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ECONOMIC ANALYSIS OF FARMING PRACTICES THAT INCREASE SUSTAINABLE PRODUCTION IN THE BARLEY CROPPING AREA OF JORDAN

by

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INTRODUCTION

Agriculturist in developing countries are often under extreme pressure to meet short and intermediate run food and income goals. Current productivity of resources available to agriculture is often insufficient for meeting the food needs of a given country or region let alone for providing an economic surplus to facilitate economic development. The farm families who make and implement most farm production decisions also are often faced with personal shortages of food and income. Consequently, policy makers and private farmers efforts are often aimed at immediate increased productivity of resources committed to agriculture.

There is an unfortunate, but understandable, tendency for short term increases in agricultural productivity to come at the expense of a depleted natural resource base. Nevertheless, there is much to be gained from adoption of more resource conserving approaches. Maintaining and possibly enhancing the resource base provides that productivity can be maintained over the longer term, that technology adopted in the future will provide the fullest possible benefits, and also tends to minimize current negative external effects.

In this paper we report on some research into long-run as well as immediate effects of crop production and land management alternatives in a barley-fallow farming area of northeast Jordan.

The research that we report here was carried out by researchers at Washington State University, Jordan University of Science and Technology, and ICARDA (The International Center for Agricultural Research in Dry Areas). This research is part of a USAID sponsored project, Technologies for Soil and Moisture Management (TSMM), which focuses on dryland agriculture in West Africa and the Middle East. TSMM economists seek to identify cropping patterns, land-use practices, and policies that will be not only attractive to farmers in the short run, but also will conserve soil resources and sustain productivity for an indefinite period of time.

PROBLEM STATEMENT

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 cultivate lands in semi-arid areas relying on only between 200-350 mm. of rainfall (Oglah and Jaradat). Livestock are produced by many of the small farmers and pastoralist graze their flocks throughout the semi-arid and arid rangelands as well as on crop aftermath and uncropped lands in the farming regions. There is also an irrigated segment of agriculture in the Jordan Valley.

The climate in Jordan is Mediterranean. Most precipitation falls in winter and is characterized by wide variability from year to year. Farming strategies that make maximum use of the available moisture and provide insurance of at least some production and income 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. Moreover, typical farming practices return very little nutrients to the soil and provide little protection from endemic wind erosion.

The purpose of this study is to identify farming practices and strategies that will increase productivity, and avoid degradation of soil productive capability in semi-arid dryland cropping areas of Jordan. Efforts to identify superior strategies and practices for these dryland areas are hampered by a lack of applicable information from past agronomic and economic research. 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 mixed-integer programming model (FPMME) has been built for the whole farm economic modelling.

Mafraq Study Area

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. Research reported here is for the eastern portion of the Mafraq area, where precipitation averages about 240 mm per year and barley is the major crop, often alternated with fallow. Farms in the 200-300 mm. rainfall area average about 18 hectares of cropland. The majority of surveyed farmers maintain flocks of goats or sheep (Oglah and Jaradat), which graze on range land, fallow cropland, and aftermath stubble. Some of the 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. On a typical farm in the Mafraq region, four out of the last ten barley crops have been grazed rather than harvested for grain (Oglah and Jaradat).

Use of yield-enhancing technologies by area farmers is, as in the rest of Jordan, 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 as well as in other agriculture areas 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. 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 physiography (Norman).

EPIC:

The Erosion Productivity Impact Calculator (EPIC) fits in an intermediate class of models. EPIC was designed, by U.S. Department of Agriculture researchers at the Blacklands Research Center in Temple, Texas (Steiner, Williams, and Jones), to analyze the inter-relationships between weather, erosion, and crop production. The original purpose for EPIC was to predict the effects over time of alternative soil conservation strategies. EPIC models crop production with different crop rotations, cultural practices, tillage techniques, residue management regimes and fertilization rates. It is a fairly complex model with nine major components that simulate hydrology, weather, erosion, nutrients, plant growth, soil temperature, plant environment control, and economics.

EPIC Jordan:

An EPIC model for a typical dryland setting in Jordan was adapted by Dr. Abdullah Jaradat from a similar model for Texas. Soil parameters and initial values were adapted from the Ramtha Agricultural Experiment Station in northeast Jordan. Daily precipitation data from Mafraq for the period 1978-87 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, and vetch was adopted from a winter pea fodder legume. Results from field trials during 1987-89 were used to calibrate and validate the EPIC models.

