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INFORMATION VALUE USING VARIABLE
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INFORMATION VALUE USING VARIABLE PRECISION DATA TO DELINEATE WHEAT EXPANSION AREAS IN SYRIA

By

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ABSTRACT

INFORMATION VALUE USING VARIABLE PRECISION DATA TO DELINEATE WHEAT EXPANSION AREAS IN SYRIA

By

Scott George Witter

For centuries wandering bands of nomads throughout Syria have created problems not only for the settled peoples, but also for the governing bodies trying to rule them. In the past these wandering bands of nomads have contributed little to Syria's overall economy. Current (1980) Syrian government goals for full employment, full agricultural land utilization, and the confinement of the nomadic movements in Syria required a complete inventory and evaluation of potential land resources available for agricultural development. However, two significant questions arise when inventory data are used to evaluate potentials for agricultural land development: "How reliable is the information?" and "What will the consequences be of identifying crop expansion areas and potential yields using these data?".

The purpose of this research was to investigate the value of information derived from using variable precision data to delineate potential wheat expansion areas. To estimate the monetary effects of using data of variable precision to forecast wheat yield (multiple regression model), a quadratic loss function was used. Loss function analysis was used to adjust the maximum potential gains obtained from the

unadjusted yield model for the three Syrian study areas of Alleppo, Swedia, and Hasseke. Maximum potential dollar losses from a combined data precision error were calculated for series of actions and states. Minimum potential gross gains for each area by each action and state were established by subtracting maximum potential dollar losses from the maximum potential gains.

The area with the highest minimum potential gross gain for all actions was Hasseke. To determine what the minimum potential net gain would be, a modified land rent analysis was used.

Information value was established by measuring the difference between the maximum potential gain (minus the total costs) and the adjusted minimum potential net gains (minus the total costs) according to the probability of occurrence based on a 20 year record. The information value equaled the potential loss from overestimating the net gains from a given expansion action. The estimated information value for the Hasseke area ranged from $2,721,776 for a 25% expansion to $7,687,099 for a 100% expansion into the available rangeland during any given 1 year period.

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The deepest gratitude is extended to my wife, Brenda, whose hard work and continual support helped us to achieve all our original goals in ten years. Most importantly, however, was her gift of our son, Gavin, who made meeting all goals truly meaningful.

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CHAPTER I

INTRODUCTION

Problem Setting

Nomadic peoples have wandered throughout Syria for thousands of years. These peoples have had no permanent residences and have lived almost exclusively in tents as they roamed the deserts looking for water and pasture for their animals. Most of these groups have been governed only by tribal laws, tribal chiefs, and tribal courts. Because no centralized governing body has had complete control over these groups, Arab history has been filled with hostilities between the settled peoples and the nomads.

"In the nineteenth century, the Ottoman [Empire] began a program of agricultural development and forced settlement of nomadic groups" (Bates, 1971, p. 121). Tribal leaders were offered large tracks of land to settle their people, however, little was known of the ability of these land tracks to provide sufficient subsistence to keep these people settled. As a result, it was continually necessary to use military force to keep these people on their designated land. Problems between the tribes and the Ottoman peaked during World War I when the Arab revolt took place. The revolt enabled several of the larger tribes to gain independence from the Ottoman. This new-gained freedom, however, was short-lived as the tribes were not able to contend with the better-equipped French army which controlled Syria until just after World War II.

The current Syrian government has sought to establish a clearer policy for dealing with the nomads. Because an immediate solution, other than military, does not exist, a series of small-scale social experiments are being undertaken. These experiments include better animal husbandry, establishing permanent water wells, and the development of new strains of drought-resistant crops to be grown on currently non-productive lands.

To meet the data needs for these experiments and the goals of the fourth Five Year Economic and Social Development Plan, full employment and full agricultural land utilization, it is necessary to first inventory and evaluate land resources available for agricultural development.

Land Assessment

Agricultural scientists have for decades conducted investigations aimed at classifying land areas and climatic conditions into information systems suitable for the prediction of potential crop yields. Agricultural land classification relies heavily on the technological meshing of a number of disciplines: a soil scientist provides soil boundaries and chemical property breakdowns; a meteorologist provides data concerning temperature and moisture regimes; a remote sensing specialist uses repeating tonal and textural patterns as keys to agricultural use; an agronomist provides information concerning the most adaptable species of crop;

an agricultural economist determines supply and demand trends associated with current and future monetary returns.

These approaches pose two significant questions: "How reliable is the information?" and "What will be the consequences of identifying crop expansion areas and potential yields using these data?".

Purpose and Objectives

Risk is involved in every decision. The way people react to this risk, however, can be extremely varied. Some individuals try to avert risk while others are either neutral or risk seeking. Information about a given situation tends to lessen or eliminate some of the inherent risk involved with decision making. In general, the greater the quantity and quality of information, the less risk involved.

To most adequately deal with the risk involved in delineating crop expansion areas, the decision maker should specify the precision level of the data needed to make a particular decision. As a result, he or she has defined the amount of risk he or she is willing to take. The precision level used, then, places a value on the information by specifying a sample size and by placing a percentage estimate that can be related to the potential monetary losses or gains associated with a given decision.

One problem is that most decision makers do not have sufficient information to specify precision levels which will yield the desired results. Statistical decision theory, through the use of a loss function, provides a means for determining potential losses from using variable precision data in the decision making process. The loss function allows the decision maker to assess or alter a common utility function[1] to more realistically reflect the outcome of a given decision.

Three Syrian test sites will comprise the study area (Figure 1). To illustrate the role of the loss function in assessing potential wheat expansion areas for domestic use, three study objectives were identified. The objectives are:

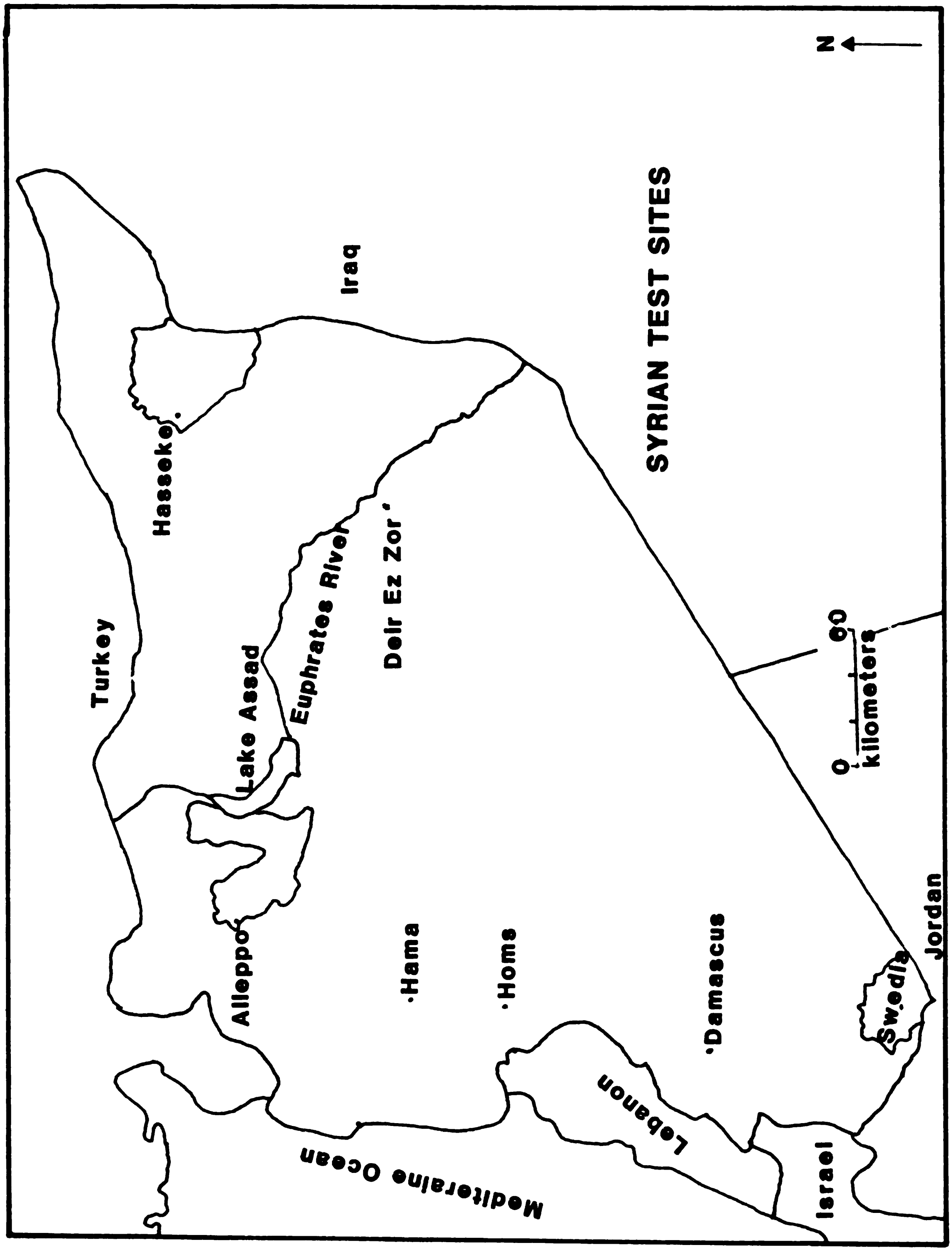
1. To identify potential areas suitable for wheat production within the Syrian test sites using remote sensing techniques, water balance equations, and the most current soil data.
2. To establish the monetary risks of making wheat yield estimates using variable precision data with a quadratic loss function.[2]
3. To compute the monetary gains or losses associated with crop expansion into the test site with the highest potential return using 1977 dollar values reported in the 1980 Syrian Agricultural Sector Assesement.

The data and spelling of place names used in this study come primarily from the]978-1980 Syrian Agricultural Sector Assessment. The author was a member of the Comprehensive

[1]Utility Function refers to a group of individuals' choices aggregated into one common choice or goal.

[2]Quadratic Loss Function is used to determine the optimal estimates of a central value based on past mean values.

Figure 1. Syrian Test Sites.



Resource Inventory and Evaluation System (CRIES) research team which was responsible for land cover/use, soils, and economic analysis during the assessment. CRIES was designed to explore basic questions about agricultural resource planning. The agencies involved at the time of the assessment were the United States Agency for International Development (AID), the United States Department of Agriculture (USDA), the Economic Surveys and Systems of the USDA, and Michigan State University (MSU).

CRIES was designed around two general objectives (CRIES, 1980):

1. To apply a consistent approach to land resource classification that is adaptable to many countries and suitable for agrotechnology transfer, and
2. To provide the training and technical assistance necessary to classify and inventory resources, to evaluate crop adaptability and productivity, and to assist in developing food strategies in participating countries.

CRIES personnel work closely with in-country representatives from the host country to inventory and classify land resources, determine present land use patterns, determine current potential agricultural production, establish computer-based information systems, and determine important socio-economic characteristics that might effect future agriculture production. Every effort is made to fully utilize all existing data sets and where necessary aid the collection of the primary data needed to meet each countries' project goals.

Procedure

A suitability classification procedure was used to select land areas within each test site that were not presently being used for crop production, but would be suitable for wheat production. The initial phase of the study combined the classification of current (1978) land cover/use patterns within the three test sites. The three areas selected were Swedia, Alleppo, and Hasseke. Certain montikas (county level) were eliminated from the Alleppo and Hasseke Mohafazas (state level) to maintain a closer approximation of site size and cropping pattern. These areas were selected because of their similarities and dissimilarities. Similarities among the sites were area size, cropping patterns, reliability of published statistics, and availability of areas for crop expansion. Dissimilarities included rainfall, crop yield, and soil types.

The second phase combined soils data at the suborder and great group level with data collected in phase one. Cross tabulations between soils and land use data were run to establish which soils were producing the rain fed crops. Procedures for soil assessment are discussed in Chapter IV of this work.

The Thornthwaite (1955) water balance procedure was used to establish past trends in soil moisture availability during each month of the growing season. Actual evapotranspiration (APE) figures derived from the Thornthwaite equation were replaced with APE figures calculated using the Penman (Safely, 1974) equation as the Penman equation is more precise in dry climates (Chapter III). Each station was plotted by the soil unit and the montika it was located within to establish their regional representation.

Each data set was overlayed, both cartographically and digitally, to determine potential wheat expansion areas. The mapped information provided the location data while the digital data provided area estimates and category composition, by percentage, for each variable within expansion areas. An expansion area was defined as an uncropped area (rangeland) capable of supporting a wheat crop. The expansion areas were then ranked within each test site according to the amount (kilograms/hectare) of potential wheat each could produce. The highest ranking went to those areas capable of producing the largest crop the highest percentage of the time. A dollar value was assigned to each potential wheat crop by multiplying the estimated kilograms per hectare of wheat by the 1977 government supported prices for wheat in Syria.

Because each step of the procedure, as well as the yield forecast, has a potential error, it was not feasible to assume that all of the expansion areas' yield could be identified. A loss function equation was used to estimate what the absolute minimal gain would be.

Potential losses resulting from using variable precision data were calculated using a quadratic loss function. Weighting values for the loss function components were derived as composite values from published situations.

Maximum potential losses from making a decision to expand wheat production into a region were derived by combining the effects of the compounding variable error (kg/hectare x $ value) plus the cost of conducting the study. The minimum potential net gains were derived by subtracting the total variable cost plus analysis cost from the minimum potential gross gain. The possible expansion areas were then ranked according to their potential return.

Because each decision maker within the Syrian Agricultural Sector might have a different utility function, it was necessary to aggregate them and consider the entire sector as one client. The common utility function was assumed to provide an estimate of the utility associated with identifying potential wheat expansion areas to increase wheat revenue with the highest potential return and at the least risk.

The potential Syrian farmers were also considered as one client to eliminate the problem of adding utility functions over individuals. The farmers' utility function was assumed to provide an estimate of the utility associated with identifying potential wheat expansion areas to increase wheat revenue with the highest potential return and at the least risk.

Research Hypotheses and Models

Two primary models were used during the study. The first was a linear regression model used as a traditional yield model The yield model is:

$y_i = b_1X_1 + b_2X_2+b_3X_3+U_4$

y_i = wheat yield in kilograms/hectare

b_1 = regression coefficient

X_1 = millimeters of potential available soil moisture

X_2 = acreage of a given soil within a given wheat producing region by study site

X_3 = acreage of rain fed wheat within each study site

U_4 = error term

The associated hypotheses are:

Null hypothesis H_o: wheat yield for Syria cannot be estimated with this model at a 90% confidence interval

Alternative hypothesis H_1: wheat yield for Syria can be predicted with this model at a 90% confidence interval

The rationale for using a linear regression yield model with a 90% confidence interval was to obtain a yield estimate similar to that considered acceptable by the Large Area Crop Inventory Experiment (LACIE). This allows a direct comparison with a major ongoing international program which does not take into consideration the potential estimation error involved with variable precision data. To determine what the maximum dollar (Syrian) loss that might be experienced by utilizing this model to estimate yield in expansion areas, the following loss function equation was used:

Maximum Potential Loss = $[(YP)\ 1-(X_1b_1 \cdot X_2b_2 \cdot X_3b_3 \cdot X_4b_4)^2 \cdot (V)]$

YP = yield model probability

X_1b_1 = soil moisture (mm) availability times soil moisture estimate precision

X_2b_2 = soil category classification area (hectares) percentage times the soil boundary estimate of precision

X_3b_3 = Landsat delineated range area (hectares) percentage times the classifying precision level of the Landsat scanning system

X_4b_4 = wheat yield estimate in kg/hectare times assigned precision level of Syrian governmental statistics

V = the 1978 Syrian value of a kg of wheat

This procedure was also meant to be hypothesis generating from the standpoint of estimating the reliability of yield information and in determining economic consequences of using variable precision data in yield modeling.

Assumptions

The major assumptions of this study were:

1. Acreage and yield statistics reported by the Syrian government were 95% precise (an estimate based on a review of variations in reported statistics).
2. Syrian cultural and/or farming practices would not change yield characteristics from one study site to the next.
3. Predetermined precision levels assigned to each variable were representative (based on Chapter III).
4. Syrian recorded moisture and temperature values were 90% precise (refer to Ward, 1967, catchment error).
5. Adjusted evapotranspiration corrections calculated for each station were 92% precise (refer to McGuinnes and Bordre, 1972, p. 15, for comparisons of Penman and lysimeter values).

The assumptions made in this study represent a composite of those conditions necessary to utilize a quadratic loss function to study the monetary effects of using variable precision data to forecast wheat yield. Precision levels of the data used and the representativeness of the information values established based on these assumptions may vary dramatically if used under different physical settings and scales of investigation intensity. However, they are considered to be necessary for this study and representative of the conditions found in Syria by the author.

CHAPTER II

THE STUDY AREA

"Over the centuries, man has shown great ingenuity in using climate, soil, and other agricultural resources of the Middle East" (Clawson et al., 1971, p. 1). Syria is no exception. Vast portions of the country receive less than 200 mm of rain per year. Limited rainfall combined with only scattered reservoirs of ground water greatly limit the development of agriculture in Syria. This is extremely important to a country where "65 percent to 75 percent" (Lieftinck et al., 1956, p. 7) of the population derive their livelihood directly from agriculture.

Lieftinck et al. (1956) found that crop production and livestock production accounted for between 45% to 50% of Syria's national income. This situation has not changed appreciably. Syria, which does not share its neighbors' oil wealth (Iran and Iraq), must rely heavily on a limited agricultural base, therefore, the reliable assessment of natural resources is important.

Agricultural Resources

Two of Syria's principal agricultural resources are undoubtedly land and water. Of Syria's approximately 46 million acres of land surface, approximately one-half is mountains, rocky areas and desert. Approximately 15 million acres of land have sufficient rainfall to support crops without the aid of irrigation. Refer to those areas receiving average annual rainfall of 200 mm or more in Figure 2.

The coastal regions receive rainfall in excess of 600 mm and are considered a Mediterranean climate. Numerous orchards are found in the coastal region which produce oranges and olives. General soil usage patterns in the coastal region are: 1) the best soil is used for citrus and cereal grains; 2) the next best for olives; 3) the third best for reforestation of pine; and 4) the remaining areas have scrub oak and assorted types of brush. These priorities are based on discussions with the Agricultural Director of the Homs region during December of 1978.

In the areas experiencing precipitation ranging from 400 to 600 mm, wheat, barley, chickpeas, and assorted orchard crops are produced. The region extending from south of Homs to just north of Alleppo is one of the most productive soil regions in all of Syria.

The areas on Figure 2 representing between 200 mm to 300 mm of precipitation are devoted primarily to the production of wheat, barley, and highbred olive trees. The dominate soils in these areas are Entisols and Aridsols.

The arid conditions found throughout the remaining portions make the development of better moisture monitoring techniques and irrigation systems essential. The major watershed found in Syria is the Euphrates River (Figure 3). Historically, the Euphrates River has flooded annually, covering its banks with fresh layers of silt. When the Tobuqa

Figure 2. Precipitation Patterns in Syria.

