Use of Crop Growth Simulation and Whole-Farm Planning Models to Analyze Barley-Livestock Production in the 200 - 300 mm. Rainfall Zone of Northern Jordan

by

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INTRODUCTION

Agriculture is an important component of the economy of Jordan and provides employment for 14 percent of the work force (el-Hurani). Most of Jordan's farmers rely on cultivation of lands in the semi-arid area with only between 200-350 mm. of rainfall (Oglah and Jaradat).

The climate in Jordan is Mediterranean. Most precipitation falls in winter and is characterized by extreme variability from year to year. Farming strategies that make maximum use of the available moisture and provide insurance of at least some production in a dry year are very important. Still, agriculture as typically practiced in these semiarid areas results in low average yields, low moisture utilization efficiency, and high year to year variability in production and income.

The purpose of this study is to identify farming practices and strategies that will increase productivity, lessen the impacts of weather variability, and avoid degradation of soil productive capability in semi-arid dryland cropping areas of Jordan. The study is a part of the USAID sponsored project Technologies for Soil and Moisture Management (TSMM), which focuses on dryland agriculture in West Africa, North Africa, and the Middle East. The Mafraq area of northern Jordan, which is in the zone of less than 350 mm. precipitation, has been chosen as the specific locale for this study.

Efforts to identify superior strategies and practices for Mafraq and similar areas are hampered by a lack of applicable information from past agronomic and economic research. Furthermore, a research program of experimental testing of new alternatives would be expensive and time consuming and not really practical because of the heavy demands for scarce research personnel and facilities. Therefore, the approach adopted in this study is to develop and apply analytical models for predicting production and income under alternative farming systems and practices.

The overall modelling utilizes a crop growth model to predict yields under alternative cropping systems and practices and a whole-farm linear programming model to determine, given the predicted yields and costs, optimal combinations of activities for a typical farm. The Erosion Productivity Impact Calculator (EPIC) has been adapted to model crop growth, and a linear programming model (FPMME) has been built for the whole farm economic modelling.

MAFRAQ STUDY AREA

The Mafraq area includes a western portion that averages up to about 350 mm. of rainfall where wheat, lentils, vetch, and summer vegetables are grown. Precipitation declines as one moves from west to east. Below 300 mm., barley is the major crop, and it is often alternated with fallow. Olives are an important crop throughout the region. Farms in the 200-300 mm. rainfall area average about 15 hectares of cropland.

Livestock are important, particularly in the drier and hence more marginal cropping areas where over 40 percent of surveyed farmers maintain flocks of goats or sheep (Oglah and Jaradat). Sheep and goats graze on range land, fallow cropland,

and aftermath stubble. In very dry years, barley is pastured rather than being harvested for grain. Some barley is fed to livestock, but in dry years barley often is purchased from outside the area to supplement local feeds. Also, livestock are sometimes moved to higher rainfall areas when local feed is in short supply.

With relatively low long-term average precipitation and a fairly high variation in rainfall patterns, cereal grain crop failures caused by drought conditions are common occurrences. On a typical farm in the Mafraq region, four out of the last ten barley crops have been grazed rather than harvested (Oglah and Jaradat).

Use of yield-enhancing technologies by area farmers, as in the rest of Jordan, is limited. Only 8 percent of all Jordanian farmers use nitrogen fertilizer (Duwayri). In the low rainfall areas, such as Mafraq, fertilizer use is even less common. Labor shortages are a problem in Mafraq agriculture as well as in the rest of Jordan (el-Hurani) primarily because many workers move to the cities where wages are higher. The labor shortages are especially acute during harvest when labor requirements are highest. Also, labor shortages may be inducing greater use of machinery either on a custom hire or less often on a cooperative basis.

CROP GROWTH MODELLING WITH EPIC

Crop growth simulation models are being increasingly used to predict crop yields for different cultivars, various cultivation and management practices, and a range of soil and weather conditions. Models in use range from simple one or two variable functions or spreadsheets (Stewart) to extremely complex models of hour by hour growth based on plant physiology (Norman).