In Jordan it is common to remove all barley straw and aftermath residue from cropland either by grazing or by gathering. Residue removal was simulated in EPIC by following the grain harvest with a second (stubble) harvest operation that removes 90 percent of all non-grain above ground biomass. After all residue is removed, there is virtually no crop residue standing or on the soil surface to provide erosion protection and to be incorporated into the soil to improve tilth and recycle nutrients.

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 check the internal consistency between the Jordan barley model's predictions of production and the indicated levels of moisture, soil nutrients, and stress conditions.

Water stress is an important source of plant stress, which limits biomass production. A separate effect of water stress occurs during the grain-fill period where it causes significant declines in crop grain yields.

Nitrogen deficiency is the most important source of plant biomass stress, in Mafraq according to EPIC Jordan. Nitrogen is deficient because of inherently low levels of soil organic matter, little or no use of nitrogen fertilizer, 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 average yields observed during 10 years of field trials at the Ramtha Agricultural Experiment Station. Parameters in the model were adjusted until simulated yields tracked closely the actual yields under the same precipitation conditions.

The Whole-Farm Planning Model

A mixed-integer programming model is used to simulate decision making for a typical farm in the Mafraq region. The model selects the combination of crop and livestock activities that will maximize expected profit given the constraints of available land and labor. A typical farm in the Mafraq area is assumed to have 18 hectares of land available for crop production and access to grazing equivalent to 20 hectares of steppe land.

Labor shortages are assumed to occur only during the June-July harvest period. Based on unpublished survey results for the region, the farm family is assumed to provide 147 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) 2.5 per man-day.

The alternative cropping activities include continuous barley cropping, barley alternated with fallow, and barley alternated with vetch hay. For each of these rotations, the model allows for choosing between fertilizing with nitrogen or not fertilizing, and either removing virtually all residue from the field by grazing or harvest (residue removal) or leaving the residue to be tilled into the soil (residue incorporation). Fallow cropland is a weedy (grazed) fallow where weeds are grazed by the farm's sheep flock instead of being controlled chemically or mechanically.

Sheep are a key component of farming in the Mafraq region and throughout Jordan. The livestock portion of the model is a "steady-state" type as described in Pannell. Sheep production activities in the mixed-integer programming model allow a choice between low, medium, and high quality feeding regimes (Nordblom and Thomson). 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 proteins. Feed can be supplied by purchases or own-farm produced barley grain and barley hay, own-farm produced vetch hay, and purchased wheat bran. The year is divided into four feed seasons (spring, summer, fall, winter) with losses in quality and quantity of barley straw and vetch hay stored over time. Steppe land, weedy fallow, stubble barley fields, and grazing in-lieu of harvest are available for seasonal grazing although stubble grazing is precluded under the residue incorporation option. Saleable outputs from the flock are lambs, cull ewes, cheese, and wool.

Integer variables represent the harvest versus grazing in lieu of harvest decision, where farmers may opt for grazing instead of harvesting a grain crop in dry years when yields are low.[1] Other integer variables represent a "fixed cost" reduction in harvest-period labor supply if either one or two farm workers are used to tend the farm sheep flock.

The model has the capability of internalizing the present economic value of future productivity losses due to soil depletion and erosion (Hughes). The erosion damage value of cropping activities depend on their conservation properties. But, the present value of the damages is very strongly affected by the time horizon and discount rate. Farmers in situations such as Mafraq generally have a short time horizon and high discount rate, but society may be more concerned about the effects of current soil erosion on future soil productivity.

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[1]The economics of the harvest versus graze decision is explored in much greater detail in Hughes, Penaranda, Butcher and Jaradat.

RESULTS

Long Run Yield Trends

The EPIC crop growth model was used to estimate barley grain, barley straw, vetch hay, and fallow land weed production over the range of weather that occurred during 1978-1987 and with soil conditions held constant at initial values. These initial condition yields were then compared to EPIC results over the same range of weather with soil conditions held constant at the level reached after 50 years of erosion and nutrient depletion. Initial soil conditions are similar to those found at agricultural experiment stations in the region, which are more fertile than most farm soils.

TABLE I: Comparison of Selected Barley Grain, Barley Straw, and Fallow Yields for the Mafraq Region Before and After 50 Years of Soil Erosion and Depletions as Predicted by the EPIC Model.

