An evaluation of satellite remote sensing for crop area estimation in the west bank, Palestine

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by

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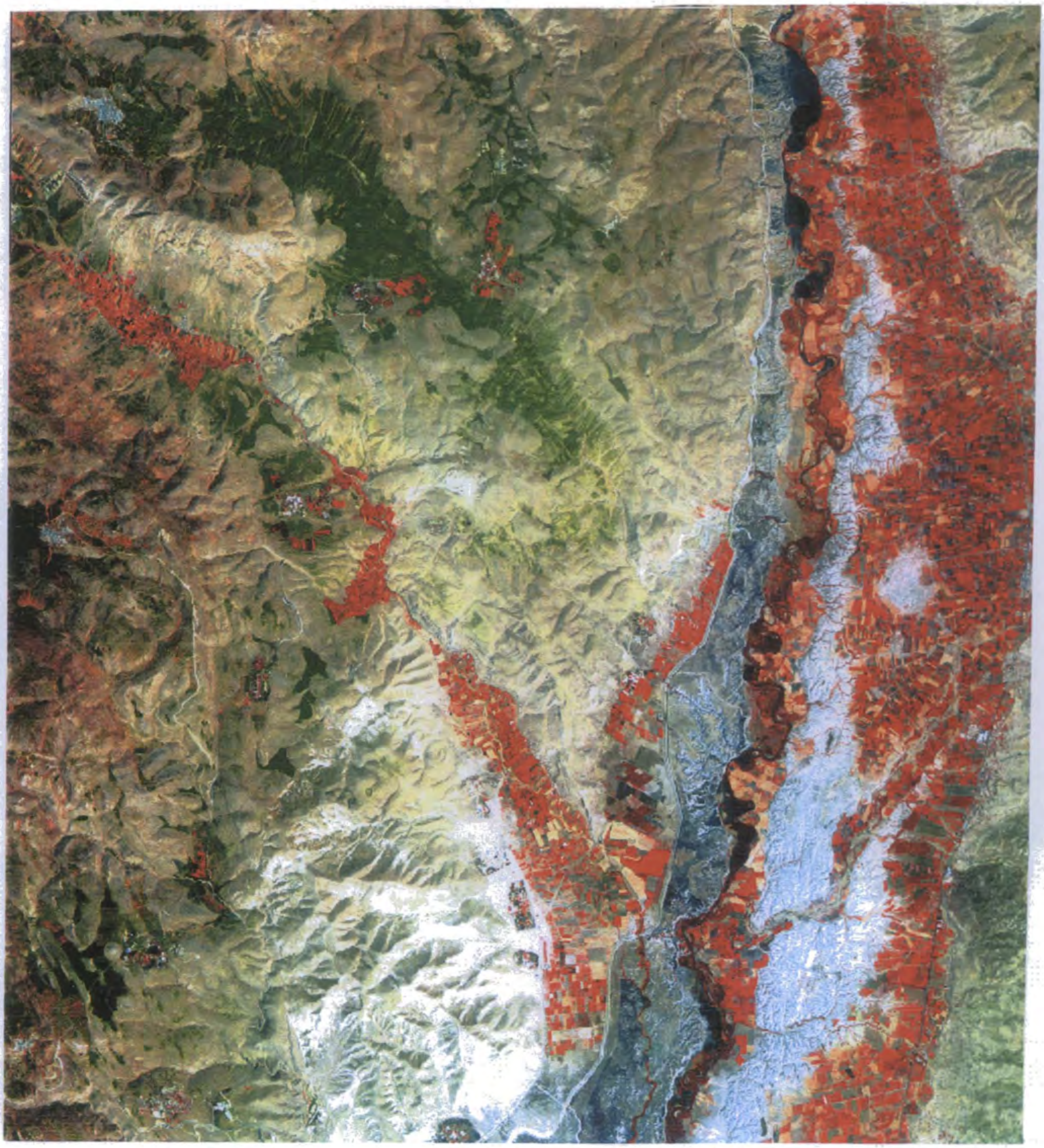
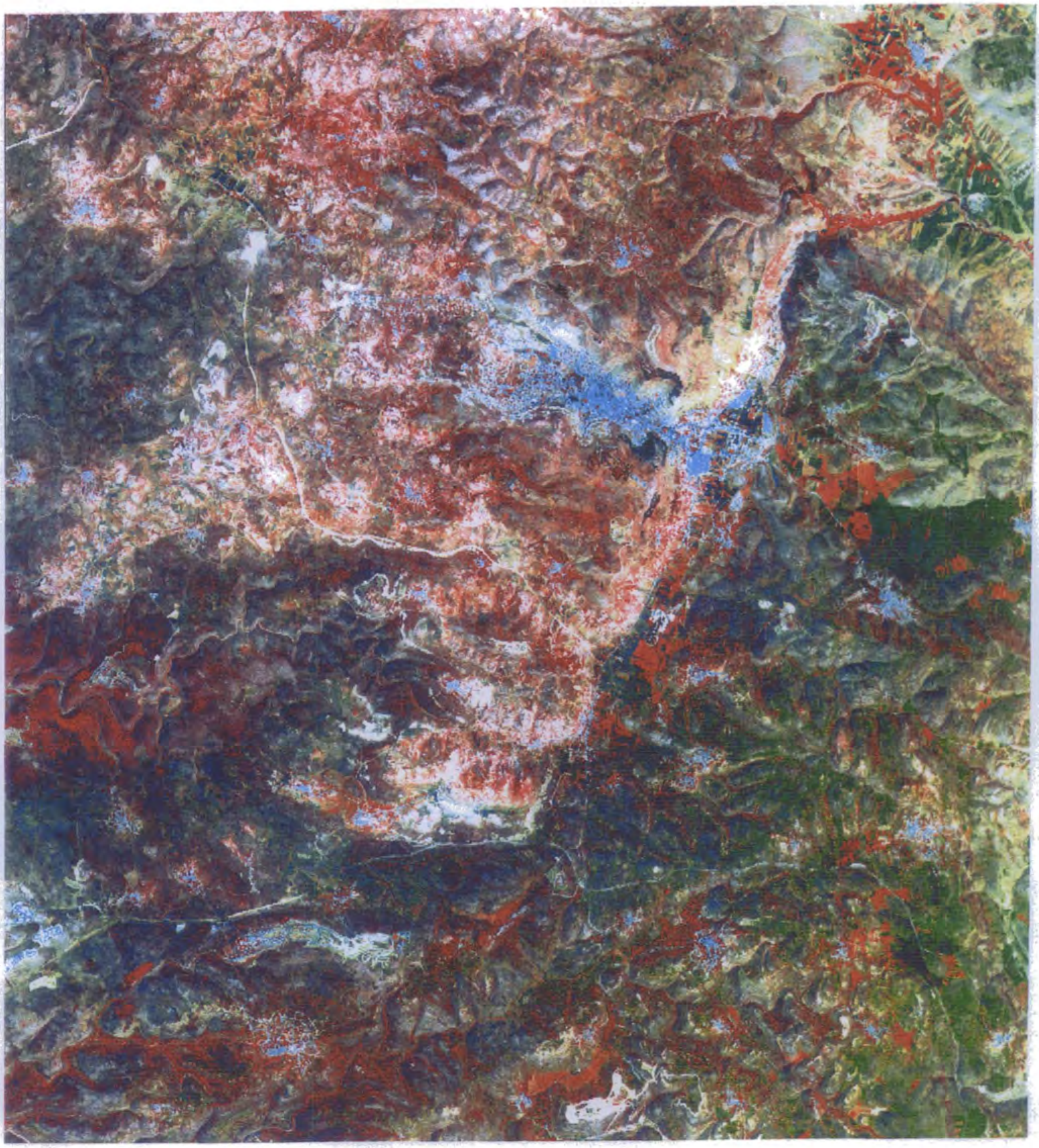
To the memory of my beloved father *SHEIKH* MUSTAFA MOHAMMAD GHODIEH, my sister SA'DA MUSTAFA GHODIEH, and my uncle *SHEIKH* IBRAHIM MOHAMMAM GHODIEH

Also to my mother, my wife Raeda, my son Qutaiba, my daughter Shatha, my sisters, my brothers and all my family



A SPOT HRV XS Enhanced Colour Composite of One of the Study Areas (the Jordan Valley).