EPIC--The Erosion Productivity Impact Calculator (EPIC) fits in an intermediate class of models. EPIC was originally designed to analyze the relationships between erosion and crop production and to determine optimal management strategies of soil conservation in the United States. EPIC models crop production with different crop rotations, cultural practices, tillage techniques, residue management regimes, and fertilizer levels. It has nine major components that simulate hydrology, weather, erosion, nutrients, plant growth, soil temperature, plant environment control, and economics.

The ability to generate weather data makes EPIC particularly suitable for areas where historical data is incomplete or unavailable. It also has built in default values for many variables and parameters that can be used whenever the corresponding data is not available.

EPIC Jordan--An EPIC model for a typical dryland setting in Jordan was adapted by Dr. Jaradat from a similar model for Texas. Many soil parameters and initial values were taken from the Ramtha Agricultural Experiment Station in northeast Jordan. Average weather data for the area were used to set parameters for the EPIC weather simulator. Barley, the principal crop in the study area, was modelled by adapting parameters from a typical U.S. barley cultivar.

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) and Maximum Potential Leaf Area Index (DMLA). The lower WA reduces the 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 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.

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
Point on Optimal leaf Area Development Curve (DLP2 or LAP2)	60.9	50.95
Leaf Area Index Decline Rate Parameter (RLAD)	0.5	1.0
Critical Labile P Concentration (CPF)	22.0	0.0
Potential Heat Units (PHU)	1959.0	1675.0
Harvest Index (HI)	0.39	0.42
Operation Parameter		
Over-ride of Harvest Index (ORHI)	0.42	0.00

The DPL2 or LAP2 helps determine when each of the crop growth stages begin. The changes made in EPIC-Jordan (Table 1) bring on the point of senescence faster, as it is adapted for a short season variety.

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 CPF parameter affects the labile phosphorous factor uptake and the phosphorous supply. As seen in Table 1, this parameter was set in the Jordan version of EPIC to be less - sensitive to suboptimal levels of plant available phosphorous.

The harvest index is the percent of above ground biomass that is harvested as economic yield (usually grain). The EPIC harvest index can be reduced by water stress in the grain-filling period, i.e., water-stress reduces grain yield per unit of biomass. In the original version of EPIC Jordan, a harvest index override was used to fix the proportion of grain to biomass at .42 for each year regardless of water stress conditions (Table 1). The harvest index 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 harvest index, 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.

Of particular interest was the means of simulating the removal of all residue from cropland (residue removal) as is currently practiced in Jordan. Based on the advice of the EPIC research team at the Blackland Research Station, residue removal is simulated by having an initial grain harvest followed by a second (stubble) harvest operation with a harvest index (HI) of 0.95. Accordingly, virtually all residue is removed as can be seen in the effect on the standing dead crop residue (STD) and crop residue on soil surface (RSD) variables.

Model Validation--After basic crop, soil, and weather parameters, initial values, and assumptions have been established it is necessary to verify that crop growth predictions are reasonably accurate for the conditions being modelled.

The first step in validation was to compare the Jordan barley model's predictions to those for an EPIC model with crop parameters that have been verified for a typical U.S. barley cultivar. For those baseline comparisons, it was assumed that: 1) available Jordanian soil and weather data would be used in both models, 2) no erosion occurs and no fertilizer was applied, 3) the harvest index was endogenously determined, and 4) crop residue was left to be incorporated into the soil. This comparison showed EPIC Jordan to predict about 10 percent less biomass, but very slightly lower yields than for the comparable U.S. model (Table 2).

Table 2. Differences in barley crop output between EPIC-Jordan and EPIC-U.S.

	Jordan Version	U.S. Version
Average annual crop yield data		
Barley yield (mt/ha)	0.81	0.78
Biomass (mt/ha)	2.26	2.95
Radiation (mj/m^2)	3329	2409
Heat units (^{o}C)	1959	1648
Average number of stress days		
Water stress	34.9	72.6
Nitrogen stress	71.4	18.7
Average annual value for selected variables		
Transpiration (EP)	112.09	106.04
Evapotranspiration (ET)	224.00	217.86

Water deficit is an important source of plant stress, which limits biomass production, in our application of the EPIC model as seen in Table 2. A separate effect of water stress occurs during the grain-fill period where it causes grain yields to decline relative to total plant biomass.