Barley and Fallow Output	Barley Fallow		Continuous Barley		Fertilized Residue Incorporated Barley-Fallow	
	50 Year Use: (mt/ha)		50 Year Use: (mt/ha)		50 Year Use: (mt/ha)	
	Before	After	Before	After	Before	After
Barley Grain	1.06	0.42	0.76	0.35	2.22	1.77
Barley Straw	1.50	0.53	1.38	0.49	----	----
Fallow Weeds	1.02	0.75	----	-----	1.02	0.99

A typical traditional barley-fallow crop rotation (Table I) with no fertilizer use and grazing of crop residue over a 50 year period of erosive and soil-depleting farming results in barley straw and barley grain yield decline of 60 percent and 65 percent. The decline in yield is fairly steady throughout the 50 year period with a slight tendency towards acceleration in the rate of yield loss due to soil erosion (Figure 1) and a slight countervailing tendency towards a deceleration in yield loss due to soil depletion (as measured by the time variable in Figure 2). The soil depletion decline in yields is caused by loss of soil organic matter and other nutrients. Top layer soil organic matter declines from 0.7 percent to 0.2 percent over the 50 year period. The slightly increasing rate of yield losses due to soil erosion results from an increased annual erosion in the later years as less vegetative crop growth means less resistance to wind, which is the primary cause of erosion in the region.

The year-to-year variation in yields that results from weather variation is much higher before erosion (continuous barley grain yields range from 0.41 metric tons per hectare to 1.0 metric tons per hectare) than after 50 years of erosion (per hectare barley grain yields vary from 0.32 to 0.38 metric tons) (Table I). 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 50 years of erosion and nutrient depletion, there will be little response of grain production to rainfall because soil infertility becomes the over-riding limit to productivity.

It is possible that development of high yielding varieties (HYVs) or other forms of technological progress could partly offset