The data obtained on May 19, 1994. This print has been produced using bands3 (0.79 – 0.89μm), 2 (0.61 – 0.68μm) and 1 (0.50 – 0.59μm).



A Pan-sharpened SPOT HRV Enhanced Colour Composite of One of the Study Areas (the Nablus Mountains).

The data obtained on May 19, 1994. This print has been produced using bands3 (0.79 – 0.89μm), Panchromatic (0.51 – 0.73μm) and 1 (0.50 – 0.59μm).

DECLARATION

The work contained in this thesis has not been submitted elsewhere for any other degree or qualification and that unless otherwise referenced it is the author's own work

The main body text (excluding references) is approximately 65,000 words in length and conforms with the word limit.

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An Evaluation of Satellite Remote Sensing for Crop Area Estimation in the West Bank, Palestine

By: AR. M. M. Ghodieh

ABSTRACT

This thesis investigates the use of field and satellite data for crop area estimation in the northern part of the West Bank, Palestine. The satellite data were obtained by the SPOT HRV on 19 May 1994. The satellite data were geometrically corrected to the Palestine Grid using 1: 50,000 Israeli topographic maps.

The study investigated the ability of SPOT HRV data to produce accurate crop area estimation of the northern part of the West Bank that is characterised with small field sizes and complex physical environment.

A land cover classification scheme appropriate to the study area was designed. Twenty three land cover classes were produced from the SPOT HRV classification. Land cover classes were developed to produce thematic land use classes. The classification accuracy obtained from SPOT HRV image classification was 81%. Classification results were assessed by using the known land use information obtained from the field during the training stage and the field sampling survey.

The study area was divided into five strata and the field survey was conducted by applying a stratified random sampling methodology. Seventy three 1 km^2 sample units were randomly chosen and surveyed by the author using maps, aerial photographs, satellite photographs, a questionnaire, camera photographs, and sketches. The field area measurements were taken and the final hectarage estimates were obtained for each crop type.

The SPOT HRV and the field data were combined in regression analysis using a double sampling method and a hectarage estimate was produced for each crop in the study area. The results obtained showed that the regression estimator was more efficient than the field estimator and a gain in precision was achieved.

The results were analysed on stratum and crop type basis. Remote sensing and thematic agricultural perspectives were used in the analysis.

Results of the study suggest that it is possible to improve image classification accuracy by using better spatial and spectral resolution imagery and the integration of remote sensing data with agricultural data using the Geographical Information Systems (GIS).

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CHAPTER ONE

INTRODUCTION

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1.1. Significance of Remote Sensing in Agricultural Studies

In the West Bank about 70% of the population live in the rural areas and basically depend on agriculture to earn their living (Applied Research Institute, 1994). Development of agriculture in the West Bank requires not only national efforts but also international efforts after the absence of national government for more than thirty years. Therefore, accurate data on agriculture in terms of crop yield, crop acreage and other relevant information are vital for decision-makers and planners. Also, governments and international organisations usually ask for accurate data on agriculture before offering aid.

Before the launch of earth resources satellites, decision makers and planners used to obtain agricultural data through traditional data collection methods such as questionnaires, field survey and aerial photography. Very often agricultural statistics have not been updated on a regular basis that would allow governments and organisations to monitor any developments and changes. Moreover, questionnaires, field survey and aerial photography data are costly, time consuming and laborious to process (Mayers, 1983). Therefore, many countries, particularly the developing countries, do not have adequate maps and data on agriculture (Parry, 1978). Lack of data on agriculture in the developing countries present a serious obstacle to economic development. For example, to start an agricultural development program in the West Bank requires data on the actual situation on the ground. These data are vital to understand and evaluate the agricultural economy and to plan for future development.

After the launch of earth resources satellites in 1972, satellite remote sensing was evaluated for its ability to provide agricultural information. The advantages of remote sensing over other traditional survey methods can be summarised as follows:

i) Remote sensing satellites acquire data on the resources of the earth including agriculture at regular time intervals. Regularity in data acquisition enables a more effective monitoring of agriculture. For example, the SPOT satellite takes images for most areas of the earth every 26 days. This means that any agricultural developments in terms of crop yields or acreage charge that occur over 26 days period can be monitored.(see chapter 4).

ii) Remote sensing satellites take images of large geographical areas. For example, a single SPOT scene covers an area of 60 × 60 km. This is equivalent to about 35 aerial photographs at 1: 50,000 scale.

iii) Planners and decision-makers like to forecast crop yields. By remote sensing it is possible to forecast crop yield before harvest time which contributes to crop price determination, and so decision makers are partially guided by these yield forecasts. A number of major research programs were established to investigate the potential of satellite remote sensing to forecast crop yields and measure acreage at both continental and regional levels. LACIE, AgRISTARS, DUTA, and MARS are examples of these agricultural programs. These are discussed in detail in chapter 3.

iv) Agriculture is highly controlled by climatic conditions. By remote sensing it is possible to monitor any dramatic climate changes and evaluate their effect on agricultural productivity. The Monitoring Agriculture with Remote Sensing project (MARS) uses meteorological data with remote sensing data for crop yield forecasts in the European Union.

The process of extracting agricultural **information** from satellite imagery is a complicated process and depends on a number of factors. These include:

i) the technical characteristics of sensors in terms of their spatial, spectral, radiometric, and temporal resolutions;

ii) the physical characteristics of the study area, including topography, geomorphology, and climate;

iii) the crop environment, and

v) the aims, techniques, and methodologies used in the study.

These issues are interrelated and should be taken into account in any agricultural image analysis.

Optical sensors such as Landsat and SPOT record the reflected radiation from objects and materials existing in the field of view of the satellite. Therefore, the recorded signal of an agricultural environment is a composition of different objects (vegetation, soil, shadow and atmospheric scattering and absorption). The intensity and spectral composition of reflected energy recorded by the sensor will depend on the atmospheric and climatic conditions during the imaging process.

The angular relationship between the sun (the main source of light), the target and the sensor, the crop conditions and environment (the growth stage, the crop density, slope and aspect) also affect the characteristics of the reflected radiation (see chapter 4).