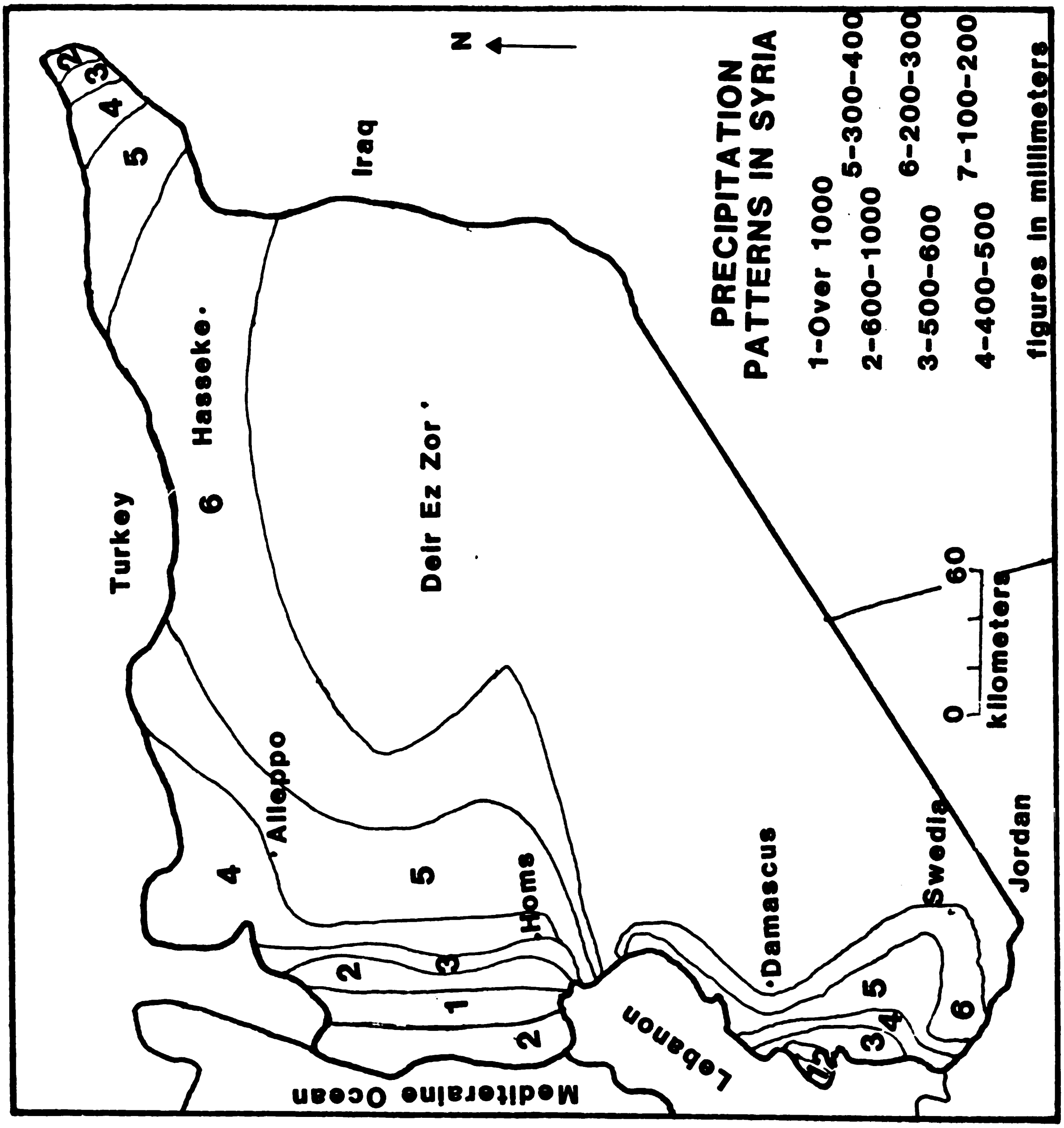
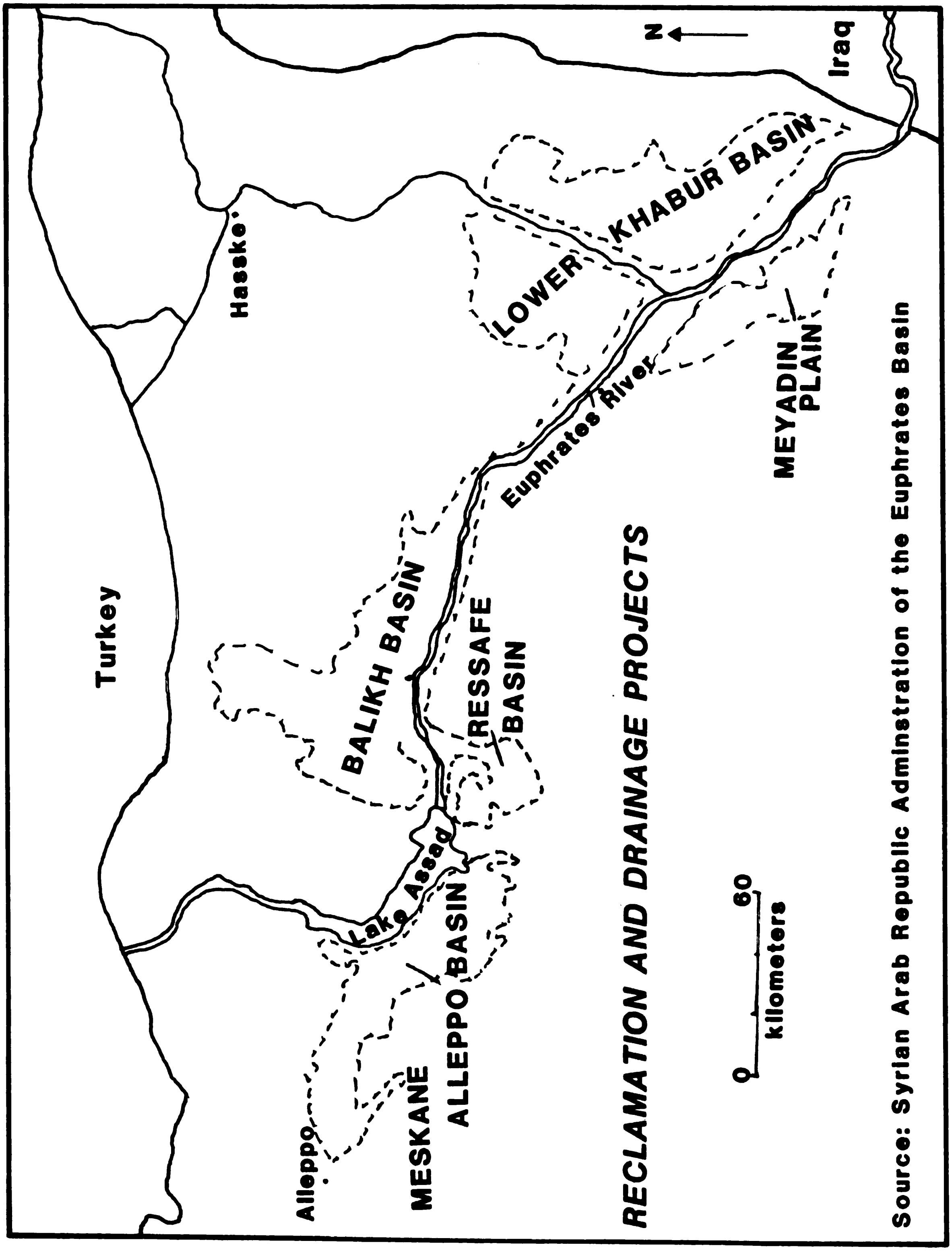


Figure 3. Euphrates Reclamation and Drainage Projects.



Dam (at Tobuqa) was completed during the early part of the 1970's, all major flooding along the Euphrates River in Syria was stopped. The land now being used for irrigation consists of the most recent alluvial deposits. The two most recent terraces are being used primarily for cotton and vegetable production (both consumed within Syria). The first terrace extends approximately 75 meters from the river's edge and is totally utilized except for old meanders and saline areas no longer flushed by yearly flood waters. The second terrace rises approximately 2 to 4 meters above the first terrace and extends an additional 100 to 200 meters. This area is also extensively cropped and has a number of small villages located along it. The saline problems on the second terrace, especially in the central and lower portions of the river, are more severe than on the first terrace.

Of the reclamation and drainage projects shown in Figure 3, only portions of the Balikh, Meskane and Alleppo Basins have been completed at this time.

Swedia

Three primary regions exist in this test site. The first extends from the western boundary east over approximately one-third of the site. The soils are deep Chromoxeverts and Pelloxererts overlying basalt (Figure 4).

The Typic Chromoxeverts are predominately on gentle slopping hills. These soils are reddish, heavy clay soils that are deep, alkaline, and well or moderately well drained. These soils are difficult to manage, but can be quite

Figure 4. Swedia Test Site.

Soil Mapping Units*

DOLA U/B - Typic Calciorthids, undulating plains.

EOHc L/B - Lithic Torriothents, level to undulating plains.

EOHc R/B - Lithic Torriothents, rolling plains.

EOHc U/B - Lithic Torriothents, undulating plains.

EOXd R/B - Lithic Xerorthents, rolling plains.

EOXv L/LS- Xerorthents, level to undulating plains.

EOXv R/B - Xerorthents, rolling topography.

VXCa U/B - Typic Chromoxererts, undulating plains.

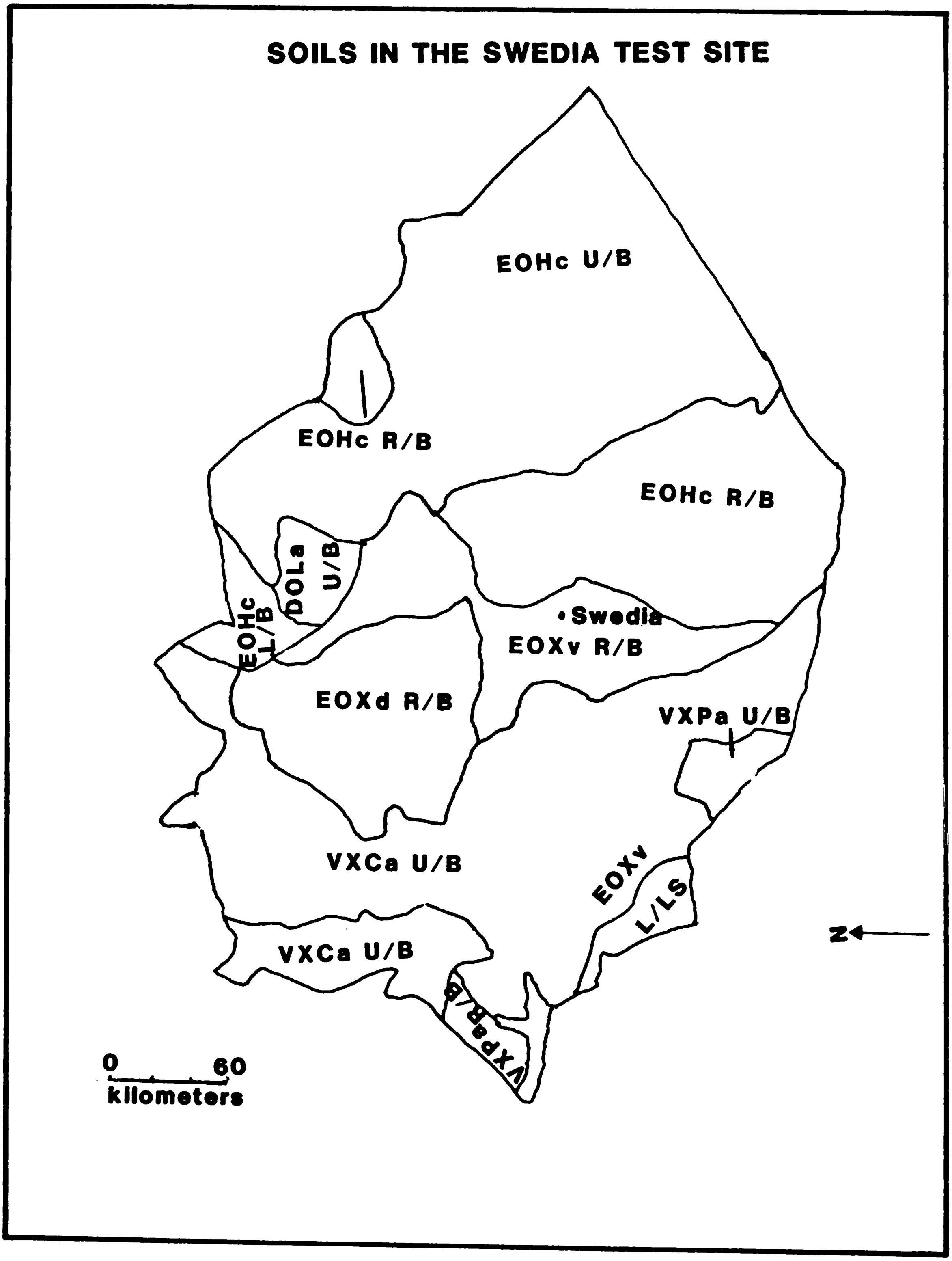
VXPa R/B - Typic Pelloxererts, rolling plains.

VXPa U/B - Typic Pelloxererts, undulating plains.

Source: Ackerson, 1980, pp. I-227 - I-334.

*See Appendix B for more complete definitions.

Figure 4. Soils in the Swedia Test Site.



productive when sufficient moisture is present and good management practices are used. The Pelloxererts have black, very dark gray, or dark grayish brown A horizons which are much darker than the deeper profiles.

The mean annual temperature ranges from 16° to 18°C, while annual precipitation ranges from 200 mm to 500 mm. The heaviest precipitation occurs primarily on the western edge during the wet season (November through March). The principal crops grown in this region (primarily domestic use) are tomatoes, pistachios, grapes, wheat, barley, melons, olives, lentils, and chickpeas.

The second area within this site encompasses the EOXu R/B and EOHc U/B soil delineations as illustrated in Figure 4. These soils are heavy clays, usually less than 50 cm deep over underlying basalt. The surface area is covered with small stones and occasional rock outcrops.

The mean temperature ranges from 12° to 16°C. Major precipitation occurs between November and March bringing between 200 mm to 400 mm of moisture. This area presents major obstacles to anything but small scale farming because of the rock outcrops. Major crops observed and reported in this region include: figs, grapes, corn, onions, olives, pistachios, citrus, wheat, barley, and date palms.

The last area delineated as EOHc R/B and EOXd R/B on Figure 4 consists of a rolling basalt plain. These soils, Lithic Xerorthents and Lithic Torriorthents, are shallow, stony soils with larger areas of rock outcrops than the two previous areas. Both major types of soil were found to be well supplied with plant nutrients and to have a moderate to high base status, but because of their shallowness over the basalt bedrock these soils had little moisture holding capacity.

The elevation ranges from 600 meters to 1600 meters. The mean annual temperature ranges between 10° to 17°C, while precipitation varies from 150 mm to 500 mm. The dominant crops in this area are cherries, peaches, plums, wheat, barley, figs, olives, grapes, eucalyptus, and poplars.

Hasseke

The Hasseke site can be subjectively split (almost equally) between the north and south border, into two main homogenious districts (Figure 5). The southern portion is the terminus of Syria's desert region with elevations ranging from 215 to 475 meters. The annual temperature varies between 16° to 21°C. Summers are hot and dry, while winters are cool and moist. The majority of the precipitation received falls from October to May with the annual moisture ranging between 100 to 300 mm.

Four main soil types are found in the southern portion of this region: Petrogypsic Gypsiorthids (DOGd L/TS), Calcic Gypsiorthids (DOGb U/TS), Typic Torriorthents (EOHa U/U), and Lithic Torriorthents (EOHc R/B). The Petrogypsic and Calcic Gypsiorthids are in the Aridisols order and the Orthids suborder of the U.S. Soil Taxonomy. The Petrogypsic Gypsiorthids are shallow with a cementing layer of gypsum.

Figure 5. Hasseke Test Site.

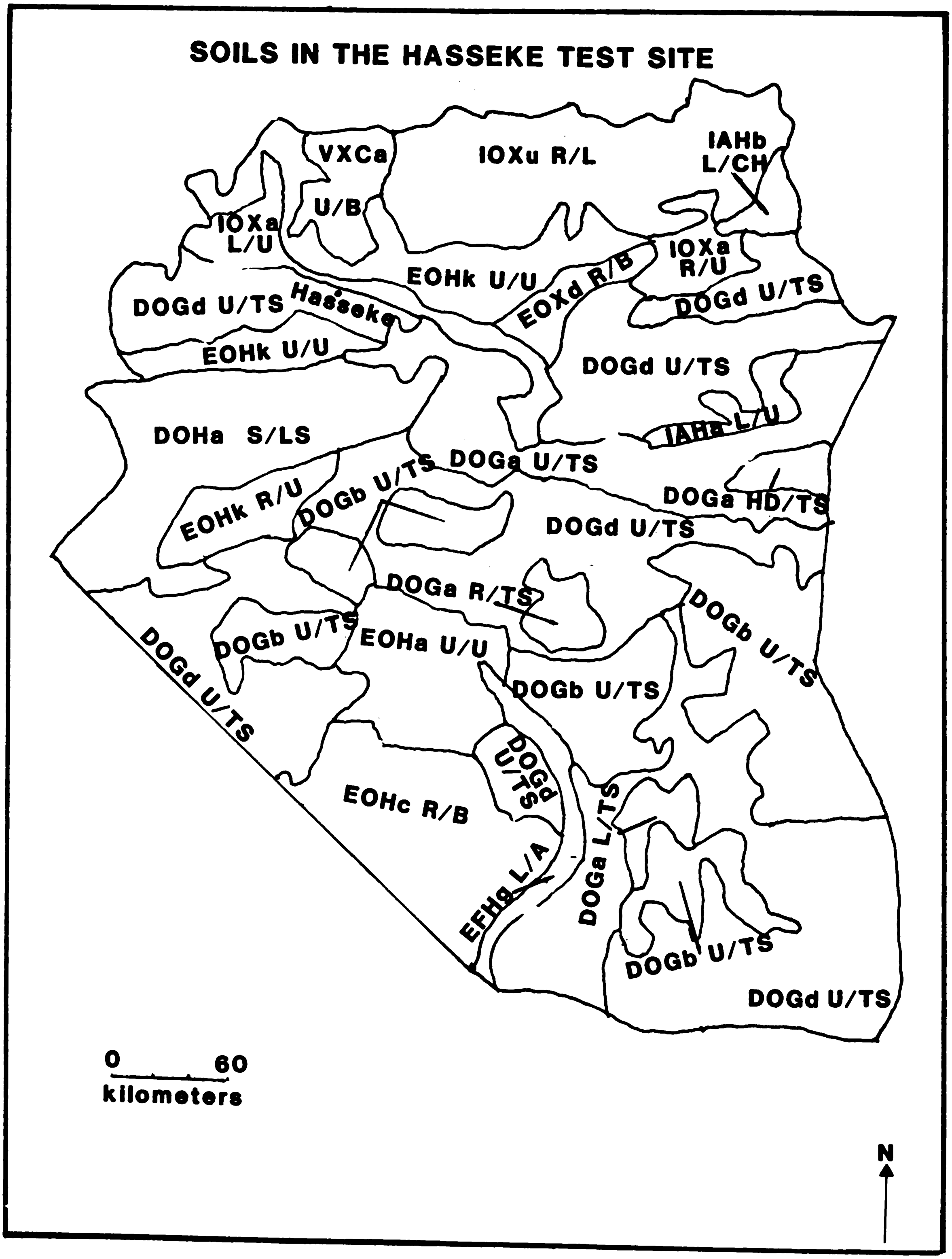
Soil Mapping Units*

DOAH S/LS	- Lithic Camborthids, steeply sloping hills and escarpments.
DOGa L/TS	- Typic Gypsiorthids, level plains.
DOGa R/TS	- Typic Gypsiorthids, rolling plains.
DOGa U/TS	- Typic Gypsiorthids, undulating plains.
DOGa HD/TS	- Typic Gypsiorthids, maturely dissected plains.
DOGd L/TS	- Petrogypsic Gypsiorthids, undulating plains.
DOGb U/TS	- Calcic Gypsiorthids, undulating plains.
EFHg L/A	- Xeric Torrifluvents, level plains.
EOHa U/U	- Typic Torriorthents, undulating plains.
EOHc R/B	- Lithic Torriorthents, rolling plains.
EOHk R/U	- Xeric Torriorthents, rolling plains.
EOHk U/U	- Xeric Torriorthents, undulating plains.
EOXd R/B	- Lithic Xerorthents, rolling plains.
IAHa L/U	- Typic Haplaquepts, level plains.
IAHb L/CH	- Aeric Haplaquepts, level plains.
IOXa L/U	- Typic Xerochrepts, level plains.
IOXa R/U	- Typic Xerochrepts, rolling plains.
IOXk U/U	- Vertic Xerochrepts, undulating plains.
VXCa U/B	- Typic Chomexererts, undulating plains.

