimum of modern, productivity-enhancing inputs.

The study area chosen to represent this marginal zone is the Mafraq area which is located in Northeast Jordan. Based on a survey conducted in 1988 (Oglah and Jaradat), the Mafraq area can be divided into eastern and western subregions. Barley is currently the major crop in the eastern zone, where rainfall averages between 200 and 250 mm. In the western zone, which averages up to 350 mm. of rainfall, wheat,

lentils, vetch, and summer vegetables are grown. Livestock, sheep and goats, is very important in both subregions as well as throughout the rest of Jordan.

The climate in Jordan is Mediterranean with hot dry summers and mild wet winters. There is extreme rainfall variability within the year and from year to year. Total precipitation declines and becomes more variable as one moves from west to east. Potential evapotranspiration exceeds precipitation during at least seven months of the year in most parts of the country. Wind erosion is a serious problem in the dry season, and occasional high-intensity rainstorms can lead to water run-off and soil erosion (Jaradat and Abu Mushrif).

Conditions in 1986 provide an example of the problems faced by Mafraq farmers. Precipitation was limited to 150 mm. In this year, 17,000 hectares in the Mafraq area were planted with barley and other winter crops. Much of the barley was needed to feed 600,000 head of livestock; however, low barley yields forced farmers to either purchase most of their feed requirements or transport their sheep to high rainfall areas for grazing (Oglah and Jaradat).

Efforts to improve productivity and welfare of farmers in the Mafraq area must address their problems which include: management of the risk inherent to dryland agriculture; control of erosion and soil degradation; management, conservation and improvement of soil moisture and fertility; and better integration between livestock and crop production.

I. MODELLING AS AN ALTERNATIVE TO EXPERIMENTAL RESEARCH.

Many technologies, which have proven to be effective elsewhere apparently posses the potential for increasing resource productivity and resource conservation in Jordan. These technologies include the use of a ley farming system where winter cereals are alternated with a nitrogen fixing forage crop such as vetch or medic incorporation of crop residue into the soil, application of fertilizers, and conservation tillage.

Because soil moisture is the most limiting factor in crop growth and productivity in the Mafraq area of Jordan, practices which increase soil moisture efficiency have the greatest potential for increasing the long run productivity of resources devoted to agriculture. For example, crop residue retention, through the use of minimum tillage techniques and refraining from grazing all crop stubble, could increase yields through higher rates of soil organic matter and improved utilization of rainfall, as well as decreasing soil erosion. The introduction of new cultivars may also boost yields and resource productivity.

Experimentation with these alternatives is by itself an expensive and time consuming way to search for solutions to these problems. Experiments designed to test new technologies may suffer from drawbacks such as the lack of necessary infrastructure, the need to train personnel who are inexperienced with the technologies being studied, and the difficulty in financing such research. Several years of study are usually required for experiments to yield meaningful results, which may indicate that the technology is inappropriate for the region under study. Therefore, time, financial,

and logistic constraints limit the use of experiments as a means of testing yield-enhancing technologies.

On the other hand, modelling crop production and the farmer's production decision process can help identify practices and policies with the greatest potential for increasing agricultural production. Furthermore, modelling results can help researchers to better understand the processes involved in agricultural production and to identity and focus on priorities for further experimental research.

A whole farm model is a useful tool for analyzing the decision making process of the farmer. Such a framework provides opportunity to specify a typical farming operation and to represent the adoption of new technologies under conditions where resources are limited. A crop production simulation model can provide the information necessary to evaluate different crops, technologies, operations and schedules suited for the area under study. It can also provide coefficients on crop yield and variability for a whole farm model.

II. THE WHOLE FARM MODEL APPROACH

A whole farm mathematical programming model is a useful and widely recommended methodology for the appraisal of small-farm technology options. Such a model can be used to evaluate the farmer's decision options under limited endowments of land, labor, capital, and time (Butcher and Day). These models can be used to examine the objectives of a typical farming operation such as utility or profit maximization given these constraints.

A critical point in building a mathematical programming model is determining crop production under a variety of available technologies given the farmer's set of resource endowments. In general, experimental and farm-level data have been used to estimate these relationships. More recently, crop simulation models have been used to generate production coefficients for mathematical programming models. Simulation models have become increasingly popular because of the expense and difficulty of obtaining experimental farm-level data.

III. CROP SIMULATION MODELS.

Crop simulation models predict the influence of climatic, soil, and managerial factors on crop production. By predicting crop yields under various farming conditions, simulation models aid in evaluating the risks and benefits of different management practices (Steiner).

A. ALTERNATIVE CROP MODELLING APPROACHES

A desirable crop model to simulate the farming conditions in the Mafraq area of Jordan should have the following characteristics:

1. Be flexible enough to simulate cropping systems such as cereal grain and legume crop rotations. Barley fallow is the main crop rotation practiced in the area. Vetch has been recommended as an alternative to fallow by area agronomists.

2. Be simple enough to require only basic data. Data is often lacking in places like the Mafraq area of Jordan. The calibration of a crop model depends on the estimation of parameters that in many cases are unavailable. It is important to find a crop model that predicts reasonably well while requiring only a minimal amount of input data.

3. Be sensitive enough to show differences when growing conditions are severe. For the Mafraq area, rainfall is the most limiting factor to crop production in most years. However, in other years, when deficiencies in soil nutrients limit production, rainfall is sufficient.

4. It must produce output on erosion rates as well as showing the influence of erosion on crop production, in addition to predicting crop yields. Such information can be employed in the whole farm model in analyzing current farming practices in the area, and in predicting the impact of new and improved technology on immediate and long-run yields in the Mafraq region.

Crop simulation models range from the very simple to the very complex, depending on the objectives of their use. For example, a simple model presented by Steward was developed to predict wheat production in Jordan based on correlations between the onset of the rainy season and the amount, duration and intensity of total seasonal rainfall. The model predicts yields based on a water-production function where a response farming system is followed. This model is site specific and useful for making decisions during the cropping season. However, it can not be used to generate the data needed for building a whole farm model.

Intermediate level models aimed at predicting crop biomass and economic yield production are in general based on the transpiration and photosynthesis processes that control crop growth (Steiner). For example, a model presented by Campbell and Diaz is based on the assumption that crop dry-matter production is closely related to the quantity of water transpired by the crop. In this model, transpiration is the residual component of the water budget in the soil-plant system. The model produces only a generic total dry-matter biomass. Though the model is fairly simple, it requires a considerable amount of specific experimental information to obtain only dry-matter

biomass, and is therefore unsuitable as the base for building a mathematical programming model.