Radar imaging systems are of two types: passive radar system and active radar system. The passive radar system records the thermal and the microwave energy emitted from objects existing in the field of view of the radar system. While the active radar system emits energy which is transmitted towards the objects of interest and scattered back to the sensors where it is recorded. The main advantage of active microwave sensing systems over the optical sensing systems is that they are not affected by cloud cover, and can gather images day or night all year round. For example, the main rice producer countries are situated in the tropics. It is difficult to ensure successful acquisition with optical imaging systems such as SPOT or Landsat because of the frequent cloud cover of this region of the earth (Ribbes & Le Toan 1999).

Despite these advantages of radar imaging systems over optical imaging systems, computer-based interpretation of radar images for crop type mapping is complicated by the presence of speckle (Schotten *et al.* 1995). Presence of speckle in radar images hampers the application of pixel-based interpretation technique. In order to reduce speckle, images are either filtered or classified on a segment basis. Image filtering or a segment-based classification may cause loss of data especially in the areas characterised by small sized fields such as the study area.

The reason for using optical remote sensing data in this study (SPOT HRV) is that the study area is cloud free for most of the year, so that the land surface can normally be sensed by optical sensors. Secondly, the spatial resolution (10 and 20 m) and the spectral resolution are adequate, and finally, radar needs multi-temporal data and is still at an experimental stage.

A study to evaluate satellite remote sensing data for its agricultural information content needs to be supported by ancillary data obtained by traditional methods such as aerial photographs, maps, reports, contextual data, and field surveys data (Harris 1981).

1.2. Statement of the Problem

Agriculture in the West Bank is the main economic sector from which the Palestinians live. About 30% of the surface area of the West Bank is devoted to agriculture and about 15% of the labour sector work in agriculture. Agriculture contributes with 30% to the Palestine gross national product (GNP). Also 25% of the Palestinian exports come from agriculture (Applied Research Institute-Jerusalem 1998 (ARIJ)).

During the last three decades the agricultural sector was exposed to many different policies from the Israeli occupation (see chapter 2). Also the political conditions under which the West Bank and Gaza Strip lives affects agriculture. For example, before 1987, some of the surplus of the West Bank agricultural production was exported to Jordan, but after 1987 Jordan imposed restrictions on its agricultural imports from the West Bank. This situation led to the disappearance of some crop types such as watermelon and so the crop type structure was affected. The repeated Israeli military closure of the West Bank also affected the agricultural sector by preventing produce from the West Bank being sold in Israel. These dramatic changes and their effects on agriculture in the West Bank need to be monitored and evaluated using a cost and time effective methodology.

The absence of reliable agricultural data and the weakness of the agricultural laws and services requires more investment in research studies in agriculture in order to be able to initiate a strategic plan for sustainable agricultural development (Ministry of Agriculture 1998).

After the Oslo agreement between Israel and the Palestinian Liberation Organisation (PLO) in 1993, when some of the agricultural responsibilities were transferred from the Israeli authorities to the Palestinian National Authority, agricultural data collection became one of the urgent matters for agricultural planning. Crop type area estimation is one of these urgent matters that the governmental and non-governmental institutions are interested in. The problem can be summarised as follows:

i) In the West Bank land use data are only available are from Israeli sources and because of the political situation in the region, the Palestinians do not trust any Israeli data. On the other hand the Palestinian data including crop type acreage are collected by means of farmer declaration to the concerned agricultural institutions. Farmers usually do not give the correct figures about their actual holdings, either because they do not know the exact areas of their fields or to avoid paying tax.

ii) The Palestinian agricultural acreage data do not take into consideration the field boundaries or the spatial distribution of the fields. For example, if someone has 10 ha divided into 5 fields, the data do not show the distribution of the fields and consider them as one field. This situation results in considerable uncertainty as to the spatial distribution of land use.

iii) In the West Bank, due to Israeli occupation, there is no possibility to update the available data by comprehensive field survey because of the difficulties in accessing of all parts of the area and the high cost of such a survey. The mountainous environment and the hot weather in summer add to the problem.

iv) The Palestinians do not have full coverage of aerial photography for the West Bank that could be used to produce agricultural land use maps. Even if these aerial photographs became available, updating the data remains a problem.

v) The valuable agricultural land in the West Bank which occupy the fertile land in the plains is threatened by urbanisation after thousands of the Palestinians came back to their homes with the Palestinian National Authority. Effective monitoring of these lands is vital.

vi) The mountainous agricultural lands that are mainly cultivated with olive and fruit trees are not paid enough attention for their relatively low productivity and the spread of Israeli settlements on the tops of these mountains.

Therefore, new techniques and methodologies are needed to create an agricultural crop database including area estimation for the West Bank. Also the existing agricultural data needs to be developed and updated.

In such complicated conditions in the West Bank, remote sensing can be a major contributor in monitoring agriculture and producing a reliable agricultural database. Since the launch of the Landsat remote sensing satellite in 1972, a revolution in data acquisition and analysis occurred. These satellites carry multispectral sensors which enable the identification and classification of different agricultural crops. Also accurate crop acreage and yield estimates can be produced with satellite remote sensing. Therefore, it is important to evaluate remote sensing in the particular environment of the West Bank to see if it can produce reliable and cost effective information.

Remote sensing satellites have different capabilities for monitoring agriculture. The spectral, radiometric, spatial, and temporal resolutions decide their capabilities. The characteristics of the area and objectives affect the choice of the most suitable sensor for agricultural monitoring. In this study because field size is small the high spatial resolution of SPOT HRV XS imagery (see chapter 4) is particularly suitable.

To maximise the outcome of the study and improve the accuracy of crop area estimates, first, crop area estimates obtained from image classification, second, crop area estimates from the field obtained using the stratified random sampling method. Third, the double sampling technique with regression analysis is applied. The double sampling method is based on a combination of remote sensing data and field survey data.

1.3. Aims of the Study

The aims of the study can be summarised as follows:

1) To investigate the ability of satellite remote sensing to produce an agricultural database for the northern part of the West Bank which can be used by decision makers for agricultural planning. Palestinians have not investigated the role of remote sensing for producing agricultural data for the study area. The only data for agriculture from Israeli and Jordanian sources. If good quality data could be produced by Palestinians, it would give decision-makers a feeling of confidence in their data.

2) To investigate the role of satellite remote sensing in producing accurate crop area estimates for the major agricultural crops grown in the study area. The available Palestinian data on crop type area is suspect because it is obtained from the individual farmers who may not give the correct information either from the lack of knowledge of the exact area or for tax avoidance.

1.4. Research Objectives

The objectives of the research study can be summarised as follows:

1) To compare area estimates obtained by field survey with that obtained by SPOT HRV XS image classification. This comparison enables the evaluation of both field survey and SPOT HRV XS results. On the other hand, sources of errors can be identified through this comparison.

2) To improve crop type acreage by combining the estimates obtained by field survey with the estimated produced by image classification. Combining the two sets of data may reduce the field sampling error on the one hand and reduce the image classification errors on the other hand.

3) To evaluate the estimates obtained from double sampling and compare it with the estimates obtained only by field survey. As one of the main objectives of the study is investigate the effectiveness of the double sampling technique in producing more accurate data, the results of the double sampling are compared with the results obtained from the field survey.

4) To learn from the results of the research for further studies in the future. As this study is the first academic Palestinian remote sensing study of agriculture in the West Bank, results of the study may help in improving the performance and the methodology of future remote sensing studies of the area.

1.5. Thesis Structure

Chapter two describes the geography and agriculture of the study area and outlines the reasons for selecting the northern part of the West Bank for detailed research. Chapter three gives a concise review of the major remote sensing agricultural programs and tries to relate the present work to that of other relevant studies. Chapter four describes in detail all sources of data used in this research project.