Source: Ackerson, 1980, pp. I-227 - I-334.

*See Appendix B for more complete definitions.

Figure 5. Soils in the Hasseke Test Site.



The Calcic Gypsiorthids have a trace of a calcium and/or magnesium carbonate layer above the gypsum.

The Typic Torriorthents are deep, coarse and medium textured soils. Desert winds have caused the removal of the fine surface material and left a thin cover of flint fragments on the surface. Torriorthents are normally well drained, moderately to rapidly permeable, and have low to moderate moisture availability. The Lithic Torriorthents are shallower than the Typic, generally less than 50 cm. Torriorthents are in the Entisols order and the Orthents suborder of the U.S. Soils Taxonomy. The major crops found in the southern area include cotton along the Euphrates (western boundary) to scatters of wheat, barley fields, and some small vegetable crops across the central to eastern portions.

The northern portion of the Hasseke site ranges in elevation from 340 meters to 500 meters with several isolated areas exceeding 500 meters. The mean annual temperature and precipitation range between 18° to 20°C and 150 mm to 300 mm, respectively.

Dominant soils (by area) other than those already discussed included Vertic Xerochrepts (IOXk R/U) and Lithic Cambrothids (DOAh S/LS). Vertic Xerochrepts have clayey textures and are dry in all parts of the profile for at least 45 consecutive days during the year. Xerochrepts are moderate to high in bases like calcium and relatively low in organic matter. Rainfall normally occurs only during the cooler months. Xerochrepts are Inceptisols in the suborder of Ochrepts.

Lithic Camborthids are shallow soils with cambic horizons that are brownish or reddish in color. The A horizons are normally light colored and usually have carbonate accumulations below their cambic horizons.

The major crops found in this region are cotton and vegetables along the rivers, and wheat and barley fields throughout the remaining sections.

Alleppo

For discussion purposes the Alleppo site was split along the western boundary of the DOGd L/TS (Petrogypsic Gypsiorthids) soil (Figure 6). Elevation ranges from 250 meters in the south-central portion to 660 meters along the Syria-Turkey border. Mean annual temperatures range from 17°C (north) to 20°C (southeast). The majority of the precipitation, 200 to 350 mm, falls between November and May. The principal crops observed in this section are cotton, vegetables, wheat, barley, and poplars.

The main soil category in the eastern section is the DOGd L/TS at Petrogypsic Gypsiorthids. Gypsiorthids are Aridisols in the suborder of Orthids. "The Petrogypsic Gypsiorthids are shallow to a petrogypsic layer (soil layer cemented with gypsum), but the other soils are deep" (Ackerson, 1980, p. 106). Because of high concentrations of gypsum and cemented layers, the productivity level is generally low.

Figure 6. Alleppo Test Site.

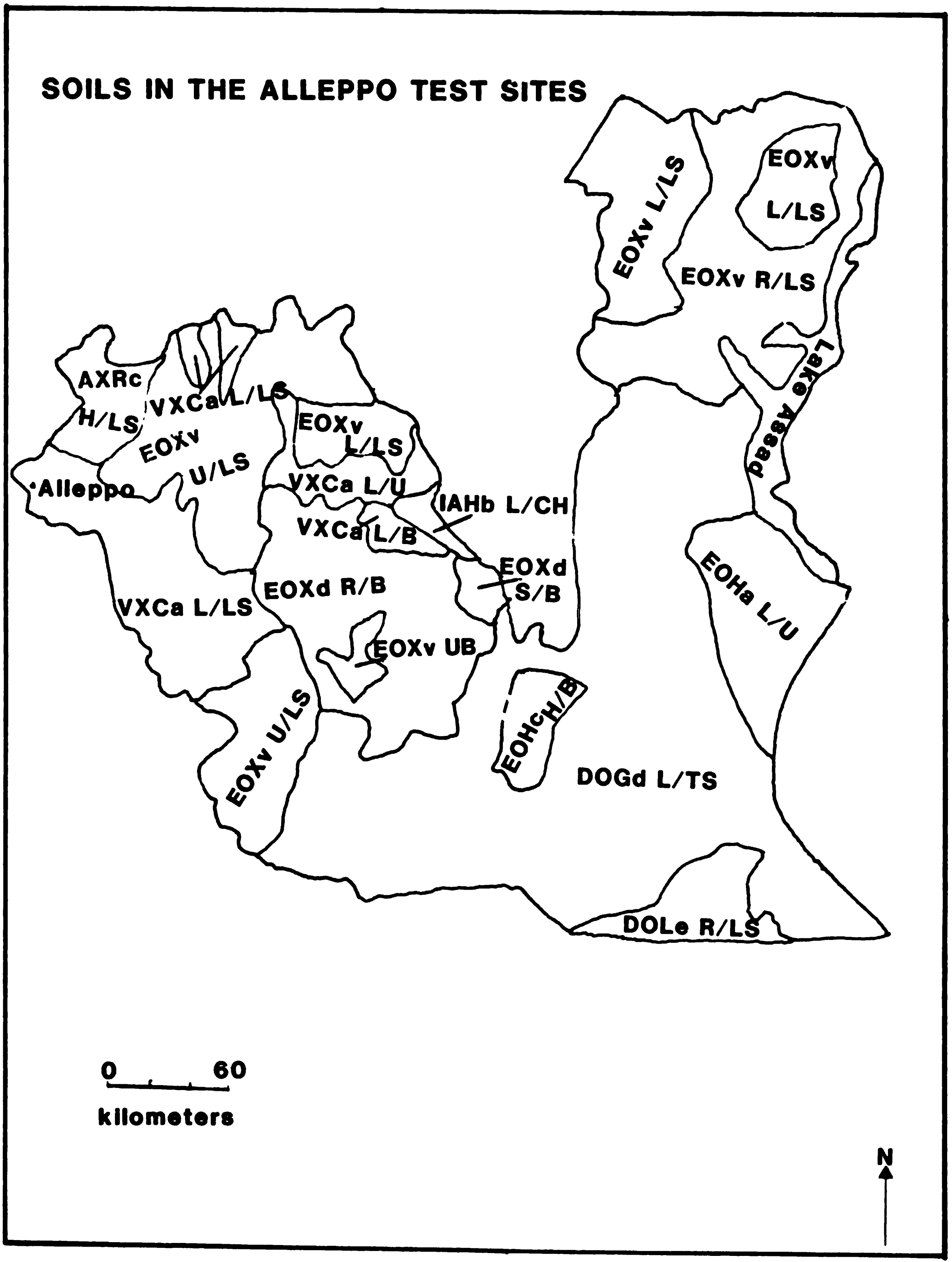
Soil Mapping Units*

AXRc H/LS	- Lithic Rhodoxeralfs, hilly topography.
DOGd L/TS	- Petrogypsic Gypsiorthids, level plains.
DOLe R/LS	- Lithic Calciorthids, rolling plains.
EOHa L/U	- Typic Torriorthents, level to undulating plains.
EOHc H/B	- Lithic Torriorthents, hilly topography.
EOXd R/B	- Lithic Xerorthents, rolling plains.
EOXd S/B	- Lithic Xerorthents, steep hills.
IAHb L/LS	- Aeric Haplaquepts, level plains.
VXCa L/LS	- Typic Chromoxererts, from limestone on level plains.
VXCa L/U	- Typic Chromoxererts, from unconsolidated materials on level plains.
VXCa L/B	- Typic Chromoxererts, from basalt on level plains.

Source: Ackerson, 1980, pp. I-227 - I-334.

*See Appendix B for more complete definitions.

Figure 6. Soils in the Alleppo Test Site.



Elevation in the western portion of the Alleppo site ranges between 350 meters (south) to 650 meters along the west-central section. Temperatures are slightly cooler than the eastern section, ranging from 15° to 17°C, while precipitation is comparable. The major non-irrigated crops include wheat, barley, olives, corn, figs, pistachios, and assorted types of fruit trees. Small fields of well irrigated lettuce, cabbage, tomatoes, beans, cotton, and poplars are also found throughout this section of the Alleppo site.

The major soils in this section are Xerorthents (Entisols in the Orthents suborder). These soils are primarily shallow, less than 50 cm, and are characterized by high clay content. Because of the high clay content, surface cracking occurs during dry periods. These soils are not very permeable and tend to have low moisture holding capacities.

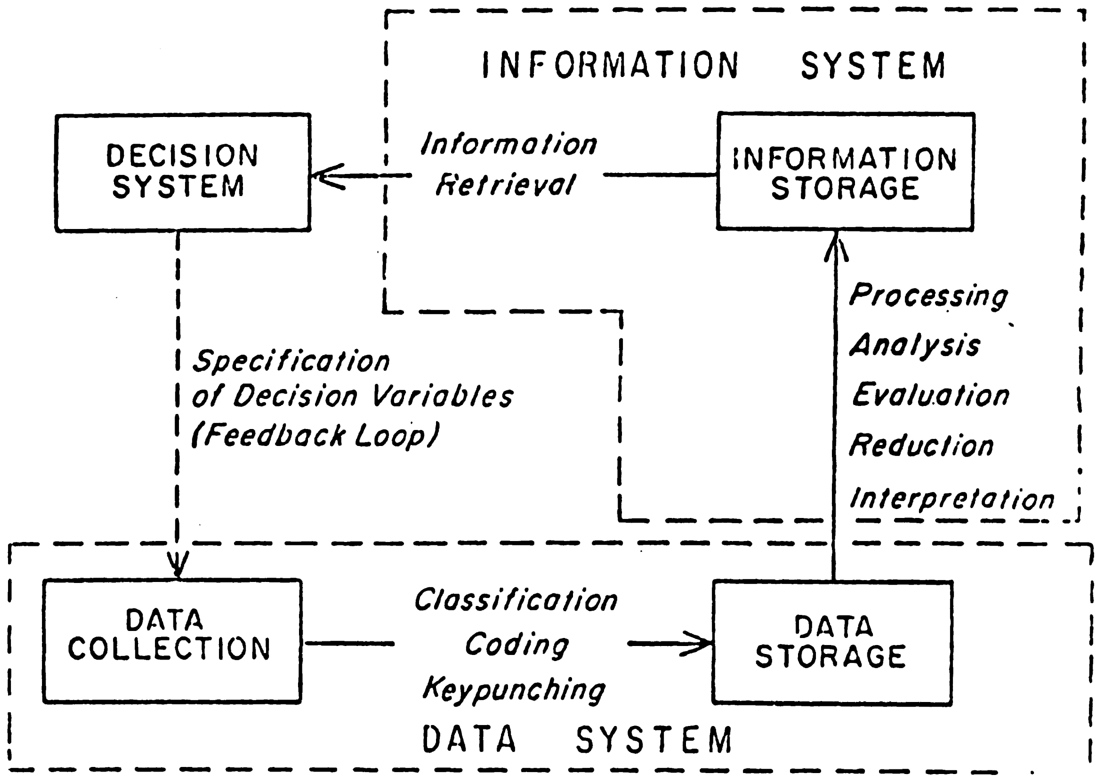
CHAPTER III

THE VALUE OF INFORMATION BY THE ESTABLISHMENT OF VARIABLE PRECISION LEVELS

"Regardless of the investment criterion used in evaluating the worth of information (e.g. alternative criteria include present net worth, internal rate of return, benefit-cost ratio), we must always be concerned with two types of factors: (a) the costs of acquiring information and (b) the benefits that accrue from having the information" (Chappelle, 1976, p. 145). "Information only acquires value in the context of a decision, i.e., the use of information in economic decisions determines its value (Arrow, 1962, p. 615). The more the risk and the greater the potential return, the more valuable the information becomes. Information problems and value of the data depend on the identification of the variables to be included in the information system and on how much data should be collected concerning these variables. "One general rule based on economic reasoning is that we should collect data until the marginal cost of the information is equal to the marginal benefit generated by the information which is developed from the data" (Chappelle, 1976, p. 145).

To determine information cost it is necessary to sum unit costs of each input required, plus the costs of the analysis. Chappelle (1976) graphically illustrates the flow of information, inputs and products (Figure 7).

Figure 7. Interactions Between Decision, Information, and Data Systems.



Source: Chappelle, 1976, p. 143.

From the information diagram depicted in Figure 7 one can see the logical flow of data inputs and manipulation. Values are easily attributed to these procedures. However, benefits are often much more difficult and complicated to derive. "The value of the information to the decision-maker or its purchaser is unknown until he has the information, but to make a decision on its value the purchaser in effect must obtain the information without cost" (Riemenschneider, 1977, p. 7). Often if an individual is forced to place a value on an information set before receiving it, the value must be established from prior experience with a similar data source (i.e., consultant). Normally, the more prior experience a consultant has, the more reliable or precise the advice. New data sources which may or may not be as reliable as previous sources must be automatically devalued until proven otherwise. Arrow (1962) explains that these and other problems such as the indivisibility of information and its non-appropriability (i.e., wrong scale or outdated) all tend to cause suboptimal allocation of resources.

Information used totally for private use can be organized under three basic methods. "Each individual or firm could collect the information that it needs or purchase it from other firms, or firms could work collectively to gather information and make it available to all the firms in the organization, or finally government could collect the information and supply it to all of the firms" (Riemenschneider, 1977, p. 7). Problems, however, are encountered at each stage. Primary data collection generally has high fixed costs, thus limiting many firms and individuals from collecting it. Competition between firms using similar data might induce mistrust, potential monopolizing and misrepresentation. Government expenditure of public funds for specific sectors (a subsidy) normally is characterized by underproduction and underutilization of the information.

Because of one or more of these problems, firms are forced to use whatever data (information from secondary sources needed to make a decision on) are available. While the quantity of these data may be vast, the quality or appropriateness (suitable and precise enough data to base a decision on) of the information may vary greatly. The firm may be faced with deciding just exactly what they need to know. Once the firm decides what they must know, they must address the appropriateness of the data needed. A common measure of data quality is the level of precision attained in the estimate. Eisgruber (1972) describes precision as the magnitude of the error of the estimate. Kendall and Buckland's definition of precision is:

> ...a quality associated with a class of measurements and refers to the way in which repeated observations conform themselves; and in a somewhat narrower sense refers to the dispersion of the observations, or some measure of it, whether or not the mean value around which the dispersion is measured approximates to the 'true' value. (Kendall and Buckland, 1960, p. 224).

Cochran (1977) explains the difficulty of ensuring no unsuspected bias enters into the estimate. Precision is normally used as a measure instead of accuracy to limit unsuspected bias being entered into the sampling procedure by inferring a measure of accuracy which generally cannot be measured. "Accuracy refers to the size of the deviations from the true mean, μ, whereas precision refers to the size of deviations from the mean m obtained by repeated application of sampling procedure" (Cochran, 1977, p. 16). Deming (1960) points out that statistical theory is useful in avoiding errors either caused by attaining more precision or insufficient precision than the decision maker requires. Many decision makers and analysts alike have chosen to use secondary data or to infer data-decision relationships (past experience) established in other studies. This may or may not pose a serious problem depending on the data precision used. It may become necessary for the decision maker to alter the original utility function to accommodate data choices which allow for larger potential risks from data precision than originally envisioned.

The risks and costs involved with variable precision decision models can be quantified using a loss function. "The loss function is an increasing function of 'errors' or discrepancies between values of the endogenous variables as determined by the model and the forecasts of them" (Fisher, 1969, p. 23). The loss function represents an aggregated utility function for all involved in the decision.

The Loss Function

Decision making under conditions of uncertainty is referred to as statistical decision theory or Bayesian decision theory. "Statistical decision theory has developed into an important model for the making of rational selections among alternative courses of action when information is incomplete and uncertain" (Hamburg, 1970, p. 614). The theory provides the principles and methods needed to make the most appropriate decision given a certain set of goals and conditions. However, the theory does not provide an actual description of how the decisions are made.

"A useful concept in the analysis of decisions under uncertainty is that of 'opportunity loss'" (Hamburg, 1970, p. 624). The opportunity loss analysis or loss function is used to identify the loss incurred because of failure to make the best possible decision. In statistical sampling problems, the optimal sample size for a given decision should be set at a magnitude where the loss plus the cost of data collection is minimized. Cochran (1963, p. 82) presents the following formula for this type of sample size determination:

$C(n) + L(n)$

$C(n)$ = the cost of sample size n

$L(n)$ = the expected loss for sample size n, in this instance this would be to set n to minimize the loss

and is equivalent to:

$L(n) = l(z)f(z,n)dz$

$l(z)$ = the loss incurred by a decision with an error in the amount of z in the estimate

"Although the actual value of z is not predictable in advance, sampling theory enables us to find the frequency distribution $\underline{f(z,n)}$ of $\underline{z}$, which for a specified sampling method will depend on the sample size $\underline{n}$" (Cochran, 1963, p. 82). The sample then, if properly taken should reduce the potential loss associated with a given decision.

The problem of measuring precision and associated loss is greatly aggregated when dealing with multi-purpose and multi-user studies.

> No definite answer can be given to the question, how much precision. The amount of precision will depend on the purpose at hand. In statistical decision theory this is taken into account by the introduction of a loss function. A loss function approach has, however, limited usefulness in survey sampling. In multivariate surveys, where data are gathered with a specific purpose in mind, the loss function approach may be valid. In multi-purpose surveys (such as those conducted by public agencies) where the potential users of the data are not known, it is apparent that no general loss function can be constructed (Chatterjee, 1968, p. 532).

As a result it is necessary to restrict the utility function to a desired precision deemed necessary by the decision maker. The decision maker, in turn, especially when dealing with agencies, must be disaggregated to one entity.

The first problem then in developing a loss function is to determine who will be the decision making entity. In the case of a public agency, even though we deal with it as one entity, we must, as Chappelle (1975) indicates, consider the remote clients involved. When dealing with a nation's natural resources (forests, water, etc.) the remote clients are those who by being citizens own a share of the resources. "Just as the determination of the level of significance (α) used in statistical testing is not a statistical question, the formulation of the appropriate loss function appropriate to the allowable cut decision [of timber] is neither a statistical nor a technical forestry question; rather it is a public policy question" (Chappelle, 1975, p. 25). To formulate a loss function which represents the public interest it must reflect an aggregated utility function for all involved, not an easy task by any means.

Theil (1964) presents the following "Committee Loss Function" to deal with group decision making.

$$lc(x) = \sum_{g=1}^{G} dg\ lg(x)$$

where: $lc(x)$ = committee loss function

dg = load of the raw loss function

g = committee member

G = number of members of the committee

$lg(x)$ = loss function of individuals

(Theil, 1964, p. 337).

The committee loss function represents an aggregation of individual loss functions of each group member. Normally these would be limited to the committee or group responsible for the decision. This concept of a committee loss function could be used to help satisfy the needs of the remote client concept.