The peanut crop-growth simulation model (PNUTGRO) is another intermediate level (much more developed) model. It was developed specifically to simulate the growth of peanuts, but could be adapted for other legumes. The model emphasizes physiology, while treating soil only as a source of water. It predicts and compares phenological characteristics and biomass production and also partitions biomass into crop, stem and leaves, and root components. With these features, the model is better suited for studying plant physiology under different environmental conditions with the goal of evaluating new crop cultivars than for predicting crop production under different rates of chemical fertilizers, under a variety of rotations, and in reaction to soil erosion.

The grain sorghum crop growth model (SORKRAM) is another intermediate level model (Rosenthal, Vamderlip, Jackson, and Arkin). This model describes the morphological development of a well fertilized, sorghum plant. It is a detailed growth model where potential evaporation and the leaf area index determine plant transpiration, which is linearly related to dry matter production. The model follows the detailed phenological development of the plant from emergence to maturity and requires input information concerning plant site, soil, and cultivar characteristics.

SORKRAM has been used to examine crop plant productivity under different population levels, alternative sowing data, and various irrigation schemes. It has also been used in examining the affect of changing levels of precipitation and soil fertility on

sorghum grain production. As with other crop specific models, SORKAM does not account for rotational effects on crop production, which are important considerations in a mathematical programming model. The model also ignores plant responses to soil erosion.

B. THE EPIC MODEL

The search for a more complete model led us to the Erosion Productivity Impact Calculator (EPIC). This model was created by a U.S. Department of Agriculture research team at the Agricultural Research Services, Blackland Experiment station in Temple, Texas (Steiner, Williams and Jones). EPIC was developed as part of a national effort to develop a method for assessing the impact of erosion upon productivity. Specifically, it was developed to examine erosion-productivity relationships on cropland throughout the U.S. It is an intermediate level model with capability for simulating different crop rotations, cultural practices, tillage techniques, residue management regimes, and fertilizer levels.

The EPIC model best fulfilled the requirements of our research on soil and moisture management alternatives for the semi-arid lands of Jordan and the Middle East. EPIC is flexible. By changing the crop parameters input file it is possible to simulate cereal grains, legumes, and even perennial crops. The ability to generate weather data makes it particularly suitable for areas, like Mafraq, where historical data is incomplete or unavailable. It also supplies reasonable estimates of many variables whenever data are not available. However, lack of actual data can reduce the model's precision.

Another factor influencing the adoption of this model was the fact that there were training sessions available and a detailed user guide (Williams, Jones, and Dyke).

EPIC was initially adapted to Jordanian conditions by Dr. Abdullah Jaradat of the Jordan University of Science and Technology. Early use of EPIC-JORDAN produced acceptable results and confirmed our choice to develop the model for use in simulating rainfed crop production in Jordan.

THE EPIC SIMULATION MODEL

EPIC is a computer model, written in FORTRAN, that uses a daily time step to simulate crop growth under a variety of soil and climate conditions. The computer program reads data, initializes variables, and calls subroutines to do the daily simulation and to summarize and output data. EPIC is also designed to examine the cumulative effects of erosion on soil productivity over hundreds of years if necessary.

The components of EPIC include hydrology, weather, erosion, nutrient cycling, plant growth, soil temperature, tillage and economics. The hydrology model simulates surface runoff volume, peak discharge rate, evapotranspiration, percolation, lateral subsurface flow, drainage, irrigation, and snow melt. Wind erosion is predicted using a modification of the Manhattan- Kansas wind erosion model. Water erosion can be simulated with any of three modifications to the Universal Soil Loss Equation.

The two plant nutrients considered in EPIC are nitrogen and phosphorus. Nitrogen processes simulated include loss of NO_3 by runoff and leaching, organic N transport by sediment, denitrification, immobilization, mineralization, and crop uptake. Fertilizer, N fixation, and rainfall can provide N to the system. Phosphorus processes

simulated include runoff of soluble P, sediment transport of mineral and organic P, immobilization, mineralization, sorption-desorption, crop uptake, and fertilization.

A general plant growth model is used to simulate light interception; energy conversion to biomass; partitioning to roots, shoots and economic yield; and water and nutrient uptake. Plant growth is constrained by water, nutrients (N and P), air temperature, and soil aeration stresses. Soil temperature is a function of the previous day's soil temperature, the present day's temperature, surface albedo, and solar radiation.

The tillage sub-model simulates row height, surface roughness, bulk density changes, and mixing of soil layers, nutrients, and plant residue by any tillage operation. The economic component uses a crop budget to calculate crop production costs, and income is determined from simulated annual crop yields.

I. INPUT REQUIREMENTS FOR EPIC

The input data is contained in three files: an input file, a crop parameters file and a tillage parameters file.

A. INPUT FILE

The input file in use is presented in Figure 1. It is divided into: general input information related to the specific run, the program control codes, general data of the drainage area, water erosion data, weather data, wind erosion data, wind data, soil data, management information and operation codes, and a set of operation variables. In addition, EPIC has two data-base files containing weather data for more than 150