Nitrogen deficiency is the most important source of plant biomass stress, however, whenever nitrogen fertilizer is not applied or nitrogen-fixing vetch is not included in the crop rotation (Table 2). Nitrogen is deficient because of inherently low levels of soil organic matter, low levels of crop residue production, and the use of crop residue as animal feed instead of incorporating it into the soil.

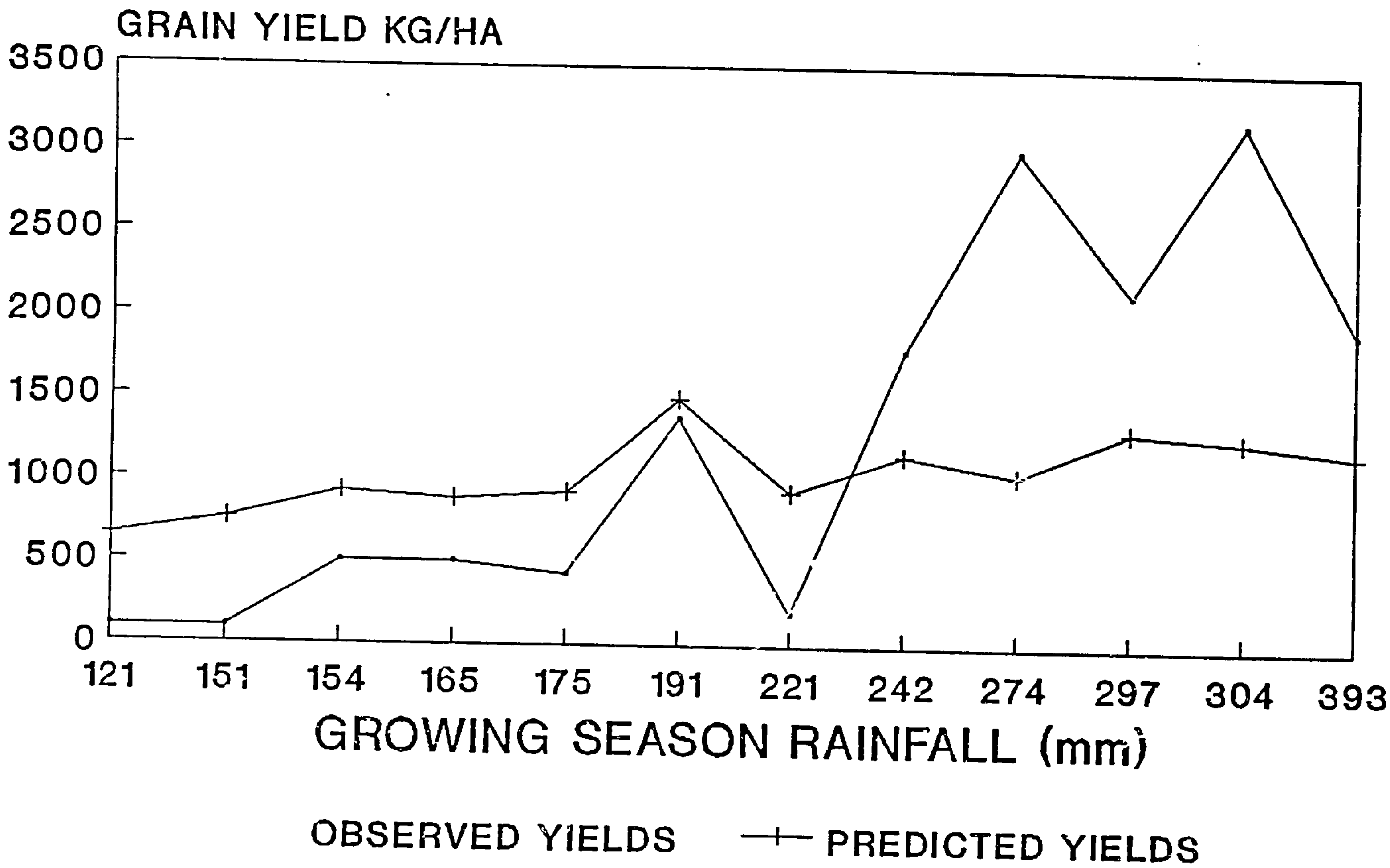
Barley yields predicted by EPIC were compared with yields observed during 12 years of field trials at the Ramtha Agricultural Experiment Station. The average of 47 years of predicted yields (0.94 mt/ha) compared well with the average of observed yields (1.27 mt/ha). However, we also wanted to compare variation in yields resulting from variation in weather. Daily weather data was not available for making simulations that exactly replicated in the model growing conditions that prevailed for the trail. Therefore, model years were selected in which model-generated growing season precipitation matched observed precipitation, and predicted yields for those years were compared to actual observed yields.