Chapter five evaluates SPOT HRV data for image classification and crop type area estimation. An accuracy assessment of the results is made and the image classification results are discussed.

Chapter six describes in detail the methodology used for crop area estimation using a field survey based on a stratified random sample. The statistical results are analysed and sources of error are discussed.

Chapter seven describes the methodology used for improving the field crop area estimates. A double sampling technique with regression estimates is used. Results of applying the double sampling are evaluated and compared with the results of the field survey. Chapter eight evaluates the situation of the main agricultural crops northern the West Bank and give suggestions to improve their productivity.

A summary of the main results of the study and recommendations for further future remote sensing research are outlined in chapter nine.

CHAPTER TWO

THE STUDY AREA

2.1. Introduction

2.2. Location

2.3. Geomorphology

2.4. Geology

2.5. Hydrology

2.6. Climate

2.6.1. Elements of climate

2.6.2. Climate Regions of the West Bank

2.7.Soil

2.7.1. Types of Soil in the West Bank

2.8. Agriculture

2.8.1. Factors Affect Agriculture

2.8.2. Agricultural Crops

2.9. Summary

2.1 Introduction

This chapter is devoted to the description of the study area. In section 2.2 location of the study area, its surface area and reasons for its selection are described. Sections 2.3 to 2.7 describe the physical characteristics of the study area (geomorphology, geology, hydrology, soil and climate) and their impact on agriculture. While section 2.9 is devoted to the description of the important developments of the agricultural sector in the West Bank over the past four decades.

2.2. Location

The study area represents the northern part of the West Bank (WB) of the River Jordan or 95% of the **District of Nablus** according to the Jordanian administrative division before 1967, figure 2.1. The District of Nablus consists of three sub-districts, see figure 2.2.

a) **Sub-District of Jenin:-** It lies in the extreme north of the WB. The surface area of this division is 553 Km^2 or 23.3% of the study area.

b) **Sub-District of Tulkarem:-** It lies in the north west part of the WB. Its surface area is 350 km or 14.7% of the study area.

c) **Sub-District of Nablus:-** It lies in the mid-north of the WB. Its surface area is 1582.4 km^2 or 62.93% of the study area. Available imagery covers 1470 km^2 or 93% of this sub-district and 62% of the study area. Therefore, the total surface area of the study area is 2373 km^2 or 40% of the total area of the West Bank which is 5877 km^2 including water bodies (Ennab, 1977).

The reasons for selecting the northern part of the West Bank for this study can be summarized as follows:

- Agricultural lands are concentrated in the northern part of the West Bank. About 75% of the agricultural production of the West Bank comes from this area.
- The available satellite data only covers this part because it was difficult to obtain satellite data for the entire area of the West Bank. Also, it is not possible for the Palestinians to pass through Jerusalem to reach the southern part of the West Bank to do the required field survey.
- It was possible for the author to access most parts of the study area because he lives in the central part of the northern West Bank.

To establish a good understanding of the geographical characteristics of the study area, it is essential to deal with the area as regions rather than administrative divisions and so the geographical thematic description will deal with the West Bank as one geographical unit.

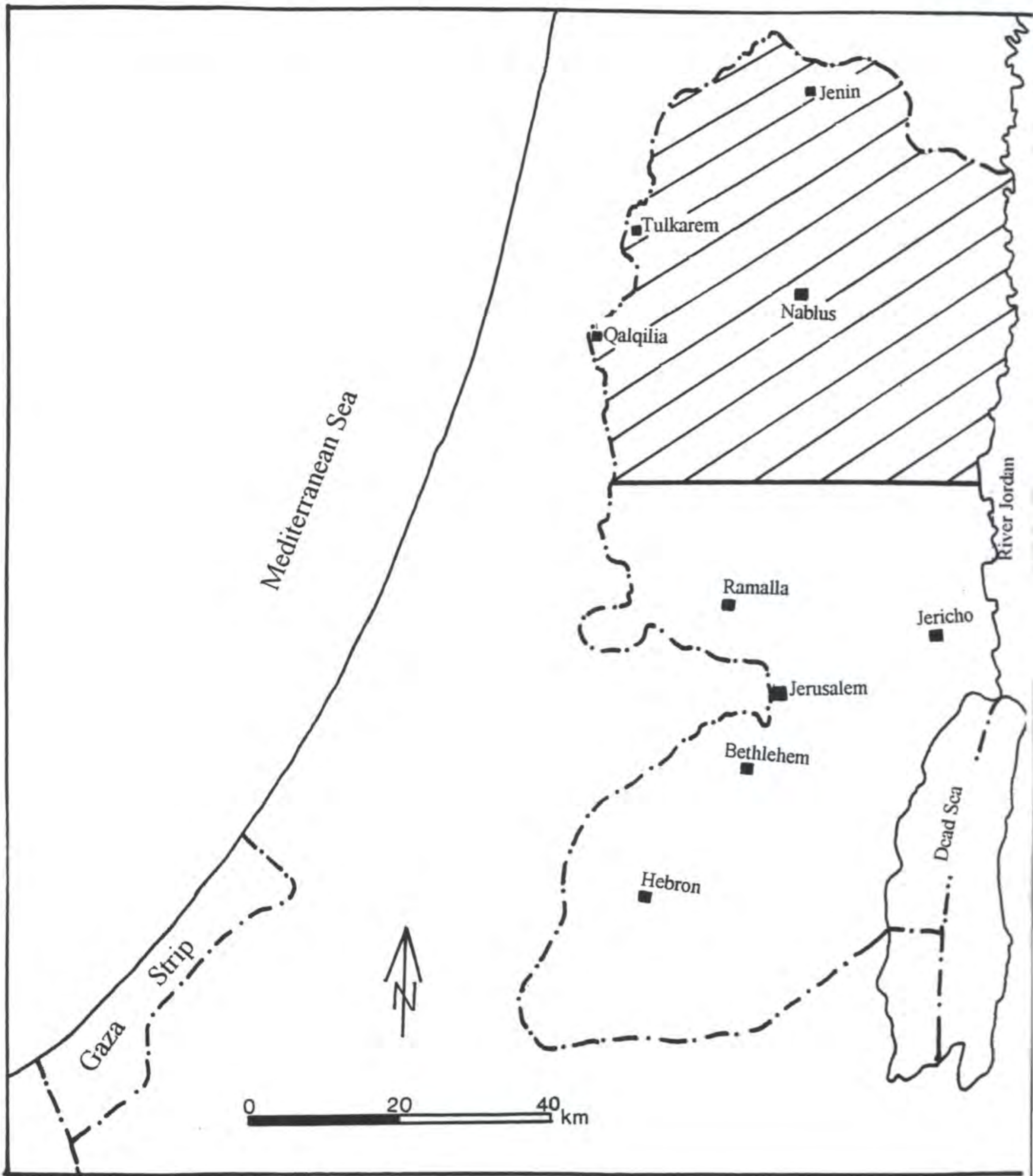


Figure (2:1): Location map of the study area

The West Bank is the area that lies between the latitudes 31° 20′ and 32° 38′ N and between the longitudes 34° 53′ and 35° 31′ E. It extends along the River Jordan for about seventy kilometers and for forty km along the western shore of the Dead Sea. While from the north, south and west it is bounded by the Jordan-Israeli Cease fire line of 1949. Although, the average width of the WB from east to west is about 40 km, it varies from one place to another. Its maximum length from north to south is around 130 km and its surface area including water of the Palestinian part of the Dead Sea is 5877 km².