Figure 1. Input Data File for EPIC.

```
BVCBT93X  6 (1-28-90)
14 YEARS  RUN STARTS=05-20
LESS THAN 300 MM OF ANNUAL RAINFALL
 141976   5  20   3   1   0 -14
   1.000  86.000    .100   .0250    .050    .050   1.000  32.340  -520.    .000
    .500 300.000  350.0
  50.000   .0100    1.0
   14.00   30.00    7.00     .00     .00
 13.30 15.20 18.20 23.40 28.00 30.80 31.90 31.60 30.50 26.80 19.60 14.60
  3.90  4.80  6.20  9.30 12.30 15.30 16.70 17.30 15.90 13.10  8.60  4.70
  1.30  2.30  1.40  1.50  1.50  1.00  1.00  1.40  1.20  1.40  2.60  1.90
  1.20  1.00  1.20  1.50  1.50  1.10  1.00  1.00  1.00  1.00  2.10  1.30
  65.1  54.3  49.2  17.3   2.6    .1    .1    .1    .1   6.7  31.5  50.7
   9.0   6.8   7.1   5.8   5.6    .1    .1    .1    .1   5.0   8.6   8.2
  4.70  1.87  1.78  2.01  2.83  2.00  2.00  2.00  2.00  2.15  2.15  2.11
  .199  .180  .139  .069  .015  .010  .010  .010  .010  .034  .089  .160
  .534  .552  .544  .367  .179  .010  .010  .010  .010  .306  .460  .468
  6.50 12.50  5.00  2.50   .10   .10   .10   .10   .10  3.50  2.50  9.00
  10.0   5.0   5.0   2.0    .1    .1    .1    .1    .1   5.0  10.0  12.0
  290.  361.  454.  584.  666.  730.  725.  680.  586.  459.  323.  259.
   .67   .62   .58   .49   .33   .41   .44   .47   .48   .50   .58   .68
  2.000  2.000 90.000   .000
    .50  80.00    .00
  5.81  5.81  6.26  6.26  5.81  5.81  4.92  4.92  4.47  4.47  4.92  5.36
   10.    9.    8.    7.    5.    2.    2.    2.    4.    7.    6.    7.
    6.    7.    6.    7.    3.    3.    2.    3.    6.    5.    9.    3.
    5.    6.    6.    6.    5.    4.    4.    4.   10.    6.    6.    3.
    2.    3.    3.    3.    4.    3.    3.    5.    5.    3.    6.    2.
    2.    3.    4.    3.    4.    3.    5.    5.    7.    3.    3.    2.
    3.    4.    5.    4.    5.    6.    6.    7.    8.    6.    4.    3.
    8.   10.    9.   12.   13.   16.   16.   17.   16.   17.    3.    8.
   12.   11.   13.   17.   17.   23.   18.   21.   15.   12.    8.   13.
   13.   11.   12.   16.   18.   21.   21.   18.   14.   12.   12.   12.
    5.    4.    5.    5.    6.    7.    8.    6.    4.    4.   15.    6.
    4.    5.    4.    3.    3.    3.    6.    5.    4.    4.    5.    5.
    1.    1.    2.    2.    1.    1.    2.    1.    1.    1.    4.    2.
    2.    3.    4.    2.    2.    2.    1.    1.    1.    2.    2.    4.
    3.    3.    4.    2.    2.    1.    1.    2.    1.    2.    2.    5.
    8.    9.    6.    4.    2.    1.    1.    1.    2.    5.    6.    9.
   10.    9.    8.    5.    3.    1.    1.    1.    1.    5.    3.    8.
    .12    .00    .00    .00    .00    .00    .00    .00    .00
   .010   .320   .580   .890  1.160  1.500   .000   .000   .000   .000
  1.110  1.210  1.290  1.290  1.260  1.230   .000   .000   .000   .000
   .227   .221   .242   .251   .272   .285   .000   .000   .000   .000
   .312   .301   .314   .312   .343   .344   .000   .000   .000   .000
   12.5   12.5   12.5   12.5   12.5   12.5     .0     .0     .0     .0
   43.0   43.0   43.0   43.0   43.0   43.0     .0     .0     .0     .0
   570.   498.   414.   404.   384.   384.     0.     0.     0.     0.
    8.1    8.1    8.3    8.3    8.4    8.4     .0     .0     .0     .0
     .0     .0     .0     .0     .0     .0     .0     .0     .0     .0
   .600   .570   .420   .340   .250   .200   .000   .000   .000   .000
   12.5   12.5   12.5   12.5   12.5   12.5     .0     .0     .0     .0
   29.0   29.0   29.0   29.0   29.0   29.0     .0     .0     .0     .0
     .0     .0     .0     .0     .0     .0     .0     .0     .0     .0
     5.     5.     4.     4.     3.     3.     0.     0.     0.     0.
    12.    12.    10.     9.     7.     7.     0.     0.     0.     0.
   .000   .000   .000   .000   .000   .000   .000   .000   .000   .000
  1.320  1.450  1.660  1.660  1.680  1.630   .000   .000   .000   .000
   .000   .000   .000   .000   .000   .000   .000   .000   .000   .000
   .000   .000   .000   .000   .000   .000   .000   .000   .000   .000
     0.     0.     0.     0.     0.     0.     0.     0.     0.     0.
    3.0    2.0    2.0    1.0    1.0    1.0     0.     0.     0.     0.
  2  0  0  0  0  0  0
   .000   .000   .000   .000   .000   .000   .000   .000   .000   .000
  5  15  48  73
  6  10   1
  9  15   2
 11  10   2
 11  15  17   6
 11  15  45        60.     0.     0.

  5  15  46   6
  5  16  47   6
  7  10   1
  9  15   2
 11  10   2
 11   1  17  73
```

RAMRAIN3.PRN

locations and soil data for more than 700 soil classes in the United States. This data is already formatted for its direct use by the model.

The first 8 characters of the first line in the input file are a run name. This identification title is printed as a heading in all the output files created by EPIC. The codes identifying the different runs in use EPIC-JORDAN are:

Column 1	Crop 1: B=Barley, V=Vetch, F=Fallow.	
Column 2	Crop 2: B=Barley, V=Vetch, F=Fallow.	
Column 3	Tillage: M=Minimum, C=Conventional.	
Column 4	Erosion: W=Water, A=Wind, B=Both, N=No Erosion.	
Column 5	Farm practices:	1=Traditional 2=Innovative
Column 6	Percentage of crop residue removed:	0=None, all incorporated 1=10% removed 90% incorporated 9=90% removed 10% incorporated
Column 7	Nitrogen (N.) fertilizer level:	N= No fertilizer 1= 20kg/ha of N. 2= 40kg/ha of N. 3= 60kg/ha of N. 4= 80kg/ha of N. 5=100kg/ha of N. 6=120kg/ha of N.
Column 8	For future use.	

In the example presented in Figure 1 the run refers to "BVCBT93X" = Barley, Vetch rotation, Conventional tillage, erosion Both (water and wind), Traditional farm practices, 90% of residue removed and 10% incorporated into the soil, and 60kg/ha of nitrogen fertilizer applied.

After the title, the program control parameters start on the 4th line. The "-10" in line four of Figure 1 indicates that a feature called multi-run (MLRN) is being used. It indicates that after running the model for the first 13 years an input file called "MLRN2779.DAT" takes over the run and uses the same set of weather input data (rainfall) to run the model over and over again. This MLRN file consists of three

columns: the first one indicates the number of years of each multi-run, the second the presence of water erosion, and the third tells if wind erosion is specified. The MLRN2779.DAT in use the run reported in Figure 2 is:

13	0.00	0.00
52	1.00	1.00
13	.00	.00

This MLRN file will produce a sequence of: a run of 13 years without erosion, a 52-year period (series of four 13-year runs) with water and wind erosion, and finally another 13-year run without erosion. The first and last 13-year runs serve to compare yields and soils before and after 52 years of erosion.

In the 5th line of the input file the negative -520 is the average watershed elevation parameter ($ELEV^2$). This parameter is used in Hargreaves' equation, a new feature in EPIC, to estimate potential evapotranspiration.

