FARM MACHINERY MANAGEMENT AND THE IMPACT OF CONSERVATION TILLAGE SYSTEMS ON SOIL EROSION AND THE SUSTAINABILITY OF WHEAT PRODUCTION IN RAINFED AREAS OF NORTHERN JORDAN

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CHAPTER I

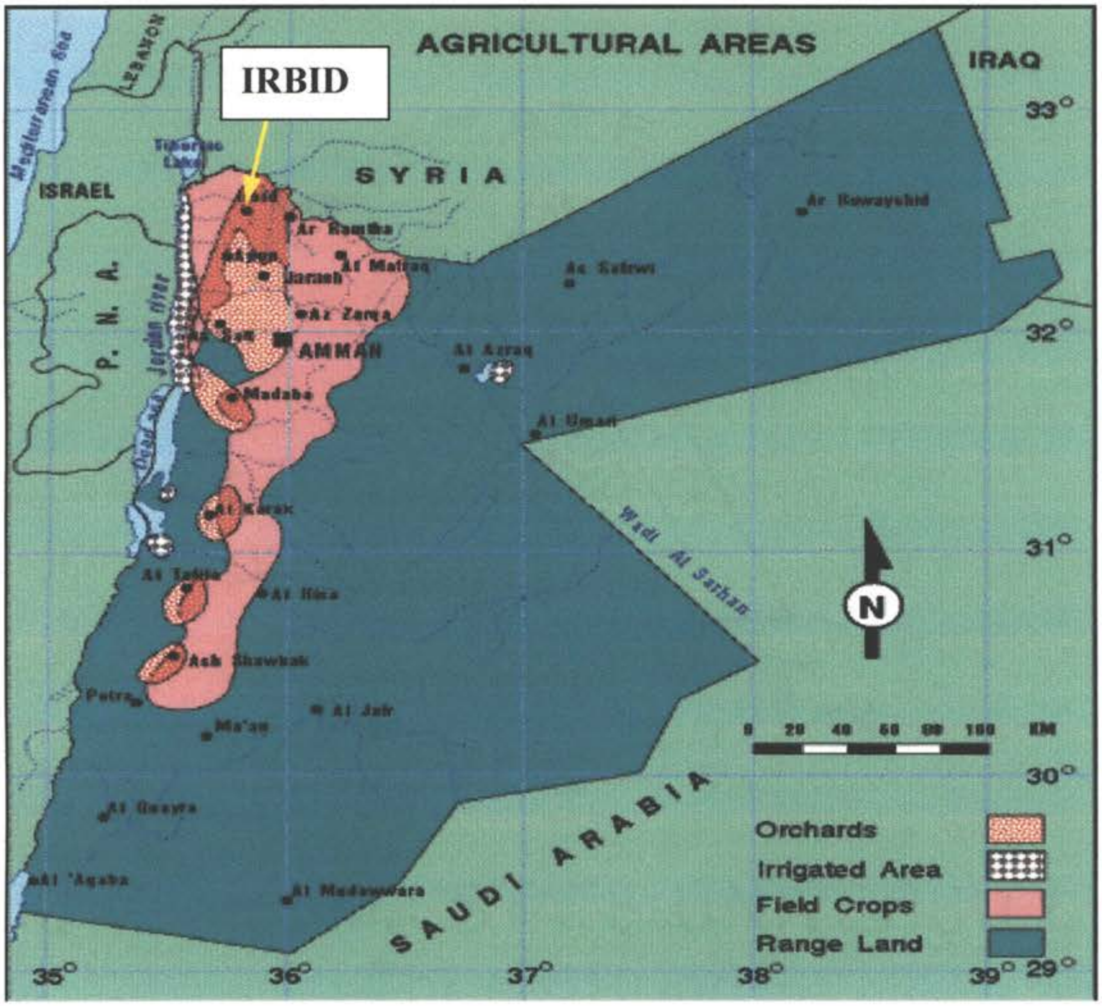
INTRODUCTION

With an expanding world population, the efficient sustainable production of food crops becomes increasingly important. This is particularly relevant to the rainfed areas where water and soil resources are limited. The rainfed areas of Jordan have been in production for a very long time, but studies indicate that productivity losses due to the use of traditional and exploitative cropping systems and through soil erosion may endanger the sustainability of food production in some areas.

Jordan is located to the east of the Mediterranean Sea between latitudes 29° 32' N - 32° 42' N and longitudes 35° 00' E - 38° 15' E (Figure 1.1). The population in 1997 was estimated at 4.6 million persons. More than half the population is under the age of 16 and so the labor force is less than one-quarter of the population. The population growth rate is about 3.6 percent per annum, one of the highest rates in the world. The high rate of growth in population was exacerbated in 1990 and 1991 with the return of 300,000 Jordanians from the Gulf States in the aftermath of the Gulf War (Kim et al., 1998).

Arable land in Jordan is a limited resource. The climate in the country is basically a Mediterranean climate characterized by dry hot summers and mild wet winters and extreme variability in rainfall within and among years.

Of Jordan's total land area of about 9 million hectares, only a small portion is suitable for producing crops. It is currently estimated that there are only 380,000 hectares of land that may be cultivated (Ministry of Agriculture, 1998). Tree crops are planted on about 90,000 hectares, leaving arable land---land that can be used to produce annual crops---at about 4 percent of the total land base. Less than 20 percent of cultivable land



Source: Royal Jordanian Geographic Center (*http://www.rjgc.gov.jo/maps/agri.html*)

Figure 1.1. The agricultural map of Jordan.

is irrigated, one-third of tree crops are produced with benefit of irrigation, but only 7 percent of the field crop area is irrigated. Thus, variation in rainfall from year to year mostly affects field crops such as wheat, barley, and pulses (Kim et al., 1998).

According to the annual rainfall, Jordan can be divided into four climatic zones, which are shown in Table 1.1.

Table 1.1. Land distribution according to climatic zones.

Climatic Zone	Average Annual Rainfall (mm)	Area (million dunums[1])	% Of the Total Area
Semi-desert	< 200	80.4	90.0
Dry	200 – 350	5.7	6.4
Semi-dry	350 – 500	2.1	2.4
Semi-humid	> 500	1.1	1.2
Total		89.3	100

Source: Ministry of Agriculture, 1998.

Actual cultivated area in 1997 totaled around 2.9 million dunums according to the Ministry of Agriculture statistics, of which 1.3 million dunums are planted with olive and fruit trees, 0.5 million with vegetables and 1.1 million with field crops. Whereas the rested area (left as uncultivated) was estimated at 0.9 million dunums.

According to the Ministry of Agriculture survey, the number of farm holdings in 1997 was around 91,500, at an average of 41.5 dunums each. In 1983 there was 57,438 holdings with an average size of 64.3 dunums each. These holdings have also became more fragmented (Jabarin, 1994).

[1] 1 Dunum = 0.1 Hectare

Agricultural Sector

The agricultural sector, a traditional recipient of subsidies in most countries, was the largest recipient of government subsidies in Jordan and therefore was an early candidate for reform. Since the mid-1990s, the agricultural sector in Jordan has undergone a process of restructuring. Agriculture represents the main income source for 15% of the population and it employs around 62,000 Jordanians (6% of the workers in Jordan). The agricultural sector contributed around 13.7% of the total exports (average 1991-1995), and around 15.4% in 1996 (Ministry of Agriculture, 1998).

The agricultural sector is characterized by un-stable production. This is because agriculture largely depends on rainfall and its distribution over the cultivation season. This directly affects production of the rainfed lands, ranges, livestock and irrigated agriculture. The latter is affected because of the impact of rainfall on the surface water and ground water storage.

Agriculture is a fundamental sector in the national economy. It is the base for integrated rural development, a source for income and employment for rural and Badia (Nomad) people and a generator of activities in the industrial and services sectors. Furthermore, it plays a central role in food security and trade balance improvement.

The agricultural sector is being developed and supervised by a group of government agencies, headed by the Ministry of Agriculture. In addition, some other governmental and semi-governmental agencies contribute, directly or indirectly, through their projects and services to the development of the sector (Ministry of Agriculture, 1998).

Wheat Production in Jordan

Wheat is the most important cereal produced in Jordan. More wheat is grown in the rainfed areas of Jordan than in other region in the country (GOJ, 1985). Approximately 140,000 ha of wheat are grown every year.

Jordan produces only durum wheat. The domestic wheat is used for freekeh[2], pasta, and for blending with imported wheat. Domestic wheat covers only about 15 percent of the total demand for wheat and wheat products. Imported wheat is typically hard winter wheat that is used to produce flat and other leavened breads. Soft wheat flour, used to produce cake and cookies, is imported by bakeries (Kim et al., 1998).

Most wheat producers in Jordan are small subsistence farmers without access to irrigation. The planted area has decline from 20-40 percent in recent years Table 2. Even so, production of wheat has been fairly constant in the past 5 years at around 50,000 tons. However, that is 30,000 tons less than the levels of the late 1980s (Kim et al., 1998).

In addition to subsistence farmers, there are some large commercial wheat farmers in the south. In 1988, the Government of Jordan (GOJ) implemented a dual-purpose program to 1) increase production of cereals and fodder and 2) to develop semi-marginal land for irrigated agriculture. At that time, the government offered low-cost long-term (25-years) leases on large tracts of land in the south to commercial operations that would build the necessary irrigation facilities on the land. The commercial operations signed contracts with the GOJ to produce wheat and fodder (Kim et al., 1998).

[2] Freekeh is durum that has been picked while still green, slightly roasted, and then crushed after thorough drying. There are two grinds available---coarse, which is cooked like rice, and fine, which is used in soup.

The planted area and production of wheat in Jordan from the years 1976 to 1995 are shown in Table 1.2.

Table 1.2. Planted area and production of wheat for the years 1976/1995.

Year	Area (1000 dunums)	Production (1000 tons)	Yield (ton/dunum)
1976	1369.5	66.6	0.0486
1977	1264.5	62.5	0.0494
1978	1345.7	53.3	0.0400
1979	989.6	16.5	0.0167
1980	1336.7	133.6	0.0999
1981	991.5	50.6	0.0511
1982	1019.6	52.2	0.0511
1983	NA	NA	NA
1984	632.3	49.7	0.0786
1985	943.6	62.8	0.0666
1986	594.4	30.8	0.0518
1987	843.2	79.8	0.0946
1988	701.8	78.8	0.1123
1989	562.1	54.5	0.0970
1990	605.3	83	0.1371
1991	564.7	61.8	0.1094
1992	534.1	75.4	0.1412
1993	679.2	57.1	0.0841
1994	424.5	46.9	0.1105
1995	512.3	58.5	0.1142
Average	837.6	61.8	0.0738

Source: Eng. Muneer I. Omar and Eng. Falah I. Salah. A national study about the future of Arabic agriculture and food production for the year 2025. Jordan Ministry of Agriculture. PP (171-172).
NA: No data available for this year, due to the comprehensive agricultural survey in that year.

Wheat Price Support

Prior to the fall of 1997, the Ministry of Supply (MOS) announced a minimum and maximum purchase price for durum wheat before or during the planting season. Announced prices would have little effect on subsistence farmers' planting decision---instead rainfall expectations are the most important factor. However, large-scale commercial operations could base their planting decisions on those prices. After harvest, most farmers with surplus wheat, transported the grain to the MOS collection centers located throughout the country. At the MOS centers, the grain is tested for quality, priced between the minimum and maximum based on its quality, and the farmer is issued a check. A very small portion of farmers sells wheat to traders at the farmgate who then in turn take it to the MOS collection centers.

The subsidy to wheat producers under the announced purchase program has varied from JD0.05 million to JD2.5 million since 1990 (Table 1.3). The value of the subsidy varies because domestic prices are measured against fluctuating world prices for wheat. For example, in 1996, when world commodity prices were quite high, wheat producers were actually taxed but then in 1997, a subsidy of about JD2 million was given to the producers.

Table 1.3. Subsidy to Wheat Producers from the Government of Jordan Announced Price Procurement Program

Year	Average price paid to producers (JD/ton)	External reference price (JD/ton)	Value of subsidy to wheat farmers (1000 JD)
1990	145	126	1,621
1991	146	105	2,522
1992	145	124	1,588
1993	147	127	1,127
1994	146	124	1,029
1995	160	159	56
1996	190	208	-762
1997	197	161	2,016

Source: Computed from data supplied by the Ministry of Supply.
Note: The average price paid to producers is the price for local durum wheat. It is compared to a durum-equivalent external (world) reference price. The external reference price was computed based on the total cost of imported wheat (delivered to Amman), plus any price discounts from wheat exporters (1995 only), and an estimated durum price premium of 12.5 percent relative to the price of the most commonly imported wheat.

The study area

This study was conducted for the rainfed conditions of Irbid area in the north of Jordan. Irbid Governorate is located in the northern plateau of Jordan (Figure 1.1) and situated about 90 km north of Amman (Harahsheh et al., 1998). The Irbid area is considered the second important regional center in Jordan. It is divided into eight districts and sub districts. The population of Irbid Governorate was estimated in 1997 to be about 835,360 inhabitants (Department of Statistics, 1997). The total area of Irbid is about 145,605.5 ha, 73% of which (106,666.3 ha) is arable land. The planted area in Irbid is about 66,754.3 ha, which constitutes about 45% of the total land and 62% of the arable land. About 99% (66,200 ha) is rainfed area (Irbid Directorate of Agriculture, 1999). Wheat is planted in an area of 13,212 ha, which is about 20% of the total planted area in Irbid, and it is the largest area used for wheat production in the country (MOA, 1997).

The climate in Irbid is classified as semiarid Mediterranean marked by four seasons with warm summers and cold winters, and annual average rainfall varies from 250 mm in the eastern part to more than 500 mm in the western part of Irbid (Abdelhadi and Baddawi, 1978). Irbid has the largest number of farm machinery compared to other areas of Jordan. The types and number of different farm machinery available in Irbid for the year 1998 is shown in Table 1.4.

Table 1.4. Types and number of farm machines in Irbid Governorate in 1998.

Farm Machine	Number
Tractor	1421
Sprayer	64
Grain Drill	21
Combine	28
Thresher	193

Source: Irbid Directorate of Agriculture, 1999. Annual Report (In Arabic).

The soils in this area are mainly calcareous or silt clay usually weathered from limestone. This is an important soil-forming material, and in the wetter areas it assumes a typically reddish brown color. Most of the good agricultural soil of the Jordanian plateau belongs to these Mediterranean soils. When deep, these soils are excellent cropland (Aresvik, 1976). Chromoxererts soils the (Vertisols) developed under a xeric soil moisture regime are deep, clayey soils, developed on hard limestone.

Thesis Content

The remainder of this thesis is outlined as follows. Chapter 2 contains a comprehensive review of the literature about agriculture, the agricultural practices related to wheat production, farm machinery, and the problem of soil erosion in Jordan. In chapter 3, the statement of the problem, the overall objective and the specific objectives of the study are discussed. The specific objectives for this study are:

1. To determine the timeliness cost of planting wheat before and after the optimum planting date in rainfed areas of Northern Jordan.
2. To determine the proper sizes and ownership costs of farm machines and equipment used in wheat production in rainfed areas of Northern Jordan.
3. To determine the impact of using conservation tillage systems on soil erosion and the sustainability of wheat production in rainfed areas of Northern Jordan.

Each of these objectives is discussed in a separate chapter. In chapter 4, the timeliness cost for planting wheat before or after the optimum planting date in rainfed areas of Irbid in the north of Jordan is studied. A crop growth model (CERES-Wheat) is used for this purpose. In chapter 5, machinery selection and ownership cost for farm machines used in Irbid area is discussed. A spreadsheet template was modified using input data related to machinery sizes and prices from Irbid area in order to determine the proper machinery complement and the annual ownership costs of farm machinery in Irbid. EPIC model is used to calculate the days available for work, which is required in the machinery size selection and annual cost analysis. In chapter 6, the problem of soil erosion and the sustainability of wheat production in Irbid area is discussed. EPIC model is used to simulate the rate of wheat yield and the rate of soil erosion over a hundred years planning period. The NPV analysis for wheat production under two tillage systems namely, conventional and conservation tillage systems using a wheat-fallow crop rotation is studied. The NPV analysis is discussed for two soil depths, two soil slopes and two discount rates for the study area. Chapter 7 contains a summary of the thesis and the conclusions obtained from the results of each chapter.

CHAPTER II

REVIEW OF THE LITERATURE

Tillage Practices in Jordan

The development of tillage practices for dryland crop production has been, and will continue to be, a dynamic process. The traditional and exploitative cropping system, which has been practiced in Jordan and other Middle Eastern countries, depleted soil resources and resulted in lower crop yields (Rafiq, 1978).

Traditional crop rotations, which are practiced in Jordan, were based on the fallow system and conventional tillage practices. This system performed reasonably well in the past. However, with the increased population pressure and mechanization of the dryland farming, new highly improved tillage practices are needed to stabilize both soil resources and crop production (Jaradat, 1988).

The general features of tillage in rainfed areas of Jordan are changing, especially after the establishment of three agricultural machinery stations by the Jordanian Cooperative Organization (JCO). The first station was established near Ramtha Agricultural Research Station in Northern Jordan. The second is located near Mushagar Agricultural Research Station, in Mdaba district in Central Jordan, and the third is located near Rabbah Agricultural Research Station in Southern Jordan. All three machinery stations were supplied with the necessary equipment, especially for conservation tillage, by the German Agency for Technical Cooperation (GTZ) (Otto, 1980).

Until recently (Tamimi, 1981), tillage in rainfed areas of Jordan was characterized by:

(a) Large number of tillage operations. In areas where wheat-fallow rotation is used, farmers felt that the more tillage operations and the deeper the plowing, the more yield they get. Four to six tillage operations during a fallow period of 16-18 months were common in these areas.

(b) The use of unsuitable tillage implements such as heavy disks and moldboard plows.

(c) Plowing up and down the slopes. This practice aggravates the problem of soil erosion.

(d) During the fallow year, some farmers tend to delay spring plowing for weed control. Weeds are left for grazing by animals until early summer. However, early plowing is a common practice for the control of summer weeds and to minimize loss of moisture through cracks, which develop in heavy soils during summer months.

Primary tillage

Primary tillage in rainfed areas of Jordan, and other Mediterranean countries, is performed from June until November. Timing of tillage is very important in dryland farming. Farmers, in rainfed areas of Jordan, practice fall tillage to break open the soil surface in order to increase infiltration of water rains and store more moisture in the soil profile. Fall plowing may be advisable for heavy, fine-textured soils. The wetting-drying action over the winter breaks large clods into smaller granules, and makes secondary tillage for seedbed preparation easier. Spring tillage, during the fallow period, usually is performed during the period from March to May. The main purpose is to control any weed growth and reduce moisture loss through evapotranspiration (Jaradat, 1988).

Secondary Tillage

Secondary tillage refers to field operations after primary tillage to prepare the seedbed for planting. The purpose of secondary tillage is to further pulverize the soil and prepare a fine seedbed.

The disk is the most popular secondary tillage implement in dryland farming areas in Jordan. Offset or tandem disks break large clods, mix some trash into the surface, and smooth a rough soil surface. A disk penetrates to a depth of 8-15 cm.

More recently, other implements were introduced for secondary tillage. These were field cultivators and harrows. A field cultivator has single-or double- pointed shovels, spikes, or small sweeps. It digs, lifts, and loosens the soil, cuts roots below the soil surface, and leaves some stubble on the soil surface. Harrows are also used for secondary tillage. The spike-tooth harrow is used to smooth the seedbed and break any clods. It loosens the surface layer of the soil to a depth of 8-10 cm (Jaradat, 1988). Early plowing (after harvest) is a common practice in Jordan to control summer weeds and minimize the loss of moisture through cracks, which develop in heavy soils during summer (Loizides, 1979).

Tillage Implements

Farm machinery was introduced into Jordan, and most Middle Eastern countries, without pretesting for suitability and without sufficient training of operators to properly use and maintain it (Tamimi, 1981). Moldboard and heavy disk plows, which were developed for high rainfall and heavy soils of Europe, were imported and used in the dryland farming regions of the Middle East without any testing (Lanzendorfer, 1985).

Lanzendorfer, (1985) estimated the number of moldboard plows in Jordan at 1270 and disk plows at 1210. However, the Jordanian Cooperative Organization (JCO) estimated the number of chisel plows at 160 and this number is on the rise as more and more farmers are realizing the benefits of chisel plows over the moldboard or heavy disk plows (JCO, 1985).

Researchers at the University of Jordan and JCO recommend the following tillage system for continuous small grain production areas: a chisel plowing is recommended 2-4 weeks after harvest, another chiseling during September-October prior to seeding, to a depth of 15 cm; a sweep plow should be the last implement for seedbed preparation. In a fallow year, sweeps are to be used for weed control during spring (April-May) (Jaradat, 1988).

Time of Fertilizer Application

Information on time of fertilizer application under rainfed conditions in Jordan is very limited (Jaradat, 1988). Usually, split application of fertilizer N is recommended with one-half applied at planting of wheat, and the remainder sidedressed just prior to the rapid growth, which coincides with tillering (Olson, 1980). The main fertilizer used for wheat is the Di-Ammonium Phosphate (DAP), which is applied with the grains (at the time of planting) using the grain drill. The Nitrogen (N) fertilizer is added in February.