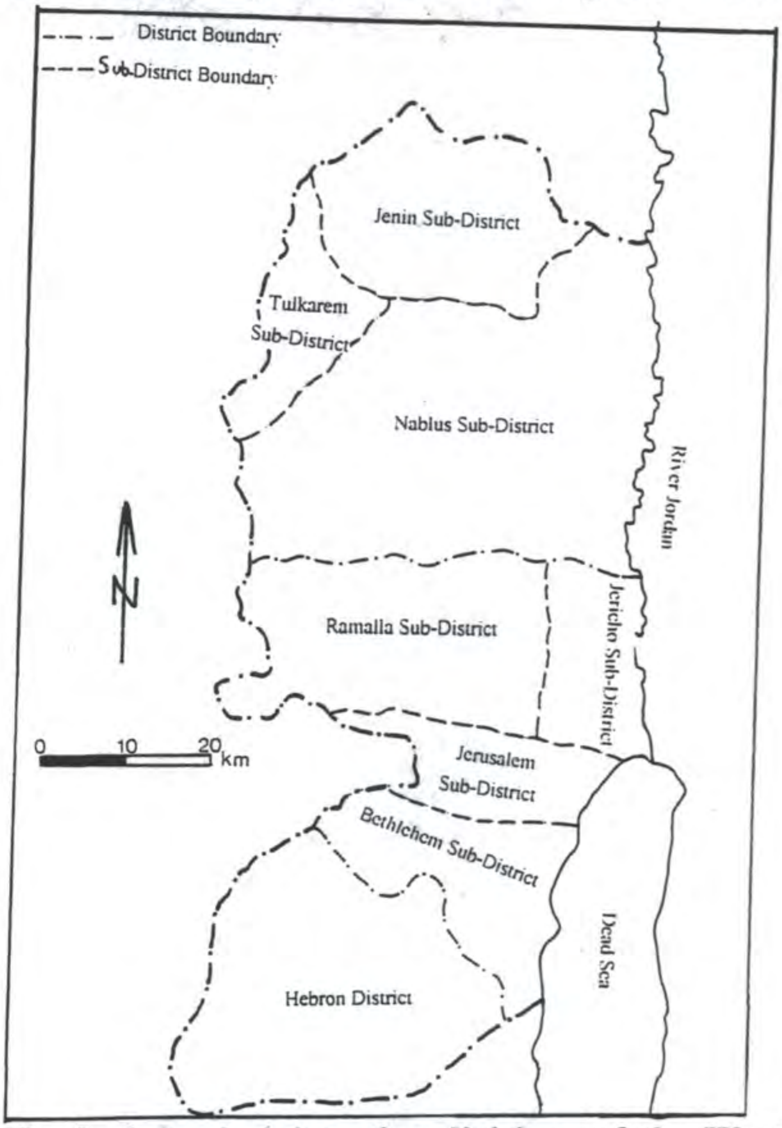


Fig (2.2): The Jordanian administrative divisions of the West Bank before 1967

Source: Atlas of Israel, 1974

2.3 Geomorphology

The landscape of the WB is dominated by mountains that trend north to south extension with the highest points around Hebron mountains in the southern part of the WB (1020m); and about 940m for the mountains of Nablus in the northern WB (figure 2.3). While these mountains descend gently to the coastal plain in the west, they are very steep and sometimes represent vertical escarpments on Al-Ghour lands (Jordan Valley).

Mountains of the WB overlook surrounding plains from four directions surrounding: They over look the Jordan Valley in the east; Marj Bin 'Amer- which lies at an elevation of about 100m above mean sea level (msl) in the north; the coastal plain in the west which in its internal margin lies at an elevation of about 100m. Hebron mountains look over the basin of Beer Al Sabe' (Negev Desert) in the south.

Benvenisti (1988) divides the WB into four geomorphological areas, which are:

a) Nablus Mountains: This area consists of hills divided by a number of wide wadis running from east to west and from north to south. The city of Nablus lies in the central part of this area between 'Eibal mountain (940m) in the north and Jerzim (880m) in the south.

The northern part of this mountainous area consists of the Jenin hills which have elevations between 300-400m. The Nablus mountains descend gradually westwards to the coastal plain and northwards to Marj Ibn 'Amer.

b) Jerusalem Mountains: These lie between the Nablus mountains in the north and the Hebron mountains in the south. The western parts of these mountains are lower than the eastern ones. From its narrow spine, deep and dry wadis descend to the west and the east. An inclined plateau extends towards the north then an anticline plateau appears with an elevation of more than 1000m above m.s.l. forming the boundary with the Nablus mountains.

c) Hebron Mountains: This plateau is moderately inclined and its width increases from 4 km near Bethlehem in the north to 20 km near Hebron in the south with elevations ranging between 700 - 1000m. The Hebron mountain is bounded from the east by the Judean desert. The eastern slopes descend precipitously towards the Syrian - African rift, and to the west; the foot of the high hills of Judea (Shphela) extend with elevations of 300 - 600 m above msl.

d) The Jordan Valley and the Dead Sea: This area lies in the eastern part of the WB, and extends to north and south to become a part of the Syrian-African Rift. In the northern part of this region land elevation is about 200m below the msl, while in the southern part and at the edge of the Dead Sea it is about 400m below the msl (the lowest area in the world).