An option is provided for inputting and/or simulating weather data. The weather input code (NGN) contains the identification numbers of the weather variables:

1. daily rainfall,
2. Maximum and minimum air temperature,
3. solar radiation,
4. wind speed, and
5. relative humidity.

Since all the other weather variables are rainfall dependent, rainfall must be input if any other variable is input. All simulations require certain monthly climatic parameters.

In the input file of Figure 1 daily rainfall is input and the other variables are simulated. The last line in this input file indicates the use of daily rainfall data contained in the file called "RAMRA1N3.PRN". The file contains 13 years of daily precipitation records starting in January of 1976 at Ramtha Agricultural Experimental Station (close to Irbid) in Jordan. The 13 complete weather years from 1976-77 through 1988-89 were used for the simulations.

B. THE CROP PARAMETERS FILE

This file includes the parameters necessary to simulate more than 60 crops from cereal grains to legumes and from annual to perennial crops. Crops now in use in EPIC-JORDAN are barley, crop number 6; weedy fallow, crop number 7; and vetch, crop number 73.

The weedy-fallow option was created to mimic Mafraq area farmers practice of letting weeds grow during the fallow year and then using the weeds as feed for grazing livestock. The EPIC parameters for weedy fallow are the same as the parameters of barley except that the Maximum Potential Leaf-Area index (DMLA), which is 4 for barley, is 0.5 for the weedy fallow. A lower DMLA reduces the rate of growth in the Leaf Area Index (LAI) thereby reducing estimated Photosynthetic Active Radiation (PAR) and the daily growth rate of biomass. The weedy-fallow "crop" is harvested (by grazing) in March, which is somewhat before the end of the growing season. The result is a reasonable simulation of biomass production and consumption of soil nutrients by the weedy fallow.

C. TILLAGE INPUT FILE

The third input file contains parameters to simulate more than 70 machinery operations. There are options for soil preparation, planting, spraying, cultivating, fertilizing, and harvesting. Harvesting operations in EPIC were modified to simulate the common Mafraq practice of removing all barley straw and aftermath by harvesting and/or grazing as discussed on page 18.

II. OUTPUT OPTIONS OF EPIC

The main output file generated by EPIC is divided into three major sections: (1) the input values and initial conditions; (2) simulation results reported daily, monthly, or annually; and (3) summary tables that include average variables, accumulated variables, and state variables. Crop production, erosion, state of the environmental variables, and a soil table are reported in the summary table after each period.

The main output file generated by EPIC can become voluminous if, for example, monthly data is produced for 50 years of simulation. An ASCII file editor, such as X-Edit for the main frame and K-Edit for microcomputers, is useful in manipulating and summarizing these large output files. The Macro options of a spreadsheet are also helpful.

CALIBRATION AND VERIFICATION OF EPIC-JORDAN

I. MODEL CALIBRATION

A. CROP GROWTH PARAMETERS

The first calibration of the EPIC model for Jordanian conditions was done by Dr. Jaradat. Barley, the principal crop in the study area, was modelled by adapting parameters from a typical U.S. barley cultivar. This model, called EPIC-Jordan, was compared to the model with the original parameters, called EPIC-U.S.

Differences in crop parameters between the two versions of the model are shown in Table 1. The Jordan cultivar has lower Biomass Energy Ratio (WA), lower Maximum Potential Leaf Area Index (DMLA), and lower Leaf Area Index Decline Rate Parameter (RLAD). The lower WA means lower efficiency with which solar energy is converted into potential (maximum) biomass. A lower DMLA reduces the rate of growth in the Leaf Area Index (LAI) thereby reducing estimated Photosynthetic Active Radiation (PAR) and the daily growth rate of biomass. On the other hand, the smaller RLAD parameter for the EPIC-Jordan model means that the decline in the LAI occurs more slowly in the Jordan version of the model.

The Optimal Leaf Area Development Curve (DPL2 or LAP2) determines when each of the crop growth stages begin. The changes made in EPIC-Jordan bring on the point of senescence faster, as it is adapted for a short season variety.

Table 1. Differences in barley-crop parameters between EPIC-JORDAN and EPIC-U.S.

Crop Parameters	EPIC-JORDAN	EPIC-U.S.
Biomass-Energy Ratio (WA)	25.0	35.0
Maximum Potential Leaf Area Index (DMLA)	4.0	8.0
Leaf Area Index Decline Rate Parameter (RLAD)	0.5	1.0
Point on Optimal Leaf Area Development Curve (DLP2 or LAP2)	60.9	59.9
Potential Heat Units (PHU)	1959	1675
Harvest Index (HI)	0.39	0.42

The PHU (potential heat units from planting to physiological maturity) parameter has an inverse effect on the heat unit index (HUI), which controls, among other important relationships, the partitioning of biomass between grain, roots and stems. The higher PHU in the Jordan version of the model (Table 1) causes, all else equal, a longer period for the crop to reach maturity.

The harvest index (HI) is the percent of above ground biomass that is harvested as economic yield (usually grain). In EPIC-JORDAN, the maximum HI for grain yield is 0.39 if there is no water stress conditions (Table 1). The HI in EPIC-JORDAN is made to be a function of water stress in the grain-filling period. If there is water stress, grain yield will be less than 0.39 kg. per kg. of biomass.

The HI also influences yields in subsequent years through its effect on crop residue (unharvested biomass) and hence on soil organic matter and soil nitrogen levels. The lower the HI, the more biomass is left on the field for incorporation into the soil and the greater yields will be in the next year due to reduced nitrogen stress.

It was necessary to find the means of simulating the removal of straw and other residue from cropland, as is currently practiced in Jordan. Residue removal is simulated by having an initial grain harvest with the HI parameter internally calculated by the model, followed by a second (stubble) harvest operation with a fixed HI of 0.90. The second harvest results in the removal of 90 percent of all non-grain above ground biomass. The removal of crop residue results in a soil that is more susceptible to erosion and has less desirable tilth and lower levels of soil nutrients.

B. MODEL SENSITIVITY TO MOISTURE DEFICIENCIES

Special interest is placed on the ability of the EPIC-JORDAN model to track observed yields under varying levels and different distributions of precipitation during the growing season. Accordingly, EPIC yields were compared to actual yields under similar weather conditions by calibrating the EPIC weather component for conditions in Jordan. Weather information such as level of solar radiation was simulated in the model based on observed monthly averages and standard deviations of critical weather variables for the Experiment Station at Ramtha, Jordan. Actual daily rainfall for a ten-year period at the experiment station was combined with three more years of synthetic daily rainfall based on observed monthly total precipitation to give rainfall data for 13 cropping years from 1976-1977 to 1988-89.