Cultural Practices

Cultural practices include all activities carried out by farmers in the process of crop production. Under semiarid conditions, these practices have been developed on the basis that soil moisture is the main factor limiting production. One of the widespread practices that has evolved in the Mediterranean climates is summer fallow. Fallow efficiency (percent precipitation stored in the soil profile) under dryland conditions in Jordan, is very low (10%) compared to its efficiency in the Great Plains of the U.S. In the Great Plains, efficiency ranges from 19-33%, the highest being associated with the use of stubble mulch, minimum tillage, and the use of herbicides for weed control (Gerb et al., 1970). In Jordan dryland farming, summer fallow has proved to be necessary and economically sound practice (Jaradat, 1988).

Seedbed Preparation

Under limited soil moisture conditions, seedbed preparation methods should conserve moisture. Water is the major factor limiting production and successful cropping practices make efficient use of it while conserving soil and water resources (Smika, 1970).

The earliest documented results on tillage operations and seedbed preparation in Jordan were reported by Hopkinson (1973,1974) and Winters (1976). The established implements, at those times, were disk plows and one-way disk harrows. Except where the land was fallowed, wheat farmers used to broadcast and plow in the seed in one operation. In the wheat-fallow system, the initial tillage operation can be performed any time during the summer or early fall. This tillage operation is usually for weed control.

Although, tilling should be done to control weeds, Jordanian farmers perform 4-6 tillage operations during this period. Consequently, at seeding time, wheat and barley are planted primarily on clean fallow land (Babb, 1976).

For Jordanian conditions, Harvey et al., (1982) and Bull et al., (1983,1984) recommended that the initial cultivation be done with a cultivator and a secondary cultivation with heavy spike-toothed harrow. The latter implement was recommended to level the ground, break down any large clods of soil and remove any residues. A final cultivation is performed with the seeding operation using a seed drill fitted with standard 8-cm sweeps to kill germinated weeds.

Sowing Methods

Two methods are common in Jordan for the seeding of small crops: broadcasting and drilling. Broadcasting is made mostly by hand, and then the seed is covered by a tillage implement (Tamimi, 1981). Seed drills are becoming more available and an increasing number of farmers are using them after realizing the advantages of seed drilling.

Sowing Dates

The date of sowing is one of the most important factors affecting crop yield under dryland conditions in Jordan (Jaradat, 1979). Farmers, practicing dryland agriculture in Jordan and other countries of the Near East Region, learned by trial and error that seeding small grains before sufficient rain is received is very risky (Tamimi, 1981). With light early showers, seeds may germinate in the absence of sufficient moisture and dry out.

However, to delay seeding until enough moisture is stored in the soil profile to ensure germination and seedling growth leads to yield reductions (Jaradat, 1979; Duwayri, 1979).

A series of seeding date experiments at three locations differing in annual rainfall were conducted to advise farmers on proper seeding dates for their regions (NCARTT, 1980; 1981; 1982). Results of these experiments, over several growing seasons and across locations, indicate that seeding before the onset of rain at a depth of 6-8 cm resulted in higher yields as shown in Table 2.1.

Table 2.1. Effect of seeding dates and depths at three stations in Jordan on grain yield (kg/ha) of wheat.

Station	Seeding date	Seeding Depth (cm)		
		5	8	Mean
Ramtha (79/80)	Before Rain 11/6/79	1066.7	1266.7	1166.7
	After Rain 1/5/80	1650.0	1458.3	1554.2
	Mean	1358.3	1362.5	
Rabbah (79/80)	Before Rain	1394.4	1433.3	1418.9
	After Rain	322.2	222.2	272.2
	Mean	858.3	827.8	
Rabbah (81/82)	Before Rain 11/1/81	1391.9	1223.0	1307.4
	After Rain 1/9/82	973.0	932.4	952.7
	Mean	1182.4	1077.7	
Maru 1981	Before Rain 11/4/81	2527.8	2972.2	2750.0
	After Rain 12/29/81	1694.4	1791.7	1743.1
	Mean	2111.1	2382.0	

Source: National Center for Agricultural Research and Technology Transfer, 1980; 1981; 1982.

Sowing Rate

Hopkinson (1975) tested a number of wheat varieties for optimum seeding rate at six locations in southern Jordan and noted that the results were not very conclusive. Seeding rates of 60, 80, and 90 kg/ha gave grain yields of 1215, 1248, and 1357 kg/ha, respectively. Duwayri (1980) studied the effect of different seeding rates on grain and straw yield of Stork 's' durum wheat. He found that when seeding rate was increased from 80 to 130 kg/ha, grain and straw yields increased significantly from 1543 to 1814 kg/ha for grain, and from 2511 to 3027 kg/ha, for straw yield.

Results obtained by Jordan Cooperative Cereals Improvement Project (JCCIP) (1984) showed that seeding rates should be specific for the variety as well as the method and date of seeding. Seeding rates in the range of 100-140 kg/ha gave the highest grain yields with high-yielding varieties under favorable environments. Perhaps a rate of 100 kg/ha would be the optimum for high-yielding environments and a rate of 80-100 kg/ha is recommended when broadcasting the seeds.

Sowing Depth

Sowing depth has a marked effect on seedling emergence and stand establishment, especially under dryland conditions. The broadcasting of small grain seeds and the subsequent tillage operation to cover them, result in placing the seed at varying depths across the field. As a result, seed germination, seedling emergence and stand establishment will not be uniform or optimal (Jaradat, 1988).

El-Quhaiwi (1979) investigated the effects of three sowing depths (2, 4 and 8 cm) on the yield of local wheat and barley varieties. His results showed consistently higher grain yields with deep (8 cm) sowing.

Generally, local wheat cultivars can emerge from deeper (10-12 cm) sowing depths due to their longer coleoptiles. In contrast, modern, semi dwarf varieties fail to emerge if sown deeper than 5-6 cm due to their shorter coleoptiles (Jaradat, 1979).

Crop Rotations

The influence of crop rotations on crop yield has been reported from most of the experiment stations around the world. Some of the advantages usually listed for crop rotations are:

1) Soil nitrogen and organic matter can be increased as a result of including a legume in the crop rotation.
2) Plant diseases, insects and weeds can be more easily controlled.
3) The presence of a growing crop reduces soil erosion and minimizes losses of nutrients by leaching.
4) Greater yields per unit area may be obtained.

Research on crop rotations in the rainfed areas of Jordan has been rather limited.

Farmers in the dryland farming regions of Jordan traditionally followed a 2-year or a 3-year crop rotation. In the northeastern region, where annual rainfall is below 250 mm, farmers practice a barley-fallow crop rotation. In areas of more than 350 mm of annual rainfall, a 2-year or 3-year rotation is followed. In these areas, a legume crop is a major component in the crop rotation. Recently, however, less area has been planted to legumes in the rainfed regions of Jordan because of the unavailability of suitable combines for harvesting the legume crop and the necessity of carrying out this operation by hand, which is costly and time consuming. Examples of typical crop rotations in the semiarid zone (350-500 mm of annual rainfall) are wheat -legume crop (lentils, chickpeas or vetch); fallow wheat; and summer crop (e.g. summer vegetables, tobacco) - wheat.

A 3-year crop rotation is practiced when annual rainfall exceeds 400 mm. Examples of such rotations are: legume crop - wheat - summer crop; or fallow - wheat - summer crop (Jaradat 1988). A summary of traditional crop rotations in different agroecological zones of Jordan appears in Table 2.2.

Table 2.2. Examples of crop rotations practiced in different agroecological zones of Jordan's dryland area.

Zone	Rainfall (mm)	Crop Rotation
Arid	< 200	No Crop Rotation
Marginal	250 – 300	Wheat – Fallow
		Barley – Fallow
Semiarid	300 – 500	Summer Crop – Wheat
		Legume Crop – Wheat
		Fallow – Wheat
Semihumid	500 – 800	Fallow – Wheat – Summer Crop
		Legume – Wheat – Summer Crop

Source: Jaradat, 1988.

Agricultural Machinery in Jordan

Agricultural mechanization in Jordan occurred on a purely private base, without public interference. The mechanization of agricultural activities is limited mainly in tillage and partly in other operations.

Land operation was, and still is, the most important field of agricultural mechanization. The first tractors were imported to Jordan in the 1930s; the very first could have been an International Harvester with about 20 h.p. bought in 1933. Prior to 1948, tractors had steel wheels or tracks. They were operated with kerosene and pulled 4-moldboard plows and 15-disk-harrows (Lanzendorfer 1985).

Further introduction of the tractor was rather slow; according to the records of the Department of Agriculture there were nine tractors in Jordan in 1939 and about 74 tractors in 1948. According to data on tractor assets from the Agricultural Censuses 1965 and 1975, the biggest advance in Jordan's tractorization must have been from the mid-1950s to the end of the 1960s.

This is supported by some case studies, e.g. by Wolffgang's investigation in 1967: "Field visits in various districts offered the impressive picture of nearly all areas suitable for mechanical cultivation being cultivated with tractors and other machinery". Moreover, in 1971/72 a sample of 112 farmers in the three pilot areas of the 'Dryland Farming Project Jordan/Kerak' revealed that tractor use had become very common, 84 percent of the farmers plowed their land with their own or hired tractors.

During the 1970s, and especially after 1973, there was only a slight increase in the total tractor population. Purchases were mainly made to replace unserviceable machines. The increase that did occur, was to a large extent, due to area extension and intensification of agricultural practices in the Jordan Valley. The articulated tractor was introduced to Jordan during the 1970s when 14 articulated tractors were bought between 1973 and 1979.

Whereas the market for conventional tractors has become rather saturated, sales of articulated tractors indicated a cautious trend towards the need for more specialized machinery. Not only were old items substituted, but total assets were also increased.

At the end of 1973, there were 3,260 tractors in the country. Of these, 1,905 tractors were used in agriculture. Table 2.3 below gives the figures for tractors and equipment sold annually during that period (Aresvik 1976).

Table 2.3. Tractors and other equipment sold during 1968 – 1973.

Years Tractors	1968	1969	1970	1971	1972	1973
Tractors at end of year	2,507	2,662	2,758	2,856	N/A	N/A
Tractors sold during year	179	155	96	98	204	284
Combines	11	15	3	22	24	N/A
Cultivators	190	232	466	94	241	90

Source: Kingdom of Jordan, Department of Statistics, Statistical Year Book, 1972 and 1973.

The available farm machinery for various districts of Jordan at the end of the year 1973 are given in Table 2.4.

Table 2.4. Farm machinery in Jordan, end of 1973.

District Equipment	Irbid	Amman	Baq'a	Karak	Ma'an	Total
Wheel tractor	670	597	202	326	110	1,905
Track-type tractor	4	20	6	3		33
Large drills		10				10
Small drills	2	5		4		11
Self-propelled combine	62	67		15		144
Pull-type combine	8	15				23
Windrowers and mowers, animal drawn	14					14
Sprayers	43		2			45
Plows, all						1,000

Source: Kingdom of Jordan, Ministry of Agriculture, "Working Paper for Developing and Increasing Wheat Production in Jordan" (Amman, 1974).

In a survey conducted to compare costs and use of government tractors with costs of operating privately-owned ones in Jordan, Harry and Fanash (1984) mentioned that the number of tractors in the different districts of Jordan was as shown in Table 2.5.

Table 2.5. Districts, and number of tractors in Jordan in 1984.

Districts	No. of tractors
Amman	597
Balga	88
Irbid	763
Karak	303
Ma'an	88
Jordan Valley	419
Total	2,258

Source: Henderson and Fanash. 1984.

Lanzendorfer (1985) estimated the assets of machinery in Jordan as follows:

Tractors

a. Based on Dealers Sales Statistics:

Allowing for an average life span of 12 years for a tractor in Jordan and leaving imports other those of dealers out of consideration, the minimum sales for all dealers from 1967 to 1978 were 2055 tractors (from 1978 to 1985 there had been no significant change).

b. Based on Vehicles Registration Statistics:

In 1977, 2782 tractors were registered. In addition, a 20 percent of non-registered tractors must be allowed. This means that there is a maximum population of 3500 tractors (from 1977 to 1985). The overall tractor population ranges between 2000 and 3500 tractors. If the registration figure of 2782 tractors is considered to be rather accurate, about 2900 seems realistic for the total number of tractors in Jordan in 1979 (Lanzendorfer 1985).

Estimation of tractors in agricultural use

a. **The Ministry of Agriculture Farm Machinery Inventory 1973.** In 1973, the Ministry counted 1905 tractors. Assuming an average life span of 12 years, approximately 160 tractors must be replaced annually in order to maintain this asset level (life-span assumption of 10 years means replacement of 190 tractors). From 1973 to 1978, dealers in fact sold an average of 193 tractors per year. If the tractors not imported by dealers during this period are added to, and the sales for non-agricultural use are deducted from this figure, one comes to the conclusion that, since 1973, there has only been a rather slight increase in Jordan's tractor population about 2000 to 2200 tractors (Lanzendorfer 1985).

b. **The Ministry Farm Machinery Inventory 1978.** The Ministry reported that there were 2200 to 2400 tractors in Jordan. The overall population of tractors in agricultural use in Jordan ranges, therefore, between 2000 and 2400 tractors in 1985.

Combines

The next major step in the mechanization of field operations was the introduction of the combine. It closely followed the increase in Jordan's tractor population: until 1960, a total of 15 combines had been sold but from then until the beginning of the 1970s, combine assets rose considerably (inventory 1973: 144). Afterwards, there was a sharp drop because, combine owners abstained from replacing unserviceable combines and because there were heavy sales of old ones (up to 1968 models) to Syria (Lanzendorfer 1985).

Comparison between the two Agricultural Machinery Inventories of 1973 and 1978, and between the two Agricultural Censuses of 1965 and 1975, showed a decreasing number of combines. The Agricultural Census 1975 lists 36 combines owned by agricultural holders. The 1978 inventory counts 77 self-propelled combines and 43 pulled combines.

Further addition can be made of those belonging to public institutions (Jordan Cooperative Organization (JCO) / FAO wheat projects, irrigation projects, etc.). According to combine owners, after the gross sale of old combines to Syria during the mid-1970s, there are no more than 40 to 60 combines left in running condition. Considering the number of combines actually encountered, a combine assets estimate of between 50 and 70 seems realistic (Lanzendorfer 1985).

A survey conducted by the Directorate of Machinery in the Ministry of Agriculture in 1992 (Shadid, 1993), revealed that the actual number of farm machinery in Jordan was as shown in Table 2.6.

In that survey the tractors in Jordan were found in 34 types of which 51.6% were Massy Ferguson, 17% Volvo, 7.7% Ford, 4.2% Kubota, 2.1% John Deere and 17.4% others. Tractors and other implements are imported by dealers. During the period 1988 - 1991 (1134) tractors, (18) combines and (5416) other implements were imported.

Table 2.6. Agricultural Machinery in Jordan in 1992.

Machine	Number
Tractor	3320
Primary tillage equipment	4908
Secondary tillage equipment	322
Combine harvester	68
Seed drill	124
Binder	34
Thresher	514
Trailer	1686
Water tank	1382

Source: Farm machinery in Jordan (Shadid 1993).

Manufacturing of farm implements in Jordan is done by some specialized small workshops and blacksmiths. They can manufacture moldboard plows, chisel plows, cultivators, harrows, field sprayers, threshers, trailers and water tanks. These implements are sold to the domestic market, which cover only 30% of the actual need.

The latest survey done by the Ministry of Agriculture in 1997 showed the number and types of different farm machines as given in Table 2.7. The number of farm machines for the different districts in Jordan for the year 1997 is shown in Table 2.8.

Table 2.7. Number of Farm Machines in Jordan for the years 1992/1997.

Year Machine	1992	1993	1994	1995	1996	1997
Big Tractor	3046	2986	3324	3436	3474	3663
Small & medium wheel tractor	394	413	506	650	680	779
Sprayer	83	167	202	186	257	328
Chain tractor	2	5	4	3	3	3
Big seed drills	65	71	75	61	56	65
Small seed drills	15	14	12	13	21	27
Combine harvesters	66	77	69	68	43	63
Harvesters pulled by a tractor	14	22	12	17	36	30
Mobile Grain & Hay thresher	502	500	559	564	539	620
Binder (harvester)	44	47	29	31	15	72

Source: Annual report 1997. Jordan Ministry of Agriculture. PP (103).

Table 2.8. Districts, and number of machines in Jordan in1997.

District / Machine	Amman	Madaba	Zarqa	Irbid	Jarash	Ajloun	Mafraq
Big Tractor	523	190	127	613	91	79	421
Small & medium wheel tractor	63	14	0	359	52	15	0
Sprayer	39	6	0	46	8	3	12
Chain tractor	0	0	0	0	0	0	0
Big seed drill	3	6	0	15	0	0	0
Small seed drill	2	0	0	10	0	0	6
Combine harvesters	9	8	2	19	0	0	0
Harvester pulled by a tractor	4	0	0	0	0	0	0
Mobile grain & hay thresher	57	39	14	161	19	17	66
Binder (harvester)	7	0	0	53	0	1	0

Table 2.8. Continued.

District / Machine	Balga	Karak	Tafileh	Ma'an	Aqaba	Jordan Valley	Total
Big Tractor	126	549	153	373	3	415	3663
Small & medium wheel tractor	14	6	18	24	36	178	779
Sprayer	4	76	6	54	9	65	328
Chain tractor	0	0	0	0	0	3	3
Big seed drill	0	17	0	17	6	1	65
Small seed drill	1	5	0	2	0	1	27
Combine harvesters	3	7	0	8	4	3	63
Harvester pulled by a tractor	2	0	0	21	0	3	30
Mobile grain & hay thresher	16	97	35	44	0	55	620
Binder (harvester)	0	0	0	0	2	9	72

Source: Annual report 1997. Jordan Ministry of Agriculture. PP (104).

Agricultural Machinery Ownership and Use

Agricultural machinery in Jordan is owned by three groups:

1. The State,
2. Parastatal institutions, such as the Jordan Cooperative Organization, and
3. Private people, who might be both holders and non-holders of agricultural units.

Agricultural machinery here is limited to the main self-propelled agricultural machinery: tractors, combines, irrigation installations and transport facilities. Except for irrigation installations, the vast majority of this machinery is privately and individually owned.

1. Agricultural machinery owned by the State consists of irrigation installations, various machines and equipment in several agricultural projects localized all over the country, and of a fleet of spraying tractors. The National Resources Authority, Operational Division, manages the irrigation installations.

The Ministry of Agriculture is a big owner of agricultural machinery. The farm machinery section within the Ministry's Department of Construction and Machinery is exclusively occupied with the management of the Ministry's own machines.

Besides the machinery of the agricultural research projects, most of the Ministry's machines were introduced by foreign donors in connection with different projects. An inventory of the Ministry's machines in 1979 included an extraordinarily wide range of types and models. Some of the agricultural machines donated from Japan to the Ministry of Agriculture through the "Increase of Agricultural Production and Food Project" in 1999 are shown in Table 2.9.

Table 2.9. Farm machines imported from Japan through the "Increase of Agricultural Production and Food Project" 1999.

Machine	Type	Number
Tractors	30 h.p	31
	45 h.p	244
	65 h.p	57
	70 h.p	126
	80 h.p	67
	86 h.p	120
Seedbed Preparation Implements	Chisel plows (different sizes)	166
	Duck foot plows (different sizes)	133
	Rotary plows (different sizes)	131
	Disc plows (3 discs)	84
	Moldboard plows	122
	Harrows (different sizes)	406
Planters	Seed drills	37
Spraying machines	Field sprayer	15
Harvesting machines	Combine harvester	10
	Binder	19

Source:Minisrty of Agriculture. the "Increase of Agricultural Production and Food Project" 1999.

The Ministry of Agriculture sells these machines to the farmers at a reduced price compared to the price of farm machinery dealers, in order to encourage farmers to buy and use these machines.

2. The Jordan Cooperative Organization (JCO) also owns machinery: in some of the desert irrigation schemes, it took over and runs the machinery assets, according to plan. JCO owns different types of farm machines like drills, combines, tractors and implements. It has many agricultural machinery stations distributed in different parts of the country, which provide machinery services to the private sector, their main purpose being the promotion of better cultivation practices.

3. Apart from the machinery of these institutions, most machines are privately owned. The owners are not necessarily agricultural holders. For those that are not,

and even some that are, contract farming is the sole or main intention of their machinery ownership. For example, combine owners are rarely actively engaged in agriculture, although many of them have an agricultural background. They belong to the groups of the landlords or supervising part-time holders and normally have a main occupation outside agriculture, where they have gained the capital necessary for the purchase of a combine.

Some owners have one tractor, while others have more. Owning several tractors is, for Jordanian standards, a big step forward in the mechanization of a holding. It is either due to personal needs (e.g. a large holding or the specific requirements of different crops, i. e. a conventional and an articulated tractor for field crops and citrus plantations) or to the desire to set up business as a custom operator with the second tractor. Holders with only one tractor performing contract services also utilize the tractor on their own holdings.

The main operations that are done by contract services are:

- land preparation: primary tillage, covering of the seed with a disc harrow, and a specialized seedbed preparation with a rotary cultivator;
- transport: all types of hired transport, the most important was the pick-up, but also lorry and tractor drawn trailers;
- threshing: with a PTO driven, stationary thresher;
- harvesting cereals: with a combine harvester;
- spraying: with self-propelled knapsack sprayers and with barrels and hoses.

Types of Domestic Agricultural Machinery Products

The domestically produced agricultural machinery can be classified by the technological level of both production and utilization into three groups:

- Self-propelled agricultural machinery,
- Tractor implements, and
- Animal-drawn implements and hand tools.