If the loss function is considered a social welfare function and each manager or agency representing the remote clients have been sampled to determine their choices or utility function, the loss function could be formulated as before

(Cochran, 1963):

$$L(n) = l(z)f(z,n)dz$$

"l(z) is the loss incurred by the individual remote client through a sampling error of amount z in the estimate" (Chappelle, 1975, p. 38). To determine the total expected loss, the results from each loss function would be summed. This could be done by groups of importances and an appropriate weighting factor assigned to each set of losses. Chappelle (1975, p. 38) adjusts Theil's committee loss function to reflect this grouping:

$$lc(x) = \sum_{g=1}^{G} dg\ lg(x)$$

(Theil, 1964, p. 337).

Where: $lc(x)$ = loss function for the committee of interest groups

dg = loading of the interest group loss function (the degree to which the interest group 'counts' in the decision)

g = interested group

G = number of interest groups involved in the decision

$lg(x)$ = loss function of the interest group g

It is apparent that if this procedure was adopted it would be time consuming, costly and the chance of bias entering through manager interpretations of group needs could be considerable. Chappelle (1975, p. 40) offers two ways to limit these problems with reference to making an allowable timber cut decision.

1. Base the loss function only on the judgement of the appropriate forest officers, thereby making the officer the sole client and internalizing the expected loss to within the origanization.

2. Base the loss function only on technical forestry considerations, rather than socio-economic variables.

By using only one representative client and then basing the loss function on more quantifiable physical data, the measurement becomes more general. The physical loss of timber, water, soil, etc. could be multiplied by their current market value and the total expected loss could be determined.

Variable Precision

Remote Sensing

Over fourteen years of research have been conducted using satellites to collect agricultural crop area data and yield estimates. Early attempts to use oblique photography taken during the Gemini missions allowed only limited crop category definition. Acreage estimates from the Gemini photography ranged from 50% to 60% area and crop type accuracy.

The first Landsat satellite was launched into orbit in June of 1972. Since 1972, two more Landsat satellites have been launched into space, making thousands of images available to scientists from all over the world. The accuracy of area and yield measurements have ranged from 50% to 100% depending on the scientists' skills, procedures used and the area under investigation.

Remote sensing-based investigations using area and yield measurements can be separated into two primary groups: whole area inventories and area samples. These measurements are usually taken from two platforms: aircraft or satellites. For the purpose of this study, discussion of data produced from aircraft platforms will be omitted. Syria strictly forbids any aerial inventory work because of the sensitivity of military installations. This situation is typical of most middle eastern nations where political tension is greatly heightened by present world politics.

The National Academy of Science (1977) in its investigation of remote sensing techniques for developing nations, concluded that total crop acreage estimates could be made from Landsat with a 95% accuracy level. NASA (1973) published acreage estimates ranging from 70-95% accuracy. Higher accuracy percentages were attained when several dates of coverage were used to map the area in question.

Adnam (1975) reported 95% accuracy in measuring wheat, oats, and barley acreages from Landsat. Bauer et al. (1973) and Baumgardner et al. (1974) while working with the Laboratory for Applications of Remote Sensing, reported 90% and 95% accuracies, respectively, in corn, wheat, pasture, and fallow field measurements. Others yielding similar levels of accuracy include Myers and Moore, 1978; Worcester and Moore, 1978; Thomas and Hag, 1977; Hanuschak, 1979; Witter and Hill-Rowley, 1979; and Witter, Schultink, and Lusch, 1980. By drawing on these sources, a justifiable case can be made for believing that the precision of using Landsat imagery to delineate major crops and their acreages is 95%. This figure is, of course, tempered by the procedures outlined by these authors (i.e., repeat coverage, collateral data, image enhancement, and a suitable mapping medium).

Several large scale Landsat based projects utilized other data sets in conjunction with crop acreage estimates from Landsat imagery. The most notorious studies are the Large Area Crop Inventory Experiment (LACIE), a joint program for Agriculture and Resources Inventory Surveys through Aerospace Remote Sensing (AgRISTARS), an Evaluation of Remote Sensing with Repsect to Crop Acreage Estimation in Canada and Programme Plan for Developing the Capability of Forecasting Crop Production.

The Large Area Crop Inventory Experiment (LACIE) was established in 1974 as a joint effort of NASA, the USDA, and NOAA to utilize remote sensing technology on an experimental basis for wheat production forecasts. "Three years of intensive evaluation of LACIE estimates for the U.S. crop and 2 years of experience in estimating the Soviet crop indicated that accuracy commensurate with USDA performance goals for foreign wheat production forecasting was achievable in regions where fields are sufficiently large to be resolved by Landsat" (MacDonald and Hall, 1980). The LACIE in-season 1977 wheat forecast was within 10% of yield statistics subsequently reported by the government of the Soviet Union. Current accuracy prediction for the Soviet wheat crop, 9 U.S. states and India, China, Australia, Argentina, and Brazil exploratory studies have results ranging from a 23/90 early season estimate (U.S.S.R.) to a 100/90 preharvest estimate (U.S.).

Yield forecast procedures used by LACIE include the use of regression models which incorporate weather variables from World Meteorological Organization network. These models are based on multiple linear regression equations of historical yields and monthly averages of temperatures and precipitation. Once crop type and acreage estimates are made using Landsat digital data, the LACIE procedure uses the following mathematical yield determination model (MacDonald and Hall, 1980, p. 673):

Yield = A (preceeding year's yield for average weather)
+ B (yearly adjustment for technology trend)
+ C (effects of current weather)

LACIE's procedures have been criticized by Baumgardner (1980) for not considering soil variations and by Thomas and Hag (1977) for the cost of the sampling design. Both criticisms are justified. However, if the project receives future funding for continued research, these problems will become better defined and the development costs less. LACIE's direct application to most developing nations is very limited. "In the developing countries cropland frequently is interspersed with noncropland, fields are small and irregularly shaped, numerous crops have similar spectral responses" (National Academy of Sciences, 1977).

In a 1975, Program Plan for Developing the Capability of Forecasting Crop Production, the FAO outlines a pilot crop forecast framework for major food crops of the world. The approach begins with the delineation of ecozone maps of wheat producing regions. A multiterrain approach is taken for the collection of key data which includes climate, botany, hydrology, and pedology to determine ecozone boundaries. Crop calendars are combined with historical synoptic weather station data to establish yield trends. Daily METSAT data are prepared into rainfall distribution maps. Periodic acquisitions of Landsat data are used to confirm vegetational responses to reported environmental stimuli. Data bases are then divided into 25 nautical mile squares and assigned production potential values for the Food Information System or soil moisture values for the Global Early Warning System. The final step incorporates a computer run establishing daily yield estimates cell by cell. The major drawbacks with a system such as this are: data at several different scales are used, a large data base is needed, substantial time is needed to establish the system, considerable cost is required to operate the system, and reported yield estimates vary dramatically from country to country.

The Program for Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS) is the most recent and largest yield forecasting project. AgRISTARS began a six-year program of research development, evaluation, and application of aerospace remote sensing for agricultural resources during the fiscal year 1980. The program represents a cooperative effort among the USDA, NASA, USDC, USDI, and AID. For a discussion of each agency's responsibilities, refer to the management/organization plan for AgRISTARS (Kibler et al., 1980).

AgRISTARS' main goals are to establish the usefulness, cost, and extent to which aerospace remote sensing data can be integrated into the USDA systems. "The overall approach comprised a balanced program of remote sensing research, development and testing which addresses domestic resource management, as well as commodity production information needs" (Kibler et al., 1980, p. 1). The technical program for this approach is broken down into 8 major phases (Kibler et al., 1980, p. 1):

1. Early Warning/Crop Condition Assessment;
2. Foreign Commodity Production Forecasting;
3. Yield Model Development;
4. Supporting Research;
5. Soil Moisture;
6. Domestic Crops and Land Cover;
7. Renewable Resources Inventory; and
8. Conservation and Pollution

Neither the Management/Organization Plan (Kibler et al., 1980) or the Technical Program Plan discuss actual models used, therefore, a review of the technical aspects of AgRISTARS is impossible. However, it does appear that the base technical program considerations are sound and have great potential for future crop forecasting. Current difficulties with the AgRISTARS, Domestic Crops and Land Cover Project includes poor quality Landsat data, late 1980 wheat estimates, and the possibility of non-available Landsat data for 1981, due to technical problems aboard the satellites.

Soils

Soil, as a term used in U.S. Soils Taxonomy (1975, p. 1), refers to the "collection of natural bodies on the earth's surface, in places modified or made by man of earthy materials, which contain living matter and supports or is capable of supporting plants in natural environment." Soils data for this study came from information already collected by the Comprehensive Resource Inventory and Evaluation System (CRIES). W.J. van Liere's (1968) 1:200,000 and 1:500,000 soil maps provided the principal source of soils information for Ken Ackerson, CRIES soil scientist. Ackerson worked on conjunction with several Syrian soil scientists who provided supplementary data as well as in-country expertise to help refine soils data to meet CRIES project needs.

The map units and soil descriptions are based on specific criteria set forth in Soil Taxonomy, 1975. Ackerson (1980) lists five soil orders, six suborders, and fourteen great group categories. These categories are, in turn, used to make 81 soil classifications on the 1:750,000 base soil map for Syria.

Perhaps the best measure of a soil classification precision would be its category purity. Purity refers to the degree of homogeneity of the soil mapping units. In discussion with Dr. Delbert Mokma (1982) brief comparisons of the purity of soil classifications were made at a detailed county, regional, and state or country level using county and state soil maps of Michigan. The estimates, based on Michigan data, are as shown in Table 1:

Table 1.--Estimated Soil Category Purity and Associated Mapping Scale.

Map Type	Percentage	Scale
Detailed	85%	1:20,000
County	70%	1:200,000
Regional	65%	1:500,000
State or Country	40%	1:1,000,000

The soil categories listed by Ackerson on the Syrian maps were at approximately the same level of detail as the regional and state or county maps reviewed. Because both the Michigan data and the Syrian data were classified using U.S. Soil Taxonomy, purity values were considered to be synonymous for this study. Consequently, the purity of soil categories on the available 1:750,000 Syrian soil maps was determined by adding the regional and state or country purity percentages and dividing by 2. The result was a purity level of 52.5% (65 + 40/2).

Soil Moisture

Numerous systems, procedures and models have been established to estimate soil moisture availability for crop growth. "The major problem which occurs when calculating moisture budgets for individual localities is the difficulty of assessing soil-moisture storage and actual evaporation"

(Barry, 1973). One of the most reliable means of establishing available soil moisture is accomplished with a lysimeter. Observations are made at regular intervals with weight changes, precipitation, evaportranspiration, and percolation measured (refer to King et al., 1956).

Use of this method to measure the available soil moisture, although accurate, is too costly and too time consuming for a countrywide assessment. Consequently, it is necessary to utilize other methods for establishing evapotranspiration rates and estimates of available soil moisture. Methods determining available soil moisture will be further confined by the meteorological data available in developing nations. Data will be limited to monthly and yearly temperature plus precipitation amounts for all but 11 stations in Syria, therefore, the moisture balance equation used must be a simple one. One of the most widely used equations was developed by Thornthwaite (1948) and revised by Thornthwaite and Mather (1955). The formula is:

$$Im = \frac{100(S-D)}{PE}$$

Where: Im = moisture index in millimeters

S = annual moisture surplus in millimeters

D = moisture deficit in millimeters

PE = potential evapotranspiration in millimeters

(Barry, 1973).

A monthly moisture budget calculated by using this approach and data collected by Thornthwaite and Hare (1965) for Alleppo, Syria is presented in Figure 8.

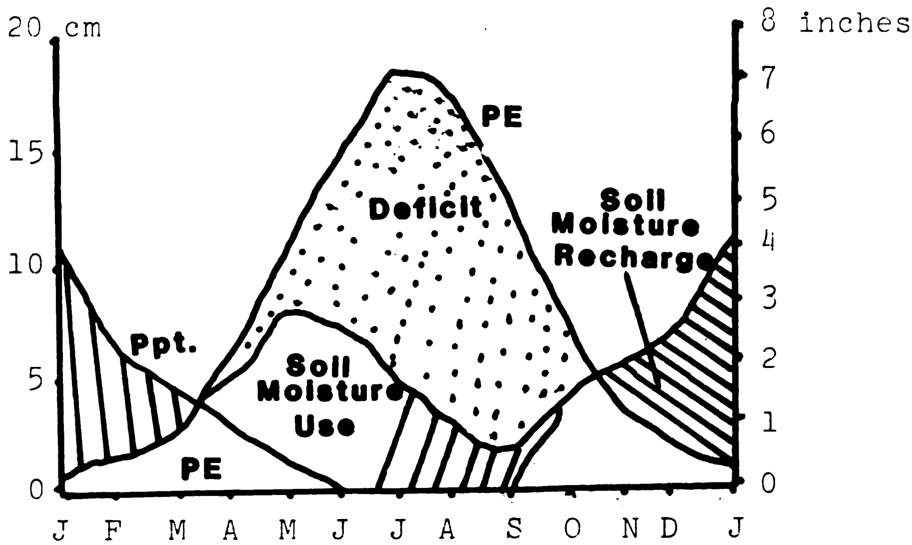


Figure 8. Monthly Water Budget of Alleppo, Syria.

The status of the moisture availability in the Thornthwaite model can be restated as:

Potential Evaportranspiration = (Precipitation - Deficit) + Surplus $\pm$ Storage Change

Potential Evapotranspiration--the evaporation and transpiration loss under optimum moisture conditions, or soil continuously at field capacity.

Precipitation--water falling onto the earth's surface from the atmosphere as rain or snow.

Water Surplus--the difference between precipitation and potential evaporation when soils are at field capacity.

Water Deficit--the difference between potential evapotranspiration and actual evapotranspiration.

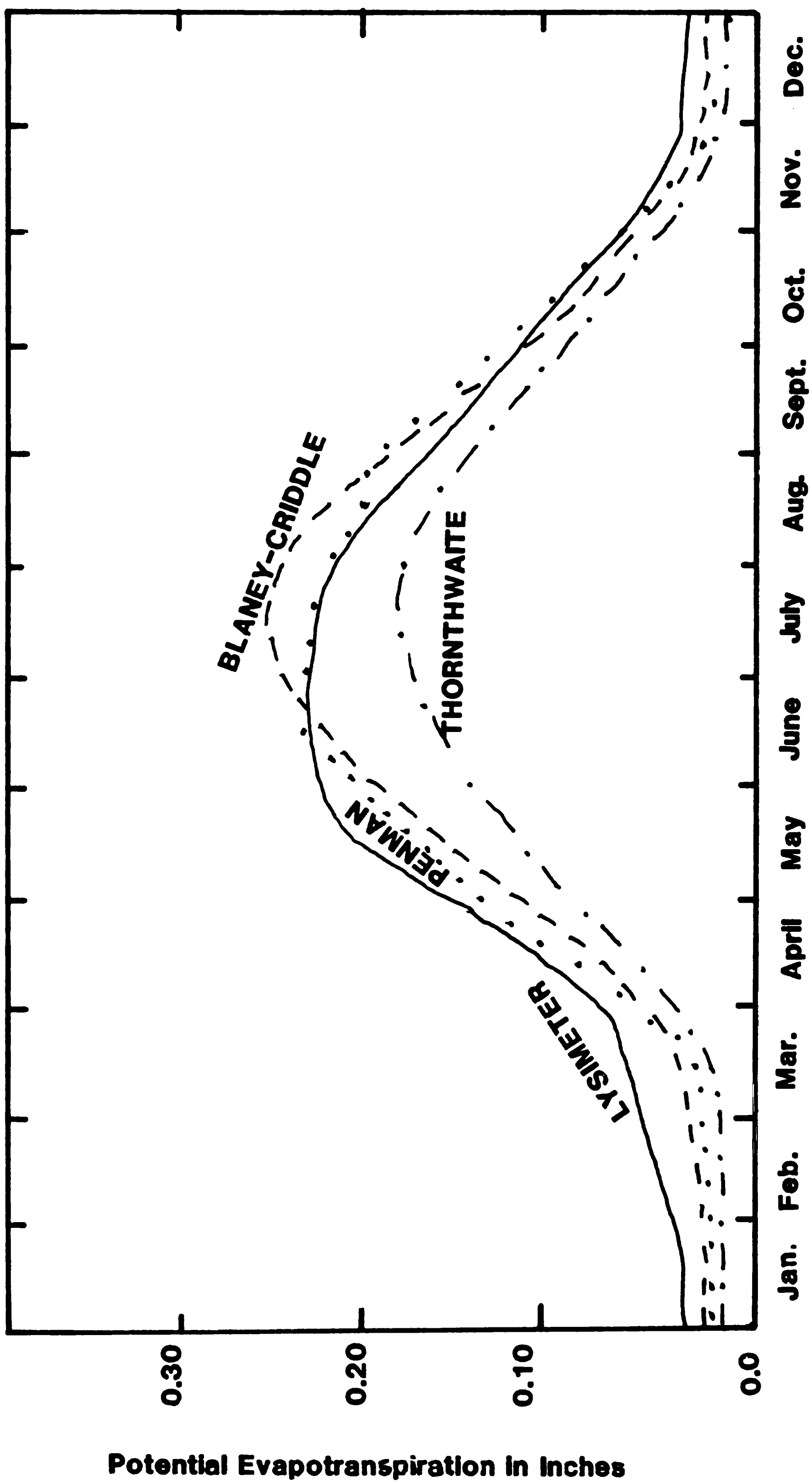
Soil Moisture Recharge (change)--the difference between precipitation that exceeds evapotranspiration when soils are not at field capacity (Thornthwaite and Mather, 1958, pp. 18-19).

The individual components of the equation are more easily compared over a long term record when presented in this manner.

Ward (1967) explains the popularity of the Thornthwaite equation in part results because the formula expresses PE as a function of mean air temperature and day length, two quantities which are independent of the rate of evaporation, and which are applicable over a wide range of conditions. A criticism of the Thornthwaite approach to water budgets is that it is empirically based (Lee, 1978; Terjurg, 1976). "Although I strongly support arguments for more rigorous and/or systematic research in climatology, it can be said that many of the critics of empirical water budgets have misinterpreted the purpose and utility of regression--broadly defined (Wilmott, 1977). Willmott (1977) indicates that researchers may correctly use such models when data for more rigorous analyses are missing or not obtainable (the case in most developing nations) and when the physical-biotic mechanisms that produce the desired answers are either well-known, unknown or unimportant. McGuinness and Bordne (1972) indicate water budgets have been very successful at satisfying the only criterion on which they should be judged--accuracy. An example of average daily potential evapotranspiration estimated by a lysimeter and as computed by the Thornthwaite (as described), Blaney-Criddle, and Penman methods is shown in Figure 9.

The estimates are very close during the cooler months, but significant variations occur between April and August.

Figure 9. Average Daily Potential Evapotranspiration as Estimated by Lysimeter Growing Deep-Rooted Grass-Legumes and as Computed by Thornthwaite, Penman, and Blaney-Criddle.



These variations can be minimized by taking the best estimate from the methods that reduces the variation between the lysimeter value and the calculated value (refer to Appendix A).

Other empirical methods which could be used to adjust Thornthwaite's potential evapotranspiration values have been developed by Penman, Blaney-Criddle, Eagleman, and Hargreaves. "Penman has made the most popular compromise of the energy balance method by eliminating factors which are difficult to measure and by substituting empirical relations where necessary to avoid complicated equipment and measurements" (Carter, 1958, p. 41). Penman considers three stages important in estimating evapotranspiration:

1. The determination of a hypothetical open body of water E_o;
2. The use of an empirical seasonal correction factor of E_o to convert potential evapotranspiration ET, over a surface covered with vegetation;
3. The value derived from part two can be further altered for the depth of a vegetation's root system.