A summary of rainfall records for 10 of these cropping years is shown in Table 2. Cropping season rainfall usually ensued in October and lasted, at most, until May of the following calendar year. Annual precipitation showed wide variation from year to year. The 10-year annual average is 233mm (9.2"), but there is wide variation from

year to year. For example, the 1979-1980 cropping year recorded 393mm (15"), but precipitation in the next cropping year declined to only 145mm (6"). Cropping decision are influenced by rainfall levels. For example, seeding usually occurs in November, but is sometimes delayed to the first part of December due to insufficient soil moisture.

Barley yields predicted by EPIC under the 13 years of observed rainfall data were compared to actual grain yields observed during the same 13 years for field trails at the Ramtha Experiment Station. The average of the predicted yields (0.94 mt/ha) compared fairly well with the average of the observed yields (1.27 mt/ha). However, simulated yields over-predicted grain yields in years with low rainfall, while under-predicting yields in years where rainfall was higher than average.

In response to this problem, the EPIC research team at Blackland Research Station in Temple, Texas made the harvest index in the EPIC model a function of the ratio between daily actual evapotranspiration and potential daily evapotranspiration. This new method of calculating the harvest index improved the responsiveness of EPIC forecasts of grain yield to changes in precipitation. However, the model still underestimated the variation that occurred in actual barley grain yields. Equally important, the response of total above ground plant biomass (stems, leaves, and grain) production to changes in the level and distribution of rainfall was not improved by the change in the harvest index. This result was unsatisfactory for conditions in Jordan because plant stem and leaves have economic value as livestock feed. An overestimate of non-grain biomass would be as serious an error as overestimation of grain yield. The new version of EPIC-JORDAN gave improved responses to changes

in precipitation by reducing both the total biomass and the level of grain production relative to plant leaf and stem production, when water-stress levels were high.

The lack of response by the EPIC model to changes in precipitation was finally solved by resetting the water deficit compensation parameter (p. 51 Williams, Jones, and Dyke) from 1.00 to 0.75. (The compensation factor is PARM 9 in the input file PARM2779.dat). The water deficit compensation parameter simulates plant rooting environment. Values close to one represent a very good rooting environment and values decreasing toward zero represent increasingly poorer rooting environments. With a good rooting environment (compensation parameter close to 1), compensation for water deficiencies between soil layers is almost total. By lowering the water compensation factor, it was possible to simulate poor development and hence poor plant growth under high water stress conditions.

C. INCREASING MODEL SENSITIVITY TO PHOSPHOROUS DEFICIENCY

Soils in Jordan tend to be phosphorus deficient, and experimental data has shown good yield responses to phosphorus fertilizer in years with average or better rainfall. The EPIC model showed a complete lack of phosphorus stress and crop response to phosphorous fertilizer even under low levels of soil phosphorous and with nonlimiting water and nitrogen. The problem of a lack of plant stress and yield response to phosphorous deficiencies was remedied by changing the phosphorous compensation factor (PARM 8 in PARM2779.dat) from .25 to .05. With the new setting of PARM 8, reasonable levels of plant phosphorous stress were reported by the EPIC

Table 2. Total Monthly Rainfall and Number of Rainy Days per Month at the Ramtha Agricultural Experimental Station, Jordan; 1979-80 to 1988-89 Cropping Seasons

	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Total per Season
1979-80									
Rainfall (mm.)	17	78	92	35	46	117	8		393
Days of Rain	5	4	11	10	12	8	6		56
1980-81									
Rainfall (mm.)	4	3	63	30	34	14	6		154
Days of Rain	1	1	11	8	13	3	3		40
1981-82									
Rainfall (mm.)		30	10	34	42	29	16	12	173
Days of Rain		10	3	9	10	9	4	3	48
1982-83									
Rainfall (mm.)	7	43	16	54	90	53	12		274
Days of Rain	1	5	4	8	13	6	3		40
1983-84									
Rainfall (mm.)		22	9	50	15	80	16		191
Days of Rain		2	3	5	2	8	6		26
1984-85									
Rainfall (mm.)	9	31	31	9	138	17	8		242
Days of Rain	3	6	4	4	15	3	1		36
1985-86									
Rainfall (mm.)	7	7	11	31	54	25	19	10	162
Days of Rain	3	3	5	7	6	5	5	4	38
1986-87	8								
Rainfall (mm.)	2	112	43	45	30	60			297
Days of Rain		10	8	9	8	13			50
1987-88									
Rainfall (mm.)	7	7	54	92	76	56	9		300
Days of Rain	4	2	12	14	12	9	2		55
1988-89									
Rainfall (mm.)	5	13	70	17	21	21			148
Days of Rain	3	2	9	9	4	5			32

model. Moreover predicted yields showed a response to applications of phosphorus fertilizer applied on the soil surface.