There is no self-propelled machinery neither produced nor even assembled in Jordan. In the mechanization process, the consequence of the import of the leading items is the dependence on the developments on the world market, which are totally orientated towards the needs in the European and North American agriculture. Specific mechanization needs of importing countries are not taken into account. In Jordan, for instance the absence of a lentil harvester has already most probably caused a decline of the area cultivated with lentils in view of the labor shortage. A second example for the specific needs of agriculture in Jordan is that combines no longer harvest straw along with the grain but drop it on the ground. Jordanian farmers, however, refuse to accept the consequent straw losses, as straw is the principal livestock roughage and has a high price (Lanzendorfer 1985).

There are some tractor implements produced in Jordan, the composition of the domestically produced implements as of 1985 can be seen in Table 2.10. The major advantage of these domestically produced implements is their lower price. This is achieved by recycling components of old machinery, utilization low-cost raw materials, grading down the implements to the basic requirements, saving the freight costs (especially important for bulky products) and the import custom duty (this applies only for trailers, the other items are exempt from duty), and paying lower wages than in the industrialized countries.

Table 2.10. Types of tractor implements produced in Jordan.

Major agricultural use	Type of implement
Land preparation	Disc plow (conventional tractor)
	Disc plow (articulated tractor)
	Moldboard plow
	Disc harrow
	Tyne harrow
	Leveling plate
	Furrower
Other field operations	Ridger (for row crops)
	Tiller
	Plastic mulching machine
	Rotary chain weeder
	Sprayer
	Potato harvester
Transportation	Single axle trailer (large, medium, small)
	Water tank trailer
Irrigation	Filters for drip irrigation systems

Source: Lanzendorfer 1985. PP (133).

The domestically produced animal-drawn implements and hand tools can be divided into three categories: traditional items, i.e. those that have been in use, and have practically remained in the same design for a long time, improved semi-traditional items, i.e. those that have been continuously improved over several decades (appreciated for the utilization of harder raw materials) and sometimes copied by local blacksmiths, and improved modern items, i.e. those that have only recently been introduced and, which are therefore still exclusively imported.

Maintenance and Repair Facilities for Agricultural Machinery:

The technical efficiency and the profitability of agricultural machinery strongly depend on the availability of maintenance and repair facilities. They must work fast (especially in the peak season), with a certain quality, and at a reasonable price. In Jordan, these requirements are only partly fulfilled, which constitutes a problem for the mechanization process. In his farming unit survey, Lanzendorfer (1985) found that 75 percent of the tractor owners had had one or several breakdowns during the previous season. With an efficient repair service, this would not constitute a problem. 38 percent of them claimed, however, that they had had difficulties in getting the agricultural operations done due to these breakdowns. This constitutes a very high figure and draws attention to the inefficiency existing in the repair sector in Jordan.

Another point is that the tractor owners are not willing or unable to pay much attention to off-season maintenance and repair: in that farming unit survey, only 13 percent stated that they had had their tractors repaired and serviced before the start of the season (Lanzendorfer, 1985).

Machine capacity

The capacity of a machine is its rate of performance. Depending on the kind of machine, the performance or capacity is measured in terms of acres per hour (hectares) per hour, tons per hour (metric tons) per hour (Siemens and Bowers 1999).

The capacity of a machine is the primary factor in selecting or purchasing farm equipment. Capacity and size of a machine are often used synonymously.

Machine capacity is based on a quantity-time relationship rather than length-number factors. The most common measures of machine capacity are in acres [hectares] per hour and tons [metric tons] per hour. Each of these measures is affected by the rate of travel, the width in feet [meters] of the machine, and the effectiveness of the time that it is used (Jacobs and Harrell 1982). The most commonly used measure of machine capacity is field capacity in hectares per hour.

Field capacity

Field capacity, when measured in hectares per hour, is determined by three factors:

1. **Speed** is one of the first values that must be determined to evaluate machine capacity. Most field machines work best at a given speed.

   Going too slow will not allow the tillage tool to provide enough breaking of the soil. Going too fast might give too much shattering of the soil. Field travel speed is measured in km/hr. Typical values of field speed for some selected field operations are shown in Table 2.11.

Table 2.11. Range in Typical Field Efficiencies and Implement Operating Speeds

Operation	Equipment	Field Efficiency, %	Operating speed (km/hr)
Tillage	Moldboard plow	88 – 74	5 – 9
	Disk harrow	90 – 77	6-10
	Spring-tooth or spike-tooth harrow	83 – 65	6 – 12
	Field cultivator, chisel plow	90 – 75	6 - 9
Cultivation	Rotary hoe	88 – 80	9 - 20
Seeding	Grain drill with fertilizer	80 – 65	5 - 10
Harvesting	Combine	90 – 63	3 – 8
	Baler, rectangular	80 – 65	5 - 10
Spraying	Sprayer	80 – 55	7 - 10

Source: Hunt, 1995

2. **Width** is the distance in meters across the processing portion of the machine.

Using full machine width is one important way to more efficiently use labor and equipment. The greater the average width of cut, the greater the capacity. Every machine should be used as close to its full width as possible (ASAE, 1998).

3. **Field Efficiency,** FE is the ratio of the effective field capacity of a machine to its theoretical field capacity. It is the ratio of how much time is spent working and total time in field. The FE factor is determined as follows:

$$\text{Field Efficiency, FE\%} = \frac{\text{EFC}}{\text{TFC}} x100 \tag{1}$$

Where:

EFC = Effective field capacity

TFC = Theoretical field capacity

The field efficiency factor is a valuable tool in estimating the productivity capacity of machinery. Usually the field efficiency in percent is provided in tables. These data are used to estimate the effective field capacity in ha/hr when the theoretical field capacity is known. Typical values of field efficiency for some filed operations in are shown in Table 2.11 (ASAE, 1998).

Theoretical field capacity

Theoretical field capacity is the maximum possible capacity obtainable at a given speed, assuming the machine is using its full width.

Theoretical field capacity, TFC, can be determined with the following formula:

$$\text{TFC, ha/hr} = \frac{\text{Speed, km/hr x Width, m}}{10} \tag{2}$$

Effective field capacity

The effective field capacity, EFC, of a machine is the actual rate at which it can do work, taking into consideration such nonproductive operations as turning at the ends of the field, stopping to add fertilizer or seed, stopping to check performance, and the amount of overlap into previously traveled area. With a field efficiency established (Hunt, 1995), an equation for effective field capacity can be determined:

$$C = \frac{S\,w\,e}{c} \tag{3}$$

where C = effective field capacity, ha/hr

S = speed, km/hr

w = rated width of implement, m

e = field efficiency as a decimal

c = constant, 10

Selecting machine size

Selecting machine size is an important part of machinery management. Proper matching of implements to tractors improves field performance while reducing operating costs, repairs, fuel consumption, and possibly, initial capital outlay (Doane Information Services 1989).

Machine size is determined using the following formula:

$$\text{Machine size (width), m} = \frac{\text{EFC, ha/hr x 10 x 100\%}}{\text{Speed, km/hr x FE}} \tag{4}$$

Selecting Tractor Size

The size of a tractor is identified by its power rating in horsepower [kilowatts]. Manufacturers give each tractor a power rating. This rating is stated as the maximum rated horsepower [kw] produced at the power takeoff (PTO) and at the drawbar. The size of tractor is chosen on the basis of the power requirements of the machine it will power. Machinery power requirements are directly related to number of hectares per hour needed to get the job done on time. When selecting a tractor only for drawbar work and light PTO work, power should match the maximum drawbar horsepower [kilowatt] requirements. In Jordan, the machines requiring the greatest drawbar power are the moldboard plow and the chisel plow or subsoiler.

There are several different kinds of power measurements, all applying to the same tractor. The various kinds of power of the tractor's engine are:

- Brake power
- Power takeoff, PTO
- Drawbar power

Brake power is the maximum power the engine can develop without alterations. The engine, before installation in a tractor, can be hooked to a dynamometer to determine how much brake power can be developed.

Power takeoff, PTO, is the power measured at the PTO shaft. Maximum PTO power is the most commonly used method to rate tractor power.

Drawbar power is a measure of the pulling power of the engine by way of tracks, wheels or tires. As a percentage of PTO power, the drawbar power varies, depending on several factors including soil surface and type of hitch.

Converting power

A factor of 87 percent can be used to convert either engine or drawbar power ratings to an equivalent rated PTO power rating (Siemens and Bowers 1999).

PTO power = 87 percent of engine power or 115 percent of maximum drawbar power.

Determining power requirements

A major task facing farmers and managers is to match power units to the size and type of machine so all field operations can be carried out on time with a minimum cost. When the amount of power of the power unit limits the size of equipment used with it, it is important to match them accurately.

If the tractor is oversized for implements, the costs will be excessive for the work done. If the implements selected are too large for the tractor, the quality or quantity of the work may be lessened or the tractor will be overloaded, usually causing expensive breakdowns.

Some of the factors to consider when selecting a power unit include:

- **Engine types**

  The three general types of engines currently in use include diesel, LP-Gas and gasoline. The tractors used in Jordan have diesel engines, due to low price of diesel compared to the other types of fuel in Jordan.

- **Power ratings**

  Power is a measure of the rate of doing work.

  Work = force x distance (5)

$$Power = \frac{\text{force x distance}}{\text{time}} \qquad (6)$$

$$\text{Drawbar power, kw} = \frac{\text{Draft, kN x Speed, km/hr}}{3.6} \qquad (7)$$

$$\text{Speed, km/hr} = \frac{\text{Drawbar power, kW x 3.6}}{\text{Draft, kN}} \qquad (8)$$

$$\text{Draft, kN} = \frac{\text{Power, kW x 3.6}}{\text{Speed, km/hr}} \qquad (9)$$

Soil Erosion

Soil is one of the vital substances necessary to human existence. Soil erosion depletes the productivity of the soils and produces sediment, which is one of the major pollutants of the environment (Beasley, 1972). Soil erosion occurs naturally, the detachment and transportation of soil particles help to shape the landscape and develop soil profiles used in different human activities as crop production and the preparation of building sites. These activities usually accelerate erosion, however, causing excessive loss of the soil's productive capacity and, in some situations, off-site environmental damage.

Field level measurement of soil erosion is difficult. Erosion is a diffuse process that occurs at relatively low rates and widely varying rates from year to year and from location to location. Mathematical equations for estimating rates of soil erosion have emerged as a major tool to overcome these difficulties. Prediction technology currently is a collection of mathematical expressions used to estimate rates of soil erosion as functions of independent variables with values that represent a given set of conditions (Elliot et al, 1991).

Soil Erosion Prediction

Erosion prediction has been most widely used as a tool to guide conservation planning. In this application an estimate of erosion at a particular site is made based on the site characteristics. Erosion prediction is a powerful tool for selecting conservation practices tailored to particular site conditions. Erosion prediction technology can be characterized as empirically based, process based, or a combination of the two. The universal soil loss equation (USLE) and the wind erosion equation (WEQ) represent empirically based technology (Elliot et al, 1991).

Zingg (1940) is often credited with the development of the first erosion prediction equation used to evaluate erosion problems and select conservation practices to reduce excessive erosion. Zingg's equation was a simple expression that related soil erosion to slope steepness and slope length. Smith and Whitt (1948) added terms to Zingg's equation to reflect the influence of cover and management on soil erosion. Beginning in the mid-1950's W. H. Wischmeier, D. D. Smith, and their associates began to assemble and analyze an extensive quantity of available plot data. The result was the universal soil loss equation (USLE) (Wischmeier and Smith, 1965), which became by far the most widely used equation for estimating interril and rill erosion.

Development of the USLE continued after 1965, resulting in a major revision of the equation in 1978 (Wischmeier and Smith 1978). The basis of a soil-erodability monograph and the cover-management factor values in the 1978 USLE version were derived from rainfall simulators. Another important USLE concept introduced in 1970 was the subfactor method for estimating cover-management factor values (Wischmeier, 1975). This method was originally introduced for computing factor values for range, woodland, and similar land uses where plot data not available, but where agencies needed to apply the USLE. This method has since been extended to all land uses (Laflen, Foster, and Onstad, 1985) and is central to the revised universal soil loss equation (RUSLE) (Renard et al., 1991).

RUSLE is a major revision of the USLE. While retaining the equation structure of the USLE, several concepts from process-based erosion modeling have been incorporated in RUSLE to improve erosion predictions. These concepts provide a basis for estimating factor values for slope length, slope steepness, and supporting practice effects. The RUSLE effort was initiated in 1985, and the effort to develop the RUSLE model in a computer program was initiated in 1987. Although RUSLE retains the basic six-factor product form of the USLE, the equations used to arrive at the factor values are significantly modified. Like the USLE, RUSLE retains a regression relation to estimate soil loss. The conceptual equation is:

$$\mathbf{A = R \cdot K \cdot (L\,S) \cdot C \cdot P}$$

Where

A = computed average spatial and temporal soil loss per unit of area, expressed in units selected for K and for period selected for R (in practice, A is usually expressed in t ac^{-1} yr^{-1}, but other units can be selected (i.e., mt ha^{-1} yr^{-1})

R = rainfall and runoff erosivity factor – the number of rainfall erosion index units plus a factor for runoff from snowmelt where such runoff is significant

K = soil-erodibility factor – the soil loss rate per erosion index unit for a specified soil as measured on a unit plot, defined as 72.6-ft (22.1-m) length of uniform 9% slope in continuous clean-tilled fallow

L = slope-length factor – the ratio of soil loss from the field slope length to that for a 72.6-ft length (22.1-m) under the unit plot conditions as above

S = slope-steepness factor – the ratio of soil loss from the field slope gradient to that from a 9% slope under unit-plot conditions. The (LS) factor is given from a table entered by using the slope and slope length.

C = cover and management factor – the ratio of soil loss from an area with specified cover and management to that from a unit plot in tilled continuous fallow

P = supporting practice factor – the ratio of soil loss with a support practice like contouring, strip cropping, or terracing to that with straight-row farming up and down the slope

Soil Erosion in Jordan

In Jordan, the interest in soil erosion and soil and water conservation started during the early 1960s (Shamout, 1966). The earliest reported case study (MacDonald, 1965) showed that more than 1100 ha were lost out of 5400 ha of the arable land in the southern Ghore region during the period 1958-1965. Other studies showed that soil erosion is taking place at varying levels throughout the country.

There is limited quantitative data available to indicate the exact extent of soil erosion problem in Jordan. A regional study (Rafiq, 1978) concluded that soil degradation by water erosion is a serious problem in most Middle Eastern countries; Jordan is no exception. Some areas in the highlands of Jordan are highly erodable as a result of high rainfall and steep slopes (Jaradat, 1988). A report by McDonald Engineering Company (1965) submitted to the Natural Resources Authority (NRA), estimated that 1,328,000 tons of soil were lost by water erosion from Jordan catchments in 1963-1964. This amount of soil is equivalent to an average loss of 14 cm of soil over that shallow catchment area during 100 years. The soil erosion map of Jordan (Figure 2.1) shows that most of the Jordan's soils are subject to erosion by water and wind (FAO/UNDP, 1979).

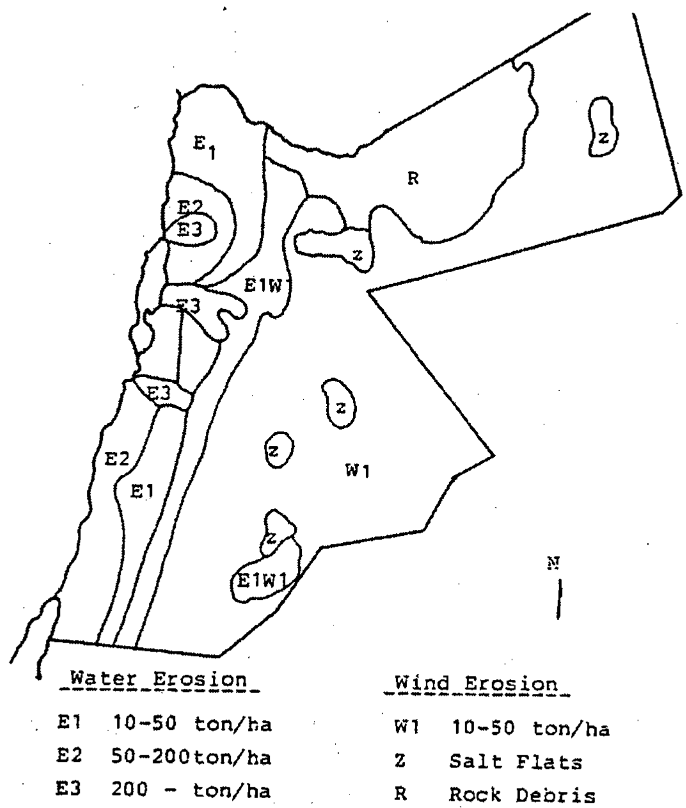


Figure 2.1. The soil erosion map of Jordan.

Source: Jaradat, 1988.

In a case study, Battikhi and Arabiat (1983) collected 331 soil samples from the highlands of Jordan, in an attempt to assess the extent of soil erosion in the country. The soil samples came from areas differing in rainfall, soil type and slope. The authors rated the samples by the FAO system for soil degradation assessment. A summary of the results is presented in Table 2.12. It is clear from the Table that most of the highlands are within the E0 category of (0 – 10 metric ton per hectare). The erosion hazard increases as rainfall and slope increase.

Table 2.12. Number of soil samples according to the level of erosion (E), as affected by topography (T), and rainfall (R) for the case study (Battikhi and Arabiat, 1983).

Slope	Erosion	Maan			Karak			Balqa			Irbid			Total
	Extent	R1	R2	R3	R1	R2	R3	R1	R2	R3	R1	R2	R3	
T1	E0	10			37	41		11	26		7	90	5	227
	E1								1			12		13
	E2	1				1								2
T2	E0				4	8						1	6	19
	E1					2						8		10
	E2											2		
T3	E0				4	2			2			1		9
	E1				6	7			4			6	2	25
	E2				1				4			5	2	12
T4	E0													
	E1											2	2	4
	E2								1				1	2
T5	E0											1		1
	E1											1		1
	E2					1						1	2	4

Source: Jaradat, 1988.
T = Slope%: T1 = 0 – 8%, T2 = 8 – 20%, T3 = 20 – 30%, T4 = 8 – 30%, T5 = > 30%.
R = Rainfall (mm): R1 = 200 – 300, R2 = 300 – 600, R3 = > 600.
E = Erosivity (t/ha): E0 = 0 – 10, E1 = 10 – 50, E2 = 50 – 200.

CHAPTER III

STATEMENT OF THE PROBLEM AND OBJECTIVES

Machinery is one of the major production inputs in agriculture. Agricultural mechanization is increasing in Jordan, either through ownership or through services. Organizations providing custom services have played an important role in recent years. There is a big concern about the use of modern farm machinery on the part of the government, cooperative organizations and farmers in Jordan. This increase in farm machinery use requires good machinery management plans in order to use these machines efficiently and economically. Costs of hiring farm machinery and equipment are lower than the cost of hiring manual labor to perform the same operations (Snobar and Arabiat, 1984).

A research report conducted by a team from the Ministry of Agriculture and the National Center for Agricultural Research and Technology Transfer (NCARTT) in Jordan, (Al-Kadi et. al., 1989) found that most farmers and custom operators misuse farm machines and equipment. For example, the chisel plow is often confused with the cultivator, and the farmers believe soil moisture can be conserved by deep plowing, which may be the opposite of the truth. According to the researchers, judicious use of a chisel plow, minimizing surface disturbance of the soil while providing for good water and plant root penetration, may be much more efficient than plowing in conserving moisture in growing cereals in the Jordan Highlands. This improper use of farm machinery is due to the lack of good farm machinery management, which shows the need for the research in farm machinery management area in Jordan.

One of the most important aspects in farm machinery management is timeliness cost. Almost every agricultural operation required for successful crop production must be timely. Untimely completion of any of these operations will cause a substantial loss of yield and quality, which ultimately will affect the farm's income. This loss is termed 'timeliness cost' (Oskoui, 1983).

Another important aspect in farm machinery management is machine selection. A basic criterion of farm machinery selection is to establish a machinery system, which is capable of completing all operations during a crop growth cycle in order to maximize the farmer's profit. The objective in selecting machinery is to purchase the machine, which will perform the required task within the time available for the lowest possible total cost (Kay and Edwards, 1994).

Owning and operating farm machinery is an important component of total farm expenses. To make informed decisions about the management of this expensive input, farmers must know the costs involved in owning and operating these machines. Therefore, calculating the ownership and operating costs are important in machinery management. Realizing the labor shortage problem and the advantages of mechanization, the government of Jordan emphasized the role of mechanization in the development of agriculture in Jordan in many five year development plans (Snobar, 1984).

Another serious problem facing agriculture and environment in Jordan is the soil erosion problem. Soil erosion, as a natural process, is continuous and easily accelerated by man. In many Third World countries, the increased demand for food due to population increase is causing a marked acceleration of man-made erosion. Soil erosion reduces crop production by decreasing water infiltration, nutrient supply, and soil water-holding capacity (Larson et al., 1983).