Thus, the availability of moisture during a deficiency period could possibly be monitored. Safely (1974) illustrated the Penman equation in an expanded form for better clarity. This equation is presented as:

$$VP = \frac{\Delta}{\Delta+\delta} R_a(1-r)\ (.18+.55n/N)$$ (to determine vapor pressure)

$$SVP = \frac{\Delta}{\Delta+\delta} \sigma T^4(.56-0.092\ VP\ (.10+.90n/N)$$ (to determine saturation vapor pressure)

$PE = \frac{\Delta}{\Delta+\delta}$ .35 (1.+W/100) (SVP-VP) (both SVP and VP are needed to determine Penman's estimate of PE)

where: Δ = slope of the saturation vapor pressure curve at mean air temperature in millibars per degrees C;

δ = constant of the wet and dry bulb psychrometer equation;

R_a = Angot's value (the theoretical income shortwave radiation at the outer limits of the atmosphere);

r = albedo;

n = actual hours of sunshine;

N = theoretical duration of sunshine;

σT^4 = black body radiation at mean temperature (T) in degrees Kelvin;

VP = mean vapor pressure at mean air temperature;

SVP = saturation vapor pressure at mean air temperature;

W = run of wind at standard height of two meters (miles per day); and

PE = evapotranspiration

(Safley, 1974, p. 7).

Penman's model has several major disadvantages which the Thornthwaite model does not have. Penman's formula requires data for radiation, humidity, and wind which are usually only collected at first-order (primary) weather stations. Consequently, large portions of underdeveloped nations normally do not have sufficient data collected. The conversion of calculated PE to ET over vegetation is very difficult to precisely calculate. In addition, the equation describes areas where optimum supply of soil moisture is maintained. Other criticisms of the Penman model are discussed by Carter (1958).

Blaney and Criddle (1950) created a simplified model estimating water requirements by various crops in arid portions of the United States. The model is presented as:

$$U = ktp$$

where: U = consumptive use (potential evapotranspiration in inches);

k = a crop water use coefficient;

t = the monthly daytime temperature in °F; and

p = the monthly percent of daytime hours on a yearly basis.

Blaney and Criddle developed their consumption coefficients from field and lysimeter studies.

The Blaney-Criddle method's main advantages are that it is easy to use and the required data is normally available at any class of weather station. However, the crop coefficients were derived from small test sites of the sort that could absorb inordinate amounts of energy, thus producing more evaporation per unit area than would be possible from large farming areas. Other problems with the model are found in assumptions made concerning the data. The assumptions are:

1. There is non-limiting water supply to the plants;
2. Consumptive use varies directly with daytime hour percent and monthly mean temperature;
3. Fertility does not vary among areas; and
4. Length of the growing season is an index to consumptive use (Safley, 1974, p. 8).

Another problem involved in using this method is that the crop coefficients have only been derived for selected areas in the United States. Consequently, it would be necessary to either set up test sites or to interpolate the coefficient values taken in the United States to the country being studied.

Eagleman (1971) investigated the linear potential evapotranspiration rate equations by Thornthwaite and Mather, 1948; Van Bavel, 1953; Viehmeyer and Hendrickson, 1955; Denmead and Shaw, 1962; Eagleman and Decker, 1965; and Van Bavel, 1967. The relationships among these models were determined under various climatic conditions. "It was found that they could be combined into a single regression model which may be useful for calculating actual evapotranspiration (AE) rates for specified amounts of soil moisture and atmospheric demands" (Eagleman, 1971, p. 1). Eagleman (1971) found that each situation tested resulted in a curvilinear relationship between soil moisture content and a ratio of actual evapotranspiration divided by potential evapotranspiration (PE). A uniform moisture ratio (MR) was established in order to compare model results.

$$MR = (SM-WP)/(FC-WP)$$

where: SM = measured soil moisture content

WP = moisture content at wilting point

FC = moisture content at field capacity

Regression coefficients were calculated for four data sets using the eight models. The coefficients produced were very similar. The regression equation used was:

$$AE/PE = A+B(MR)+C(MR)^2+D(MR)^3$$

where A, B, C, D = regression coefficients.

These data were plotted and correlation coefficients compared. The coefficients for each data set were then used as expressed functions of PE. Actual evapotranspiration rates were then calculated in terms of MR and PE. This procedure was then tested against actual field measurements over a 25-day period. Results between measured soil moisture and estimated soil moisture varied by 5 to 6%.

Hargreaves (1977) took a slightly different approach by first establishing precipitation probabilities for a given location using these equations:

$$F = m/n+1$$

and

$$P = 100-F$$

Where: m = the order number assigned to the date;

n = total numbers of data points;

F = frequency number; and

P = percentage probability of occurrence.

Precipitation data published by the World Meteorological Organization for a 30-year period between 1931-1960 was used to obtain mean values and the 97, 79, 60, 40, 21, and 3% probabilities of occurrence. Hargreaves (1977) maintained that crop water requirements could be obtained using published climatic data for ambient air temperature and solar radiation. "The best relationship between these elements and crop water requirements exist when mean temperature is expressed in degrees Fahrenheit, TMF, and incident solar radiation, RSM, is expressed in equivalent mm of water evaporation" (Hargreaves, 1977, p. 3).

RSM data, however, is often not directly measured. Hargreaves offered a conversion equation using tabular values of extraterrestrial radiation (RMM) in equivalent mm of water evaporation per month with the percentage of possible sunshine (S) occurring at a given location. The equation reads as:

$$RSM = 0.075\ RMM \times S\ 1/2$$

Percentages of S were determined from actual duration of S in hours (SH) from day length (DL) and from the number of days in the month (DM). The equation then reads:

$$S = 100\ SH/DL \times DM$$

If SH data were not available, S could be approximated from mean monthly relative humidity (HM) using:

$$S = KS\ (100-HM)^{1/2}$$

KS = adjustment coefficients (using a computer program developed by Hargreaves, 1977).

Hargreaves (1977) estimated potential evapotranspiration (ETP) using mean temperature in degrees Fahrenheit (TMF) and RSM. Values for ETP are derived in mm per month using:

$$ETP = 0.0075\ RSM \times TMF$$

a 75% probability of precipitation occurrences was considered dependable precipitation (PD). "The moisture availability index, MAI, is a moisture adequacy index at the 75 percent probability level of precipitation occurrence" (Hargreaves, 1977, p. 4). The MAI was defined as PD/EPT. If a value of 1.00 was attained, it means PD = ETP.

The Thornthwaite potential soil moisture values were derived using adjusted potential evapotranspiration figures for each test site using the Penman equation. The actual potential evapotranspiration (APE) recorded by the Penman equation were used to replace the PE values obtained using the Thornthwaite equation. The difference between the values derived for available soil moisture using APE and the Thornthwaite model derived PE values were compared. The percentage difference between the Penman equation and Thornthwaite approach was calculated and used as a correction factor to alter the potential soil moisture values obtained for all other stations using the Thornthwaite model.

CHAPTER IV

IDENTIFICATION OF CROP EXPANSION AREAS

A crop expansion area can be defined as an area having the same soils as a producing region with similar moisture availability and potential to produce wheat. For the purpose of this study it has been assumed that farming practices for dry land wheat would not be significantly different for the three test sites and would not change for any future expansion.

Method

Soils

The initial step was to reduce the Syrian master data file, a 185,000 cells per data set (soils, land cover/use, political boundaries, etc.), down to those variables and test sites pertinent to this study. Cross tabulation of soils by land use were run for each montika to determine which soils were producing the rain fed wheat and where similar soils were currently used for rangeland. Comparisons of soils currently producing wheat and the same soils currently in rangeland for each test site are listed in Tables 2-4.

By reviewing Tables 2-4 it was obvious that not all the soils available for crop expansion were also capable of producing rain fed crops. Those soils not currently (1977) producing crops were not considered as potential crop expansion areas because there would not be comparable yield

Table 2.--Swedia Test Site--A Comparison of Soil Areas Being Used for Rain Fed Agriculture and Rangeland (by Montika).

Land Use	Dar'a RF* (sq. km.)	Dar'a R** (sq. km.)	Izra RF (sq. km.)	Izra R (sq. km.)	Swedia RF (sq. km.)	Swedia R (sq. km.)	Shuhba RF (sq. km.)	Shuhba R (sq. km.)	Salkhae RF (sq. km.)	Salkhae R (sq. km.)	Total
Soils***											
19							0	163			
28			1	14							
34			15	25			0	25			
35					382	113	186	106	721	357	
36					2	1366	0	717	0	711	
43			164	29	380	0	5	30	65	0	
45	100	185			239	0	86	240	53	117	
48	64	0	3	25			1	0			
61	83	0	5	0							
71	696	197	1005	106							
74	71	7	2	7							
75			230	80							
	1014	389	1425	286	1003	1479	278	1281	839	1185	4559 Rain Fed 4620 Rangeland

*RF = Rain Fed
**R = Rangeland
***Complete soil descriptions in Appendix B.

Table 3.--Alleppo Test Site--A Comparison of Soil Areas Being Used for Rain Fed Agriculture and Rangeland (by Montika).

Land Use	Manbaj		Jab Samon		
	RF*	R**	RF	R	
	(sq. km.)		(sq. km.)		
Soils***					
1			24	153	
10	0	20			
15	1142	577	936	646	
25	k98	178			
26	85	116			
29	496	112			
31	1	0	99	64	
43			155	714	
44			3	51	
45	782	225	90	92	
46	651	205			
47			691	406	
50			2	58	
53	44	0	54	10	
56	1	0	37	7	
68			54	17	
69			153	43	
71			4	3	
72			274	89	
79			34	29	
81	0	26			Total
	3310	1459	2610	2382	5920 Rain Fed 3841 Rangeland

*RF = Rain Fed
**R = Rangeland
***Complete soil descriptions in Appendix B.

Table 4.--Hasseke Test Site--A Comparison of Soil Areas Being Used for Rain Fed Agriculture and Rangeland (by Montika).

Land Use	Hasseke RF*	Hasseke R**	
	(sq. km.)		
Soils***			
6	302	472	
10	0	92	
11	12	96	
12	349	609	
13	0	11	
14	652	1184	
15	0	3	
16	8	91	
17	1558	2446	
26	3	113	
30	59	339	
35	9	625	
38	90	138	
39	593	0	
43	82	42	
51	30	62	
53	118	0	
57	148	30	
58	152	0	Total
66	866	0	
71	172	0	5203 Rain Fed
			6352 Rangeland

*RF = Rain Fed
**R = Rangeland
***Complete soil descriptions in Appendix B.

statistics. This eliminated 1,616 sq. kil. from the Swedia test site, 20 sq. kil. from the Alleppo site, and 106 sq. kil. from the Hasseke site. The total area available to wheat expansion was 3,004 sq. kil. in Swedia, 2,821 sq. kil. in Alleppo, and 6,247 sq. kil. in Hasseke.

Because it was not known exactly which soils were producing just rain fed wheat versus barley, legumes, etc., it was necessary to make the following assumption. It was assumed that the wheat would be distributed equally among all soils based on the percentage of area each soil represented of the total rain fed cropped areas. Because the area planted in wheat and other crops varied from year to year, it was necessary to assume that the reduction in area was also spread equally among each soil category.

To determine the total area of each soil within the producing regions of each test site, cross tabulations between rain fed crops and soils were produced using the Syrian master file. Area percentages were calculated for each soil, soil area ÷ total area of rain fed wheat (Syrian Agricultural Statistics). Once the soil area percentages were established, it was necessary to assume that as the area planted in wheat increased or decreased, it would do so equally on each soil type. The results of one set of these calculations for the period 1970 to 1977 are shown in Table 5.

Soil Moisture Storage

Monthly soil moisture storage values were calculated using the Thornthwaite water balance procedure described in

Table 5.--Yearly Wheat Acreage (hectares) Correction Procedure for the Swedia Montika.

Soils	1970*	1971	1972	1973	1974	1975	1976	1977	Percentage of Total Producing Area
35**	6,558	5,634	5,463	5,102	6,362	3,812	5,232	5,530	(38.2)***
36	34	30	29	26	33	20	27	29	(.2)
43	6,488	5,575	5,405	5,049	6,295	3,772	5,178	5,472	(37.8)
45	4,085	3,510	3,403	3,179	3,964	2,375	3,260	3,445	(37.8)
Total Producing Area	17,165	14,749	14,300	13,356	16,654	9,980	13,697	14,476	(100.0)

*Yearly wheat yield areas from the Syrian Agriculture Abstracts, 1978 (i.e., Procedure, 1977).

**Soils: 35 = 5,530/14,476 = 38.2%
36 = 29/14,476 = .2%
43 = 5,472/14,476 = 37.8%
45 = 3,445/14,476 = 23.8%

***Percentages of Total Producing Area

Chapter III. The Thornthwaite adjusted potential evapotranspiration (APE) figure was altered by using Penman potential evapotranspiration. This was done to make the PE more representative of the actual conditions, as the Thornthwaite PE varies most where temperatures are extreme as in Syria. The Penman PE figures were taken from mean averages (1955-1969) published in the Syrian Meteorological Atlas (1978) for the 11 first order stations in Syria. PE conversions for non-first order stations were made by determining what the percentage differences were between the Thornthwaite adjusted PE for the closest first order station and the non-first order station (non-first order PE/first order PE). The percentage change was multiplied by the Penman PE figure and recorded as the true adjusted PE.

The adjusted PE was then subtracted from the available precipitation to determine the storage change. Positive storage changes added to the available soil moisture while negative values depleted the moisture availability. Soil moisture carryover from one year to the next was taken as the available soil moisture at the end of December of the preceding year (refer to Thornthwaite and Mather, 1950).

Mean (1955-1969) precipitation (Ppt), adjusted potential evapotranspiration (APE), and soil moisture storage (St) for each reporting station by study site are presented in Table 6.

One representative first order station was selected from each region. The cities were Swedia, Alleppo, and Hasseke. Percentage differences between these stations and mean

Table 6.--Mean Precipitation, Adjusted Potential Evapotranspiration, and Soil Moisture Storage Values for 1955-1969 for the Wheat Growing Period by Study Area.

	Station		January *Ppt mm	January APE mm	January St mm	February Ppt mm	February APE mm	February St mm
Swedia	Swedia		83	45.6	37.4	62	46.1	53.3
	Izra		71	45.6	33.4	47	46.1	34.3
	Tel Shehab		69	50.0	27.9	52	53.7	26.2
	Sananen		74	33.6	40.4	40	46.1	34.3
	Salkhad		81	25.3	57.1	58	30.6	84.9
	Fiq		120	59	92	84	61	100
Alleppo	Alleppo		67	25	82	53	43	92
	Manbej		64	16.4	88.3	46	31.9	100
	Jarabluss		72	16.4	100	49	31.9	100
	Khansser		41	24.6	40,9	34	53	21.9
	Abu Dhur		59	24.6	69	28	53	44
	Jandeeress		106	32.8	100	86	53	100
	Messelmiyah		71	24.6	100	54	42.2	100
	Kuweiress		60	24.6	71.9	39	42.2	68.7
	Izaz		98	24.3	100	76	42.2	100
Hasseke	Hasseke		64	25	59	38	42	55
	Tel Tamer		65	25.2	51.9	37	55.3	33.6
	El Hall		51	38.2	12.8	35	41.8	6.0
	Swedia	Mean	72.7	43.2	37.7	52.5	47.3	44.1
	"	SD**	34.9	12	37.3	23.6	10.1	47.8
	Alleppo	Mean	67.5	23.6	81.5	48.6	43.8	78.3
	"	SD	18.4	5.3	20.6	17.7	8.8	30.5
	Hasseke	Mean	60.0	29.5	41.2	36.7	46.4	31.5
	"	SD	7.8	7.6	24.9	1.5	7.7	24.6
	All Areas	Mean	67.3	31.5	58.8	47.2	45.8	56.1
	"	SD	25.8	12.6	37.1	19.9	9.6	43.4

*Ppt = precipitation; APE = Adjusted Potential Evapotranspiration; St = Soil moisture storage (reported for 100 mm level).

**Standard Deviation.

Table 6.--(cont'd.)

	Station		March *Ppt mm	March APE mm	March St mm	April Ppt mm	April APE mm	April St mm
Swedia	Swedia		62	86.6	28.7	21	132.7	- 83
	Izra		44	91.2	-17.9	12	140.6	-128.6
	Tel Shehab		53	105.9	-26.7	15	51.6	- 36.6
	Sananen		34	96.2	-27.9	16	132.7	-116.7
	Salkhad		61	67.3	78.6	16	116.1	- 21.6
	Fiq		72	106	53	21	140	- 84
Alleppo	Alleppo		37	90	39	32	132	- 61
	Manbej		34	89.9	44.1	26	124	- 53.9
	Jarabluss		39	89.9	49.1	30	131.7	- 52.6
	Khansser		33	101.2	-46.3	26	139.5	-113.5
	AbuDhur		32	101.2	-25.2	16	131.7	-115.7
	Jandeeress		70	112.5	57.5	36	139.5	- 46
	Messelmiyah		46	101.2	44.8	33	131.7	- 54.7
	Kuweiress		25	89.9	3.8	22	131.7	-105.9
	Izaz		67	100.8	66.2	35	124	- 22.8
Hasseke	Hasseke		37	83	9.0	45	121	- 6.7
	Tel Tamer		38	68.8	2.9	36	120.6	- 81.6
	El Hall		33	68.9	-29.8	37	127.7	90.7
	Swedia	Mean	51	94.6	4.0	16.2	125.4	- 85.6
	"	SD**	20.4	15.5	61.9	4.1	40.4	52.6
	Alleppo	Mean	39.5	97.0	20.9	27.6	132.7	- 75.4
	"	SD	13.7	8.4	38.7	6.5	5.0	30.4
	Hasseke	Mean	36.0	73.6	- 6.0	39.3	123.1	- 79.8
	"	SD	2.6	8.2	20.8	4.9	4.0	11.9
	All Areas	Mean	42.4	93.2	6.9	24.1	128.4	- 81.8
	"	SD	16.7	51.1	48.9	9.2	25.7	39.6

*Ppt = precipitation; APE = Adjusted Potential Evapotranspiration; St = Soil moisture storage (reported for 100 mm level).

**Standard Deviation.

precipitation, adjusted potential evapotranspiration, and potential soil moisture storage from all other stations in each region were calculated to illustrate the station's representativeness within each region (Table 7).

Mean monthly precipitation (Ppt), adjusted potential evapotranspiration (APE), and soil moisture storage (St) for the representative stations in each test site for 1970-1977 were also calculated (Table 8).

When reviewing Table 8 note that in all instances $St_1 + Ppt_2 - APE_2 = St_2$ except where St is equal to or larger than 100 mm (maximum storage level used) and, in the last portion, when using the mean values. The mean values are from a times series 1970-1977 and reflect both positive and negative deviation from the mean.

Yield Equation

The yield equation proposed for this study was:

$$Y = b_1X_1+b_2X_2+b_3X_3+U$$

where: Y = yield in kilograms per hectare

b_1-b_3 = regression coefficients

X_1 = millimeters of potential soil moisture by months of the growing season

X_2 = percentage of category acreage of given soil in wheat producing region

X_3 = acreage of rain fed wheat within each study area

U = error term

It became apparent after running cross tabulations of the soils and land cover/use and comparing them with wheat acreage

Table 7.--Percentage Differences from the Mean Region Response for the Selected First Order Stations by Month, Precipitation, Adjusted Potential Evapotranspiration and Potential Soil Moisture Storage (1955-1969).