D. SOIL INPUT DATA FOR EPIC-JORDAN

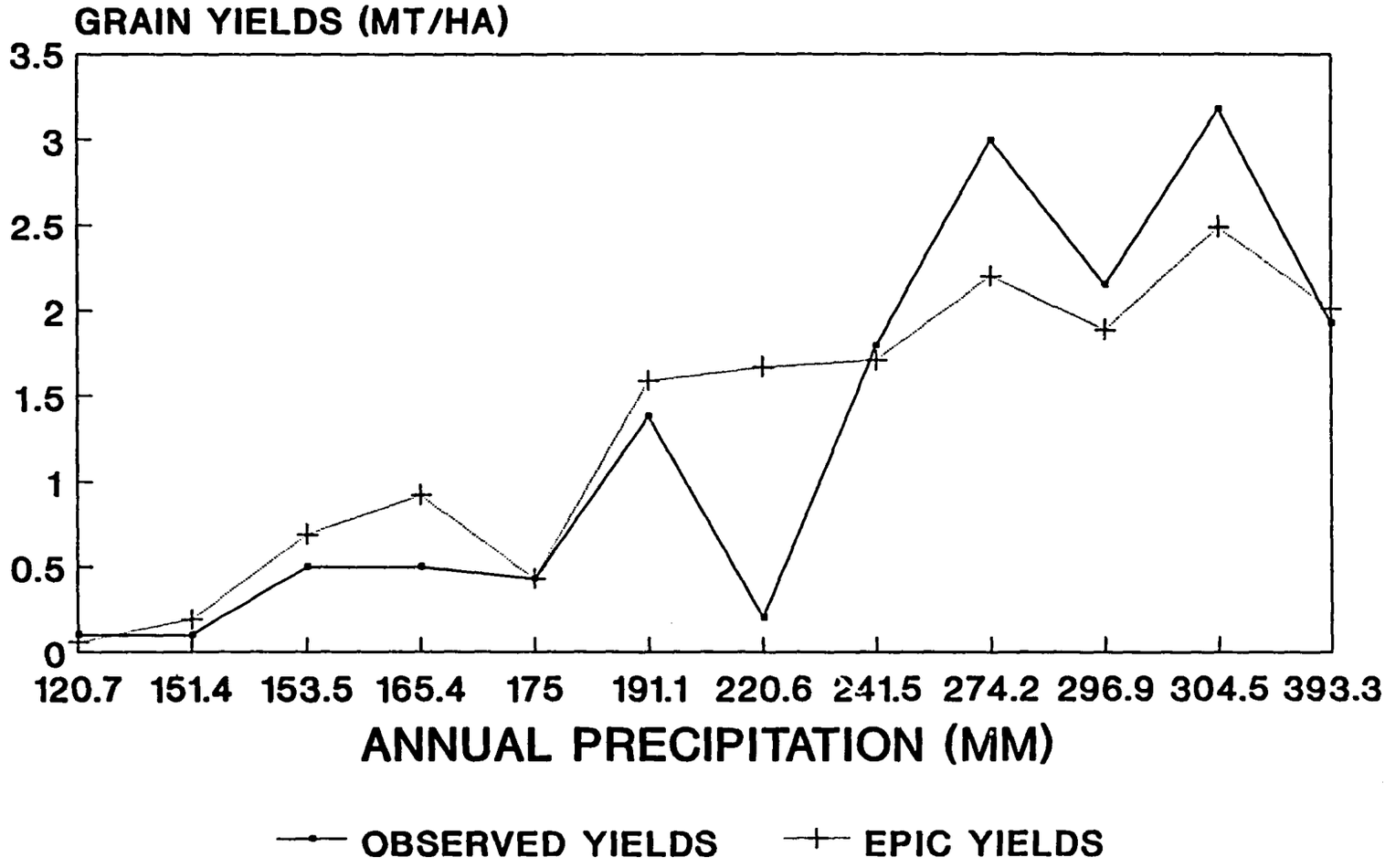
The soil input parameters for EPIC-JORDAN were based on the Blacklands soils file, with changes to more closely match soils found in farmers' fields in the Mafraq area. Soil survey data taken from a number of farm fields (provided by Jaradat), was used to reset soil organic nitrogen, phosphorous, and carbon to considerably lower levels. Soil pH, physical composition (sand, silt, and clay), CaCO3, and ionic exchange capacity were also altered slightly to match conditions found in farm fields.

II. MODEL VALIDATION

A. COMPARISON TO ACTUAL YIELDS

The ability of the improved version of the EPIC-JORDAN model to accurately simulate actual grain yields at the Ramtha experiment station is shown in Figure 2. The mean of EPIC predicted yields was just 5.9 percent higher than the mean of observed yields. EPIC yields still showed less overall variation than observed yields (a standard deviation of 0.859 for predicted yields versus 1.125 for observed) and somewhat less variation relative to the mean. However, it should be noted that observed yields are affected by disease and pests and management deviations that are not reflected in predicted yields. The risk of low yield, i.e., deviations below the mean, was 19 percent less for simulated yields than for the observed yields. A zero

Figure 2. Observed Versus EPIC Predicted Grain Yields for Ramtha, Jordan



intercept regression between predicted and observed yields (Aiger) gave an excellent fit (R^2 value of .892) with a slope coefficient that did not significantly differ from 1.0.

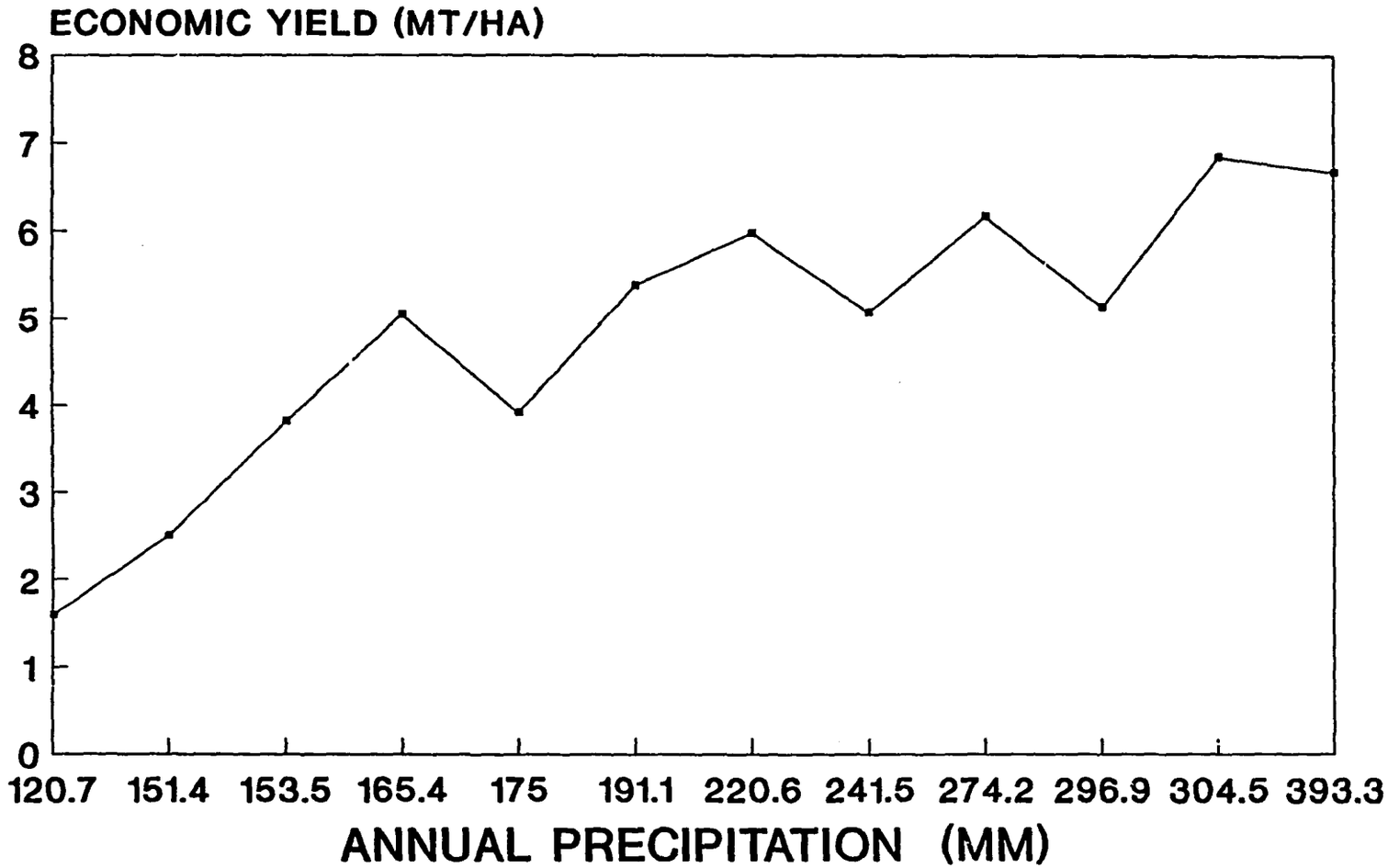
As shown in Figure 3, total above ground biomass production also showed a marked reaction to changes in precipitation.