Accelerated erosion is usually the result of improper management of productive soils or exploitation of marginal lands, both of which are taking place in Jordanian dryland agriculture (Rafiq, 1978). The conservation of soil and water resources in Jordan is a necessity because these resources are very limited, and the population pressure on the land is increasing dramatically. Increased population pressure means that people must carefully exploit the limited arable area by considering that land is lost due to erosion, desertification and urbanization (Jaradat, 1988). From these studies and others, it is clear that there is a severe and extended soil erosion problem in Jordan due to the rainfall intensity, overgrazing, uprooting of forest trees, and urbanization. The dryland agricultural resources in Jordan are very limited. It is only through the effective conservation of these resources that productivity in the country can be maintained.

Quantitative data on soil and water losses in Irbid area are lacking. There is an urgent need to quantitatively identify the most appropriate practices or modify existing ones for more efficient soil and water conservation. An alternative way to obtain these data is the use of a simulation model, such as Environmental Policy Integrated Climate (EPIC).

OBJECTIVES

Farm machinery represents a large investment on farms. Therefore, it is very important to properly manage and control the size of this investment and the related ownership and operating costs.

The overall objective of this research is to provide an insight to the state of agricultural machinery in Jordan, in general, and to determine economically the optimum complements of machinery for wheat production and soil conservation in the rainfed areas of Irbid in the north of Jordan.

The specific objectives are:

1. To determine the timeliness cost of planting wheat before and after the optimum planting date in rainfed areas of Northern Jordan.
2. To determine the proper sizes and ownership costs of farm machines and equipment used in wheat production in rainfed areas of Northern Jordan.
3. To determine the impact of using conservation tillage systems on soil erosion and the sustainability of wheat production in rainfed areas of Northern Jordan.

CHAPTER IV

Timeliness costs for planting wheat in rainfed areas of Irbid in Northern Jordan

Introduction

When an operation extends beyond the desired finishing time, a timeliness penalty occurs. Timeliness cost is defined as the cost of farm product loss due to late completion of sowing or planting operation (Eradat Oskoui 1981). Link (1967) proposed that the use of yield/time function is the most comprehensive procedure for evaluating timeliness cost. Sowell et al (1971) defined the timeliness function as a relationship between the time of performing some operations on a crop and some measure of output, e.g return, yield, etc.

Link (1967) suggested that a quadratic yield/time function exists for every timely agricultural operation. The general form of the equation can be expressed in the following form:

$$Y = at^2 + bt + c \qquad (1)$$

Where: Y = crop yield for an operation executed at time t,

t = time at which the operation was carried out,

a, b and c = yield/time coefficients.

This relationship was applied to calculate the timeliness cost for sowing or planting wheat in rainfed areas of Northern Jordan.

In order to calculate the timeliness penalties incurred by a given crop, values of the yield/time coefficients, a, b and c, must be known. Normally, numerous experiments are required to determine the optimal sowing date for a given environment. In this study, due to the unavailability of data about wheat yields at different sowing dates in rainfed areas of Northern Jordan, a growth and yield simulation model was used.

In recent years, the use of crop simulation models to evaluate cultivars and cropping practices has been greatly expanded. Seligman (1990) discussed the potential and the limits of dynamic simulation models as predictive tools. He concluded that, although there had been many disappointments in the past, crop modeling had also produced impressive achievements in education and research, and had a very promising future, particularly as a tool for testing our understanding of crop behavior and falsifying hypotheses in the context of the real cropping situation.

Seligman (1990) argued that crop modeling could provide unique advantages in several situations, for example providing a quick response when new needs arise. It also seems the easiest way to account for stochastic weather events and to extrapolate from experiments to real farm conditions. Moreover, modeling allows time and space, dimensions that are often difficult to represent adequately using field experimentation, to be added to agronomic research.

A model that has been tested and validated for this purpose is the CERES-Wheat model (Claborn 1998). CERES (Crop Estimation through Resources and Environment Synthesis)-Wheat is a computer model that simulates growth, development and yield of both spring and winter wheat (Otter-Nacke et al., 1986). The model operates on a daily time step and is designed to work in any location where wheat can be grown.

With proper calibration, the CERES-Wheat model demonstrated the ability to predict yields and important phonological dates (Claborn 1998). The CERES-Wheat model had been used widely by many researchers in different places of the world. It proved that it is a reliable model for simulating growth and yield of wheat.

Different planting dates in the model give different amounts of yield. These yield values and the corresponding planting dates were used to find the relationship between planting time and amount of yield.

Method

The CERES-Wheat crop-growth model, version 3, was used to simulate the performance of durum wheat cultivar at Irbid area (32° 33' N, 35° 51' E, 614 m asl). Actual daily weather values for solar radiation ($MJ/m^2/day$), maximum temperature (C°), minimum temperature (C°), and precipitation (mm) for the years 1994 – 1998 for Irbid Meteorological Station were obtained from the Jordan Department of Meteorology and used as inputs for the model. Actual soil texture, bulk density and soil organic matter content information for the location of the study were obtained from (*The Soils of Jordan*, 1993, a national soil map and land use project). Other parameters including the lower limit of soil water availability (wilting point), the drained upper limit of soil water availability (field capacity), and saturation moisture content, were estimated by the model. Fertilizing with N and P_2O_5 at rates of 60 and 30 kg/ha, respectively, where applied during sowing (Snobar, 1987). These values were used as inputs to the model.

When using the CERES-Wheat model, it is important to have measured data for the occurrence of several physiological events. The model uses coefficients for six of the nine defined growth stages of wheat as shown in Table 4.1.

Table 4.1. Growth Stages Used in CERES-Wheat (Larrabee and Hodges, 1985).

Stage	Coefficient		Description
7			Pre-sowing
8			Sowing to Germination
9			Germination to Emergence
1	P1V	0.5	Emergence to Terminal Spikelet
2	P1D	1.5	Terminal Spikelet to End of Vegetative Growth
3	P5	2.0	End of Vegetative Growth to End of Pre-Anthesis Ear Growth
4	G1	3.6	End of Pre-Anthesis Ear Growth to Beginning of Linear Grain Fill
5	G2	1.6	Linear Grain Filling
6	G3	1.9	End of Grain Filling to Harvest

Source: Tsuji et al., 1994.

The genotype coefficients

Growth duration is important in determination of potential crop yields. In general, the longer the growth duration for the crop, the higher the yield potential. The duration of different growth stages is referred to as phasic development. Phasic development is affected primarily by genetic and environmental factors (Ritchie, 1991).

Growth stages after seeding emergence

Stage 1: Emergence to terminal Spikelet. The thermal time for this growth is highly dependent on the genotype and environment. Vernalization, photoperiod, and genetic characteristics cause the total thermal time from emergence to terminal spikelet to vary considerably (Ritchie, 1991).

Vernalization is the low temperature requirement by winter wheat varieties for flowering. Usually it begins at germination. Even though there is genetic variability in sensitivity to vernalization between cultivars, 50 vernalization days are assumed to be sufficient to completely vernalize all cultivars. The genetic specific coefficient (P1V) is used to calculate the influence the influence of vernalization on stage 1 growth. For winter wheat, the scaled values for (P1V) and as model input range from 0 to 8. The photoperiod sensitivity of the genotype is expressed in genetic-specific characteristic (P1D). The scaled values of P1D used as model inputs range from 0 to 3.

Phyllochron is the interval of time between leaf tip appearances PHINT (degree-days). Tests of models on a global sale have shown that some apparent environmental stimulus, in addition to temperature, causes the interval between leaf appearance to vary. When the phyllochron is not known, a good estimate is 95 degree-days.

Stage 2: Terminal Spikelet initiation to the end of leaf growth. This stage is considered to be strictly under temperature control and takes three phyllochrons from terminal Spikelet to the appearance of the final leaf. Thus, if the phyllochron is 95 degree-days, the duration of stage 2 is 285 (95 x 3).

Stage 3: Preanthesis ear growth. The ear develops very rapidly in this stage and is a major sink for assimilates. This is probably the most important stage determining grain numbers per plant expected to develop into full size kernels. The duration of stage 3 is equivalent of two phyllochron, even though no new leaves are developed.

Stage 4: Preanthesis ear growth to the beginning of grain filling. During this stage flowering takes place. Several measurements have indicated that it takes approximately 200 degree-days during this stage to go from the maximum ear size and volume to the time when linear grain mass accumulation begins.

Stage 5: Grain filling. The size of the grain is determined during this stage. The thermal time for stage 5 varies among genotypes and is determined by the input genotype-specific constant P5. Although the thermal time is not constant for all genotypes, all values for it is near 500 degree-days. P5 takes a scale value of 0 to 8.

Stage 6: Physiological maturity to harvest. A value of 250 degree-days can be used to approximate the thermal time from physiological maturity to harvest (Ritchie, 1991).

Average wheat yield value for the study area in Jordan was used to validate the model. The model was run using calibrated values of the original genotype coefficients given in the genotype file of the model. The results of the simulations gave predicted yield values similar to the average yield value. Twenty sowing dates were simulated for all seasons: starting from October15 and ending on January18 (the following year) with 5 days interval.

Results

Results of the different simulation runs for the different planting dates are given in Table 4.2. The actual average yield of durum wheat in Irbid area ranges from (2000 – 3500) kg/ha, and the optimum sowing date for that area is the middle of November (Al-Delki, 1999). The average simulated yield by CERES-Wheat model for the same area was 3014 kg/ha when planted on November 14. This means that the results of the model simulations are reliable and they could be used in the following calculations with some confidence.

The average predicted yields for the different sowing dates for all seasons were calculated. The values of these yields are given in Table 4.2 (column 7). The average predicted yields were plotted against time, (t) corresponding to dates of sowing (in Table 4.2 and Figure 4.1, t = 0 means Oct. 15, t = 3 means Nov. 14, t = 95 corresponds to sowing date of Jan. 18, the following year). The plot is shown in Figure 4.1.

Table 4.2. The CERES-Wheat simulated yields for the seasons 1994-1997.

Sowing Date	Time (t)	1994 Yield (Kg/Ha)	1995 Yield (Kg/Ha)	1996 Yield (Kg/Ha)	1997 Yield (Kg/Ha)	Average predicted Yield (Kg/Ha)
15-Oct	0	2619	2648	2212	1932	2353
20-Oct	5	2859	2962	2528	2037	2597
25-Oct	10	3156	3026	2528	2472	2796
30-Oct	15	3101	2897	2398	2797	2798
4-Nov	20	3187	2762	2674	2814	2859
9-Nov	25	3325	2773	2931	2963	2998
14-Nov	30	3337	2834	2943	2914	3014
19-Nov	35	3256	2860	2861	2790	2942
24-Nov	40	3192	2904	2825	2631	2888
29-Nov	45	3024	2801	2762	2597	2796
4-Dec	50	3024	2782	2553	2612	2743
9-Dec	55	2990	2777	2346	2516	2657
14-Dec	60	2945	2748	2225	2502	2605
19-Dec	65	2969	2734	2227	2334	2566
24-Dec	70	2850	2679	1977	2169	2419
29-Dec	75	2731	2536	1713	1981	2240
3-Jan	80	2627	2358	1557	2013	2139
8-Jan	85	2400	2368	1439	1991	2050
13-Jan	90	2374	2269	1274	1964	1970
18-Jan	95	2194	2315	975	1845	1832

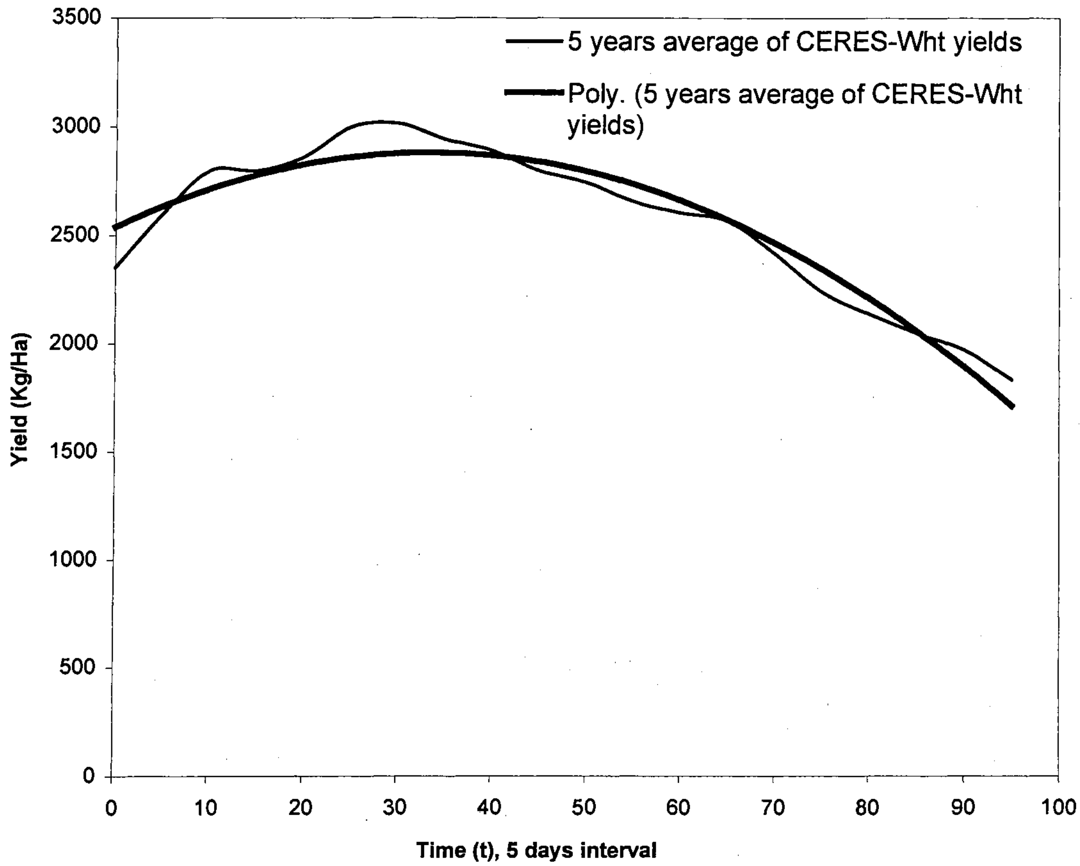


Figure 4.1. The Yield/time function for planting durum wheat in Irbid/Jordan.

From the plot in Figure 4.1, a polynomial trend line of 2nd degree is fitted to the average predicted yields. The quadratic yield/time function equation for this line was obtained using regression analysis in Excel. The quadratic yield/time function equation obtained for different planting dates of wheat in Irbid is:

$$Y = -0.3072t^2 + 20.477t + 2538.8 \quad (2)$$

From this equation, the values of yield/time coefficients are:

a = -0.3072

b = 20.477

c = 2538.8

The optimum planting date as value of time (t) is the one, which corresponds to November 14 and a yield of 3014 kg/ha.

Substituting the values of these coefficients in equation (1), the wheat yields (Y) for different sowing dates were calculated. The calculate wheat yields (Y) at different planting dates, are given in Table 4.3.

Table 4.3. Predicted wheat yield for different planting dates in Irbid at 5 days interval.

Planting Date	Time (t)	(t^2)	Y (kg/ha)
Oct. 15	0	0	2539
Oct. 20	5	25	2634
Oct. 25	10	100	2713
Oct. 30	15	225	2777
Nov. 4	20	400	2825
Nov. 9	25	625	2859
Nov. 14	30	900	2877
Nov. 19	35	1225	2879
Nov. 24	40	1600	2866
Nov. 29	45	2025	2838
Dec. 4	50	2500	2795
Dec. 9	55	3025	2736
Dec. 14	60	3600	2662
Dec. 19	65	4225	2572
Dec. 24	70	4900	2467
Dec. 29	75	5625	2347
Jan. 3	80	6400	2211
Jan. 8	85	7225	2060
Jan. 13	90	8100	1893
Jan. 18	95	9025	1712

To calculate the timeliness cost for different planting dates in Jordan, the method developed by Abo el Ees (1978), that complemented the method used by Link (1967) was followed. According to this method, timeliness cost due to untimely sowing of a crop (departure from the optimum date) can be calculated by using the following equation:

$$TC = (Y_o - Y') AP \tag{3}$$

Where: TC = timeliness cost (JD[1])

Y_o = optimum (maximum) yield for planting or sowing operations executed at optimum time t_o,

Y' = average yield when planting operation started at t_1 and completed at t_2,

A = area to be planted (ha)

P = price of commodity produced (JD/metric ton).

Optimum yield, Y_o, can be calculated by differentiating the yield function equation (1) and setting the resultant equation to zero as follows:

$$t = -b/(2a) \tag{4}$$

The time, t_o, calculated here is the time at which maximum yield occurs, by substituting t_o in equation (1), the value of Y_o can be calculated thus:

$$Y_o = -b^2/(4a) + c \tag{5}$$

To calculate average yield, Y', over a sowing period, $(t_2 - t_1)$, the yield function equation (1) can be integrated over the given period of time, so that:

$$Y' = \frac{\int_{t1}^{t2} Y(t)\,dt}{t_2 - t_1} \tag{6}$$

[1] JD = Jordan Dinar, (JD = $1.41)

Abo el Ees (1978) solved this equation and found that the following equation can be used to calculate average yield over the time span ($t_2 - t_1$) so that:

$$Y' = a\,t_1^2 + D\,t_1 + Q \qquad (7)$$

Where: $$D = a\,L + b \qquad (8)$$

$$Q = a\,L^2/3 + b\,L/2 + c \qquad (9)$$

$$L = t_2 - t_1 \qquad (10)$$

By substituting the values of Y_o and Y' in equation (2), the value of the timeliness cost can be calculated by the following equation:

$$TC = (c - b^2/(4a) - a\,t_1^2 - D\,t_1 - Q)\,A\,P \qquad (11)$$

Substituting the following values of the coefficients in equation (11), the timeliness costs (TC) at different planting time spans of 5 days interval are obtained.

T_o = (time from 30 to 35), the optimum planting time span (the time at which maximum yield occurs), obtained by solving equation (4), or from Table 4.4.

t_1 =the beginning of the planting time period.

t_2 = the end of planting period, 5days after t_1.

a = -0.3072

b = 20.477

c = 2538.8

A = 1 ha, solving for a unit area.

P = 0.15 JD/kg, the price of wheat in Jordan (1998 price) was 150JD/metric ton.

The results of the calculations are given in Table 4.4. The timeliness costs (TC) are given in column 5, Table 4.4.

Table 4.4. Timeliness costs (TC) for planting wheat (earlier or later than optimum time) in Irbid.

Planting Period	Time (t_1)	t_2	Y'	TC	Y loss (kg/ha)
Oct. 15 – 20	0	5	2587	44	292
Oct. 20 – 25	5	10	2674	31	205
Oct. 25 – 30	10	15	2746	20	133
Oct. 30 – Nov. 4	15	20	2802	11	77
Nov. 4 – 9	20	25	2843	5	36
Nov. 9 – 14	25	30	2869	2	10
Nov. 14 – 19	30	35	2879	0	0
Nov. 19 – 24	35	40	2874	1	5
Nov. 24 – 29	40	45	2854	4	25
Nov. 29 – Dec. 4	45	50	2818	9	61
Dec. 4 – 9	50	55	2766	17	113
Dec. 9 – 14	55	60	2700	27	179
Dec. 14 – 19	60	65	2618	39	261
Dec. 19 – 24	65	70	2521	54	358
Dec. 24 – 29	70	75	2408	71	471
Dec. 29 – Jan. 3	75	80	2280	90	599
Jan. 3 – 8	80	85	2137	111	742
Jan. 8 – 13	85	90	1978	135	901
Jan. 13 – 18	90	95	1804	161	1075

The timeliness costs were plotted against the planting dates with 5-day intervals. The plot is shown in figure 4.2.

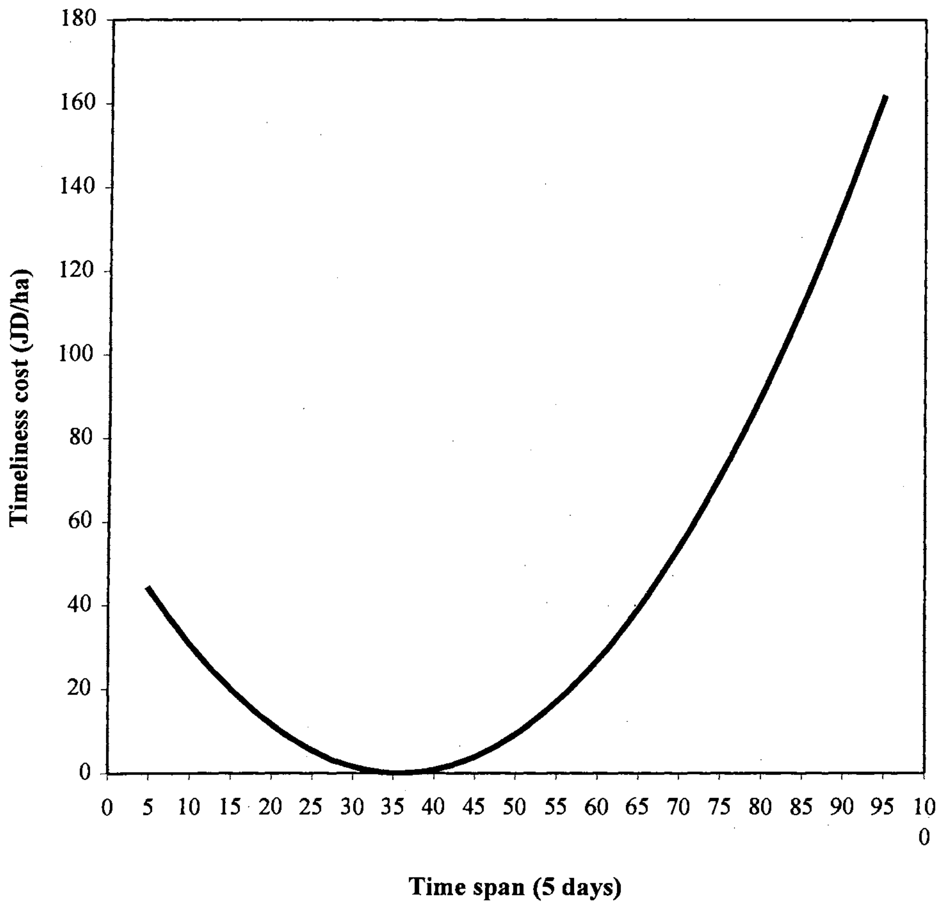


Figure 4.2. The timeliness cost for planting wheat earlier or later than the optimum time in rainfed areas of Irbid (5 days interval) starting October 5 until January 18 (the following year).