Simulated yields apparently track actual yields more closely under low as opposed to high precipitation conditions as seen in Figure 1. A zero intercept regression between actual yields and simulated yields (Aigner) did not give a good fit. Only 31 percent of the variation in actual yields was predicted by simulated yields. Moreover, predicted yields appear to be less responsive to rainfall than observed yields especially for higher levels of precipitation. The coefficient of variation (standard deviation as a percentage of the mean) for EPIC predicted yields shown in Figure 1 is 23.7 percent where as the coefficient of variation for observed yields shows much greater dispersion at 88.4 percent.

Exact information about weather and other conditions at Ramtha may help explain why EPIC results under respond to precipitation and improve the accuracy of EPIC predicted yields. Changes in the EPIC model such as modification of the crop drought sensitivity parameter (WSYF) may also be in order.

Water and wind erosion preliminary tests were done using EPIC generated weather based on precipitation records from Jordan and wind direction and speed data from the Blackland Research Station. Estimates of yield reduction due to erosion were about 50% over a 45 year period (Table 3) or a one percent decrease in yield per year. With erosion, the number of days of water stress decrease, but nitrogen stress days increased by about 20 percent. Estimated wind erosion was 10 times greater than water erosion, which agrees with the general perception of the area, but data from Jordan is needed to confirm erosion relationships. The average crop yield (both grain and fodder) from a barley-fallow rotation was 70 percent greater than the estimated yield from a continuous barley rotation despite a 30 percent higher erosion

FIGURE 1. OBSERVED RAMTHA VS EPIC PREDICTED BARLEY GRAIN YIELDS, 1977-88



rate for the barley-fallow rotation. Erosion erosion, show a sharp effect on yields during the first 10 years. After that, the difference in yields becomes more uniform over the next 35 years. Future work in EPIC will include further exploration of erosion and yield loss relationships and the use of wind erosion data from Jordan.

Table 3. Effect of wind and water erosion versus no erosion for continuous barley and barley fallow: Averages of 45 year EPIC simulation for the Mafraq area of Jordan

	Continuous Barley	Barley - Fallow rotation	
		Barley[1]	Fallow[2]
<u>No Erosion Case</u>			
Average Yield (mt/ha)			
Grain	0.46	0.80	0.40
Fodder	0.86	1.46	0.73
Water Stress (days)	31	28	
Nitrogen Stress (days)	83	85	
<u>Wind and Water Erosion Case</u>			
Average Yield (mt/ha)			
Grain	0.23	0.41	0.20
Fodder	0.43	0.75	0.37
Water Stress (days)	25	25	
Nitrogen Stress (days)	103	99	
Average Soil Loss from:			
Wind Erosion (mt/ha/yr)	27.62		34.94
Water Erosion (mt/ha/yr)	0.68		1.12
Thickness of soil eroded (mm)	112		148
<u>Erosion Case as Percent of No Erosion Case</u>			
Average Yield			
Grain	50%	50%	
Fodder	50%	50%	
Water Stress	80%	90%	
Nitrogen Stress	120%	120%	

[1]Fallow year not included when calculating average.
[2]Fallow (non-crop) year means two hectares of land are used to produce one hectare of barley. Fallow year is included in all calculations in this column.