FIGURE 1. NON-EROSION MINUS EROSION YIELD DIFFERENCE AS A FUNCTION OF CUMMULATIVE EROSION

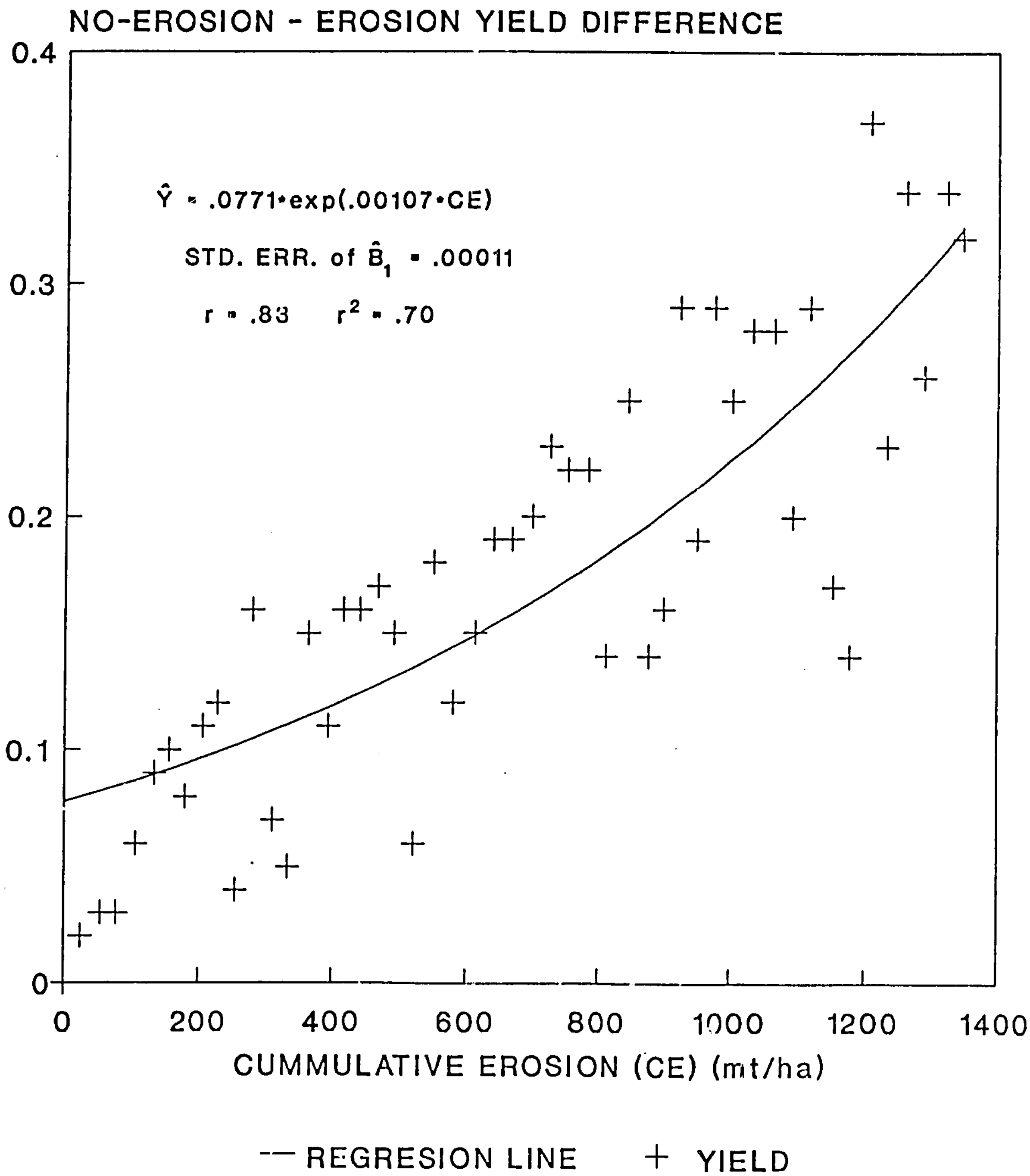
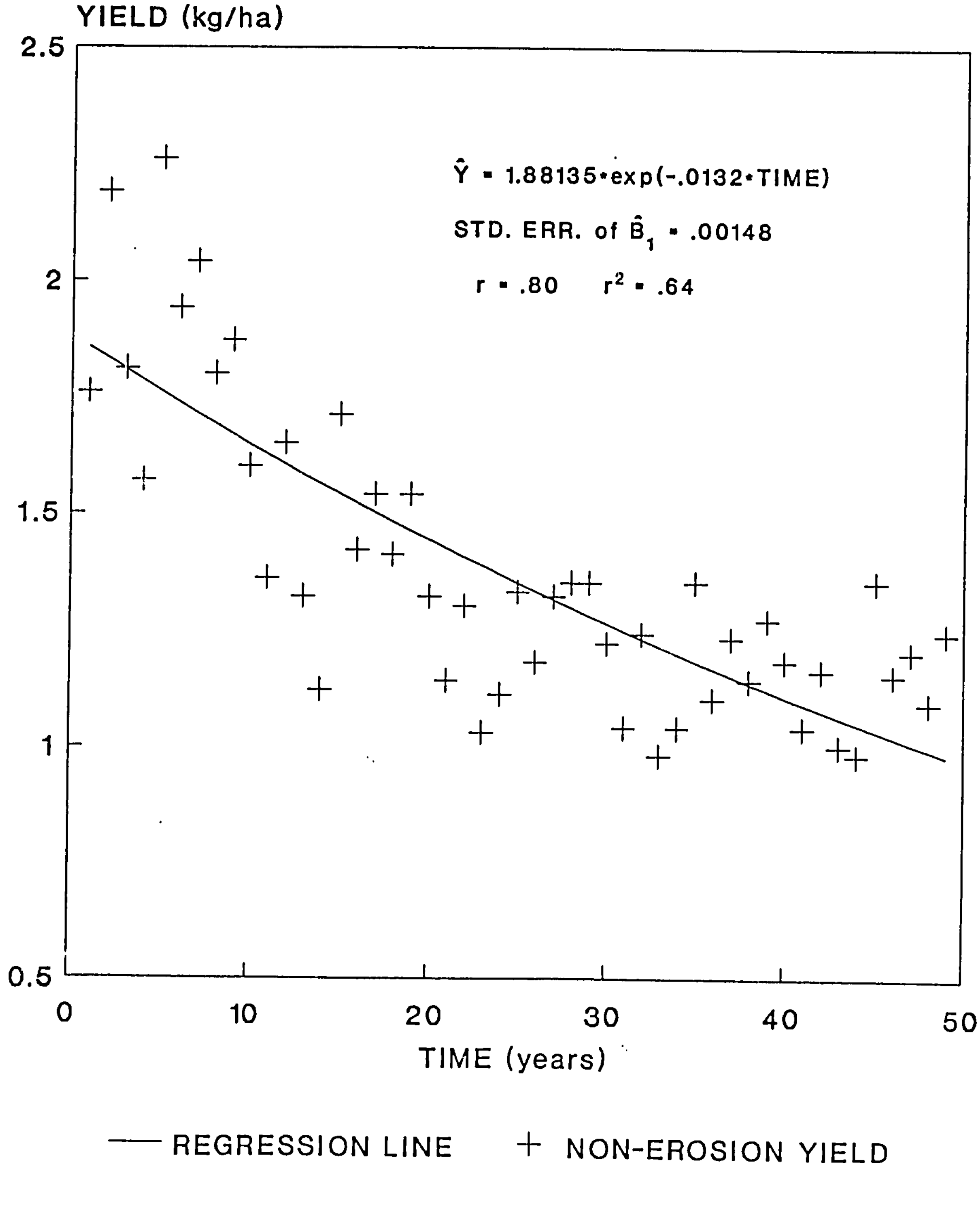