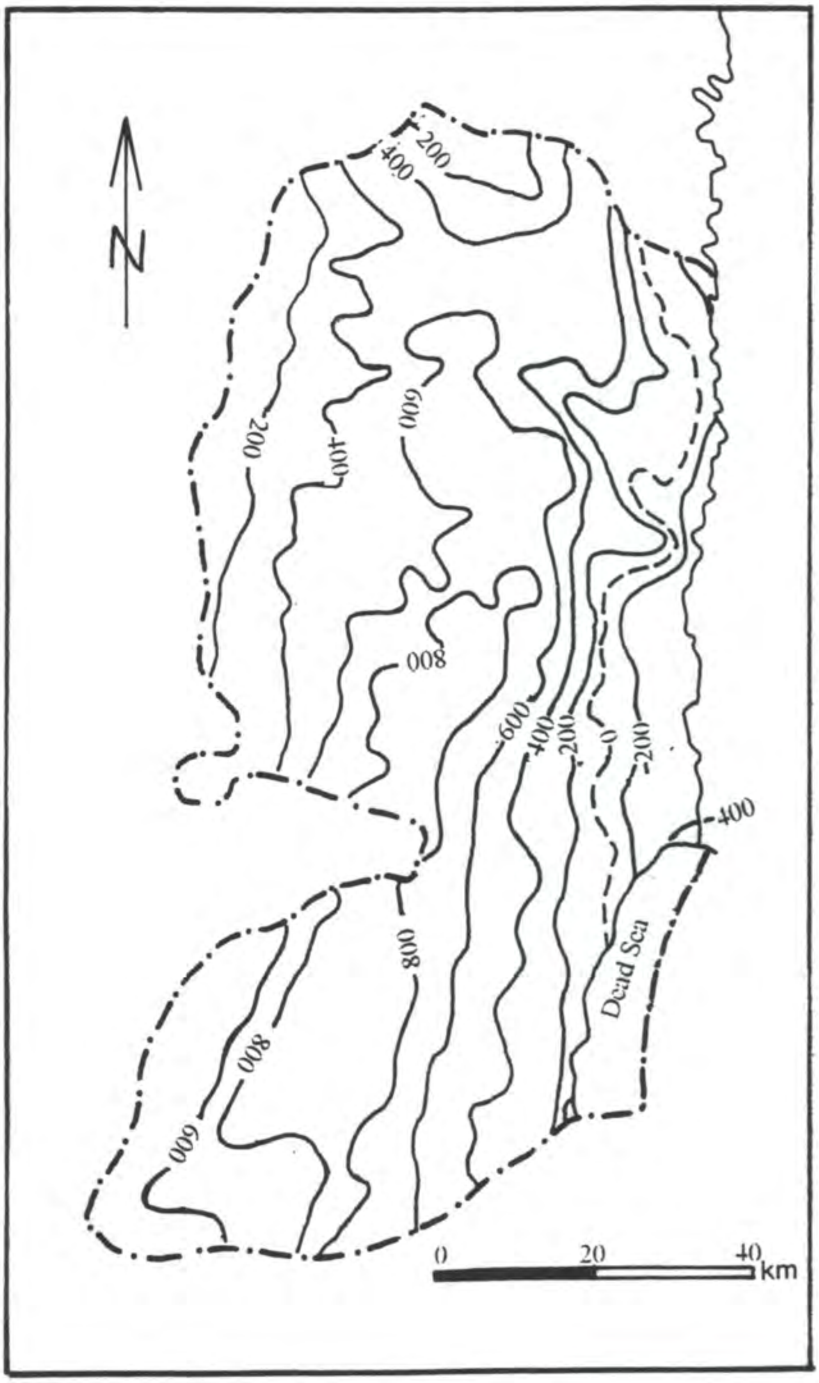


Figure (2:3): Topography of the West Bank (heights in metres)

Source: Applied Research Institute- Jerusalem (ARIJ), 1994

2.4 Geology

The geological structure of the WB is similar to those structures from the north, south and west but it is different from the east, figure 2.4. The mountains of Transjordan are of the high plateau type with synclines that together constitute the large Judean upwarp. The flanks of the anticlines of the Judean body are directed in the east towards the Dead Sea graben, and west of it towards the coastal trough (Picard, 1974).

Limestone and dolomite of the Cenomanian and the Turonian period dominates the upper parts of the mountains of Hebron and Nablus. In the low lying areas (foot of Nablus and Hebron Mountains) chalky rocks exist. These rocks date from the Cenomanian, Eocene and sometimes to Olegene and Miocene periods. While some Cretaceous basalt rocks can also be found in the mountains of Nablus (Efrat, 1973).

As the WB is far from the Nubian-Arab Shields and exists in the tectonically active area of the sea of Titus, it is dominated by marine deposits. These marine deposits are thicker than the similar deposits that exist in the south-east and south of Jordan (Bender, 1974).

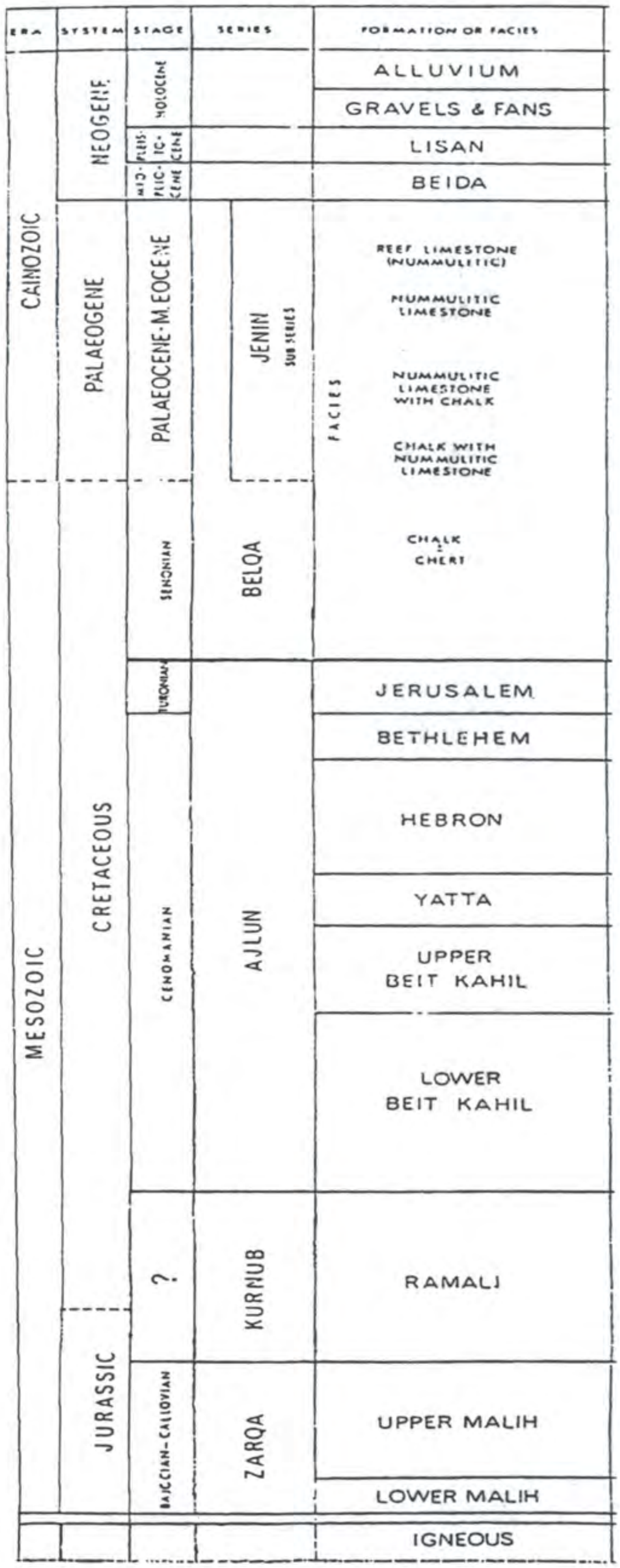


Figure (2:4): Geological formation in the West Bank

Source: Rofe anf Rafftey, 1965

2.5 Hydrology

It is too difficult to study the hydrology of the WB as an independent region of the surroundings. This is because of the fact that the drainage of its wadis is outside the Jordan-Israeli cease- fire line and so the final water basins are in Israel.

The only source of the ground water in the WB is rainfall. Rainfall levels differ from one geographical region to another. It is between 500-800 mm for the western flanks and 200-400 mm for the eastern ones, see figure 2.8.

The geology of the WB is mainly formed of sedimentary rocks (limestone and dolomite) that water can easily penetrate. In addition, cracks, carstic events, dip of strata and the graduated slope westward played a major role in increasing the amount of ground water running towards the coastal plain and the Mediterranean Sea. While for the eastern flanks, the small average annual rainfall, the steep slopes and strata inclination towards the Dead Sea and the Jordan Valley played major roles in decreasing the amount of ground water flowing eastwards.