Grain Yield and Fodder/Residue Estimates

The EPIC model was used to generate crop biomass and barley grain yield estimates for each cropping system and set of practices examined in this study. Yields were estimated under continuous barley, barley-fallow, and barley-vetch rotations both with conventional and minimum tillage. Yield estimates were also made under conditions of residue incorporation into the soil or residue removal from the field as well as with and without fertilizer. A vetch-barley rotation, the use of minimum tillage, the extensive use of chemical fertilizers, and the residue incorporation option are all largely untried, but potentially yield and productivity enhancing techniques, for farmers in the region. Grain yield and biomass estimates shown in Table 4 are an average of values from 47 years of runs with EPIC and represent expected values under long-term farming conditions. The EPIC model is especially useful for indicating relative yield of crop rotations, such as barley-vetch, or practices, such as incorporating residue into the soil, for which no actual farm or experimental data from the region is available.

Table 4. Yield, water and nitrogen stress for continuous barley, barley-fallow, and barley-vetch rotations under residue removed and residue incorporated management alternatives: Averages of 47 year EPIC simulations for the Mafraq area of Jordan

	Continuous Barley	Barley-Fallow Rotation[1]	Barley - Vetch Rotation: Barley	Barley - Vetch Rotation: Vetch[2]
All Residue Removed				
Average Yield (mt/ha)				
Grain	0.46	0.80	1.21	----
Fodder	0.86	1.46	3.06	2.35
Water Stress (days)	31	28	52	54
Nitrogen Stress (days)	83	85	11	51
All Residue Incorporated				
Average Yield (mt/ha)				
Grain	0.77	1.22	1.44	----
Straw Incorporated	1.63	2.42	4.46	5.09
Water Stress (days)	42	35	50	68
Nitrogen Stress (days)	45	57	2	22
Residue Incorporated as Percent of Residue Removed				
Average Yield				
Grain	170%	150%	120%	---
Fodder	190%	170%	150%	120%
Water Stress	140%	130%	100%	130%
Nitrogen Stress	50%	70%	20%	40%

[1]Fallow year not included when calculating average.
[2]All vetch was harvested as fodder and never incorporated.

EPIC generated yields indicate slightly lower yields for minimum tillage rotations as opposed to conventional tillage for the same cropping systems. Minimum tillage is less effective in reducing soil bulk density than conventional tillage (Appendix V, Williams, Jones, and Dyke), and increases in mineralized (plant available) nitrogen are directly related to decreases in bulk density (p. 38-39 Williams, Jones, and Dyke). Hence, the number of nitrogen stress days is lower, and yields are higher, for conventional as opposed to minimum tillage.

The EPIC model predicts that a barley-vetch (ley farming) rotation will produce barley yields that average about three times as much as yields with continuous barley primary because nitrogen deficiency stress is reduced (Table 4). Total grain production from every other year barley under the barley-vetch rotation would be greater than total production under every year continuous barley. In addition, the vetch would provide more than 2 metric ton per hectare of high quality fodder every other year. Also, barley straw production would be much higher and more could be utilized as feed or marketed with less impact on yields.

Chemical fertilizers also increase crop yields by reducing nitrogen stress; however, the response rate to fertilizers is decreased by insufficient soil moisture and low levels of soil organic matter.

Allowing crop residue to be incorporated into the soil instead of being grazed or removed for animal feed also increases long-term crop yields as seen in Table 4. Incorporation of residue increases soil organic matter and mineralized nitrogen levels, which reduces nitrogen stress and leads to higher predicted yields. Under current farming conditions throughout Jordan, however, most residue is removed because of its value as a livestock feed and because stockmen hold grazing rights to any crop stubble that is left in the field by farmers.

The Linear Programming Model

Structure of the Model-- A linear programming model is used to simulate decision making for a typical farm in the Mafraq region. Economists seek to predict how farmers will react to the introduction of new technologies and ascertain the reasons why farmers may or may not accept new practices. Models of farm management decisions, such as linear programming models, incorporate the biological and agronomic conditions under which choices are made. Such models also account for the constraints and tradeoffs that farmers make in deciding whether to use new technologies.