FIGURE 2. NON-EROSION YIELDS AS A FUNCTION OF TIME



the productivity decreasing effects of erosion and fertility decline. But improved technologies tend to perform much better in deeper topsoils with high levels of fertility and adequate soil moisture (Walker and Young). Therefore, high rates of nitrogen and phosphorous fertilization, incorporation of soil residues to increase soil fertility and moisture retention, and use of legumes in rotation may be required to prevent or restore soil productivity and take advantage of new technologies such as HYVs.

Applications of yield-enhancing technologies may also markedly slow the decline in yields resulting from erosion and soil fertility depletion over time. A barley-fallow crop rotation with an application of 60 kilograms of nitrogen per hectare and with residue incorporated into the soil shows not only an immediate increase in yield but also only about one-half as much productivity decline over time as does the traditional barley-fallow rotation (Table I). The percent decline in grain yields is lower for the yield-enhancing technology because applications of fertilizer and incorporation of residue slow the loss in soil fertility and because higher levels of crop residue production and retention reduce wind erosion rates.

<u>Whole Farm Model Results</u>

The mixed-integer programming model was used to evaluate six different cases that differ in the availability of certain yield-enhancing production techniques, the assumed soil conditions--either before or after 50 years of depletion and erosion, and the consideration given to the present value of future productivity

Table II: Selected Results of Mixed Integer Program Farm Decision Model for the Mafraq Area of Jordan.

Scenario	Net Returns (JD)[1]	--Barley Grain-- Output (MT)	Fed (MT)	--Barley Straw-- Sold (MT)	Fed (MT)	Grazed Aftermath (MT)	Fallow Grazed (MT)
1. TRADITIONAL PRACTICES							
a. Current yields	4225	9.5	7.2	0.0	11.0	2.5	9.2
b. 50 Year yields	2812	3.9	9.2	0.0	9.4	0.8	6.8
2. FULL MODEL[2]							
a. Current Yields	4704	17.0	6.2	15.3	10.3	5.7	9.2
b. 50 Year Yields	3932	11.4	7.2	7.6	9.4	3.8	8.7
3. RESIDUE INCORPORATED[3]							
a. Current Yields	4275	20.0	9.3	0.0	8.3	0.0	9.3
b. 50 Year Yields	3572	5.0	9.3	0.0	8.3	0.0	8.9

NOTE: All scenario solutions result in 18 hectares of a barley-fallow rotation. The flock size varies between 61 ewes and 63 ewes for each of the various scenarios. a high quality feeding regime is optimal for all solutions. Reported levels of fed barley grain and hay include both own-farm production and purchased inputs. 6336 kilograms of wheat bran are also fed to livestock in each of the scenarios.

[1] A JD is a Jordan Dinar with an exchange rate in 1987 of $2.95 US Dollars per JD.
[2] All barley hectares are fertilized in both full model solutions.
[3] Barley is fertilized with initial soil conditions but not after 50 years.

lost due to erosion damage. Results for a typical Mafraq farm are reported in Table II.