Summary and Conclusions

From the above results, it is concluded that:

The optimum time span for planting wheat in rainfed areas of Northern Jordan is the week of November 14 to November 19. Planting wheat in the rainfed areas of Northern Jordan at any time before Nov. 14 or after Nov. 19 leads to timeliness penalties. The amounts of yield lost and cost of this loss to the farmers in rainfed areas of Northern Jordan are shown in Table 4.4.

CHAPTER V

Machinery selection and machinery ownership cost in rainfed areas of Northern Jordan

Machinery Selection

Introduction

In today's agriculture in Jordan as in many parts of the world there is more dependence on large, expensive machines that let one person produce much more. So the farmer or manager must select from a large number of sizes and types of machines. It is very important to know the basic information necessary for selecting the best machine for a given farm situation.

One of the more difficult problems in farm management is proper machinery selection. This process is complicated not only by wide range of types and sizes available, but also by capital availability, labor requirements, the particular crop and livestock enterprises in the farm plan, tillage practices, and climate factors. The objective in selecting machinery is to purchase the machine, which will perform the required task within the time available for the lowest possible total cost (Kay and Edwards 1994).

In this study, a program that determines the size of alternative machinery complements, namely Machsel was used. Machsel is a spreadsheet template that was developed in the department of Agricultural Economics at Oklahoma State University, by D. Kletke and R. Sestak in 1991. Machsel is used to study farm machinery complements and costs. It is also used to evaluate alternative machinery complements with the intent of selecting the one that is able to satisfactorily perform all needed field operations in the time available for each operation with the lowest cost possible. One of the major input parameters in Machsel is the number of days available for work.

Days avialable for field work

Agricultural fieldwork is strongly weather dependent. Variations in weather have an impact on soil workability and ultimately the number of days suitable for soil tillage, planting and other subsequent field operations. In turn, these affect machinery use and performance. The estimation of suitable days for different field operations forms an essential part of machinery management, since the capacity of a machinery system to complete a given task is inversely proportional to the amount of time available (Simalenga and Have, 1992).

Major economic decisions made by farmers raising grain crops include selection of machinery complements and choice of enterprise mix. Year to year variation in weather and its resultant impact on the number of good days available for soil preparation, planting, spraying, cultivation and harvest has been a major uncertainty in making good selections and choices. To control this problem, scientists and farmers have adopted a framework in which machinery complements are selected such that the completion of the assigned tasks is accomplished in an allotted time period (Rosenberg et al., 1982).

The field workdays suitable for tillage and crop establishment operations are governed by the soil moisture and workability of the soil. A soil is workable if it has sufficient compressive strength to withstand the weight of the machinery, has sufficient shear strength to meet the traction requirement with acceptable wheel slip and soil damage and a suitable soil tilth can be produced (Simalenga and Have, 1992).

It was found (Simalenga and Have, 1992) that when soil moisture content was at or below 95% of field capacity, the soil could be worked easily, while above it, the quality of the resulting seedbed was poor and excessive wheel slippage was experienced. In this study the workability criteria was defined when the soil moisture in the top 15 cm is at or below 95% field capacity. The EPIC model was modified to estimate the days available for fieldwork by allowing the model to write out the daily soil water and soil table. Daily soil moisture content was modeled by estimating movement of water into and out of the soil profile. Precipitation was the only inflow of water (Rosenberg et al., 1982). Water infiltrating the soil is retained against gravity by cohesion and out of the soil profile. In EPIC the soil profile was divided into two layers defined at depths of 0-7.5 cm and 7.5-15 cm. The program also creates an output file containing the calendar year, and the calendar day as mmdd (month/day). The crop year runs from September through March with a 5-day period beginning on September 1 and continuing through February. The program reads the ratio soil moisture/field capacity for layer one (0-7.5 cm) and layer two (7.5-15 cm). The output file of EPIC containing these data is opened in Excel. The Go-NoGo data is recorder depending on the criterion provided by the user. A value for the moisture content equal to or less than 95% of the field capacity was used in this study to determine the field working days. Then the number of days available for fieldwork in each 5-day period in each year is obtained. During the 5-day period the maximum number of days available for work could be 5, and the minimum number could be 0. The frequency function in Excel was used to count the number of times there are 0, 1, 2, 3, 4, or 5 days available for fieldwork in each five day period. Then the number of days that are available at least a certain percent of the time was determined. In this study 90% certainty was considered. The number of available working days obtained from EPIC were used an inputs in Machsel. The number of available days for work during the crop season in Irbid is shown in Figure 5.1.

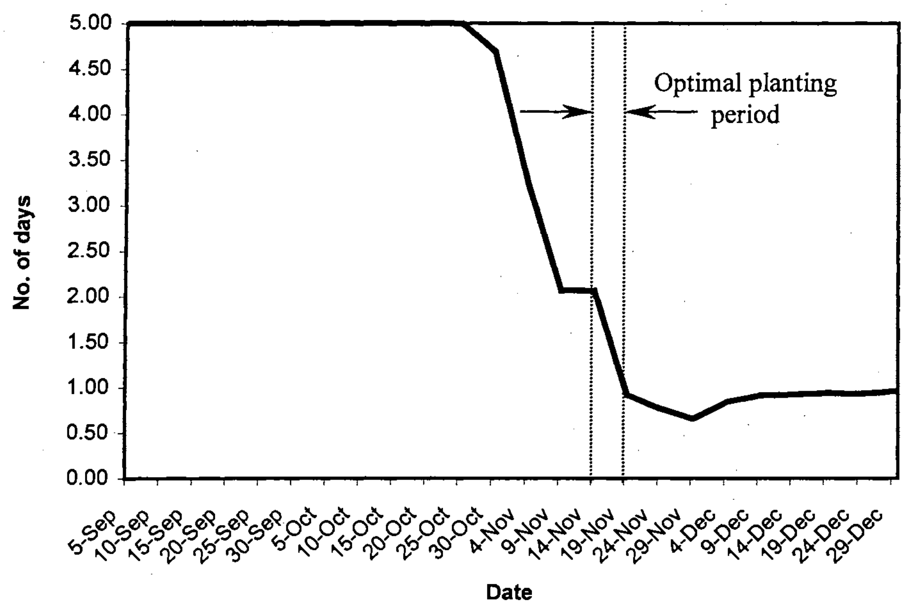


Figure 5.1. The number of days available for work and optimal planting date in Irbid area as simulated by EPIC.

The Machsel program was modified to determine the sizes, speeds and annual costs of different tillage complements used in wheat production in Irbid. The necessary input data used by the spreadsheet related to the study area were provided. Thes data include the different sizes of tractors used, the crop planted, the size of the planted area and the type of tillage system. After the required data were entered, the template was calculated. The outputs of the template calculation include the proper sizes of implememts (width) in (ft) and the operating speeds for each tracotor size with the associated implement size in (mile/hr). The values of the implement size (width) and tractor speed were converted to (m) and (km/hr) respectively. The calculated sizes and operating speeds for different complements by Machsel are given in Table 5.1.

Machine Ownership Cost

The annual cost of owning and operating farm machinery, is a major portion of the total crop production costs. In fact, machinery costs can often account for as much as 50% of the annual total cost of producing a crop if land costs are not considered.

One of the most important costs influencing profit in farming operations is the cost of owning and operating machinery. The Machsel spreadsheet was modified to calculate the costs of owning and operating the most popular farm machines used for wheat production in the rainfed areas of Jordan.

Cost Estimation

The costs associated with owning and operating various combinations of farm machines are divided into fixed, variable and timeliness costs.

The total costs, abbreviated TC, for operating selected farm equipment in Jordan are obtained by adding total fixed (FC) costs to total variable costs (VC), using the formula:

Table 5.1. Sizes of selected tractors (Hp) used in Irbid, with the proper sizes of the implements they can pull in meters and operating speeds in km/hr.

Implement	Tractor (Hp)	45	50	60	65	70	75	80	90	100
MB plow	size (m)	0.80	0.90	1.00	1.10	1.20	1.30	1.40	1.60	1.75
	speed (km/hr)	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25	7.25
Chisel plow	size (m)	1.40	1.60	1.90	2.00	2.20	2.30	2.50	2.80	3.00
	speed (km/hr)	6.60	6.60	6.60	6.60	6.60	6.60	6.60	6.60	6.60
Sweep plow	size (m)	2.20	2.50	3.00	3.20	3.50	3.70	4.00	4.50	5.00
	speed (km/hr)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00
Grain drill	size (m)	6.5	6.5	8.10	8.10	11.00	11.00	11.00	11.00	11.00
	speed (km/hr)	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Sprayer	size (m)	9.10	12.20	12.20	18.30	18.30	18.30	18.30	18.30	18.30
	speed (km/hr)	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00	9.00

$$TC = FC + VC + TimeC \quad (1)$$

Fixed costs (FC): those depending more on how long a machine is owned rather than how much it is used. They include depreciation, taxes, shelter insurance and interest. **Variable costs** (VC): those varying in proportion to the amount of machine use. They include fuel, lubrication, labor, maintenance and repairs. **Timeliness costs** (TimeC): the cost of farm product loss due to late completion of sowing or planting operation.

Fixed costs and there effect on machinery management

Depreciation

As a cost, depreciation means a loss in the value of a machine due to time and use (Siemens and Bowers, 1999). Often it is the largest of all costs. Machines depreciate, or have a loss of value, for several reasons, including:

1. Age – even though model changes may have resulted in little difference in the function of a machine, the newer machine is worth more than an old one.
2. Wear – the more a machine is used, the greater the wear. As a result, the ability to function like new may be reduced or it may keep breaking down, meaning it has lost its reliability.
3. Obsolescence – if there has been a major model change or a machine no longer has enough capacity, its value may be greatly reduced – even though it may not be worn out. New machine concepts may also be introduced which may obsolete existing similar machines.

An estimated value method may be the most realistic determination of depreciation. At the end of each year the value of a machine is compared with its value at the start of the year (Hunt, 1995). Two specific methods of calculating depreciation are:

1. Straight-Line Method
2. Declining-Balance Method

Straight-Line Depreciation

With the straight-line depreciation method, an equal reduction of value is used for each year the machine is owned. This method can always be used to estimate costs over a specific period of time, provided the proper salvage value is used for the age of the machine (Siemens and Bowers, 1999). Two decisions must be made before average annual depreciation can be calculated: the years of useful life and the salvage value at the end of the useful life must be estimated. The useful life of the machine is the period of years the owner plans to use the machine. The estimated useful life of a tractor in Jordan is 12 years, and for all other farm equipment it is 10 years (Al-Kadi et al., 1989).

Once the length of useful life has been selected and the salvage value estimated, average annual depreciation can be calculated using the following equation:

$$\text{Annual Depreciation} = \frac{\text{Purchase Price - Salvage value}}{\text{Years owned}} \qquad (2)$$

Declining-Balance Depreciation

A uniform rate is applied each year to the remaining value (includes salvage value) of the machine at the beginning of the year. The depreciation amount is different for each year of the machine's life (Hunt, 1995). A modified double declining balance method is used in the Machsel program, which is used to calculate the machinery ownership costs in this study. The major modification is the addition of a facto which yields a very high first year depreciation. Salvage value for determining depreciation costs is obtained with the following equation:

$$\text{Salvage Value} = \text{RFV1} * \text{List Price} * \text{RFV2}^{\text{YEARS}} \tag{3}$$

List price is the suggested selling price. RFV1 is proportion of the machine value remaining immediately after purchase. For example, if RFV1 = 0.8, then 20% of the machine value is lost when the machine changes from a new to a used machine. RFV2 is the proportion of value remaining each successive year. For example, if RFV2 = 0.93, then an additional 7% of value is lost each year (including the first year). YEARS is the number of years the machine is expected to be owned by the current operator (Kletke and Sestak, 1991).

Using the above definition of salvage value, depreciation costs are estimated as follows:

$$\text{Annual Average Depreciation Cost} = \frac{\text{Purchase Price - Salvage Value}}{\text{YEARS}} \tag{4}$$

Other fixed costs

In Jordan, fixed costs consist of interest and (insurance + licensing) beside depreciation. There are no taxes on farm machinery and no shelter costs.

Interest is a large expense item for agricultural machinery. It is a direct expense item on borrowed capital. Interest rate in Jordan is about 10%. Interest is computed using the following formula:

Interest, JD per year = 0.5 (purchase price + salvage value) × interest rate

Insurance + **licensing**, JD per year = JD30 (this amount must be paid to the licensing authority, which covers license fees and liability insurance. Other forms of insurance are optional and farmers usually pay the least required amount).

Variable costs

Consist of fuel, lubrication, repair and labor.

Fuel and lubricant: estimating fuel and lubricant costs is of great importance in machinery management. Fuel and lubrication coasts are true operating costs, because fuel consumption is directly proportional to the amount of use.

The most accurate methods for estimating these costs are accurate records for the machines or similar machines and operations. Estimating these costs is possible because the amount of fuel consumed is directly related to the amount of energy exerted.

Fuel consumption

For the most accurate estimate of fuel and lubricant costs, records on each tractor and machine should be kept and used. But if accurate fuel consumption records are not available, using methods described in the standards of the ASAE can make suitable cost estimates. In Jordan, the fuel (diesel) consumption for the tractor is about 7 liters per hour (Al-Kadi, et al., 1989). The price of diesel = JD0.105 per liter, as of March 1999 prices.

Estimating lubricant costs

Modern tractors use a wide variety of lubricants, engine oil, grease, transmission oil and hydraulic fluid. Lubricant costs are approximately 15 percent of the fuel cost of agricultural machinery (Kay and Edwards, 1994). This value (15%) is also used in calculating lubricant costs in Jordan.

Estimating repair costs

Repair costs, usually considered as operating costs, are other important part of machinery costs. The more a machine is used, the greater is its need for repairs.
The purpose of repairing a machine is to maintain its reliability and to keep it performing its task properly. Repair cost is considered a necessary and important part of machinery ownership. Repairs are essential in order to maintain a high level of reliability. Past repair expenses are the best data for predicting repair costs.

Labor cost

In Jordan, a tractor is used about eight hours per day, an average of about five months per year. The operator's salary (the only considered labor cost) is JD150 per month, which is equal to JD0.75/hr.

Results

The necessary input data used by the Machsel spreadsheep were provided, this data include different tractor sizes and prices, the prices of different complements, field sizes, fuel price, wage rate, interest rate. The prices of the different tractors and implents were those of 1999 obtianed from the Jordan Ministry of Agriculture. The fuel price, wage rate and interest rate were those of Jordan in 1999 values (Table 5.2).

Table 5.2. The prices of items used as inputs for Machsel to calculate machinery cost in Irbid (1999) prices.

Item	Price ($)	Unit
Fuel price	0.60	Per gallon
Interest	0.10	Per $ borrowed
Taxes	0.00	Of purchase price
Insurance	0.02	Of average value
Hired wage rate	1.00	Per hour

After the required data were entered, the template was calculated. Annual machinery costs were computed for the complement, each tractor with its implement, for each tillage system. Costs were estimated for a hectare of wheat produced. The cost analysis includes the annual fixed cost, annual variable cost and timeliness cost. The costs for the different tractor sizes used under conventional and conservation tillage systems for different field sizes in Irbid are given in Table 5.3 and 5.4 respectively. The least cost tractor for each size of land area are shaded. For example, a 50 hp tractor has the least cost when used for a 50 hectare field size under a conventional wheat-fallow tillage system. For a 200 hectare field, the 70 hp tractor costs the least when used under vonventional tillage system. For the conservation tillage system (Table 5.4), a 65 hp tractor costs the least when used over a 200 hectare field, while a 50 hp tractor costs the least for a 50 and a 100 hectare land sizes under conservation tillage system.

Table 5. 3. Costs of tractors with their implements used in conventional wheat-fallow tillage system for wheat production in Irbid area at selected field sizes in ($/ha).

Tractor (Hp)		Area (ha)			
		50	100	150	200
45	FC	34.90	17.45	11.63	NA[1]
	VC	23.81	28.24	32.46	
	TC	0.28	0.28	0.23	
	Total C	58.99	45.97	44.32	
50	FC	35.60	17.80	11.87	8.9
	VC	22.28	26.09	29.71	33.24
	TC	0.28	0.28	0.23	0.32
	Total C	58.16	44.17	41.81	42.46
60	FC	40.22	20.11	13.41	10.05
	VC	20.16	23.20	26.12	28.95
	TC	0.28	0.28	0.28	0.22
	Total C	60.66	43.59	39.81	39.22
65	FC	41.33	20.66	13.78	10.33
	VC	20.16	22.45	25.16	27.80
	TC	0.28	0.28	0.28	0.22
	Total C	61.77	43.39	39.22	38.35
70	FC	47.21	23.61	15.74	11.80
	VC	17.60	19.92	22.13	24.27
	TC	0.28	0.28	0.28	0.28
	Total C	65.09	43.81	38.15	36.35
75	FC	53.23	26.62	17.74	13.31
	VC	18.20	20.69	23.08	25.42
	TC	0.28	0.28	0.28	0.28
	Total C	71.71	47.59	41.1	39.01
80	FC	58.52	29.26	19.51	14.63
	VC	18.05	20.62	23.09	25.50
	TC	0.28	0.28	0.28	0.28
	Total C	76.85	50.16	42.88	40.41
90	FC	60.62	30.31	20.21	15.16
	VC	17.22	19.39	21.47	23.51
	TC	0.28	0.28	0.28	0.28
	Total C	78.12	49.98	41.96	38.95
100	FC	66.92	33.46	22.31	16.73
	VC	16.75	18.75	20.68	22.57
	TC	0.28	0.28	0.28	0.28
	Total C	83.95	52.49	43.27	39.58

FC = Fixed Cost; VC = Variable Cost; TC = Timeliness Cost and Total C = Total Cost. Only 50 percent of field size is considered planted each year in the wheat-fallow rotation.

[1] NA = Tractor cannot do the job on time.

Table 5.4. Costs of tractors with their implements used in conservation wheat-fallow tillage system for wheat production in Irbid area at selected field sizes in ($/ha).

Tractor (Hp)		Area (ha)			
		50	100	150	200
45	FC	35.53	17.76	11.48	8.88
	VC	15.79	17.60	19.33	21.03
	TC	0.28	0.28	0.23	0.32
	Total C	51.60	35.64	31.04	30.23
50	FC	36.23	18.11	12.08	9.06
	VC	15.07	16.71	18.27	19.79
	TC	0.28	0.28	0.23	0.32
	Total C	51.58	35.10	30.58	29.17
60	FC	41.00	20.50	13.67	10.25
	VC	13.74	15.05	16.31	17.55
	TC	0.28	0.28	0.28	0.22
	Total C	55.02	35.83	30.26	28.02
65	FC	41.88	20.94	13.96	10.47
	VC	13.39	14.60	15.75	16.88
	TC	0.28	0.28	0.28	0.22
	Total C	55.55	35.82	31.99	27.57
70	FC	48.24	24.12	16.08	12.06
	VC	12.62	13.65	14.64	15.60
	TC	0.28	0.28	0.28	0.28
	Total C	61.14	38.05	31	27.94
75	FC	54.25	27.13	18.08	13.56
	VC	12.48	15.58	14.63	15.65
	TC	0.28	0.28	0.28	0.28
	Total C	67.01	40.99	32.99	29.49
80	FC	59.46	29.73	19.82	14.87
	VC	12.38	13.51	14.60	15.67
	TC	0.28	0.28	0.28	0.28
	Total C	72.12	43.52	34.70	30.82
90	FC	61.56	30.78	20.52	15.39
	VC	11.96	12.93	13.87	14.79
	TC	0.28	0.28	0.28	0.28
	Total C	73.8	43.99	34.67	30.46
100	FC	67.68	33.93	22.62	16.97
	VC	11.73	12.65	13.55	14.44
	TC	0.28	0.28	0.28	0.28
	Total C	79.69	46.86	36.45	31.69

FC = Fixed Cost; VC = Variable Cost; TC = Timeliness Cost and Total C = Total Cost.
Only 50 percent of field size is considered planted each year in the wheat-fallow rotation.

CHAPTER VI

Soil Erosion

Introduction

Soil erosion is a serious problem in Jordan. Quantitative data required to study this problem and find the proper solutions are lacking. Therefore, the Environmental Policy Integrated Climate (EPIC) model was used for this purpose. EPIC was developed by the US Department of Agriculture researchers at the Blacklands Research Center in Temple, Texas (Williams et al., 1983). EPIC simulates soil erosion caused by wind and water. Sheet and rill erosion/sedimentation result from runoff from rainfall, snowmelt, and irrigation. The model uses a daily time step to simulate weather, hydrology, soil temperature, erosion-sedimentation, nutrient cycling, crop management and growth, pesticide and nutrient movement with water and sediment, and field-scale costs and returns.