Most wadis in the WB flow seasonally. The surface water is affected by a number of factors: - seasonality, topography and geology of the WB. The steep flanks of the Nablus mountains result in a rapid flow of drainage westwards to the Mediterranean Sea. However, the relatively dry soil and the rock type allow water to penetrate the land and feed the ground water. In addition to these factors, low temperature in winter decreases the rate of evaporation.

Due to the geological structure, many springs exist down the western flanks of the WB (more than 200). While the number of these springs does not exceed a hundred for the eastern ones, figure 2.6. These springs feed a number of wadis and can be used for irrigation during summer months. The discharge of these springs varies from one geographical area to another; table 2.1 shows the discharge of each group of the springs.

Table (2:1): Average discharge of the principal springs

a) Western drainage to Mediterranean Sea

Springs or group of springs	Average annual discharge (m.m^3)
Jenin area	0.8
N. Yarqon (basic flow)*	220
Ramalla area	0.3
Jerusalem area	0.2

* Springs in Israel are included

b) Eastern drainage to Jordan Valley and Dead Sea

Spring or group of springs	Average annual discharge (m.m³)
South Betshea'n	5
Nablus area	8
Upper Wad Fari'a	16-17
Lower Wad Fari'a	2
Wad Fuqin	0.7
'Auja	7-12
Jericho & Wad Nu'eima	12-13
Wad Qilt	5-6
Jerusalem area	2
Fashkha Saline	40
Ghuweir	10-20
Turaba	0.4-1
Hebron area	0.8
N. 'Arugot Ein Gedi	3

Source: Atlas of Israel, 1974

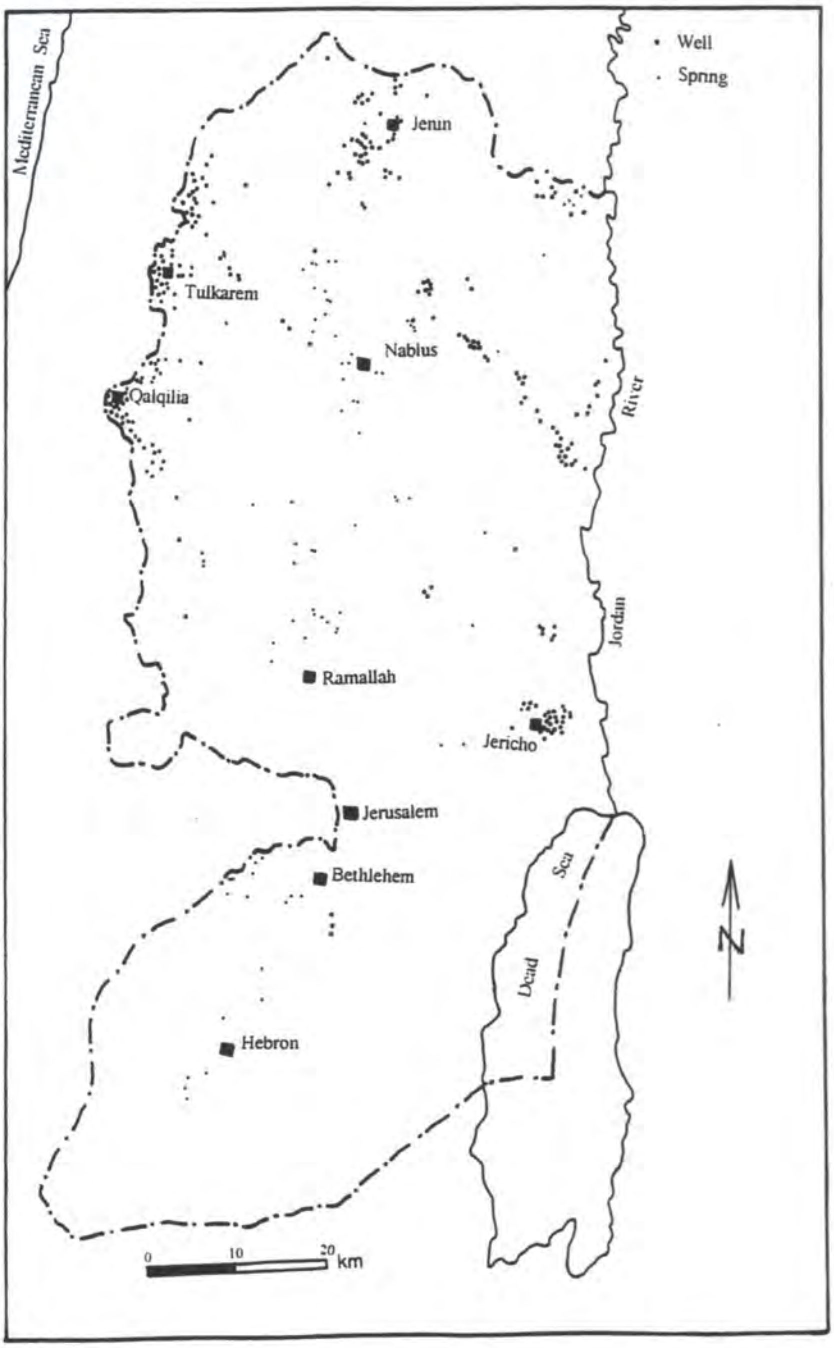


Figure (2.5): Distribution of wells and springs in the West Bank

Source: Palestine Ministry of Planning and International Co-operation, 1996

It has been found that about 61.5% (1400 m m^3) of the total rainfall (2276 m m^3) penetrate the rocky mountains of Palestine and goes to aquifer recharge. About 57% of this amount go to the western aquifers and the rest go to the eastern aquifers. It has been also found that 21% (478 m m^3) of the total rainfall flow in rivers and wadis of which 62% flow westward and 32% flow eastward (Willatts, 1946). Due to Israeli restrictions on the use of water in the West Bank, only about 84 m m^3 of the ground water are used in agriculture (Palestine Ministry of Planning and International Cooperation-MOPIC, 1996).

Two main catchments can be well recognized in the WB: The western catchment and the eastern one, figure 2.6.

The Western Catchment: The wadis and streams of the western catchment form two main groups, one draining the mountains and the other draining the valleys and large basins. In the streams of the first group relatively slight gradients are found near their head, steeper gradients on the principal mountain slopes, and finally very mild gradients in the coastal plain.

These streams have extremely small gradients over much longer distances back from their mouths on the Mediterranean coast than the streams of the first group. The streams of the second group are also distinguished by their considerable geological age, the basins drained by them having become stabilized back in the Neogene era (Picard and Kadmon, 1974).

The Eastern Catchment Area: The Jordan Valley generally shows slight gradient. It is also incised in the soft sediments of the Lisan series.

Steeper gradients in the Jordan River are found in all its tributaries, but the steepest are found in the transversal streams on their descent to the Dead Sea. This serves as a true expression of the precipitous relief around the Dead Sea, which, in turn, is the result of the powerful tectonic forces that have formed the Jordan-Dead Sea rift in the Pleistocene. These forces formed steep escarpments and fault scarps along the Rift Valley, mainly along the western edge where they extend, with interruptions along the Jordan Valley down to the southern end of the Dead Sea. The streams were compelled to negotiate the precipices and cliffs by steep gradients and waterfalls (Picard & Kadmon, 1974).

The Dead Sea: A long tectonic rift or graben extends from the Taurus Mountains in Southern Anatolia southward through Syria, Palestine and Israel to the Red Sea and East Africa.