	January			February			March			April		
	Ppt	APE	St	Ppt	APE	St	Ppt	APE	St	Ppt	APE	St
Swedia	.14	.06	-.01	.18	-.03	.08	.21	-.08	7.2*	.30	.06	-.03
Alleppo	-.01	.06	.01	.09	-.02	.17	-.06	-.07	.87*	.16	-.01	-.19
Hasseke	.07	-.15	.43*	.04	-.09	.75*	.03	.13	.50*	.15	-.02	-.91*

*Mean values significantly different at the .90 confidence level.

Table 8.—Mean Monthly Precipitation, Adjusted Potential Evapotranspiration, and Soil Moisture Storage Values for 1970-1977 for One Representative Station in Each Test Site.

Station	Year	January Ppt (mm)	January APE (mm)	January St (mm)	February Ppt (mm)	February APE (mm)	February St (mm)	March Ppt (mm)	March APE (mm)	March St (mm)	April Ppt (mm)	April APE (mm)	April St (mm)
Swedia	1970	99.9	59.2	40.7	33.4	61.2	12.9	114	115.5	11.4	17.2	162.3	-133.7
	1971	55.7	76	2.8	86	38.3	50.5	37.1	105.9	-18.3	164.4	92.8	71.6
	1972	57.5	33.9	100	95.4	30.6	100	49.1	86.6	62.5	54.4	147	-30.1
	1973	84.2	33.9	50.3	10.7	76.7	-15.7	48.4	86.6	-38.2	18.3	123.7	-105.4
	1974	164.9	25.3	100	124.5	53.7	100	33.8	125.2	8.6	32.4	131.5	-90.5
	1975	23.9	42.4	0	118.5	46.1	72.4	33.6	115.5	-9.5	15.3	170.3	-155.3
	1976	41.1	42.4	12.3	88.7	30.6	70.4	83.9	116.1	58.1	26	116.1	-32
	1977	89.7	45.6	44.1	20.4	46.1	18.4	41.1	86.6	-26.8	82.7	132.7	-50
Alleppo	1970	23.1	32.5	30.6	19.7	73.9	-23.6	40.5	123.7	-83.2	3.3	193.7	-190.4
	1971	29.5	32.5	20.5	42.8	42.2	.6	34.9	101.2	-66.3	96.1	108.5	-12.4
	1972	31.8	0	100	31.7	2.1	100	74	101.2	72.8	77.6	146.9	3.5
	1973	42.4	8.2	100	25.7	63.4	62.3	43.8	101.2	4.9	23.1	131.7	-126.8
	1974												
	1975	45.1	16.7	84.5	85.3	43	100	7.6	112.6	-5	42.4	170.8	-128.4
	1976	60.3	24.7	83.1	66.9	21.5	100	53.9	90	63.9	60.2	116.5	7.6
	1977	32.5	24.7	29.9	37.1	54	13	55.8	101.3	-32.5	61.9	132	-70.1
Hasseke	1970	29.1	50	-.9	4.3	97.6	-93.3	30.1	145.5	-115.4	9.8	185.1	-175.3
	1971	13.3	37	-5.1	22	55.6	-33.6	65.3	124.7	-59.4	107.5	113.9	-6.4
	1972	48.7	0	100	49.3	14.2	100	86	83	100	77	149.7	27.5
	1973	32.7	12.5	20.2	15	83.5	-48.3	1.5	103.8	-102.3	23.7	142.4	-118.7
	1974	85.9	12.5	73.4	60.5	42	91.9	126.7	124.7	93.9	45.7	113.9	-68.2
	1975	18.6	25	2.6	61.8	53.6	10.8	9.4	93.4	-73.2	7.8	163.7	-155.9
	1976	19.9	37.5	22.6	68.2	27.8	63	46.7	83	26.7	91.5	121	-2.8
	1977	4.1	25	-12.6	13.7	42	-28.7	24.8	83	-58.2	24.4	121	-96.6

Table 8.—Continued

Station & Year		January			February			March			April		
		Ppt (mm)	APE (mm)	St (mm)	Ppt (mm)	APE (mm)	St (mm)	Ppt (mm)	APE (mm)	St (mm)	Ppt (mm)	APE (mm)	St (mm)
(1970-1977)													
Swedia	Mean	77.11	44.84	43.78	72.20	47.91	51.11	55.16	102.26	5.98	51.34	139.55	-65.68
"	SD	43.76	16.08	39.57	44.48	15.75	42.43	28.8	15.41	37.42	51.18	25.12	72.06
Alleppo	Mean	40.8	19.5	60.35	46.41	42.89	57.65	58.01	105.48	1.68	47.13	145.75	-81.54
"	SD	14.31	11.43	34.5	22.78	22.77	45.66	43.09	10.32	68.35	36.61	29.19	75.64
Hasseke	Mean	31.54	24.94	25.03	36.18	52.04	7.73	48.81	105.14	-23.49	48.43	138.81	-62.81
"	SD	25.76	16.31	40.51	24.79	27.52	70.76	42.16	23.92	85.50	38.73	26.09	83.12
All Areas	Mean	49.82	29.76	43.05	51.59	47.6	57.13	54.0	104.29	-5.28	48.96	139.70	-70.01
"	SD	35.37	17.98	39.44	34.45	21.87	37.23	37.07	16.72	65.19	39.75	26.09	74.13

estimates published by the Syrian government that it is necessary to break the soils down by area percentage. Refer to Table 4 for an example. The independent variables are presented for each station as they were entered into the regression model, therefore, the first independent variable represents the best one independent variable model to predict yield, the first and second independent variable represent the best two variable model, etc. The results of the multiple stepwise regression equations are illustrated in Table 9. The computer software used to determine the regression coefficients in Table 9 was the Statistical Package for the Social Sciences.[1]

The initial null hypothesis was rejected in each instance and the alternative accepted. The Durbin-Watson test for the Swedia and Hasseke sites indicated zero autocorrelation, while the Alleppo station had a negative value for the d statistic. A negative autocorrelation would indicate that the dependent variable was smaller than the actual value. This would indicate that the error terms were negatively correlated (Neter and Wasseman, 1978). The Durbin-Watson statistics were plotted at the minimum sample size for each equation and no autocorrelation was indicated.

In an attempt to determine what the explanation power and significance level would be for the dependent variable yield, available independent variables were loaded into the

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[1]Nie, N.H. Statistical Package for the Social Sciences. New York: McGraw-Hill, 1975.

Table 9.--Multiple Regression Wheat Yield Estimates for Swedia, Alleppo, and Hasseke for 1970-1977--Storage and Soils First Run.

Independent Variables*	R^2	α	b	S.E. $(\hat{b})$	F	D.F.	Durbin-Watson
Swedia							
1. Storage April**	.58	.029	3.23	1.40	8.18	1-6	1.59
2. Storage March	.71	.046	4.10	3.58	6.04	2-5	
Intercept			913.4	745.9			
Alleppo							
1. Storage March	.63	.018	-4.43	15.10	10.30	1-6	2.81
2. Soil X 12***	.67	.064	-4.62	12.77	4.99	2-5	
Intercept			-221.51	750.00			
Hasseke							
1. Storage February	.72	.008	8.43	6.92	15.44	1-6	1.70
2. Storage January	.74	.032	-16.74	19.56	7.41	2-5	
3. Storage April	.77	.094	-3.71	4.85	4.38	3-4	
Intercept			3833.16	4518.95			

*R^2=coefficient of multiple determination, a value which reflects accumulated explanatory power; α=significance level; b=regression coefficients; S.E. $(\hat{b})$= standard error of regression coefficient; F=F-statistic; and D.F.=degree of freedom.

**Storage = potential soil moisture storage.

***Soils refer to Tables 1, 2, and 3 plus Appendix B.

equation. The equation read:

$$\text{Wheat yield} = b_1 St(Jan) + b_2 St(Feb) + b_3 St(Mar) + b_4 St(Ap) + b_5 Ppt(Jan) + b_6 Ppt(Feb) + b_7 Ppt(Mar) + b_8 Ppt(Ap) + b_9 APE(Jan) + b_{10} APE(Feb) + b_{11} APE(Mar) + b_{12} APE(Ap) + b_{13} X_{13} \ldots b_{33} X_{33} (soils)$$

Where: Wheat yield = kilograms per hectare

St = soil moisture storage

Ppt = precipitation

APE = adjusted potential evapotranspiration

b_1-b_{33} = regression coefficients

X_{13}-X_{33} = percentage of each producing soil found in each study set (Tables 2-4)

The results are shown in Table 10.

The second run allowed the rejection of H_0. Consequently, the alternative was accepted, H_1. Actual wheat yield for Syria can be predicted with this model at a 90% confidence level. The variable with the highest explanatory power remained the same for each test site for both runs.

Soils data failed to play a significant role in explaining wheat yield for any of the three test sites. The yield equation for the Hasseke site recorded soils as the sixth variable adding 6% to the explanatory power of the model, but at 74.5 confidence level, which indicates it is a nonsignificant variable.

The Durbin-Watson test for the Swedia and Hasseke sites indicated zero autocorrelation. While the same test recorded a negative value for Alleppo on the first run, a positive value was recorded for the second run. In this instance the

Table 10.--Multiple Regression Wheat Yield Estimates for Swedia, Alleppo, and Hasseke for 1970-1977--All Variables--Second Run.

Independent Variables*	R^2	α	b	S.E. $(\hat{b})$	F	D.F.	Durbin-Watson
Swedia							
1. Storage April	.58	.029	16.01	2.87	8.18	1-6	1.61
2. April Adjusted P.E.	.86	.008	21.78	3.76	14.98	2-5	
3. March Precipitation	.90	.015	-3.37	2.52	13.27	3-4	
4. February Adjusted P.E.	.92	.050	12.78	4.16	9.11	4-3	
Intercept			-1704.59	449.19			
Alleppo							
1. Storage March	.63	.018	-1.82	.585	10.30	1-6	.74
2. January Precipitation	.75	.031	-26.12	.795	7.51	2-5	
3. February Precipitation	.87	.027	19.97	.549	9.64	3-4	
4. March Precipitation	.91	.058	8.79	.477	8.12	4-3	
5. January Adjusted P.E.	.98	.028	-13.27	.569	34.6	5-2	
6. February Adjusted P.E.	.999	.023	-8.41	.972	1107.37	6-1	
Intercept			838.26	26.99			
Hasseke							
1. February Precipitation	.76	.005	9.17	3.83	18.83	1-6	2.33
2. February Adjusted P.E.	.81	.016	-12.66	5.29	10.50	2-5	
3. April Adjusted P.E.	.86	.033	4.16	3.56	8.45	3-4	
4. April Precipitation	.91	.059	-1.23	3.42	8.06	4-5	
Intercept			1565.3	1466.26			

*R^2=coefficient of multiple determination, a value which reflects accumulated explanatory power; α=significance level; b=regression coefficients; S.E. $(\hat{b})$=standard error of regression coefficient; F=F-statistic; and D.F.=degree of freedom.

**Storage = potential soil moisture storage.

positive autocorrelation indicated that the predicted value of the dependent variable was larger than the actual value. Once again the plot of the Durbin-Watson test indicated no autocorrelation problems were present for any of the sites.

Final Yield Equation

Upon closer review of the variables, a number of strong interrelationships among the independent variables (multicollinearity) were present. Where high correlations ($\geq$70%) were present, the explanatory power of each independent variable was checked against the dependent variable. The independent variable with the highest explanatory power was maintained and the other eliminated. This process was repeated for each test site. Those independent variables remaining were reloaded into the equation and run for a third time. The revised equation based on the previously described analysis was run for each test site.

Swedia

$$\text{Wheat yield} = b_1 St(Jan) + b_2 St(Feb) + b_3 (Mar) + b_4 Ppt(Jan) + b_5 Ppt(Feb) + b_6 Ppt(Mar) + b_7 APE(Jan) + b_8 APE(Mar) + b_9 APE(Ap)$$

Where: Wheat yield = kilograms per hectare

b_1-b_9 = regression coefficients

Alleppo

$$\text{Wheat yield} = b_1 St(Feb) + b_2 St(Mar) + b_3 Ppt(Feb) + b_4 Ppt(Mar) + b_5 Ppt(Ap) + b_6 APE(Jan) + b_7 APE(Mar) + b_8 APE(Ap)$$

Where: Wheat yield = kilograms per hectare

b_1-b_8 = regression coefficients

Hasseke

$$\text{Wheat yield} = b_1\text{Ppt(Feb)} + b_2\text{Ppt(Ap)}$$
$$+ b_3\text{APE(Mar)} + b_4\text{APE(Ap)}$$

Where: Wheat yield = kilograms per hectare

b_1-b_4 = regression coefficients.

The results are shown in Table 11.

Once the multicollinearity was adjusted for each equation, the positioning of the independent variables changed appreciably. The best one term predictor became precipitation in April for Swedia, potential soil moisture storage in March for Alleppo, and precipitation in February for Hasseke. The primary reason for the difference in the placement of the predictor variables is explained by the fairly wide variations in the meteorological phenomena between sites (Table 6). The reduction of the multicollinearity and the repositioning of independent variables, however, did not change the R^2 estimates significantly.

The H_0: was again rejected and the alternative accepted for each test site. The minimum confidence levels were .911 for Swedia, .916 for Alleppo, and .922 for Hasseke. The Durbin-Watson statistic for Alleppo was positive by .07, while the statistic for Swedia and Hasseke were both in the zero region of the scale. The plot of the Durbin-Watson statistic failed to identify autocorrelation for any of the sites.

Further comparisons of the models for each region showed that only two variables were common to all three models.

Table 11.--Multiple Regression Wheat Yield Estimates for Swedia, Alleppo, and Hasseke for 1970-1977--Selected Variables--Third Run.

Independent Variables*	R^2	α	b	S.E. $(\hat{b})$	F	D.F.	Durbin-Watson
Swedia							
1. April Precipitation	.41	.087	9.73	.674	4.18	1-6	2.46
2. Storage March**	.81	.016	46.50	6.28	10.56	2-5	
3. Storage February	.86	.034	-38.15	5.75	8.39	3-4	
4. April Adjusted P.E.	.91	.067	8.14	1.09	7.33	4-3	
5. March Adjusted P.E.	.98	.089	39.48	6.68	73.79	6-1	
Intercept			-1389.8	269.98			
Alleppo							
1. Storage March	.63	.018	1.82	1.88	10.30	1-6	1.43
2. March Adjusted P.E.	.68	.060	26.54	6.12	5.20	2-5	
3. April Precipitation	.89	.021	9.64	2.08	11.03	3-4	
4. January Adjusted P.E.	.94	.032	-14.50	5.21	12.70	4-3	
5. February Precipitation	.97	.084	6.32	3.28	11.25	5-2	
Intercept			-2862.5	715.69			
Hasseke							
1. February Precipitation	.76	.005	14.01	3.86	18.83	1-6	2.85
2. April Precipitation	.80	.018	5.02	2.80	10.08	2-5	
3. April Adjusted P.E.	.87	.030	6.49	4.19	8.93	3-4	
4. March Adjusted P.E.	.90	.078	-3.44	3.97	6.47	4-3	
Intercept			-761.94	764.60			

*R^2=coefficient of multiple determination, a value which reflects accumulated explanatory power; α=significance level; b=regression coefficients; S.E. $(\hat{b})$=standard error of regression coefficient; F=F-statistic; and D.F.=degree of freedom.

**Storage = potential soil moisture storage.

These variables were the precipitation in April and the adjusted potential evapotranspiration during March.

To test the significance of the R^2 using these variables, an analysis of variance was run for all regions together. The first run compared April precipitation against wheat yield for all three test sites combined. The results were:

	R^2	D.F.	Mean Square	F	Significance of F
April Precipitation	.20	1	665502.75 (explained) 119489.87 (residual)	5.56	.028

The second run compared March adjusted P.E. against wheat yield again for all three test sites combined. The results were:

	R^2	D.F.	Mean Square	F	Significance of F
March Adjusted P.E.	.25	1	421717.50 (explained) 116654.52 (residual)	3.61	.045

The third run compared both of the previous independent variables against wheat yield with the following results:

	R^2	ΔR^2	F	Significance of F
April Precipitation	.20	.20	5.56	.028
March Adjusted P.E.	.25	.05	3.61	.045

The F values were highly significant, thus indicating a direct relationship between wheat yield and these variables. The best one term explanatory variable, based on this analysis, was April precipitation with March adjusted P.E. only adding .05 to the overall R^2 value. Under these conditions, 1970-1977 data for all three test sites would be of doubtful use in calculating the March adjusted P.E.

Further analysis with combinations of variables and regions indicated that the most significant estimates of wheat yield were obtained with equations reported in Table 11. Consequently, Table 11 reflects the models and responses that were used in the following loss function analysis.

Loss Function

The final regression equations used for each test site have been used to estimate wheat yield at $P \geq .90$ confidence interval. However, data used to establish these yield estimates were not collected with a 100% precision (none ever is). In this instance, the margin of variable precision error accepted was $\pm$ 10% at a .90 confidence interval. The difference between a $\pm$ 10% sampling error versus $\pm$ 10% precision error is that sampling determines the representativeness of the composition of the population while precision refers to the representativeness or continual recurrence, through observation, of a unit within the population based on numerous runs. As a result, a sample size of n with a $\pm$ 10% sampling error may also have a $\pm$ 10% data precision error. As a result, the decision maker basing his decision on the .90 confidence interval without taking into consideration the effects of the variable precision of the data could be taking a considerable risk. In order to quantify what the potential monetary risk would be for each test site using mean value variable precision data, a quadratic loss function was used. The quadratic loss function is used to determine the optimal estimator of a central value based on past mean values. In this instance the quadratic form was used to calculate the monetary loss incurred with a decision through a given data precision error. The quadratic loss function used was based on work by Wonnacott and Wonnacott (1972) using Bayesian Analysis.

Assumptions

As noted previously (page 11), five assumptions had to be made before the potential monetary losses could be calculated:

1. Acreage and yield statistics reported by the Syrian government were at least 95% precise (an estimate based on review of variations in reported statistics).
2. Syrian cultural and/or farming practices would not change yield characteristics from one study site to the next.
3. Pre-determined precision levels assigned to each variable were representative of that variable (based on Chapter III).
4. Syrian recorded moisture and temperature values were 90% precise (refer to Ward, 1967, catchment errors).
5. Adjusted evapotranspiration corrections (Penman values) calculated for each station were 92% precise (refer to McGuinness and Bordre, 1972, p. 15 for comparisons of Penman and lysimeter values).

Refer to Chapter I, Assumptions, for a discussion of the appropriateness of these assumptions to the study.