EPIC is applicable to a wide range of soils, climates and crops. It is efficient, convenient to use, and capable of simulating the particular effects of management on soil erosion and productivity in specific environments. EPIC is designed to help decision-makers analyze alternative cropping systems and project their socioeconomic and environmental sustainability. It is used to evaluate crop productivity, degradation of the soil resource, impacts on water quality, response to different input levels and management practices, response to spatial variation in climate and soils, and long-term changes in climate.

Method

The main objective of this chapter was to compare the net present value (NPV) of using different tillage systems for wheat production in Red Mediterranean Soils of Irbid. If estimates of long-term crop yields are available for each soil depth when each tillage system is used, then the NPV of each tillage system is easily calculated, and the system with the highest NPV can be selected. Longer study periods are required to illustrate impacts of soil erosion on yield. The longer study period permits analysis of intergenerational yield damages from erosion (Aden and Stoecker, 1995). A one hundred (100) year study period was chosen for this study. So the sustainability of the conventional and conservation tillage systems could be compared.

Data requirements

Data needed to determine the NPV include the crop budget for each tillage system used for wheat production in the study area, the impact of each tillage system on soil loss, and an estimate of the wheat yield-soil depth relationship.

Simulation of yield and erosion rates

The NPV analysis requires an estimate of the expected crop yield – soil depth relationship. The traditional USLE and RUSLE methods provide estimates of soil erosion but do not estimate the impact of the erosion on crop yield. The EPIC model was used to simulate the performance of durum wheat cultivar and the rate of soil erosion for about 5300 ha of the Red Mediterranean soil in Irbid area (about 40% of 13212 ha planted with wheat in Irbid). A fallow – wheat crop rotation under two tillage systems, namely conventional (moldboard plow) and conservation (chisel and sweep plows) tillage systems, over a 100-year period was used in the study. EPIC was used to estimate the annual rate of soil erosion and crop yield for each tillage system.

The results of the model simulations produce about 40 output parameters. The main output parameters used in this NPV analysis include the soil erosion (tons/ha/yr) given by the USLE equation, the remaining depth of the soil profile in meters, and wheat yield in metric ton/ha. The values of these parameters for the simulated tillage systems were used to compare wheat yield and soil erosion rate for each tillage system over the planning period used in the study.

The EPIC model requires data that include weather (rainfall, temperature, solar radiation, wind and relative humidity), soil profile characteristics, topographic factors (slopes), and crop management data (including tillage, crop, and dates of field operations). The weather variables necessary for driving the EPIC model are precipitation, air temperature, solar radiation, wind speed and direction, and relative humidity.

Precipitation. The model requires monthly means of precipitation in (mm) and the monthly probabilities of receiving precipitation. On any given day, the input must include information as to whether the previous day was dry or wet. If wet-dry probabilities are not available, the average monthly number of rainy days may be substituted (a day was counted as "rainy" if 0.1 mm of rain or more was recorded on that day). The probability of a wet day is calculated directly from the average number of rainy days in each month. Actual daily values for precipitation (mm) and the number of rainy days for the years 1992 – 1998 were obtained from Irbid Meteorological Station (ABCDJ).

Air temperature and solar radiation. The temperature model requires monthly means of maximum and minimum temperatures in (C^o) and their standard deviations as inputs. The monthly means of daily solar radiation in ($MJ/m^2/day$) are required as inputs by the model. Actual daily values for solar radiation ($MJ/m^2/day$), maximum temperature (C^o), and minimum temperature (C^o) for the years 1992 – 1998 were obtained from Irbid Meteorological Station (ABCDJ).

Relative humidity. The model requires the monthly average relative humidity in decimal form. Actual daily values for relative humidity for the years 1992 – 1998 were obtained from Irbid Meteorological Station. The values of different weather parameters used as inputs in EPIC are shown in Table 6.1. The monthly average values of maximum temperature, minimum temperature and solar radiation are plotted in Figure 6.1.

Table 6.1. The monthly average values and standard deviation of Irbid weather parameters used in EPIC.

	Month											
Parameter[1]	Jan.	Feb.	March	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Max. T	12.83	12.68	15.83	21.82	27.12	30.78	30.78	31.22	29.87	27.12	19.34	14.65
Min. T	4.88	4.75	6.85	10.37	14.97	17.67	19.65	19.97	18.72	15.88	9.77	6.27
St.D (Max)	2.03	2.45	1.42	2.10	1.97	2.01	0.71	1.02	1.09	1.77	1.23	2.55
St.D (Min)	5.62	5.61	6.35	8.10	8.59	9.27	7.87	7.95	7.88	7.94	6.84	5.93
Precipitation	103.37	124.22	71.95	11.15	8.92	3.00	0.00	0.00	2.05	12.98	62.45	85.72
St. D (ppt)	65.04	118.69	40.61	10.04	12.67	7.35	0.00	0.00	3.22	9.02	49.13	66.94
Pr. W A D	0.14	0.16	0.12	0.07	0.05	0.01	0.01	0.00	0.00	0.07	0.08	0.11
Pr. W A W	0.26	0.23	0.25	0.09	0.03	0.00	0.00	0.00	0.00	0.06	0.15	0.19
No. of rainy days	9.80	13.00	9.6	4.40	2.80	0.60	0.00	0.00	0.40	3.20	7.00	10.04
Solar Rad.	240	300	406	522	622	664	646	598	519	388	274	247
R. humidity	0.73	0.71	0.66	0.51	0.45	0.50	0.58	0.61	0.57	0.52	0.60	0.73

1 Abbreviations: Max. T = maximum temperature (C^o); Min T = minimum temperature (C^o); St.D = standard deviation; ppt = precipitation (mm); Pr. W A D = probability of wet day after dry day; Pr. W A W = probability of wet day after wet day; Solar Rad. = solar radiation in (LY), LY = [(MJ/m^2)/0.0419]; R. humidity = relative humidity.

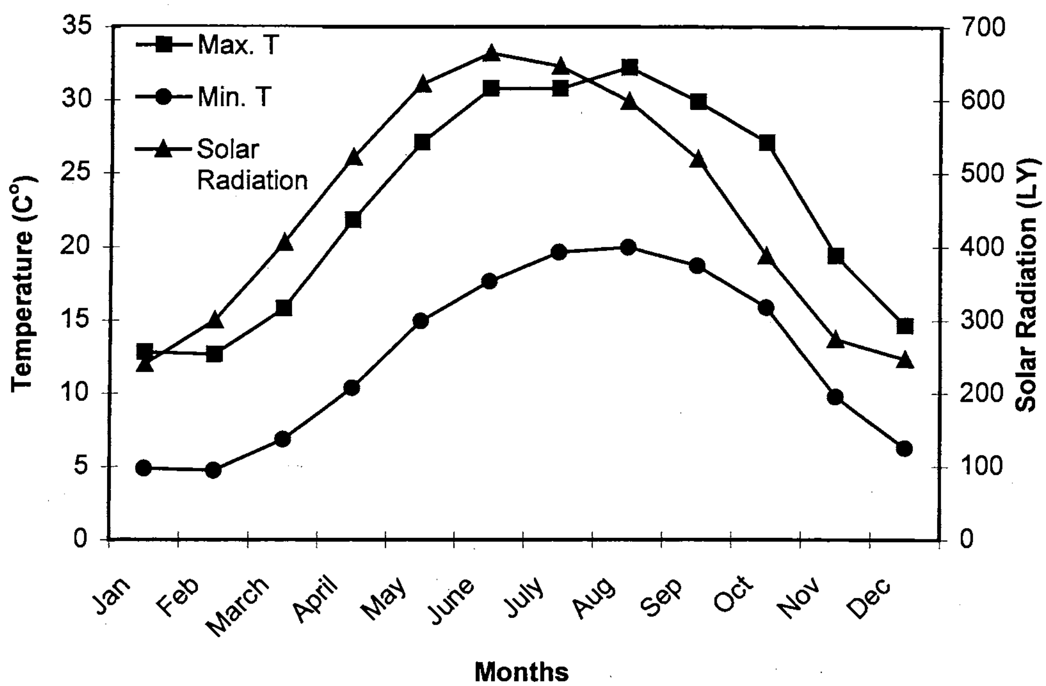


Figure 6.1. Monthly average maximum temperature, minimum temperature and solar radiation for Irbid.

Wind Speed and wind Direction. The EPIC wind erosion model requires wind speed distribution within the day and the dominant direction. Wind direction expressed as radius from north in a clockwise direction is generated from an empirical distribution specific for each location. The empirical distribution is simply the cumulative probability distribution of wind direction. Data files containing hourly observations of wind speed and direction for Amman Airport (about 80 km south east of the study area) were obtained from a CD-ROM containing Global Weather data sets, which was produced by the U. S. Air Force Combat Climatology Center (AFCCC) for the years 1982 through 1997 (16 years of hourly observations).

The file containing wind speed was then processed to estimate the monthly average wind speed in (m/s). The observations on wind speed were collected by month over the 16-year period. A simple average for each month was used as input for EPIC.

The wind direction is reported in degrees. The degrees were assigned to one of 16 compass points (N, NNE, NE, ENE, E, ESE, SE, SSE, S, SSW, SW, WSW, W, WNW, NW, NNW). Then the number of observations in each of the 16 cells was counted. The total number of observations in each cell was divided by the number of observations recorded for the month. The data for wind speed and wind direction are shown in Table 6.2.

Table 6.2. Monthly average wind speed (m/s) and wind direction (No. of occurrences) used as inputs for the EPIC model.

	Month											
	Jan	Feb	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct	Nov.	Dec.
W speed	5.81	5.81	6.26	6.26	5.81	5.81	4.92	4.92	4.47	4.47	4.92	5.36
W direction												
N	2	2	4	3	3	4	3	3	5	4	1	2
NNE	1	1	1	1	1	1	1	2	2	3	2	2
NE	2	1	1	1	1	1	0	1	1	2	2	2
ENE	2	2	2	1	2	1	0	0	1	3	4	3
E	10	5	4	4	3	1	0	1	3	7	13	10
ESE	8	4	4	3	1	0	0	0	1	4	9	7
SE	4	4	4	2	1	0	0	0	1	3	5	5
SSE	3	3	3	3	1	0	0	0	0	3	3	5
S	4	4	5	4	2	1	0	0	1	3	4	7
SSW	6	6	4	4	4	2	2	2	2	4	4	8
SW	13	14	10	8	9	7	7	6	6	8	10	14
WSW	16	19	16	16	16	17	17	14	13	13	14	16
W	17	22	21	24	24	27	31	27	21	18	16	13
WNW	7	8	11	12	13	17	19	21	17	12	6	4
NW	4	3	7	9	11	14	13	15	16	10	3	2
NNW	2	2	4	5	6	7	6	7	9	5	2	1

The soil profile characteristics. The soil profile characteristics required as model inputs include the soil albedo, the number of layers of the soil profile, depth, bulk density, wilting point, field capacity, sand content, silt content, soil PH, organic carbon, calcium carbonate, Cation Exchange Capacity CEC, and course fragment for each layer. These data were obtained for (Ramtha Experiment Station) in Irbid from a soil data file in DSSAT3 (Decision Support System for Agrotechnology Transfer) model (Tsuji et al., 1994). The soil profile characteristics used as inputs in EPIC are shown in Table 6.3.

Table 6.3. The characteristics for a 1.5 m deep soil profile in Irbid that were used in EPIC.

Depth of layer (m) Soil property	0.01	0.12	0.32	0.58	0.89	1.16	1.5
Bulk density (g/cc)	1.11	1.11	1.21	1.29	1.29	1.26	1.23
Wilting point	0.197	0.197	0.206	0.261	0.272	0.280	0.281
Field capacity	0.333	0.333	0.339	0.388	0.399	0.406	0.407
Sand content %	7.9	7.9	7.4	8.3	7.5	7.7	7.3
Silt content %	55	55	53.9	40.4	39.1	37.1	37.3
PH	8.3	8.3	8.3	8.4	8.4	8.5	8.5
Organic carbon	0.6	0.6	0.57	0.42	0.34	0.25	0.2
Calcium carbonate	16.5	16.5	17.5	16.5	20.4	12.6	12.6
Cation Exchange Capacity	35.8	35.8	35.6	35.1	35.3	35.3	35
Coarse fragment	2	2	2	2	1	1	1

For the topography of the area, the slopes of the land in the study area range from 5 to 10 percent (*The Soils of Jordan, 1993*). The EPIC model was run using 5% and 10% slopes for each tillage system.

EPIC generates daily stochastic estimates of yield and erosion rates for each tillage system for a given soil point. In this study, two soil profile depths were selected, namely 1.5 and 0.7 m. The simulation involving two beginning soil depths was necessary in order to obtain estimates of wheat yields over a wide range of soil depths.

Crop management data

Tillage systems. In this study two tillage systems used for Durum wheat production in Irbid area were selected, namely conventional tillage system and conservation tillage system.

Conventional Tillage

Is the tillage system in which farmers in the dryland regions of Jordan, use moldboard or one-way disk plows to incorporate crop residues into the soil. These implements partially or completely invert the surface layer of the soil, and penetrate to a depth of 16-20 cm (Lanzendorfer, 1985). Several (4-6) tillage operations are performed during the summer and fall months to control weeds and prepare the seedbed (Tamimi, 1981). This tillage system controls weeds effectively, but results in bare soil surface with few clods making it highly susceptible to erosion (Papendick, 1984). The conventional (traditional) practices being used in Jordan (Snobar, 1987) are as follows:

1. Land preparation is performed by using moldboard plow, disk plow, or disk harrow during Oct-Dec. This operation is practiced late in the season in order to allow the growth of weeds after heavy rains.

2. Sowing is performed after land preparation and cultivation for weed control during late Nov-Jan by hand broadcasting. Then seeds are covered by disk harrow. This method of sowing results in an uneven seed depth.
3. No fertilizers or herbicides are added or used.

Conservation Tillage

Conservation tillage system is defined as reducing tillage only to those operations that are timely and essential to producing the crop and avoiding damage to the soil. It normally refers to a tillage system in which the number of field operations is reduced as compared to the number required in a conventional system. Conservation tillage is designed to conserve crop residues, increase water uptake, reduce wind and water erosion, and save energy (Jaradat, 1988).

Researchers at the University of Jordan and Jordan Cooperative Organization (JCO) recommend the following conservation tillage system: a chisel plowing (2 – 4) weeks after harvest, another chiseling during September – October prior to seeding, to a depth of 15 cm; a sweep plow should be the last implement for seedbed preparation. In a fallow year, sweeps are to be used for weed control during spring (April – May) (Jaradat, 1988).

Based on the results of a study about the Impact of mechanization on wheat production in rainfed areas of Jordan (Snobar, 1987) recommended the following:

1. Early tillage operation (Sept – Nov), using chisel plow should be practiced for better soil moisture conservation.
2. Seedbed preparation should follow using a sweep.

3. Early sowing (Late Oct – early Dec) should be practiced using grain drill with hoe-type furrow openers. Covering device behind the furrow openers on the drill are not needed in most rainfed areas of Jordan. Leaving furrows and ridges after sowing would help retain more moisture and reduce runoff.
4. Fertilizing with N and P_2O_5 at rates of 60 and 30 kg/ha, respectively, should be applied during sowing, using grain drill.
5. Herbicides should be used to control broad-leaved weeds, using 2-4-D sprayed by boom sprayer.

Since farmers in the dryland farming regions of Irbid traditionally follow a 2-year crop rotation, a fallow – wheat crop rotation was used. Different field operations performed in a 2-year fallow-wheat system by each tillage system with the date of performance are given in Table 6.4.

Table 6.4. Tillage operations for both conventional and conservation tillage systems practiced during a fallow-wheat crop rotation*.

Conventional							
Operation	MB	MB	Disk	Disk	Disk	D. H.	Planting
Date	June	August	Oct.	April	June	Oct.	Nov.
Conservation							
Operation	Chisel	Sweep	Sweep	Sweep	Sweep	Field C.	Planting
Date	June	August	Oct.	April	June	Oct.	Nov.

*Abbreviations used: MB = Moldboard plow; D. H. = Disk Harrow; Field C. = Field Cultivator; the first tillage operation begins after harvest in early to mid June.

In order to determine, which tillage system is more economical to use in the study area for the long run, an economic analysis of alternative tillage systems, namely the Net Present Value *(NPV)* model was used. The *NPV* of the *i'th* tillage system is

$$NPVi = \sum_{t} \frac{(PYti(dt) - WiXi)}{(1+dr)^t} \qquad (1)$$

Where

P = the product price (assumed constant);

$Y_{ti(dt)}$ = the yield in year t for soil depth dt when the *i'th* tillage system is used;

dt = soil depth in year t;

X_i = 1 when the *i'th* tillage system is used, *0* otherwise;

W_i = the cost of the inputs required by the *i'th* tillage system; and

dr = the discount rate.

The *NPV* analysis requires an estimate of the expected crop yield-soil depth relationship and the soil loss for the soil type in the study area. The estimates of long-term crop yields and erosion rates were obtained from EPIC output and the *NPV* of each tillage system was calculated. The system with highest *NPV* could be selected.

Selection of Production Function and Estimation of Remaining Soil Depth

First a reliable crop yield-soil depth relationship is essential for any economic analysis of soil erosion. Hoag and Young (1983) argue that the yield-topsoil depth function must have a non-zero intercept and a non-negative and diminishing marginal return to topsoil, and that the yield must asymptotically approach a maximum at full topsoil depth. A modified Mitcherlich-Spillman (M-S) production function, which relates the wheat yield to soil depth was used:

$$Y = M - A \times Rd^{D}$$

where Y = final wheat yield

M, A and Rd are parameters to be estimated

$0 \leq \text{Rd} \leq 1$

D = soil depth of the A, B, and C soil horizons in meters.

The mathematical properties of the function illustrated in Figure 6.12 indicate that as soil depth increases the yield approaches the maximum yield M. M-A is the yield with zero soil depth. A is expected to be greater than M because some minimum soil depth is required before any yield can be obtained.

Next the remaining soil depth each year must be adjusted to reflect the average loss of soil by erosion. It is assumed that average soil loss is determined by the choice of tillage system.

Results of EPIC Simulations

Erosion by Tillage System. As stated above ten 100-year simulation runs were made with the conservation tillage system, and the conventional tillage system on a Red Mediterranean Soil where the beginning profile depth was 1.5 and 0.7 meters. The same ten weather simulations were used for the two tillage systems and beginning soil depths.

Each of the ten weather simulations was generated by selecting a random number of cycles for the weather generation before the simulation run began. The first year's simulation results were deleted (by EPIC) from each simulation run. The main results (average wheat yield, average rate of soil erosion and the remaining soil depth) from the EPIC simulations for 1.5 and 0.7 m deep soil profiles at 10 and 5% slopes for both conventional and conservation tillage systems for Irbid area are summarized in Tables 6.5, 6.6, 6.7 and 6.8 respectively.

Table 6.5. EPIC simulation results for a 1.5-meter deep soil profile at 10% slope using conventional and conservation tillage systems.

Beginning depth 1.5 m EPIC output	Conventional	Conservation
Average yield (tons/ha/yr)	2.2	2.3
Average erosion (tons/yr)	40.16	26.12
Eroded depth (m) for 99 yrs	0.45	0.25

Table 6.6. EPIC simulation results for a 0.7-meter deep soil profile at 10% slope using conventional and conservation tillage systems.

Beginning depth 0.7 m EPIC output	Conventional	Conservation
Average yield (tons/ha/yr)	0.93	1.1
Average erosion (tons/yr)	47.70	28.95
Eroded depth (m) for 99 yrs	0.45	0.27

Table 6.7. EPIC simulation results for a 1.5-meter deep soil profile at 5% slope using conventional and conservation tillage systems.

Beginning depth 1.5 m EPIC output	Conventional	Conservation
Average yield (tons/ha/yr)	2.44	2.53
Average erosion (tons/yr)	15.31	9.68
Eroded depth (m) for 99 yrs	0.31	0.15

Table 6.8. EPIC simulation results for a 0.7-meter deep soil profile at 5% slope using conventional and conservation tillage systems.

Beginning depth 0.7 m EPIC output	Conventional	Conservation
Average yield (tons/ha/yr)	1.04	1.56
Average erosion (tons/yr)	15.75	10.62
Eroded depth (m) for 99 yrs	0.26	0.14

In this study the rate of soil erosion obtained from EPIC simulation runs was for 5 and 10% slopes at 50 ft slope length for the soil type in study area of Irbid. In order to generalize these results to other slopes for the same soil type, the erosion rates obtained from EPIC runs at 5 and 10% slopes for different soil depths and tillage practices used in the study (Tables 6.5, 6.6, 6.7 and 6.8), along with the values of Slope Factor (*LS*) used in the Universal Soil Loss Equation (USLE) and obtained from Table 6.9 can be used to predict the soil erosion rate at any desired slope in study area. The predicted erosion at any slope can be found using the following relation:

$$\textit{Predicted Erosion at S\%} = \textit{(EPIC Result) at 5 or 10\%} \times \left(\frac{LS\ for\ S\%}{LS\ for\ 5\ or\ 10\%} \right)$$

Where S = Slope at which erosion rate is desired (%),

EPIC Results = Soil erosion rate predicted by EPIC model at 5 or 10% soil slopes,

LS = values for topographic factor (*LS*) corresponding to the desired slope obtained from Table 6.9.