B. LONG-RUN YIELD DECLINE DUE TO EROSION AND SOIL DEPLETION

Water and wind erosion were estimated within EPIC using precipitation records from Jordan and wind direction and speed data from the Blackland Research Station. As expected, estimated wind erosion was ten times greater than water erosion. Predicted erosion for a rotation of barley and weedy fallow with residue grazed and no fertilizer applied averages 29.1 tons of soil lost per hectare per year, which is within the range of average annual erosion rates reported for the Mafraq region by Jaradat and Abu Mushrif.

The EPIC crop growth model was used to estimate barley grain and straw production for a barley-fallow rotation over the range of weather that occurred during 1976-1989 and with soil conditions held constant at initial values. Runs were then made for 52 years (four sets of the same 13 years of weather) with soil conditions allowed to change through time as a result of erosion and depletion. Yields were then estimated over the same range of weather with soil conditions held constant at the level reached after 52 years of cropping with attendant erosion and nutrient depletion. Results are presented in Table 3. After 52 years of erosive and soil-depleting farming (residue grazed and no fertilizer), predicted grain and economic (straw plus grain) yields average 57 and 65 percent below the initial yields Soil depletion, rather than

Figure 3. Economic Yield Predicted by EPIC for Varying Rainfall Levels



Annual Precipitation at the Agr.
Experiment Station at Ramtha, Jordan

soil erosion, is the major cause of decline in crop productivity for this set of practices. The decline in economic yield due to depletion alone (no erosion occurring) is more than two-thirds of the total decline due to both erosion and depletion.

The annual rate of yield decline is not constant throughout the 52-year period. Yield decline due to soil depletion tended to be greater in earier years.

The year-to-year variation in yields that results from weather variation is much higher before erosion and soil depletion than after the 52 years of erosion and soil depletion. For a barley-fallow rotation with no fertilizer and all residues removed by grazing, the standard deviation of barley-grain yield declines from 0.45 before erosion and depletion to 0.045 after the 52 years of cropping (Table 3). Yield variability is higher in the initial period because limited soil moisture in a dry year is a fairly important constraint on crop growth and grain production. EPIC predicts that, after 52 years of erosion and nutrient depletion, there will be relatively little response in grain production to rainfall because soil infertility becomes the over-riding limit to productivity.

When crop residues are incorporated into the soil and fertilizer (80 kg of nitrogen and 20 kg of phosphorous) applied annually over the 52 years, grain yield is 17 percent lower but economic yield unchanged after 52 years. The decline in grain yield is due almost entirely to erosion. Decline due to soil depletion is unimportant, and the effect of erosion is reduced because retaining residue and fertilizing the crop helps reduce the rate of soil erosion. Increased vegetative crop growth and crop

TABLE 3. Mean and Standard Deviation (SD) for 13 Years of Simulated EPIC Barley Yields for Two Residue Management Practices in Combination with Two Fertilizer Regimes for a Barley-Fallow Rotation, Before and After 52 Years of Soil Depletion and Erosion

	FARM PRACTICES							
	RESIDUE GRAZED				RESIDUE INCORPORATED			
	NO FERTILIZER		FERTILIZER		NO FERTILIZER		FERTILIZER	
	MEAN	SD	MEAN	SD	MEAN	SD	MEAN	SD
GRAIN YIELD:								
Before 52 years	1.04	0.447	1.84	0.690	1.19	0.459	2.10	0.793
After 52 years	0.45	0.045	1.38	0.406	0.55	0.045	1.74	0.599
ECONOMIC YIELD[1]:								
Before 52 years	3.42	1.358	6.74	1.359	4.16	1.410	7.56	1.533
After 52 years	1.19	0.089	6.77	1.040	2.70	0.265	7.63	1.10

1 -- Economic yield is all grain harvested plus 90 percent of the remaining plant biomass.

residues on the soil surface increase resistance to wind, which is the primary cause of erosion in the region.

Values in Table 4 show the economic effect of one year of current farming on future farm productivity (i.e., the user cost of current farming) for selected crop practices. The user cost is not an actual current expenditure. Rather, it is the anticipated opportunity cost, in the form of permanent loss of future farm income, due to one year of current farm practices. In this analysis, productivity losses over a 52-year planning horizon are valued at current output prices, discounted at a given rate of interest and summed. Prices for grain of 68 JD/kg and for straw of 29 JD/kg were assumed. The undiscounted sum of predicted yield losses over the 52-year period was 23.4 JD/ha for one year of the traditional barley-fallow rotation and 15.4 JD for the same rotation with residue incorporated and fertilizer applied. A discount rate of 10 percent reduces the present value of the yield losses to 4.6 JD/ha for the traditional practice and 2.9 JD/ha for the barley fallow with fertilizer and residue incorporated. The differences of 8.0 JD when not discounted and 1.7 JD at 10 percent discount represent the present value of gains (reduced losses) in future production that can be obtained for each year of following the more conservative practices. For economic analysis, the savings in user cost must be compared to the added cost of the fertilizer and the net change in value of production in the initial year (i.e., grain yield is higher but straw is no longer salable).

Adoption of yield-enhancing technologies has the beneficial effect of reducing the user cost (Table 4). Under the residue incorporated and fertilizer option, the user

TABLE 4. User Costs for a Barley-Fallow Rotation for Various Farm Practices Under Differing Discount Rates Over a 52-Year Planning Horizon

FARMING PRACTICES	DISCOUNT RATE (JD/HA)			
	0	4	8	10
Residue Incorporated, No Fertilized				
Grain	14.77	6.18	3.48	2.82
Economic Yield	23.37	9.78	5.52	4.63
Residue Incorporated, Fertilized:				
Grain	11.25	4.70	2.65	2.15
Economic Yield	15.42	6.45	3.64	2.95

NOTE: Users costs assumes a constant price of 68 JD per metric ton of Barley grain and a price of 29 JD per ton of Barley straw.

cost is 34 percent less than when no fertilizer is applied. The cost is reduced because erosion rates are lower and soil fertility and tilth are better maintained and hence crop productivity is retained, when fertilizer is applied on a regular basis.