Actions and States

The Syrian Department of Agriculture's (SDA) utility function was assumed to be the "determination of potential wheat expansion areas to increase wheat revenue with the highest potential return and the least risk." To assess this utility function, four potential actions were investigated:

A_1 = Expand into 100% of the available rangeland

A_2 = Expand into 75% of the available rangeland

A_3 = Expand into 50% of the available rangeland

A_4 = Expand into 25% of the available rangeland

The SDA's choices were assessed under five states of variable probability of occurring for each test site, which reflect potential reductions in key variables and wheat yield. They were:

B_1 = Precipitation, potential evapotranspiration, soil moisture and yield equal the mean reported values

B_2 = Precipitation, potential evapotranspiration, soil moisture, and yield are reduced to 95% of the mean values

B_3 = Precipitation, potential evapotranspiration, soil moisture, and yield are reduced to 90% of the mean values

B_4 = Precipitation, potential evapotranspiration, soil moisture, and yield are reduced to 85% of the mean values

B_5 = Precipitation, potential evapotranspiration, soil moisture, and yield are reduced to 80% of the mean values

Quadratic loss functions were calculated for each test site. The maximum potential gross gain (MPG) to be derived by wheat expansion for each State by each Action was calculated. The reported yield was multiplied by .95 to reflect the potential observation error made by the Syrian reporting services. The .95 was based on the variation in yield reported in the Syrian Statistical Abstracts, 1978. The $ (U.S.) reflects the 1977 government supported local wheat price in Syria--61 Syrian piastors per kilogram of wheat = .15 U.S.

$$\text{MPG} = [\text{Reported Yield } (.95)] \cdot \text{Expansion Area} \cdot \$ \text{ in U.S. per kilogram of wheat}$$

The maximum potential dollar loss (MPDL) was calculated as:

$$\text{MPDL} = [1-(\text{Precision } X_1 \cdot \text{Precision } X_2 \cdot \text{Precision } X_3 \cdot \text{Precision } X_4 \cdot \text{Precision } X_5)^2] \cdot [\text{Observation error } (.95) \cdot R^2\ (\%)] \cdot \text{Expansion Area} \cdot \$ \text{ in U.S. per kilogram of wheat}$$

The R^2 (%) reflects the potential error from using the yield model to estimate potential wheat yield using only the variables reported in Table 11 for each test site.

The minimum potential gross gain (MPGG) was calculated as:

$$\text{MPGG} = \text{MPG} - \text{MPDL}$$

Examples for a 100% expansion into the available rangeland are provided at the end of Tables 12, 13, and 14.

Loss Function Comparisons Between Sites

When State 1 Action 1 was compared between Swedia and Alleppo, the MPGG for Alleppo was found to be 41% larger than

Table 12.--Quadratic Loss Function Analysis of the Swedia Test Site Showing Maximum Potential Gain, Maximum Potential Dollar Loss, and Minimum Potential Gross Gain.

State	Action A_1(1.0)	Action A_2(.75)	Action A_3(.50)	Action A_4(.25)	
B_1(1.0)	25,470,165	19,102,262	12,735,508	6,367,541	MPG[a]
	17,941,089	13,455,816	8,970,544	4,485,272	MPDL[b]
	7,529,076	5,646,446	3,764,964	1,882,269	MPGG[c]
B_2(.95)	24,196,656	18,147,148	12,098,732	6,049,164	
	17,044,034	12,783,025	8,522,017	4,261,008	
	7,152,622	5,364,123	3,576,715	1,788,156	
B_3(.90)	22,923,148	17,192,035	11,461,957	5,730,787	
	16,146,698	12,110,023	8,073,349	4,036,674	
	6,776,168	5,082,012	3,388,608	1,694,112	
B_4(.85)	21,649,640	16,236,922	10,825,181	5,412,410	
	15,249,925	11,437,443	7,624,962	3,812,481	
	6,399,715	4,799,479	3,200,219	1,599,929	
B_5(.80)	20,376,132	15,281,809	10,188,406	5,094,033	
	14,352,287	10,764,215	7,176,143	3,588,071	
	6,023,261	4,517,594	3,012,263	1,505,961	

Example: State B_1(1.0), Action A_1(1.0)

a. Maximum Potential Gain (MPG) = [595(.95)·300,400·.15]
= $29,470,165 (100% Expansion)

b. Maximum Potential Dollar Loss (MPDL) = $[1-(.90\cdot(.90\cdot.92)\cdot(.90\cdot.92)\cdot(.92\cdot.92)^2]$
·[595(.95)·.98]·300,400·.15
= $[1-(.524776)^2]\cdot[553]\cdot300{,}400\cdot.15$
= [1-.28]·[553·300,400·.15]
= .72·553·300,400·.15
= $17,941,089 (100% Expansion)

c. Minimum Potential Gross Gain (MPGG) = MPG-MPDL
= $7,529,076 (100% Expansion)

Table 13.--Quadratic Loss Function Analysis of the Alleppo Test Site Showing Maximum Potential Gain, Maximum Potential Dollar Loss, and Minimum Potential Gross Gain

State	Action: $A_1(1.0)$	$A_2(.75)$	$A_3(.50)$	$A_4(.25)$	
$B_1(1.0)$	31,961,709	23,971,281	15,980,054	7,990,427	MPG[a]
	21,085,042	15,813,781	10,542,521	5,271,260	MPDL[b]
	10,876,667	8,157,500	5,438,333	2,719,167	MPGG[c]
$B_2(.95)$	30,363,623	22,772,717	15,181,811	7,590,906	
	20,030,789	15,023,091	10,015,394	5,007,697	
	10,332,834	7,749,626	5,166,417	2,583,209	
$B_3(.90)$	28,765,538	21,574,153	14,382,769	7,191,385	
	18,796,537	14,232,402	9,488,269	4,744,134	
	9,789,001	7,341,751	4,894,500	2,447,250	
$B_4(.85)$	27,167,452	20,375,589	13,583,726	6,791,863	
	17,922,285	13,441,713	8,961,143	4,480,571	
	9,245,167	6,933,876	4,622,583	2,311,292	
$B_5(.80)$	25,569,367	19,177,025	12,784,683	6,392,342	
	16,868,033	12,651,024	8,434,017	4,217,008	
	8,701,334	6,526,001	4,350,666	2,175,334	

Example: State $B_1(1.0)$, Action $A_1(1.0)$

a. Maximum Potential Gain (MPG) = [587(.95)·382,100·.15]
= $31,961,709 (100% Expansion)

b. Maximum Potential Dollar Loss (MPDL) = $[1-((.90\cdot.92)\cdot.92\cdot.90\cdot.92\cdot.90)^2]\cdot[587(.95)\cdot.97]\cdot382,100\cdot.15$
$= 1-(.569)^2\cdot541\cdot382,100\cdot.15$
$= .68\cdot541\cdot382,100\cdot.15$
= $21,085,042 (100% Expansion)

c. Minimum Potential Gross Gain (MPGG) = MPG-MPDL
= $10,876,667 (100% Expansion)

Table 14.--Quadratic Loss Function Analysis of the Hasseke Site Showing Maximum Potential Gain, Maximum Potential Dollar Loss, and Minimum Potential Gross Gain

State	$A_1(1.0)$	$A_2(.75)$	$A_3(.50)$	$A_4(.25)$	
$B_1(1.0)$	46,913,408	35,185,056	23,456,704	11,728,353	MPG[a]
	22,398,306	16,798,729	11,199,153	5,599,576	MPDL[b]
	24,515,102	18,386,327	12,257,551	6,128,776	MPGG[c]
$B_2(.95)$	44,567,737	33,425,802	22,283,868	11,141,934	
	21,278,390	15,958,792	10,639,195	5,319,597	
	23,289,347	17,467,010	11,644,673	5,822,337	
$B_3(.90)$	42,222,067	31,666,550	21,111,033	10,555,516	
	20,158,475	15,118,856	10,079,237	5,039,618	
	22,063,592	16,547,694	11,031,796	5,515,898	
$B_4(.85)$	39,876,396	29,907,297	19,938,198	9,969,099	
	19,038,560	14,278,920	9,519,280	4,759,640	
	20,837,836	15,628,377	10,418,918	5,209,459	
$B_5(.80)$	37,530,726	28,148,044	18,765,363	9,382,681	
	17,918,644	13,438,983	8,959,322	4,479,661	
	19,612,082	14,709,061	9,806,041	4,903,020	

Example: State $B_1(1.0)$, Action $A_1(1.0)$

a. Maximum Potential Gain (MPG) $= [527(.95)\cdot 624{,}700\cdot .15]$
$= \$46{,}913{,}408$ (100% Expansion)

b. Maximum Potential Dollar Loss (MPDL) $= [1-(.90\cdot .90\cdot .92\cdot .92)^2]\cdot[527(.95)\cdot .90]\cdot 624{,}700\cdot .15$
$= [1-(.68558)^2]\cdot[451]\cdot 624{,}700\cdot .15$
$= .53\cdot 451\cdot 624{,}700\cdot .15$
$= \$22{,}398{,}306$ (100% Expansion)

c. Minimum Potential Gross Gain (MPGG) = MPG-MPDL
$= \$24{,}515{,}102$ (100% Expansion)

Swedia. The Alleppo site, however, is 27% larger than the Swedia. To compare how much of the MPGG difference was due to the overall precision levels, .28 for Swedia and .47 for Alleppo, and how much was due to area, the Swedia MPDL was calculated using the area and yield values for Alleppo. The MPGG for Swedia became $16,485,521 or 67% less MPGG than the Alleppo area, thus, a 19% difference in overall precision could result in a potential loss of $8,028,581.

The same procedures were used to compare Swedia versus Alleppo and Alleppo versus Hasseke. The results were:

1. Swedia, using Alleppo data = $9,636,371 MPGG or 11.4% difference, or $1,240,296 for a 4% difference in overall precision.
2. Alleppo, using Hasseke data = $18,175,959 MPGG or 26% difference, or $6,339,143 for a 15% difference in overall precision.

Probability of Moisture Occurrence

To better establish the risk in commercial value the decision maker would face in taking any one action, the probability of moisture occurring at each State was introduced. The MPGG values were multiplied by the probability of moisture occurrence. The resultant value represents the adjusted minimum potential net gain to be expected from any future Action based on a 20 year record. The procedure is illustrated for each test site in Tables 15, 16, and 17. Normally, 35 years of data is considered the minimum to estimate these variations (refer to Ward, 1967). However, in this instance

Table 15.--Minimum Potential Gross Gains (MPGG) Adjusted by the Probability of Moisture Occurrence for the Swedia Site by Each State and Action.

%Ppt Occurrence	State	Action $A_1(1.0)$	$A_2(.75)$	$A_3(.50)$	$A_4(.25)$
50	$B_1(1.0)$	3,764,538	2,823,223	1,882,482	941,134*
10	$B_2(.95)$	715,262	536,412	357,671	178,815
10	$B_3(.90)$	677,617	508,201	338,861	169,411
0	$B_4(.85)$	0	0	0	0
5	$B_5(.80)$	301,163	225,880	150,613	75,299
25**	$B_6(0)$	0	0	0	0
	MPGG =	5,458,580	4,093,716	2,729,627	1,364,659***

*All reported values are in U.S. dollars, based on 1977 official exchange rates.

**25% of the recorded Ppt values were less than 80% of the overall mean value for a 20 year record. State B_6 was added to represent this percentage and B_6 was given a value 0 to represent 0 potential commercial return. The crops produced during these periods were assumed to be sufficient only for local consumption.

***MPGG = $B_1(.50) + B_2(.10) + B_3(.10) + B_4(0) + B_5(.05) + B_6(.25)$.

Table 16.--Minimum Potential Gross Gains (MPGG) Adjusted by the Probability of Moisture Occurrence for the Alleppo Site by Each State and Action.

%Ppt Occurrence	State	Action $A_1(1.0)$	$A_2(.75)$	$A_3(.50)$	$A_4(.25)$
55	$B_1(1.0)$	5,982,167	4,486,625	2,991,083	1,495,542*
10	$B_2(.95)$	1,033,283	774,962	516,641	258,320
0	$B_3(.90)$	0	0	0	0
0	$B_4(.85)$	0	0	0	0
0	$B_5(.80)$	0	0	0	0
35**	$B_6(0)$	0	0	0	0
	MPGG =	7,015,450	4,251,587	3,507,724	1,753,862***

*All reported values are in U.S. dollars, based on 1977 official exchange rates.

**35% of the recorded Ppt values were less than 80% of the overall mean value for a 20 year record. State B_6 was added to represent this percentage and B_6 was given a value 0 to represent 0 potential commercial return. The crops produced during these periods were assumed to be sufficient only for local consumption.

***MPGG = $B_1(.55) + B_2(.10) + B_3(0) + B_4(0) + B_5(0) + B_6(.35)$.

Table 17.--Minimum Potential Gross Gains (MPGG) Adjusted by the Probability of Moisture Occurrence for the Hasseke Site by Each State and Action.

%Ppt Occurrence	State	$A_1(1.0)$	Action $A_2(.75)$	$A_3(.50)$	$A_4(.25)$
35	$B_1(1.0)$	8,580,285	6,435,214	4,290,153	2,145,072*
10	$B_2(.95)$	2,328,935	1,746,701	1,164,467	582,234
10	$B_3(.90)$	2,206,359	1,654,769	1,103,180	551,590
10	$B_4(.85)$	2,083,783	1,562,834	1,041,892	520,946
5	$B_5(.80)$	980,604	735,453	490,302	245,151
30**	$B_6(0)$	0	0	0	0
	MPGG =	16,179,966	12,134,971	8,089,984	4,044,993***

*All reported values are in U.S. dollars, based on 1977 official exchange rates.

**30% of the recorded Ppt values were less than 80% of the overall mean value for a 20 year record. State B_6 was added to represent this percentage and B_6 was given a value 0 to represent 0 potential commercial return. The crops produced during these periods were assumed to be sufficient only for local consumption.

***MPGG = $B_1(.35) + B_2(.10) + B_3(.10) + B_4(.10) + B_5(.05) + B_6(0)$.

the available 20 year cycle (1958-1977) was used to illustrate the procedure.

Monetary Risk

The previous three tables (15-17) would allow a Syrian decision maker to determine the percentage chance (potential risk) of no commercial crop associated with each Action. Based on the probability of a wheat crop versus no commercial crop for Swedia, the chance or risk of no MPGG was 25% (B_6) with a potential average yearly return of $5,458,580 (100%). The risk of no commercial crop in the Alleppo region was 35% with a potential average yearly return of $7,015,450. The 10% greater risk of no commercial crop in the Alleppo site represented a $1,556,870 greater potential of an average yearly return, or $31,137,400 over 20 years (total value not discounted). The difference in risk of no commercial crop between the Swedia site and the Hasseke site was 5% for the 20 year period. The 5% additional risk of no commercial crop, however, carried a $10,721,386 greater potential of an average yearly return or $214,427,720 based on the 20 year record (total value not discounted).

Based on this information alone the Syrian decision maker would conclude that the least risk of no commercial crop would be the Swedia site, while the largest MPGG would come from the Hasseke site. Yet, the decision maker would be basing this decision on a yield estimate with an overall model precision of 28% for Swedia.[2]

When overall model precision levels (Tables 12-14) were multiplied by the percentages of Ppt occurrence (Tables 15-17), the overall confidence in the estimate became .28 (.75) = 21% for Swedia, .32 (.65) = 20.8% for Alleppo, and .43 (.70) = 32.9% for Hasseke (Wonnacott and Wonnacott, 1972, Bayesian analysis). Expanding into the Swedia test site presented the least risk in the overall estimate with the highest MPGG.

Expansion Site

Expansion into the Hasseke site best fulfills the common utility function of the Syrian Agriculture Sector, "To provide an estimate of the utility associated with identifying potential wheat expansion areas to increase wheat revenue with the highest potential return and the least risk." The Syrian farmers' common utility function, "To provide an estimate of the utility associated with identifying wheat expansion areas to increase wheat revenue with the highest return and the least risk," would also best be satisfied by acquiring land in the Hasseke site.

The decision maker must also answer which Action(s) should be taken. To determine this, the cost of production, harvest, and the analysis must be considered with respect to MPGG and the yearly Agricultural Ministry's budget.

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[2]Model Precision

$$\begin{aligned} &= [.90\cdot(.90\cdot.92)\cdot(.90\cdot.92)\cdot(.90\cdot.92)]^2 \\ &= (.524776)^2 \\ &= .28 \end{aligned}$$

Cost Versus MPGG

Production costs and returns per 100 kilograms for the 1976-77 rainfed wheat crop in northeastern Syria were:

Variable Costs	$ 6.75 (U.S.)
Family Labor (planting and harvest)	.45
Total Cost	$ 7.20
Value of Wheat (supported price)	$15.00
Net Earnings	$ 7.80

Sixty percent of the variable costs were accounted for in seed and power costs (animal and tractor). Hired labor and fertilizers accounted for another 20% and 20% was spread over new equipment, repairs, etc.

The mean yearly wheat yield for the Hasseke site adjusted by potential reporting error was 501 kilograms of wheat per hectare. The total costs per hectare became $36.07, while the total net earnings were $39.08.

The total costs of conducting the analysis of the study sites was based on a breakdown of actual CRIES expenditures for the remote sensing, computer, digitizing, materials, and personnel during the Syrian project (1978-1980). The condensed budget, as it would reflect this project, was:

Salaries and Wages	
Investigator (100%)	$ 30,000
Interpretation (100%)	25,000
Computer Programmer (75%)	18,750
Cartographer (50%)	12,500
Secretarial Support (75%)	9,000
Subtotal	$ 95,250

Fringe Benefits (18%)	$ 17,145
Subtotal	$112,395
<u>Travel, Transportation and Per Diem</u>	
Two, four-week TDY's for two (air fare, P.D., misc.)	$ 9,600
<u>Materials</u>	
Landsat imagery (from Italy), diazo film, equipment rental, mapping supplies and miscellaneous	$ 6,000
Total Direct Cost/Year	$127,995
Indirect Cost (21%)	$ 26,879
Total Adjusted Project Cost	$154,874

The total cost of the analysis per hectare for all three test sites combined was:

$154,874/1,307,200 hectares = $ .12 per hectare

The adjusted minimum potential net gain (MPNG) per hectare in the Hasseke site was $7.80 - .12 = $7.68 or 51.2% of the government supported price. To determine what the actual MPNG for each State and Action would be, the total costs of production were subtracted from the MPGG reported in Table 17 (Table 18).

By subtracting the total MPNG values in Table 18 from the MPGG values in Table 17, the total cost for each Action excluding the expenditures during periods when only subsistence crops were recorded, was determined: A_1 = 7,766,385; A_2 = 5,824,787; A_3 = 3,883,194; A_4 = 1,941,598. The percentage return on expenditures was 8%.

Table 18.--Minimum Potential Net Gains (MPNG) Minus the Variable and Analysis Costs for the Hasseke Site.

State	Action: A_1(1.0)	A_2(.75)	A_3(.50)	A_4(.25)
B_1(1.0)	4,461,748	3,346,311	2,230,874	1,115,437
B_2(.95)	1,211,046	908,284	605,523	302,761
B_3(.90)	1,147,306	860,479	573,653	286,836
B_4(.85)	1,083,567	812,675	541,783	270,892
B_5(.80)	509,914	382,435	254,957	127,478
*Total MPNG =	8,413,581	6,310,184	4,206,790	2,103,395

*Example: Action 1 Value of Net Earnings per 100 kilograms of wheat $7,80/15 = .52;

MPNG = .52 (8,580,285) + .52 (2,328,935) + .52 (2,206,359) + .52 (2,083,783) + .52 (980,604) + .52 (0)

State values used in the equation are the MPGG values from Table 17.

Action Versus Budget

The question of which Action the decision maker should take became one of how large the agricultural sector's yearly budget would be. If the Syrian government provides money for both the total variable costs of planting and harvesting, plus a guaranteed wheat price, the government must have reserves large enough to pay both the MPG and the MPGG. Based on the analysis, the minimum reserves needed are reported as MPGG values in Table 18 and the maximum would be the MPG values reported in Table 14.