A typical farm in the Mafraq area is assumed to have 15 hectares of land available for crop production and an unlimited supply of steppe land for sheep grazing. Labor shortages are assumed to occur only during the June-July harvest period. The farm family is assumed to provide 240 man-days of labor for the gathering, processing, and transport of harvested crops. Additional harvest-period labor can be purchased at the rate of JD (Jordan Dinar) 2 per man-day.

The farmer has a choice of cropping activities including continuous barley cropping, barley alternated with summerfallow, and barley alternated with vetch hay. For each of these rotations, the model allows for choosing between minimum tillage and conventional tillage, fertilizing with nitrogen and phosphorous or not fertilizing, and either removing virtually all residue from the field during harvest (residue removal) or allowing it to be tilled into the soil (residue incorporation).

Sheep are a key component of farming in the Mafraq region and throughout Jordan. Sheep production activities in the linear programming model allow a choice between low, medium, and high quality feeding regimes. Higher quality feeding results in higher lambing rates, higher milk production, and better quality wool, but it also requires more energy from feeds and greater concentration of crude protein in feeds. Feed can be supplied by purchased or own-farm produced barley grain and barley hay, own-farm produced vetch hay, and purchased wheat bran. Steppe land and stubble barley fields are available for grazing although stubble grazing is precluded under the residue incorporation option. Saleable output from the flock are lambs, cull ewes, cheese, and wool.

<u>Model Results</u> The linear programming model was used to evaluate four different scenarios that relate to the availability of certain yield-increasing techniques. Results for a typical Mafraq farm are reported in Table 5.

Table 5. Results of linear program farm decision making model for the Mafraq area of Jordan

	Net Returns (JD)	Fert-lizer	Residue Remains	Barley Fallow	Barley Vetch	Minimum Tillage	Hired Labor
		--------(Hectare)				-----------	(days)
Scenario One:							
Profit Maximized	387	8.0	15.0	15.0	0	15.0	0
Labor Price JD 0.69	387	15.0	15.0	15.0	0	15.0	54
Hay Price JD .07	395	15.0	0.0	15.0	0	15.0	0
Sheep Prices 77							
Percent Increase	389	3.5	14.5	14.5	0.5	15.0	0
10 Ewe Flock	-91	0	13.2	13.2	1.8	15.0	0
Scenario Two:							
Profit Maximized	355	0	13.8	13.8	2.2	15.0	0
10 Ewe Flock	-91	0	13.2	13.2	1.8	15.0	0
Scenarios Three And Four							
Profit Maximized	263	0	0	15.0	0	15.0	0
10 Ewe Flock	-202	0	0	13.4	1.6	15.0	0

Scenario one represents the fullest range of choice for the farmer because the use of all new yield-enhancing technologies, as well as traditional practices, is allowed. The use of fertilizer is disallowed in scenario two while a choice can be made between the residue removal and residue incorporation options. On the other hand, under scenario three residue removal is enforced, but the farmer is allowed to choose between using or not using chemical fertilizer. Scenario four represents traditional farming in the region in that the use of fertilizer is precluded and all residue is removed from the field at harvest time. For all scenarios at least two runs are presented, one run being the optimal solution to the linear programming model under the scenario's assumptions and the second run simulating optimal farming practices under the requirement that the farm maintains a flock of at least 10 ewe sheep.

The profit-maximizing solution obtained under scenario one includes fertilizer use on some cropped areas and residue incorporation on all areas as selected technologies for a barley-fallow minimum tillage rotation (Table 5). Expected profit is JD 387 per year. All family labor is utilized during the harvest period, but no hired labor is employed. Reducing the price of hired labor from JD 2 to JD 0.69 per day would result in 54 man-days of hired harvest labor and a change to yield enhancing, and therefore more labor demanding, fertilizer on all of the barley crop.

Net returns become negative when 10 ewes are required under scenario one. The major change in the optimal crop pattern, shown in Table 5, is to switch to less costly unfertilized barley.