C. RESPONSE TO CHEMICAL FERTILIZERS

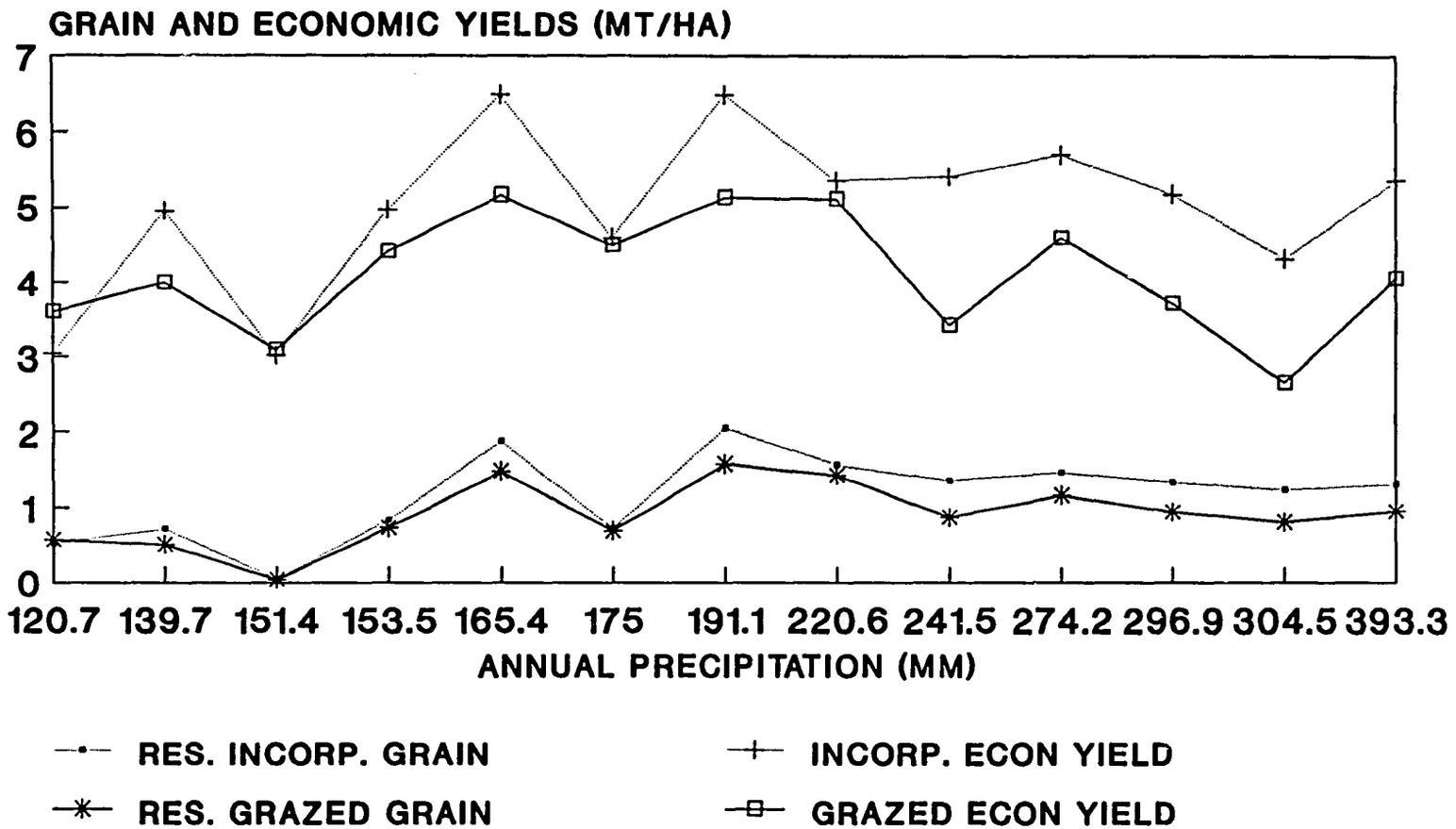
The response of grain and economic yields for a barley weedy-fallow rotation to 80 kilograms of nitrogen fertilizer and 20 kilograms of phosphorous fertilizer under different levels of cropping season rainfall can be seen in Figure 4. As expected, yield responses to fertilizer is low in years of extremely low rainfall. For example, when precipitation is 151 mm there is no response to fertilizer. Grain yields show no higher response in years with relatively high (more than 221 mm) precipitation. Levels of yield response for year with higher than average rainfall may increase under higher fertilizer rates than those discussed here.

Grain and economic yields tend to be higher whenever residue is incorporated into the soil as opposed to being grazed (Figure 4). The increase in yield response when residue is incorporated is slightly larger in years with relatively high rainfall. On average, the grain yield response is 29 percent higher and the economic yield increase is 21 percent higher when residue is incorporated rather than grazed.

D. COMPARISONS OF MINIMUM AND CONVENTIONAL TILLAGE

Analysis with previous versions of the EPIC-JORDAN model showed a slight current-year yield penalty for minimum tillage continuous barley and barley-fallow rotations. The reduction of 4 to 5 percent occurred because minimum tillage resulted in lower levels of plant available (mineralized) organic nitrogen. The yield penalty for

Figure 4. EPIC Predicted Grain and Economic Yield Response to Fertilizer For Varying Levels of Rainfall



Note: 80 Kg. of N and 20 Kg. Kg. of P Applied Annually

minimum tillage is expected to be present for the current version of the Jordan EPIC model.

SUMMARY AND CONCLUSION

EPIC was chosen from among a number of alternatives as the best suitable crop model for examining the adoption of yield-enhancing, sustainable technologies in the Mafraq region of Jordan. A number of adjustments to the model were made to more accurately reflect barley-crop responses to the low precipitation and nutrient-deficient soils found in the region. The resulting EPIC-JORDAN model provides sufficiently accurate information for use in economic studies.

The model indicated long-run declining crop productivity under current farming practices in the region. Technologies such as chemical fertilizers and incorporating crop residues were predicted to enhance current yields and sustain long-run crop production capability. Current research on the model includes further examination of the relationship between chemical fertilizers and precipitation. It also includes calibrating the model for vetch, a forage-legume crop, to examine the desirability for vetch-barley rotations.

The EPIC-JORDAN model has been used in several economic studies of farming practices in the Mafraq region. Current research will provide crop productivity information to be used in future economic examinations of current and potential technologies in the Mafraq region of Jordan.

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