For example, the rate of soil erosion at 8% slope for a 1.5 m deep soil in Irbid area using a conventional tillage system at 10% slope and 50 ft slope length used in (EPIC) for a wheat-fallow crop rotation is predicted as follow:

Erosion rate from EPIC result for conventional tillage system, 1.5 m deep at 10% slope soil is 40.16 (tons/yr) Table 6.5.

LS for 8% = 0.74 (Table 6.9)

LS for 10% = 0.97 (Table 6.9)

Hence, the predicted soil erosion rate at 8% slope = (40.16) x (0.74/0.97) = 30.64 (ton/yr)

Table 6.9. Values for topographic factors (*LS*) for moderate-ratio rill to interril erosion, such as for row-cropped agricultural and other moderately consolidated soil conditions with moderate cover.

	Slope length (ft)											
Slope (%)	25	50	75	100	150	200	300	400	500	600	800	1000
0.5	0.08	0.08	0.08	0.09	0.09	0.09	0.09	0.1	0.1	0.1	0.1	0.1
1	0.12	0.13	0.14	0.14	0.15	0.16	0.17	0.18	0.18	0.19	0.2	0.2
2	0.19	0.22	0.25	0.27	0.29	0.31	0.35	0.37	0.39	0.41	0.44	0.47
3	0.25	0.32	0.36	0.39	0.44	0.48	0.55	0.6	0.64	0.68	0.75	0.8
4	0.31	0.4	0.47	0.52	0.6	0.67	0.77	0.86	0.93	0.99	1.1	1.2
5	0.37	0.49	0.58	0.65	0.76	0.85	1	1.1	1.2	1.3	1.5	1.6
6	0.43	0.58	0.69	0.78	0.93	1	1.2	1.4	1.6	1.7	1.9	2.1
8	0.53	0.74	0.91	1	1.3	1.4	1.8	2	2.2	2.5	2.8	3.2
10	0.67	0.97	1.2	1.4	1.7	2	2.4	2.8	3.2	3.5	4.1	4.6
12	0.84	1.2	1.5	1.8	2.2	2.6	3.3	3.8	4.3	4.8	5.6	6.3
14	1	1.5	1.9	2.2	2.8	3.2	4.1	4.8	5.4	6.1	7.2	8.1
16	1.2	1.7	2.2	2.6	3.3	3.9	5	5.9	6.5	7.4	8.8	10
18	1.3	2	2.6	3	3.8	4.6	5.8	6.9	7.9	8.8	9.5	12
20	1.4	2.2	2.8	3.4	4.4	5.2	6.7	8	9.1	10.2	12.2	14

Source: Modified from Renard et al., 1991. Cited in Troeh et al., 1991.

The wheat yield and the remaining soil depths for the two tillage systems used in the study (conventional and conservation) on 10 and 5% slopes for 1.5 and 0.7 m deep soils of Irbid are plotted against the planning period (100 years). These plots are shown in Figures 6.2, 6.3, 6.4, 6.5, 6.6, 6.7, 6.8, and 6.9. The wheat yields corresponding to the remaining soil depths for 1.5 and 0.7 m deep soils at 10% slope under conventional tillage system are plotted in Figures 6.10 and 6.11 respectively. In these plots, the linear trend was fitted to the data obtained from EPIC model.

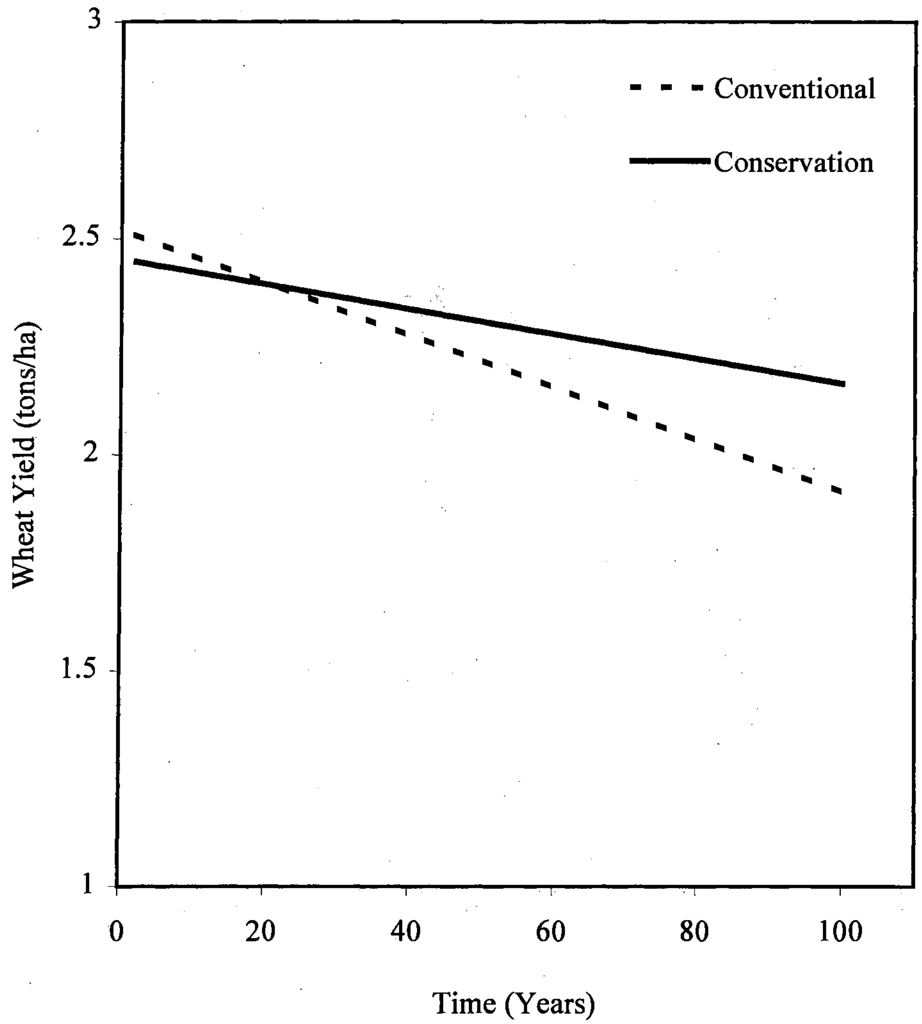


Figure 6.2. Yield by Tillage System on 10% slope for 1.5 m deep soils of Irbid area.

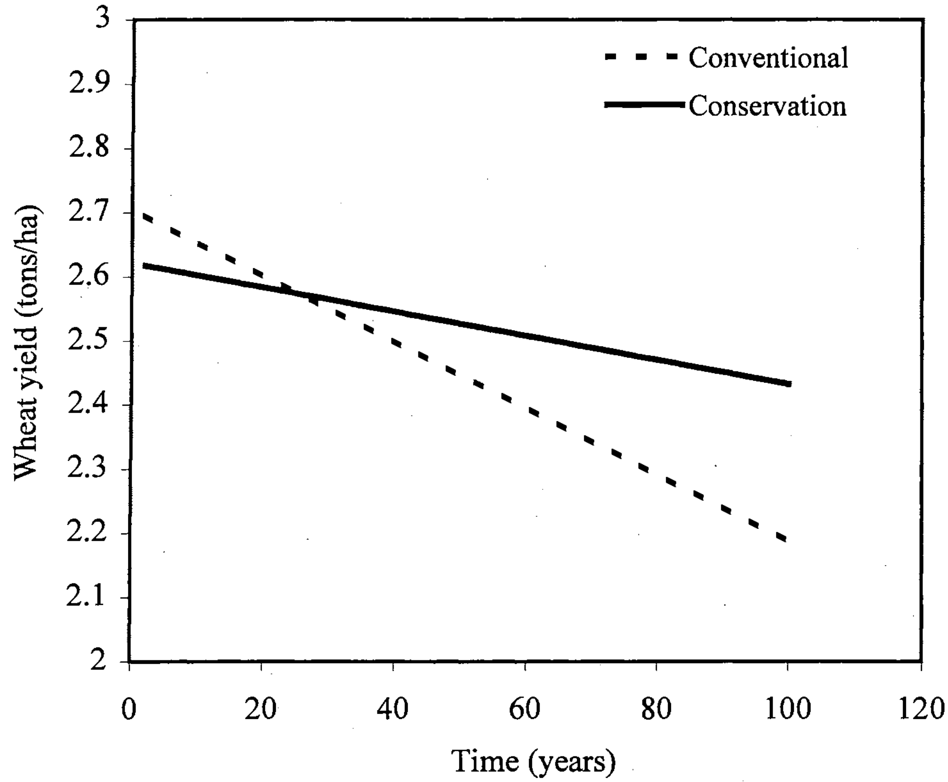


Figure 6.3. Yield by Tillage System on 5% slope for 1.5 m deep soils of Irbid area.

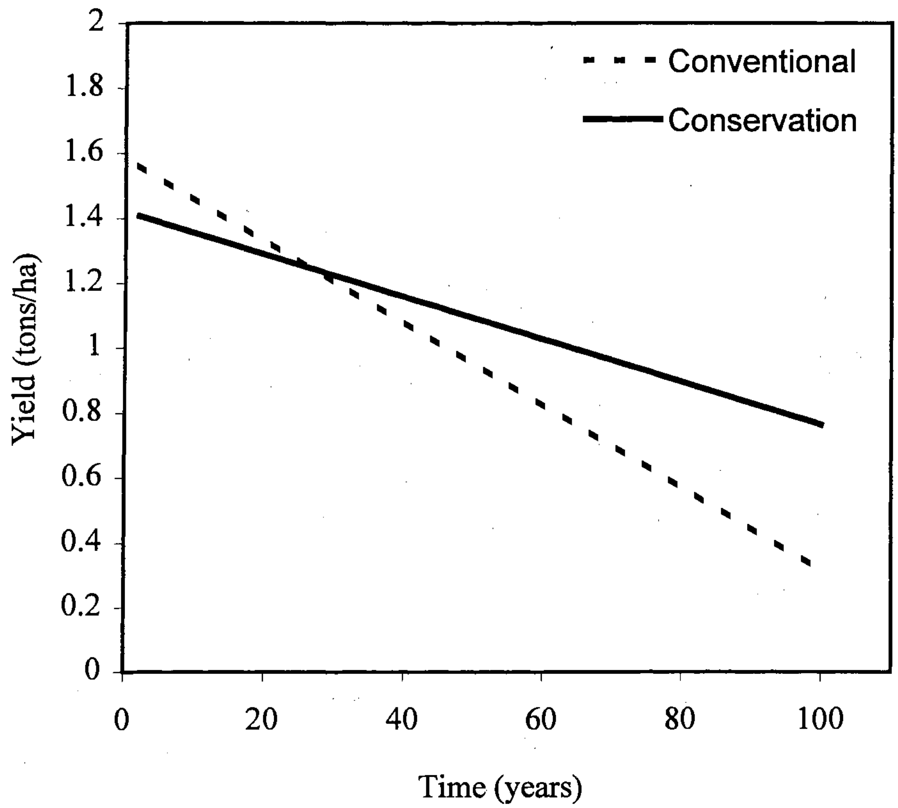


Figure 6.4. Yield by Tillage System on 10% slope for 0.7 m deep soils of Irbid area.

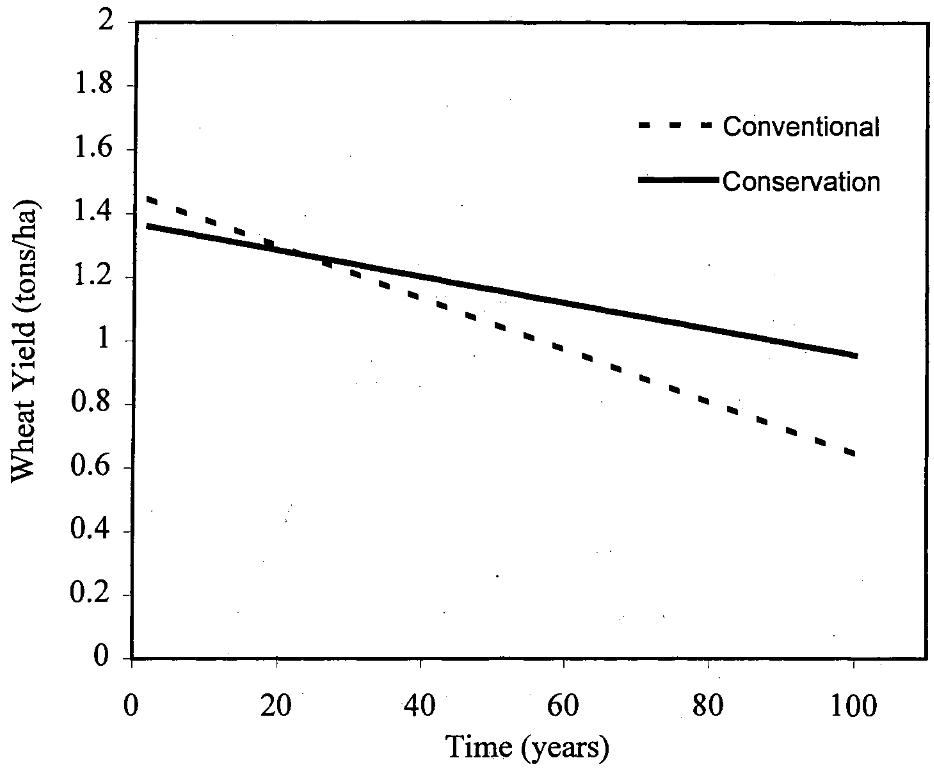


Figure 6.5. Yield by Tillage System on 5% slope for 0.7 m deep soils of Irbid area.

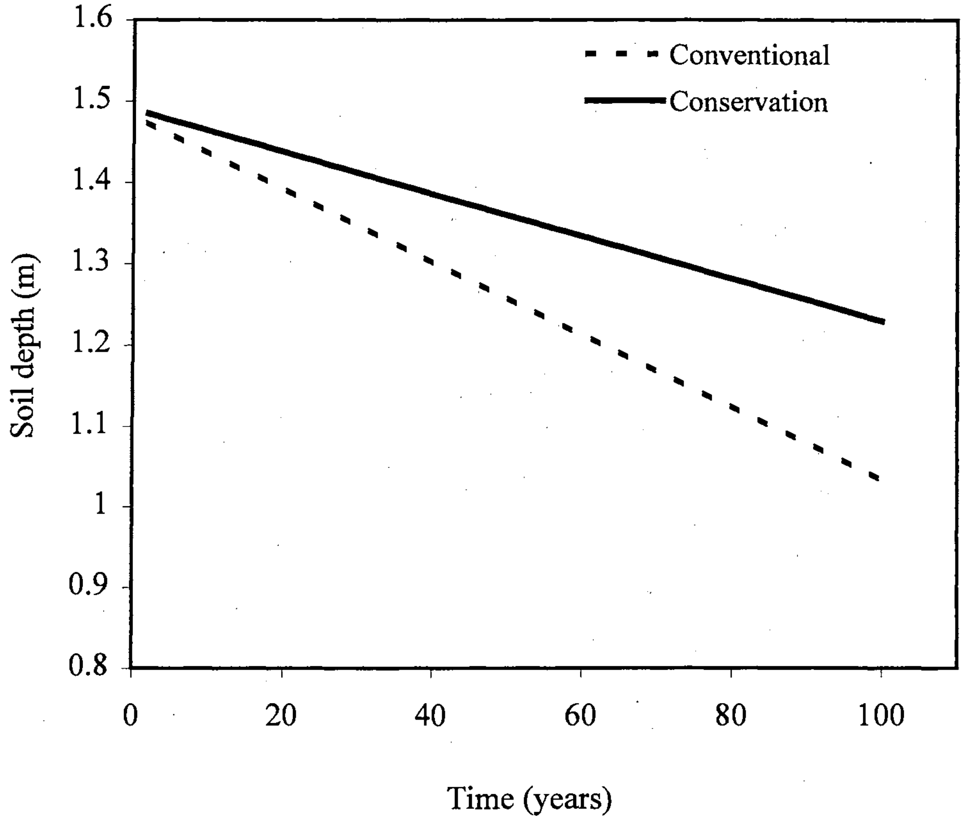


Figure 6.6. Soil Depth by Tillage System on 10% Slope for 1.5 m deep soils of Irbid area.

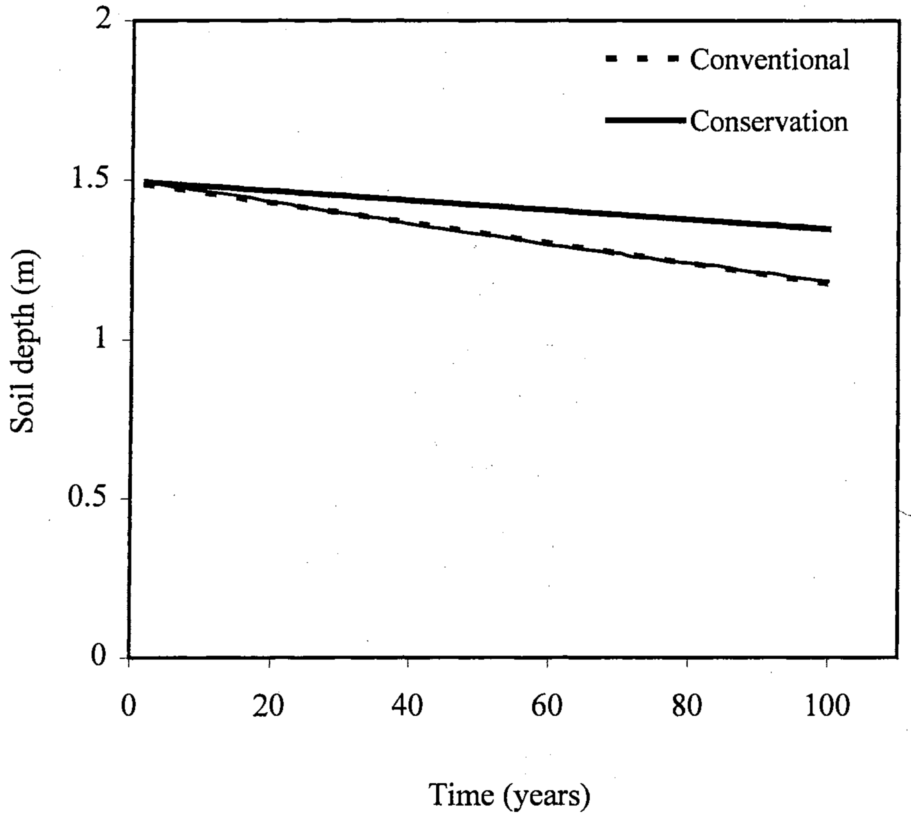


Figure 6.7. Soil Depth by Tillage System on 5% Slope for 1.5 m deep soils of Irbid area.

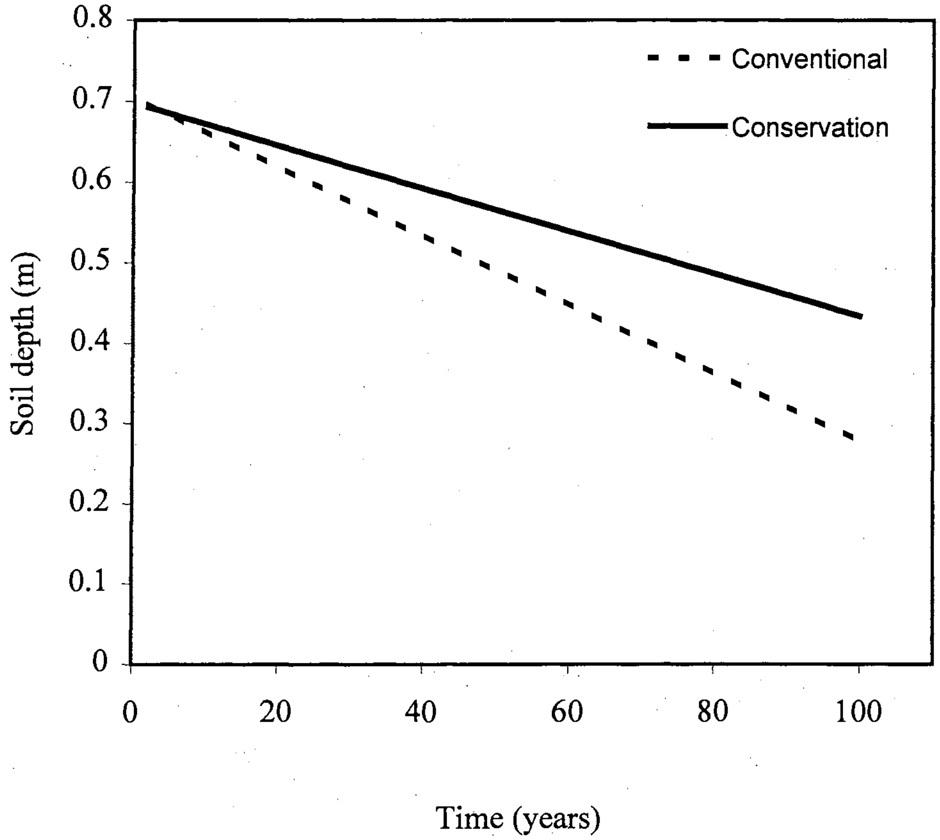


Figure 6.8. Soil Depth by Tillage System on 10% Slope for 0.7 m deep soils of Irbid area.