At $15 per kilogram, Action 1 would require risking $16,179,966 (MPG) to $46,913,408 (MPGG); Action 2, $12,134,971 to $35,185,056; Action 3, $8,089,984 to $23,956,704; and Action 4, $40,044,993 to $16,728,352. However, if the government just opened the land and let the farmers bear the risk for the total expenditures, the government would only be responsible for the guaranteed wheat price. The minimum reserves required are reported as MPNG values in Table 18, while the maximum reserves needed were calculated by multiplying the MPG values in Table 14 by the percentage of net return per kilogram of wheat (.52). Action 1 would require a minimum of $8,413,581 to $24,394,972; Action 2, $6,310,184 to $18,296,229; Action 3, $4,206,790 to $12,197,486; and Action 4, $2,103,395 to $6,098,743. Obviously, a careful analysis of world market prices for wheat would have to accompany the yearly setting of the government's supported price for wheat.

Information Value

The information value was measured as the difference between the total MPGG (Table 14) and the total adjusted MPNG (Table 18) or the potential loss from overestimating the net gains from a given Action. The information value for each Action, based on the 20 year period, was calculated by subtracting the potential returns from the costs of production and analysis (Table 19).

Under each Action the decision maker would have anticipated a 50% higher return if the variability in the precision levels were not considered. By utilizing the adjusted MPNG values based on a 20 year probability of occurrence, a future plan of action could be determined with a more realistic potential return value.

The Syrian government could use this procedure to regionalize the country's best potential agricultural areas. By grouping crops such as wheat, barley, lentils, etc., yield equations and quadratic loss functions could be run to determine where the highest yield potentials could be expected. Minimum potential net gain values could be derived for each crop grouping. The MPNG values could then be used to determine the minimum farm acreage allotment needed to produce the median or subsistence income. By running different simulations of this procedure, those regions offering the highest MPNG could be prioritized for development. Those regions having marginal MPNG values for subsistence incomes could be prioritized with the highest ranking going to those regions

Table 19.--Information Value Using Variable Precision Data to Delineate Wheat Expansion Areas in the Hasseke Site.

State	Action A_1(1.0)	A_2(.75)	A_3(.50)	A_4(.25)	
B_1(1.0)	8,538,240	6,403,680	4,269,120	2,134,560	Total Maximum Potential Gain
	4,461,748	3,346,311	2,230,874	1,115,437	Adjusted Maximum Potential Net Gain
	4,076,492	3,057,369	2,038,246	1,819,123	Information Value
B_2(.95)	2,317,522	1,738,141	1,158,761	579,380	
	1,211,046	908,284	605,523	302,761	
	1,106,476	829,857	553,238	276,619	
B_3(.90)	2,195,547	1,646,660	1,097,773	548,887	
	1,147,306	860,479	573,653	286,826	
	1,048,241	786,181	524,120	262,061	
B_4(.85)	2,073,572	1,555,179	1,036,786	518,393	
	1,083,567	812,675	541,783	270,892	
	990,005	742,504	495,003	247,501	
B_5(.80)	975,799	731,849	487,899	243,950	
	509,914	382,435	254,957	127,478	
	465,885	349,414	232,942	116,472	
	7,687,099	5,765,325	2,843,549	2,721,776	*Total Value by Action

*All values reported in U.S. dollars.

needing further study with the potential of returning study costs.

The break down of regions using this procedure could also be the basis for developing new agricultural tax assesments based on the MPNG or the MPGG values. Needs in regional marketing and transportation networks could also be compared to the various simulations of crop groups and MPNG values. However, caution should be used in applying this procedure beyond the regional level it was designed for without re-evaluating the precision of the independent variables needed to make the yield estimate. Soils, for example, should be reassessed at each level to determine their significance to the overall yield equations.

CHAPTER V

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE RESEARCH

The purpose of this research was to investigate the value of information derived from using variable precision data to delineate potential wheat expansion areas in Syria. To illustrate the value of the information derived, three objectives were formulated.

The _first objective_ was to identify potential areas suitable for wheat production within three Syrian test sites using remote sensing techniques, water balance equations, and the most current soil data available. An expansion area was defined as an uncropped area (rangeland) capable of supporting a wheat crop. A multiple stepwise regression analysis was used for each test site. Soil moisture availability, precipitation, potential evapotranspiration, and the percentage of each soil within the crop producing area were used as independent variables. Wheat yield was the dependent variable. In every instance the soils data, when considered only by area composition, failed to play a significant role in the explanation of wheat yield.

The expansion areas within the test sites were then ranked according to their potential wheat production. The mean yield values from each test site were multiplied by the 1977 government supported price for wheat per kilogram to determine the potential net gains from wheat expansion.

Each variable used in the regression analysis has a potential measurement error. Consequently, it was not feasible to anticipate that the potential net gains obtained from multiplying the mean yield and the dollar value would reflect the actual gains to be derived over time. To measure what effect the variability in the precision levels among the independent variables would be, a quadratic loss function analysis was used.

The second objective was to establish the monetary risks of making wheat yield estimates using variable precision data with a quadratic loss function. Before the potential monetary losses could be calculated, five assumptions had to be made. The assumptions made in this study were considered to be appropriate at the macro level at which they were used, but the representativeness of the precision levels could vary considerably at a micro level.

The Syrian Department of Agriculture's (SDA) utility function was the "determination of potential wheat expansion areas to increase wheat revenue with the highest potential return and the least risk." To assess the SDA's utility function, four potential Actions were considered: A_1 = 100% expansion, A_2 = 75% expansion, A_3 = 50% expansion, and A_4 = 25% expansion. These four Actions were tested by five States reflecting the effects of potential reductions in the mean values of the independent variables: B_1 = no reduction, B_2 = 5% reduction, B_3 = 10% reduction, B_4 = 15% reduction, and B_5 = 20% reduction (i.e., for precipitation B_1 = 40 mm, B_2 = 38 mm, B_3 = 36 mm, B_4 = 34 mm, and B_5 = 32 mm).

The maximum potential gross gain, maximum potential net loss and the minimum potential gross gain were calculated for each Action and State. To better establish the monetary risks the Syrian decision maker would face over time, the available 20 year precipitation record was used to establish an adjusted minimum potential net gain value that represented the MPGG to be expected from any future Action based on the available record. Based on this information, the test site with least risk of no commercial crop and the highest MPGG was Hasseke. The Hasseke site also best fulfilled the Syrian Agricultural Sector's and the potential farmer's utility functions.

The third objective was to compute the monetary gains or losses associated with expansion into the test site with the highest return using 1977 dollar values. To determine what the potential gains might be, it was first necessary to establish what the costs and returns for local rainfed wheat were. Included in the costs were the variable cost, family labor, and the cost of conducting this study. The value of the wheat reflected the 1977 government supported price. The actual MPNG for each State and Action was calculated by subtracting the total costs from the adjusted MPGG (reflecting the probability of occurrence). The potential percentage return on each dollar spent by the Syrian Agricultural Sector for wheat production in the Hasseke test site was 8%.

Information Value

Information value was established by measuring the difference between the total MPG minus total costs and the total adjusted MPNG minus total costs according to the probability of occurrence. The information value equaled the potential loss from overestimating the net gains from a given Action. If the MPG was overestimated, the size of the farm allotments could be underestimated, thus, not deriving enough income to keep the farmers on the land. This would also violate the farmers' common utility function.

Recommendations for Future Research

How reliable the information should be and what the consequences are of using variable precision data to identify crop expansion areas and potential yields pose difficult questions to a decision maker. Ideally the decision maker should specify the precision level for data required for the project prior to beginning a study. By identifying a combined precision level, he has specified how large of a risk he is willing to take. This type of risk can then be quantified into monetary gains or losses.

However, the major problem in identifying crop expansion areas lies in the need for time series data to establish trends. The measurement devices set up 20 or more years ago and the resultant data do not allow a present day decision maker the luxury of being able to specify precision levels needed and the resultant risk he is willing to take.

The procedure described in this work provides a framework for establishing precision levels and the determination of monetary risks from a given decision. By calculating minimum potential net gains using a quadratic loss function for several Actions and States, the decision maker can assess several alternatives at one time. For example, for crop groupings that have particularly high national priority or high international market value, the Syrian government supported prices could be set high to induce local farmers to produce those crops. By calculating corresponding yields and MPNG values for each crop grouping (prior to growing periods) and corresponding them to the optimum yield regions, government crop support prices could be set. If dollar returns are not sufficient (too much risk), the decision maker can increase the MPNG by prioritizing the regions and collecting more primary data.

Regions prioritized for increased crop production but indicating too much risk using regional level data could have the risk reduced through further primary data collection at a more refined level. Areas with the most fertile, well drained soils could be identified through fieldwork and given a high priority. Next, areas adjacent to rivers or streams could be mapped and soil bores taken to determine the feasibility of irrigation. Once the region's area had been reduced to those sections with the highest potential, MPNG values could be recalculated for several crop groupings to determine the optimum return based on the established utility function. These MPNG values would reflect higher precision levels for moisture availability and moisture quantities in the prioritized areas.

To assess how effective this procedure actually is, it would be necessary to track the MPNG over time and compare it to the estimated MPNG. It is recommended that in similar future projects where multiphase (reconnaissance to regional to detailed) studies will be completed, that this procedure be used. Identification of independent variables for yield estimates and the required precision levels needed at each planning level would be beneficial not only to Syrian planners but also to all decision makers throughout the Middle East.

Future studies should give specific attention to the handling of soils data and its overall value as a variable in the yield equation. More attention should be given to ranking the texture of the soil as an independent variable. Comparisons to illustrate how detailed the soil mapping unit descriptions must be to be economically feasible would be extremely beneficial to international studies in underdeveloped nations, as soil mapping is extremely time consuming and costly at the semi-detailed and detailed levels. Similar comparisons need to be made concerning the type and density of meteorological stations required to provide data at an economically feasible precision level at each study level.

APPENDICES

APPENDIX A

Monthly Comparisons of Average Daily Potential Evapotranspiration
by Actual Lysimeter Readings and
the Thornthwaite, Blaney-Criddle, and Penman Empirical Methods

	J	F	M	A	M	J	J	A	S	O	N	D	Mean
Lysimeter	.05	.07	.08	.11	.20	.23	.23	.18	.14	.08	.04	.04	.12
Blaney-Criddle	.04	.04	.05	.09	.16	.23	.25	.24	.15	.07	.03	.02	.11
Penman	.03	.03	.04	.10	.17	.23	.24	.23	.17	.08	.03	.01	.11
Thornthwaite	.02	.02	.03	.07	.12	.16	.17	.16	.12	.06	.02	.01	.08

Based on work by McGuinness, J.L. and Bordne, E.F., 1972.

APPENDIX B

Syrian Map and Map File Codes for the Soils Map

Numeric Code Used in the Computer Map File	Legend Symbol on the 1:500,000 Display Maps	Description
1	AXRc H/LS	Lithic Rhodoxeralfs and associated soils from limestone on hilly topography.
2	AXRc M/LS	Lithic Rhodoxeralfs and associated soils from limestone on mountains.
3	DOAh H/LS	Lithic Camborthids and associated soils from limestone on hilly topography.
4	DOAh HD/LS	Lithic Camborthids and associated soils from limestone on maturely dissected plains.
5	DOAh R/LS	Lithic Camborthids and associated soils from limestone on rolling plains.
6	DOAh S/LS	Lithic Camborthids and associated soils from limestone on steeply sloping hills and escarpments.
7	DOAh U/LS	Lithic Camborthids and associated soils from limestone on undulating plains.
8	DOGa H/TS	Typic Gypsiorthids and associated soils from weakly consolidated sedimentary rocks on hilly topography.

Appendix B (cont'd.)

Numeric Code Used in the Computer Map File	Legend Symbol on the 1:500,000 Display Maps	Description
9	DOGa HD/TS	Typic Gypsiorthids and associated soils from weakly consolidated sedimentary rocks on maturely dissected plains.
10	DOGa L/TS	Typic Gypsiorthids and associated soils from weakly consolidated sedimentary rocks on level plains.
11	DOGa R/TS	Typic Gypsiorthids and associated soils from weakly consolidated sedimentary rocks on rolling plains.
12	DOGa U/TS	Typic Gypsiorthids and associated soils from weakly consolidated sedimentary rocks on undulating plains.
13	DOGb L/TS	Calcic Gypsiorthids and associated soils from weakly consolidated sedimentary rocks on level plains.
14	DOGb U/TS	Calcic Gypsiorthids and associated soils from weakly consolidated sedimentary rocks on undulating plains.
15	DOGd L/TS	Petrogypsic Gypsiorthids and associated soils from weakly consolidated sedimentary rocks on level plains.
16	DOGd R/TS	Petrogypsic Gypsiorthids and associated soils from weakly consolidated sedimentary rocks on rolling plains.

Appendix B (cont'd.)

Numeric Code Used in the Computer Map File	Legend Symbol on the 1:500,000 Display Maps	Description
17	DOGd U/TS	Petrogypsic Gypsiorthids and associated soils from weakly consolidated sedimentary rocks on undulating plains.
18	DOLa R/LS	Typic Calciorthids and associated soils from limestone on rolling plains.
19	DOLa U/B	Typic Calciorthids and associated soils from basalt on undulating plains.
20	DOLa U/LS	Typic Calciorthids and associated soils from limestone on undulating plains.
21	DOLe L/LS	Lithic Calciorthids and associated soils from limestone on level plains.
22	DOLe R/LS	Lithic Calciorthids and associated soils from limestone on rolling plains.
23	DOLe U/LS	Lithic Calciorthids and associated soils from limestone on undulating plains.
24	DOPa L/LS	Typic Paleorthids and associated soils from limestone on level plains.
25	DOPa U/LS	Typic Paleorthids and associated soils from limestone on undulating plains.

Appendix B (cont'd.)

Numeric Code Used in the Computer Map File	Legend Symbol on the 1:500,000 Display Maps	Description
26	EFHg L/A	Xeric Torrifluvents and associated soils from alluvium on level plains.
27	EFXa L/A	Typic Xerofluvents and associated soils from alluvium on level plains.
28	EOHa L/L	Typic Torriorthents and associated soils from loess on level to gently sloping plains.
29	EOHa L/U	Typic Torriorthents and associated soils from unconsolidated materials on level to undulating plains.
30	EOHa U/U	Typic Torriorthents and associated soils from unconsolidated materials on undulating plains.
31	EOHc H/B	Lithic Torriorthents and associated soils from basalt on hilly topography.
32	EOHc H/LS	Lithic Torriorthents and associated soils from limestone on hilly topography.
33	EOHc HD/LS	Lithic Torriorthents and associated soils from limestone on maturely dissected plains.
34	EOHc L/B	Lithic Torriorthents and associated soils from basalt on level to undulating plains.
35	EOHc R/B	Lithic Torriorthents and associated soils from basalt on rolling plains.

Appendix B (cont'd.)

Numeric Code Used in the Computer Map File	Legend Symbol on the 1:500,000 Display Maps	Description
36	EOHc U/B	Lithic Torriorthents and associated soils from basalt on rolling plains.
37	EOHk L/U	Xeric Torriorthents and associated soils from unconsolidated materials on level plains.
38	EOHk R/U	Xeric Torriorthents and associated soils from unconsolidated materials on rolling plains.
39	EOHk U/U	Xeric Torriorthents and associated soils from unconsolidated materials on undulating plains.
40	EOXa L/U	Typic Xerorthents and associated soils from unconsolidated materials on level plains.
41	EOXd H/CH	Lithic Xerorthents and associated soils from marl on hilly topography.
42	EOXd L/LS	Lithic Xerorthents and associated soils from limestone on level plains.
43	EOXd R/B	Lithic Xerorthents and associated soils from basalt on rolling plains.
44	EOXd S/B	Lithic Xerorthents and associated soils from basalt on steep hills.
45	EOXv L/LS	Xerorthents, lithic vertic phase and associated soils from limestone on level to undulating plains.

Appendix B (cont'd.)

Numeric Code Used in the Computer Map File	Legend Symbol on the 1:500,000 Display Maps	Description
46	EOXv R/LS	Xerorthents, lithic vertic phase and associated soils from limestone on undulating plains.
47	EOXv U/LS	Xerorthents, lithic vertic phase and associated soils from limestone on undulating plains.
48	EOXv R/B	Xerorthents, lithic vertic phase and associated soils from basalt on rolling topography.
49	EOXv H/LS	Xerorthents, lithic vertic phase and associated soils from limestone on hilly topography.
50	EOXv U/B	Xerorthents, lithic vertic phase and associated soils from basalt on undulating plains.
51	IAHa L/U	Typic Haplaquepts and associated soils from unconsolidated materials on level plains.
52	IAHb L/A	Aeric Haplaquepts and associated soils from alluvium on level plains.
53	IAHb L/CH	Aeric Haplaquepts and associated soils from marl on level plains.
54	IAHb L/D	Aeric Haplaquepts and associated soils from colluvium on level plains.
55	IASa L/A	Typic Haplaquepts and associated soils from alluvium on level plains.

Appendix B (cont'd.)

Numeric Code Used in the Computer Map File	Legend Symbol on the 1:500,000 Display Maps	Description
56	IASb L/A	Aeric Haplaquepts and associated soils from alluvium on level plains.
57	IOXa L/U	Typic Xerochrepts and associated soils from unconsolidated materials on level plains.
58	IOXa R/U	Typic Xerochrepts and associated soils from unconsolidated materials on rolling plains.
59	IOXh H/TS	Lithic Xerochrepts and associated soils from weakly consolidated materials on hilly topography.
60	IOXh R/LS	Lithic Xerochrepts and associated soils from limestone on rolling plains.
61	IOXh S/B	Lithic Xerochrepts and associated soils from basalt on steep hills.
62	IOXh S/CH	Lithic Xerochrepts and associated soils from marl on steep hills.
63	IOXh S/LS	Lithic Xerochrepts and associated soils from limestone on steep hills.
64	IOXh U/LS	Lithic Xerochrepts and associated soils from limestone on undulating plains.
65	IOXk L/U	Vertic Xerochrepts and associated soils from unconsolidated materials on level plains.

Appendix B (cont'd.)

Numeric Code Used in the Computer Map File	Legend Symbol on the 1:500,000 Display Maps	Description
66	IOXk R/U	Vertic Xerochrepts and associated soils from unconsolidated materials on rolling plains.
67	IOXk U/U	Vertic Xerochrepts and associated soils from unconsolidated materials on undulating plains.
68	VXCa L/LS	Typic Chromoxererts and associated soils from limestone on level plains.
69	VXCa L/U	Typic Chromoxererts and associated soils from unconsolidated materials on level plains.
70	VXCa R/B	Typic Chromoxererts and associated soils from basalt on rolling plains.
71	VXCa U/B	Typic Chromoxererts and associated soils from basalt on undulating plains.
72	VXCa U/LS	Typic Chromoxererts and associated soils from limestone on undulating plains.
73	VXPa L/SD	Typic Pelloxererts and associated soils from calcareous sandstone on level plains.
74	VXPa R/B	Typic Pelloxererts and associated soils from basalt on rolling plains.
75	VXPa U/B	Typic Pelloxererts and associated soils from basalt on undulating plains.

Appendix B (cont'd.)

Numeric Code Used in the Computer Map File	Legend Symbol on the 1:500,000 Display Map	Description
76	DOLe HD/LS	Lithic Calciorthids and associated soils from limestone on maturely dissected plains.
77	EOXd U/B	Lithic Xerorthents and associated soils from basalt on undulating plains.
78	EOHc S/LS	Lithic Torriorthents and associated soils from limestone on steep hills.
79	VXCa L/B	Typic Chromoxererts and associated soils from basalt on level plains.
80	EOXd R/U	Lithic Xerorthents and associated soils from basalt on rolling topography.
81	DOPa HD/LS	Typic Paleorthids and associated soils from limestone on maturely dissected plains.

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