Incorporating residue into the soil instead of removing it from the field enhances barley grain yields in the long run. The opportunity cost of incorporating residue is either the loss of its value as own-farm animal feed or as a marketable product. Therefore, increasing the selling price of barley hay from JD 0.03 per kilogram to JD .07 per kilogram causes the removal of all residue from all cropped areas to become profitable (Table 5, scenario one hay price JD .07). Increasing the price of all saleable items from the farm sheep flock (i.e., lambs, culls ewes, cheese, and wool) by 77 percent (scenario one, sheep price 77 percent increase) causes the number of ewes to increase from zero to seven. Residue is removed from only a portion of all cropped areas because the farmer has sources of feed other than hay and because of the relatively large yield increases that are derived from incorporating residue.

A mixture of minimum tillage barley-fallow with residue incorporation and minimum tillage barley-vetch is the optimal cropping pattern when fertilizing is not allowed but residue is allowed to remain on the field (scenario two, Table 5). Requiring 10 ewes under scenario two results in negative returns to farming of JD -91, with only a few changes in the cropping pattern.

A minimum tillage barley-fallow rotation is optimal under scenario three (residue removal) and scenario four (residue removal and no fertilizer use) (Table 5). The use of fertilizer is an option for scenario three, but the removal of all crop residue reduces barley fertilizer yield responses and the profitability of fertilizer use. Because residue removal is a universal farming practice in Jordan, this result may help explain the lack of chemical fertilizer use by farmers in the Mafraq area.

Conclusions

The model results provide some basis for tentative conclusions about farming in the Mafraq region. First, the low profitability of farming in the region under all four scenarios--JD 387 is the highest net return--implies that new technologies not included in the model, such as new high yield cultivars adapted to very arid conditions, will be needed to significantly increase farm income. Second, labor shortages in the harvest period may inhibit the adoption of yield boosting technology. Mechanized harvest programs might help to bring about adoption of yield-increasing technology. Third, the practice of removing all residue from the field may be discouraging the use of fertilizer as a yield-enhancing technique as is shown by results from scenario three. Finally, one may question the profitability of livestock on farms in this area. Imposing livestock in model solutions reduced farm profits under all scenarios. Not examined in this study, however, is the value of livestock as a means of reducing risk or as a status symbol.

We feel that the EPIC model is currently reasonably reliable for crop growth modelling in semi-arid dryland areas of Jordan. It is very useful for research, such as ours, into the relative profitability of inadequately tested alternative farming systems and practices in areas where there is only limited documented agronomic research. However, a considerable input of agronomic and modelling expertise is required for calibration of EPIC to developing countries with conditions that differ distinctly from those in areas of the U.S. where EPIC has been widely used. Conditions in Jordan are not so different from those in some parts of the U.S. However, adapting EPIC to other developing areas with tropic and subtropic climates and soils, monsoon weather patterns, "informal" farming systems, and few plant scientists, will be considerably more difficult and time consuming. An early commitment of resources to this task would appear to be appropriate.

Future research efforts in this project will aim to improve EPIC's ability to give predicted yields that more closely track actual yields observed at the Ramtha Experiment Station. More detailed information concerning the actual conditions under which the Ramtha yields occurred, especially detailed weather data, would facilitate the calibration of EPIC Jordan to accurately simulate crop growth under alternative conditions in Jordan. An important part of the calibration process will be validating model results for extreme levels of precipitation.

Further extensions of EPIC Jordan include more work on estimating wind and water erosion rates in Jordan and validating the yield losses that erosion can cause. An additional extension includes the effects of grazing on vetch and medic, including nutrient recycling, and the study of a weedy (grazed) fallow crop rotation.

Further extensions of the farm mathematical programming model include accounting for yield variability and farmer ability and willingness to take risks in the face of such variability. Risk analysis should include the farmer's ability to respond within a season to changes in conditions. For example, a farmer may alter level of fertilizer applications in response to changing expectations of precipitation during the current season.

Other adaptive type decision should include interactive livestock-crop strategies in the face of variable conditions. For example, a current mixed integer version of the Mafraq planning model allows for a choice between harvesting and grazing the barley crop.

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