The first scenario models traditional farming practices with yields that could be expected now, before 50 years of erosion and soil depletion (Scenario 1 a. Current Yields). It is assumed that the farmer will consider only a barley-fallow rotation or continuous barley cropping, both without fertilizer and with all residue grazed. As shown in Table II, barley grain and straw production is mainly used to support the livestock flock of 62 ewes. Net returns to land, capital, management, and labor in periods other than harvest are 4225 JD from one year of crop and livestock activity.

After 50 years of soil erosion and depletion and resulting yield decline (Scenario 1 b. 50 Year Yields, Table II), the optimal farm program is virtually unchanged, but net returns decline by 33 percent. Income is lower primarily as a result of declines in barley grain sales.

In the second scenario, fertilization, incorporating residue (as opposed to complete grazing), and a barley-vetch crop rotation are allowed as options (Table II). With initial soil conditions (Scenario 2 a. Current Yields), the model indicates that it is most profitable to continue to use a barley-fallow crop rotation but to apply nitrogen fertilizer to the barley crop. Fifty years of soil erosion and depletion would cause soil productivity and net farm returns to decline (Scenario 2. b. 50 Year Yields), but the drop in returns is only 16.4 percent as compared to the 33 percent decline when fertilization was not an option. Profitability is maintained because fertilizer applications increase soil fertility and biomass production which helps maintain organic matter levels and also reduces wind erosion.

Forcing farmers to incorporate crop residue (Table II Scenario 3. Residue Incorporated) by eliminating the options of selling, feeding, or grazing leads to very little change in the optimal production pattern. The most profitable rotation is barley-fallow with nitrogen fertilizer applied and a flock of about 60 ewes is optimal. However, farm income is about 9 percent less than in Scenario 2 where the option to graze aftermath was available and used. The difference is due to the cost of replacing the feed that is lost when the crop residue is saved for incorporation in the soil. This opportunity cost is only partly recouped by higher yields realized when the residue is not removed. But, for typical Mafraq farmers with livestock the feed value is considerably greater than the short-run grain yield. and, according to EPIC, incorporating residue and fertilizing does not maintain yields any better in the long run than would fertilizing and continuing to graze or harvest all residue. Residue incorporation as an actual arm option would also require a change in the structure of property rights. Nomadic herders currently have the right to graze (sometimes without charge) crop stubble, which is not utilized as a feed source by the farmer.

CONCLUSIONS AND AREAS OF FUTURE WORK

Several yield-enhancing technologies such as fertilizer and incorporating residue into the soil are sustainable because these practices also slow markedly the rate of degradation of the soil resource. Included in the farm options, but not required in any scenarios, are other combinations of yield enhancing and soil conserving technologies, such as vetch rotations. Whole farm model results indicate that a short run profit maximizing farmer would not voluntarily adopt yield enhancing and productivity conserving practices with the exception of fertilizer use. Accordingly, we can tentatively conclude that the technologies examined in the model may have to be accompanied by other new technologies such HYVs to be used by farmers.

Model results also predict that farming may continue to occur int he region over an extended period of time (at least over the next 50 years) even if yield enhancing and productivity conserving technologies are not adopted. Farming would be maintained because mixed-livestock farming as found in the Mafraq area can be supported by a rather nonproductive resource base. Farm productivity at these reduced levels would not meet the policy goal of increasing the productivity and conservation resources devoted to agricultural production, however.

One major area for further research is the improvement of both short- and long-run yield forecasting capability. Experiments, with combination of practices, such as residue incorporation with nitrogen fertilization are needed to calibrate changes in soil properties that can be used for calibrating EPIC models. Improving the responsiveness of the EPIC model to shortages in available phosphorus would, for example, improve EPIC as a modeling tool. The relationship between yield as a function of soil erosion and soil depletion needs to be evaluated further by correlating yield changes with both effects in a single equation or systems of equations, and by replacing time with variables such as organic matter, for which time currently serves as a proxy.

Another area of investigation concerns the farm model. Changes in resource endowments over time, and the inherent riskiness of farming in an area such as Mafraq may be important influences on farmer decision making. Farmers may be reluctant, for example, to use fertilizers because of the riskiness of low response rates if precipitation levels are lower than expected. Farmer decisions about adoption of new technologies and changing the level of their livestock flock hinge on their perception of variability of events over time. Accordingly, a dynamic programming model may provide further insight into the reasons why farmers do or do not use technologies that increase current productivity while conserving future productive capability of the soil resource.

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