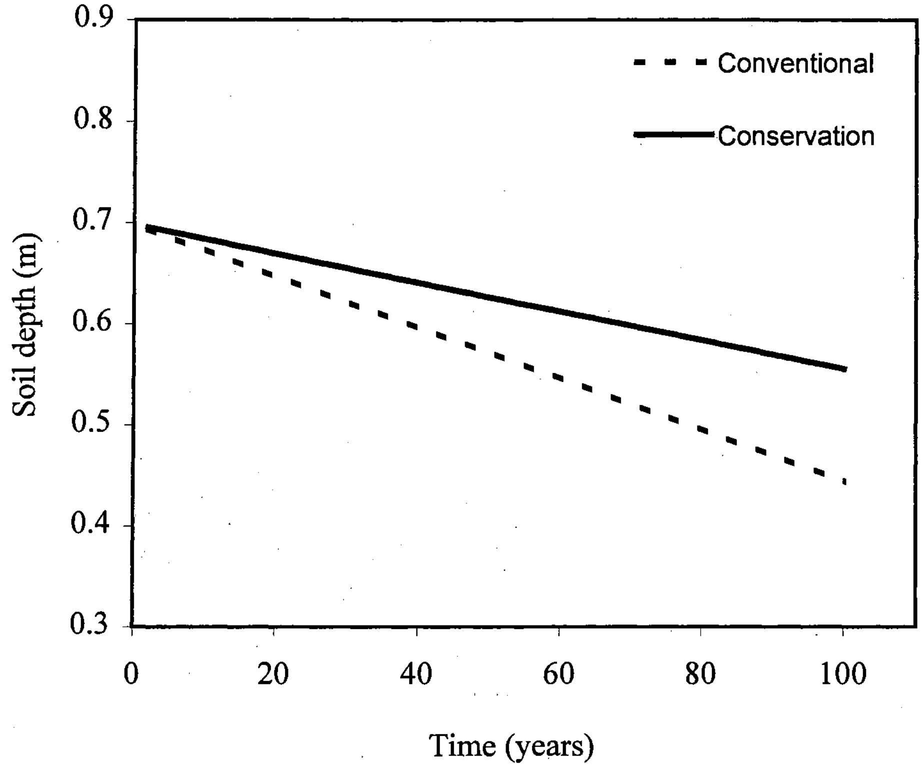


Figure 6.9. Soil Depth by Tillage System on 5% Slope for 0.7 m deep soils of Irbid area.

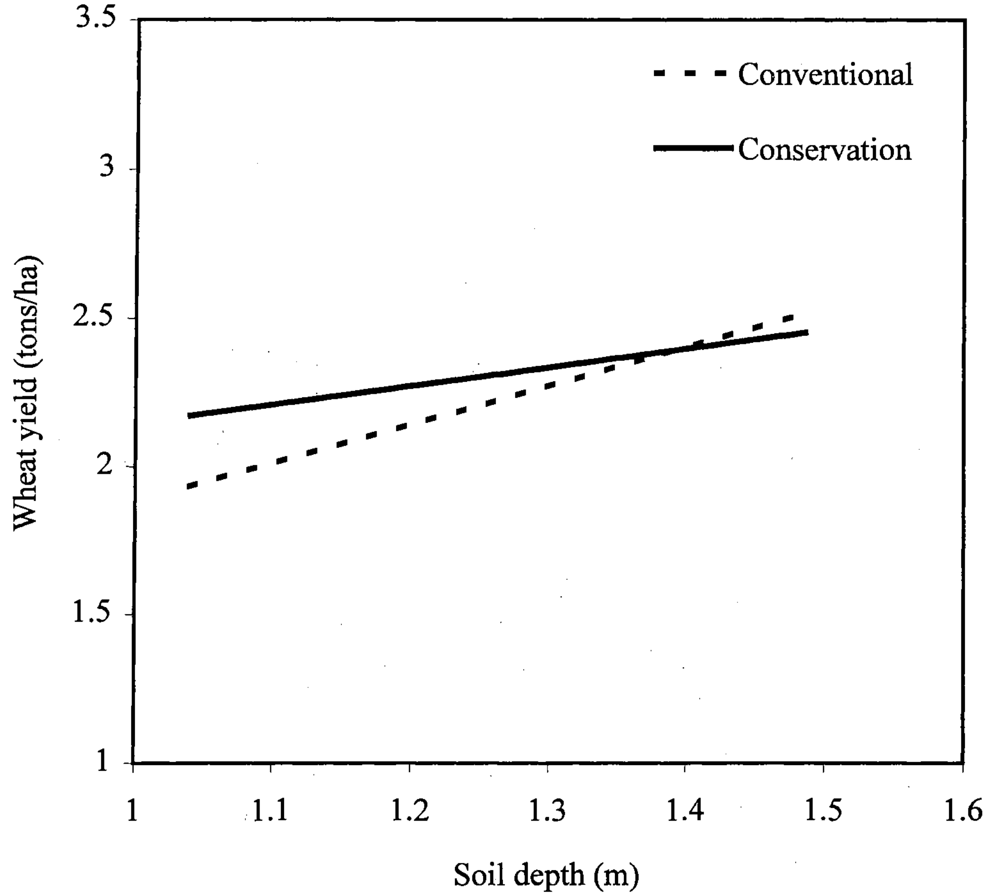


Figure 6.10. Wheat yield by Soil Depth on 10% Slope for 1.5 m deep soils of Irbid area.

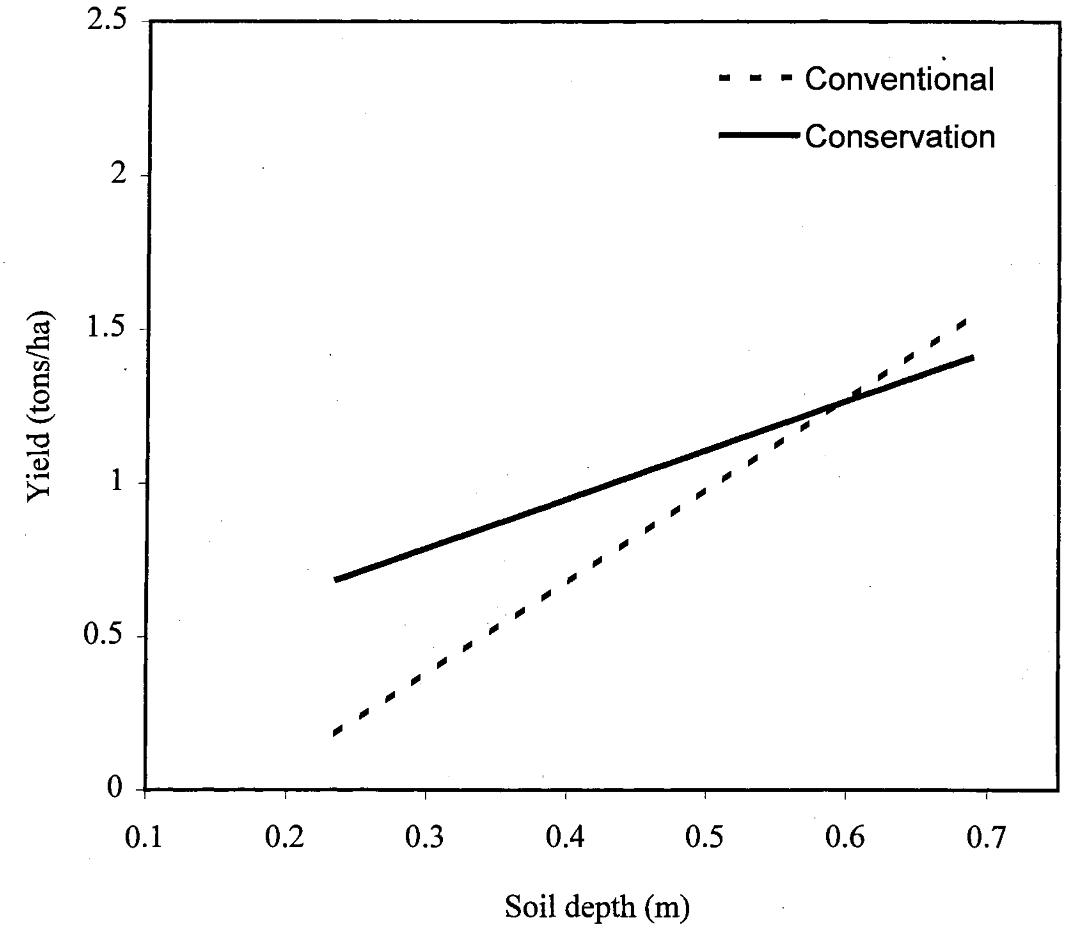


Figure 6.11. Wheat yield by Soil Depth on 10% Slope for 0.7 m deep soils of Irbid area.

Function to relate yield to soil depth

Because of the stochastic effect of weather on EPIC yields, the yield obtained from different simulation runs varies. To account for this variability, ten simulation runs were done. To obtain a better estimate of the yield output, the average wheat yield at a soil depth interval of 0.1 meter starting from the top of the soil profile (1.5 m for example) for the ten simulations was determined. An example of the average yield estimate corresponding to average soil depths at 0.1 m intervals for a 1.5 m deep soil profile using the conventional tillage system is given in Table 6.10. The wheat yield-soil depth function for this data is shown in Figure 6.12.

Table 6.10. The average wheat yield at a 0.1 m soil depth interval for a 1.5 m deep soil profile, for a conventional tillage system used at a 10% slope land.

Average yield (tons/ha)	Soil depth (m)
2.44	1.45
2.3	1.35
2.39	1.25
2.06	1.15
1.78	1.05
1.78	0.95
1.54	0.85
1.41	0.75
1.24	0.65
1.25	0.55
0.91	0.45
0.43	0.35
0.15	0.25
0.10	0.15

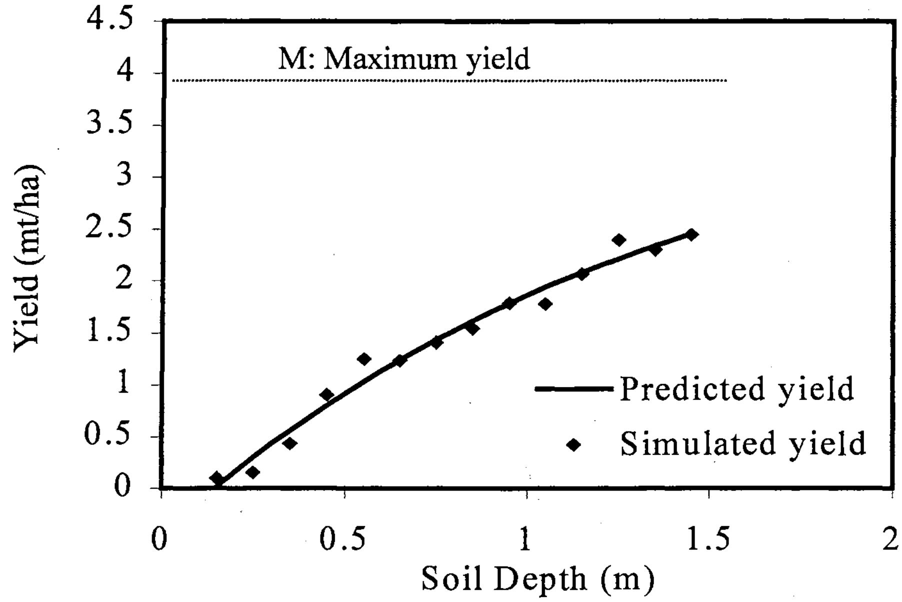


Figure 6.12. The wheat yield-soil depth function for a 1.5 m deep soil profile at a 10% slope using a conventional tillage system in Irbid.

The data in Table 6.10 were used as inputs for the (PROC NLIN) procedure in SAS version 8, in order to estimate the values of the parameters M, A and Rd used in the (M-S) production function. The results of the SAS run are shown in Table 6.11.

Table 6.11. The values of the parameters used in the yield-soil depth function for wheat production in Irbid.

Parameter	Estimate	Standard deviation	t test
M	3.9031	0.8177	4.7733
A	4.3581	0.7005	6.2214
Rd	0.4686	0.1178	3.9779

The results of the t test (Estimate/standard deviation) show clearly that all of these parameters are significant (having values > 1.96). The remaining soil depth (D) was determined using the average soil erosion parameter given by the USLE equation in EPIC over the planting period, and the bulk density of the soil in the study area. The average soil erosion in (tons/ha) was divided by the weight of one hectare of soil one meter deep. For the above-mentioned example, the average rate of soil erosion for a conventional tillage system at 10% slope in a crop year is 54.3 (tons/ha/yr); the weight of soil one meter deep over a hectare is 12316.67 (tons/ha/m). The average annual depth of soil eroded in this case = 0.00441 m/yr (54.3/12316.67). The remaining soil depth D (at any point) = soil profile depth (at that point) – depth of soil eroded. For the 1.5 m profile example, the remaining soil depth = 1.5 – 0.00441 = 1.49559 m after one year. The value of D changes with time over the planning period. Using the values of these parameters, the estimated wheat yield-soil depth relationship became:

$$Yit = 3.9031 - 4.3581 \times 0.4686^{Dt}$$

$$D_{t+1} = D_t - ed_{it}$$

Where D = original soil depth

ed_{it} = the eroded depth in year t when the *i'th* tillage system is used.

Since the soil depth D_t changes with time in right hand side of the wheat yield-soil depth relationship, this means that the wheat yield will change accordingly over time. The current choice of tillage system affects the future of remaining soil depth and hence future's wheat yields.

Partial Budget Comparison of Conventional and Conservation Tillage Systems

The objective of this chapter was to compare the NPV of producing wheat under conventional and conservation tillage systems used in wheat-fallow crop rotation for two soil depths (1.5 and 0.7 m), at two soil slopes (5 and 10%) for two discount rates (5 and 10%). The projected yields (obtained from M-S production function) were used to determine expected costs and returns under each tillage system for a given soil depth, slope and discount rate.

The NPV analysis requires the knowledge of the amount of wheat yield produced, the price of wheat, the type of tillage system used and the cost of inputs required by the tillage system. The value of yield (*Yit*) from the (M-S) production function was used in the NPV analysis for the different tillage systemss. The value of ($211.5/metric ton) was used as the price of wheat in Jordan (MOA, 1998). The cost of input parameters required to determine the NPV for usinga 65 hp tractor on a 200 ha field in Irbid area under conventional and conservation tillage systems are given in Table 6.12.

Table 6.12. The cost ($/ha) of input parameters used in conventional and conservation tillage systems using a 65-hp tractor on a 200 ha field in Irbid.

	Tillage system	
Parameter	Conventional	Conservation
Machinery[1]	38	28
Seeds[2]	17	17
Grain drill	0	8
Fertilizers	11	11
Weed control	0	9
Harvesting	18	18
Sacks and transport	10	13
Total	94	104

1 = Machinery cost was obtained from Table 5.3 And 5.4 Respectively.
2 = the cost of all other parameters were obtained from (Snobar, 1987).

Results

The results of the NPV analysis for the conventional and conservation tillage system for the given soil depths, soil slopes and discount rates are given in Tables 6.13 and 6.14.

Table 6.13. NPV values for different tillage systems at 10% discount rate.

Depth of soil profile (m)	Slope (%)	Tillage System Conventional	Tillage System Conservation
1.5	10	2071	2043
1.5	5	2091	2056
0.7	10	878	866
0.7	5	916	891

Table 6.14. NPV values for different tillage systems at 5% discount rate.

Depth of soil profile (m)	Slope (%)	Tillage System Conventional	Tillage System Conservation
1.5	10	4112	4096
1.5	5	4198	4153
0.7	10	1601	1655
0.7	5	1760	1759

CHAPTER VII

SUMMARY AND CONCLUSIONS

The purpose of this research was to provide an insight to the state of agricultural machinery use in Jordan, in general, and in Irbid area in particular, and to determine the economic optimum complement of machinery to be used in wheat production and soil conservation in the rainfed areas of Irbid North of Jordan. The specific objectives were to:

1. Determine the timeliness cost of planting wheat before and after the optimum planting date in rainfed areas of Northern Jordan.
2. Determine the proper sizes and ownership costs of farm machinery and equipment used in wheat production in rainfed areas of Northern Jordan.
3. Determine the impact of using conservation tillage system on soil erosion and the sustainability of wheat production in rainfed areas of Northern Jordan.

In Chapter 1, an introduction about Jordan and the study area of Irbid was given. In Chapter 2, the literature on the agricultural sector, farming practices, farm machinery use, and the soil erosion problem in the country and in Irbid area was reviewed. In Chapter 3, the statement of the problem, the overall objective and the specific objectives of the study were discussed. In Chapter 4, the timeliness costs for planting wheat in the rainfed areas of Irbid was studied. The timeliness penalties (timeliness costs) incurred by planting wheat at times earlier or later than the optimum time for the study area was calculated. The CEREC-Wheat crop-growth model was used to simulate the performance of durum wheat cultivar at Irbid area. The wheat yield predicted by the model with the corresponding time (sowing dates) were used to determine the yield/time function, which was used in calculating the timeliness cost for planting wheat in Irbid area at times other than the optimum time. The results obtained showed the importance of planting wheat during the optimum planting period (the middle of November) in order to avoid timeliness costs associated with planting at times earlier or later that the optimum time.

In Chapter 5, the machinery selection and machinery ownership cost in rainfed areas of Irbid were studied. Machsel program was used to calculate the proper sizes of machinery complements to be used in wheat production in Irbid area. Machsel program uses the methods and equations used in the Standards of the American Society of Agricultural Engineers (ASAE) and the Agricultural Engineers Yearbook. An important input used in Machsel was the number of days available for fieldwork. The number of days available for fieldwork was determined in EPIC using the percentage of soil moisture content criteria. A soil moisture content of 95% of the field capacity was used in determining a working day.

In Chapter 6, the soil erosion problem, its measurement and impact on wheat production in the soils of the rainfed areas of Irbid were studied. The EPIC model was used to simulate the rate of soil erosion and wheat yield associated with remaining soil depth for a long term planning period (100 years) in the study area. A 2-year wheat-fallow crop rotation was used under conventional (MB plow) and conservation (chisel and sweep plows) tillage systems. The study was applied to 1.5 and 0.7 meter soils deep at 5 and 10% slopes with 2 land discount rates, namely 5 and 10%.

The NPV for the two tillage systems used in the study at the different soil depths, slopes and discount rates was calculated. The wheat yield obtained from EPIC simulations, the price of wheat produced in Irbid area, the type of tillage system used, the machinery input costs and the time corresponding to years in the planning periods were used in calculating the NPV.

Conclusions

It was found that planting at times earlier or later than the optimum planting time in Irbid area leads to reduction in wheat yield produced, which causes timeliness penalties (timeliness costs). Planting one month earlier than the optimum planting date (middle of November for Irbid area) leads to the loss of JD44, planting a month later leads to the loss of JD54, while planting two months later than the optimum date leads to the loss of about JD160.

The proper sizes of tractors with the implements that should be used for wheat production, and the proper operating speeds for the different field operations in Irbid area were determined. The sizes of these complements are given in Table 5.2. The annual machinery cost analysis under conventional and conservation tillage systems used in a wheat-fallow crop rotation for different field sizes used in the study showed that a 65 hp tractor is the most economical to use for wheat production in a 200 ha field, while a 70 hp tractor was found to have the least annual cost when conservation tillage system was used for wheat production in the same field size (200 ha).

The results of EPIC model simulations indicated that the use of conservation tillage system produces more wheat yield than the use of conventional tillage system over the planning period. The results also showed that the use of conventional tillage system increases the rate of soil erosion with time. It was very clear that the wheat yield was decreased dramatically in shallow soils.

The NPV analysis showed that it is more economical for the farmers (on the long run) to use the conventional tillage system for producing wheat in deep soils (1.5 m) with 5 or 10% land slopes at 5 or 10% discount rates, NPV for the conventional tillage system over 100 years was $2071, while it was $2041 when conservation tillage system was used under the same soil conditions, the same discount rates and the same planning period. The NPV analysis for wheat production in a 0.7 m deep soil showed that it is more economical to use conventional tillage system for 5 and 10% slopes with a 10% discount rate, while it is more economical to the conservation tillage system for a 0.7 deep soil having 5 or 10% slopes with a 5% discount rate.

It is concluded that the depth of the soil affects the wheat yield production. The rate of soil erosion was higher and the long-term average yield production was lower for the conventional tillage system compared to the conservation tillage system, which produces more yield and less soil erosion rates. However the NPV was higher for the conventional tillage on deeper soils and higher discount rates because of the higher value of input costs associated with the use of the conservation tillage system. Having a deep soil (1.5m), it takes a long time for the yield to be affected by soil erosion. In the case of the shallower soil (0.7 m), the wheat yield at this depth is dramatically reduced compared to that produced from the 1.5 m deep soils (for both tillage systems). Therefore, any further reduction in the soil depth due to erosion will lead to more reduction in wheat yield. Since the conservation tillage system has less soil erosion than the conventional tillage system, the long-term average wheat yield produced with the conservation tillage system is higher than that produced when using the conventional tillage system. This is why the NPV is higher when using the conservation tillage system at a shallow soil (0.7 m), especially at the 5% discount rate.

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