The Dead Sea occupies the deepest part of the terrestrial section of the rift. The greatest depth measured by Lynch, in 1848 was 398.7m below the surface of the Dead Sea (800m below the level of the Mediterranean Sea). The surface of the Dead Sea, at an elevation of approximately -396m, covers an area of about 1050 km^2.
The Dead Sea is a remnant of the Lisan Lake of the Pleistocene, so named after the series of Lisan marls deposited in it. The lake reached at the time of its maximum north to south extent a level of 175 m below the mean level of the ocean.

Evidence of the stages of shrinking of the lake is presented by some thirty shore terraces. In the north, the lake, whose salinity was subject to variations, apparently extended to the area of the present Sea of Galilee (Tiberias Lake), while in the south it reaches a point near present day Hazeva. Therefore, at its maximum extent it would have been over 600m deep.

The escarpments on both sides of the Dead Sea, though formed in an identical way by faulting, differ considerably from one to another in their characteristics. The differences are especially conspicuous in the southern part of the rift: igneous rocks, mainly granite, are found on its eastern side, as against sedimentary rocks on the western side; there are, however, marked differences also in the Dead Sea region. Here, hard rocks of the Cretaceous period, mostly dolomites, are found on the western side, while the escarpments delimiting the rift on its eastern side are built of softer Nubian Sandstone formed at different periods between the Paleozoic and the middle Cretaceous. The mountains of the east are higher than those on the west and the slopes facing the Dead Sea are steeper. These steeper escarpments are an expression of the stronger rift faults on the eastern side. As against this, vertical cliffs are found on the western bank of the Dead Sea, but on the whole the slopes on this side, including the submarine ones, are gentler.

Today the Dead Sea is about 80 km long and it is about 17km wide. The lake is divided into two basins: a deep northern one, and a shallow southern one. The two basins are separated by the Lisan peninsula (Lisan means tongue). Between the two basins lies a narrow shallow passage with a present depth of 6m or less. The western half of the southern basin has by now been turned mostly into evaporation pans. Its deepest point lies near the eastern side of the northern basin. The slope of the bottom near the western bank is gentler, although vertical or near-vertical cliffs bound part of the Dead Sea on this side.

The entire southern basin is shallow, its depth is less than 10m. The southern basin receives a considerable amount of sediment from the streams discharging into the 'Arava Valley south of the Dead Sea. The slope of the western bank of the southern basin is slightly steeper than that of its southern bank.

The level of the Dead Sea has always been subject to great fluctuations, as evidenced by the horizontal terraces visible along many sections of its banks. A part from long-term fluctuations, also seasonal fluctuations are evident, since the Dead Sea has no outlet and its catchment area is characterized by a well-defined seasonal climatic cycle. The water surface generally drops to its lowest annual level in November, after the end of the dry Summer, and its highest level is recorded between March and May, after the rainy season. The range of annual fluctuations is normally between 30 and 60 cm, but on many occasions reaches one meter.

The water balance of the Dead Sea is mainly governed by evaporation, the rate of which has been computed by Neuman as approximately 155cm per annum. Being a closed lake with no outlet, the Dead Sea is characterized by high salinity; the mineral content of the Dead Sea is shown in table 2.2.

The total salinity of the Dead Sea as shown in the table 2.2 is 26.35 parts per hundred by weight, as against 3.9 in the Mediterranean and 4.1 in the Gulf of Aqaba which is among the most saline of the open seas on the globe (Kadmon, 1974).

Table (2:2): Mineral content of Dead Sea water

Mineral	Percentage by weight
KCl	1.07
NaCl	8.55
$CaCl_2$	3.46
$MgCl_2$	12.30
$MgBr_2$	0.90
$CaSO_4$	0.07

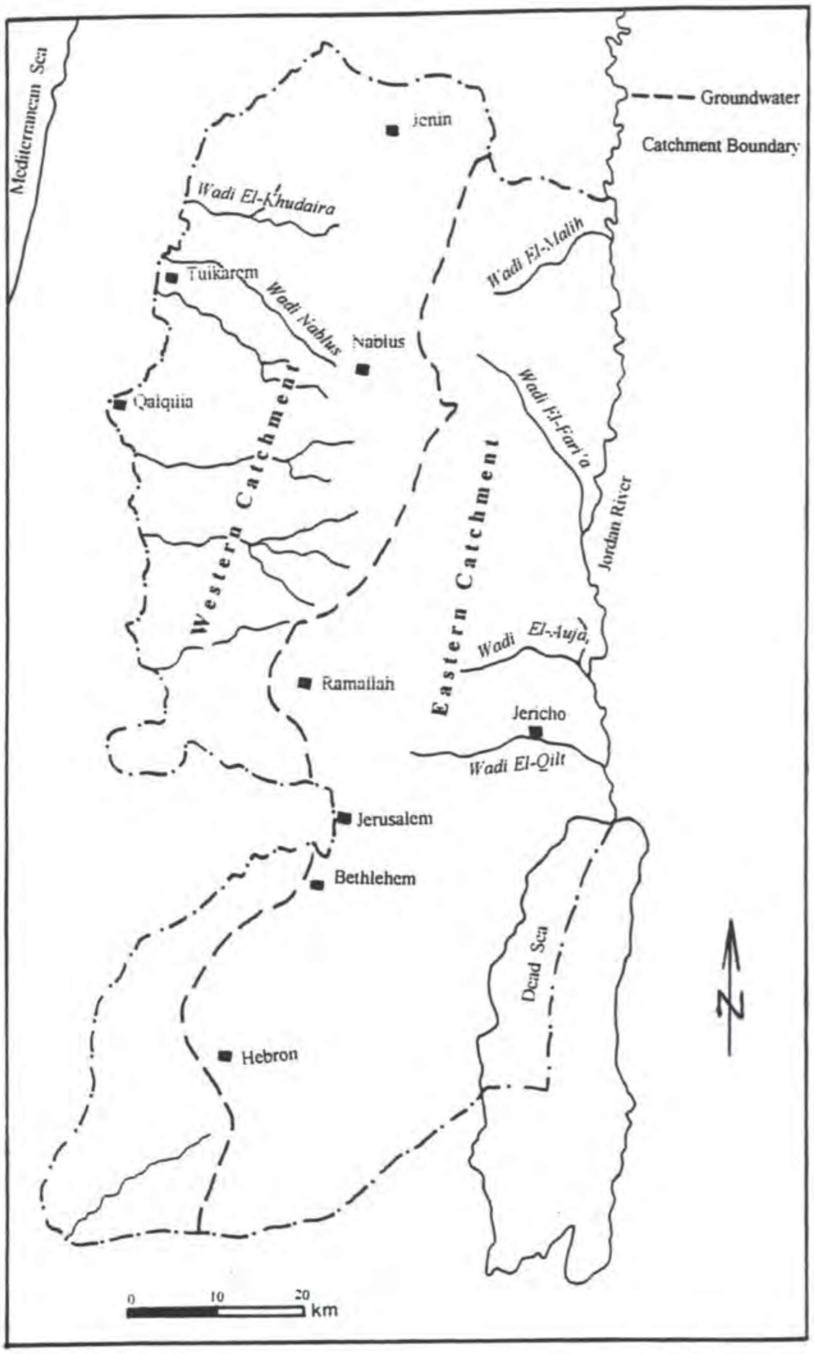
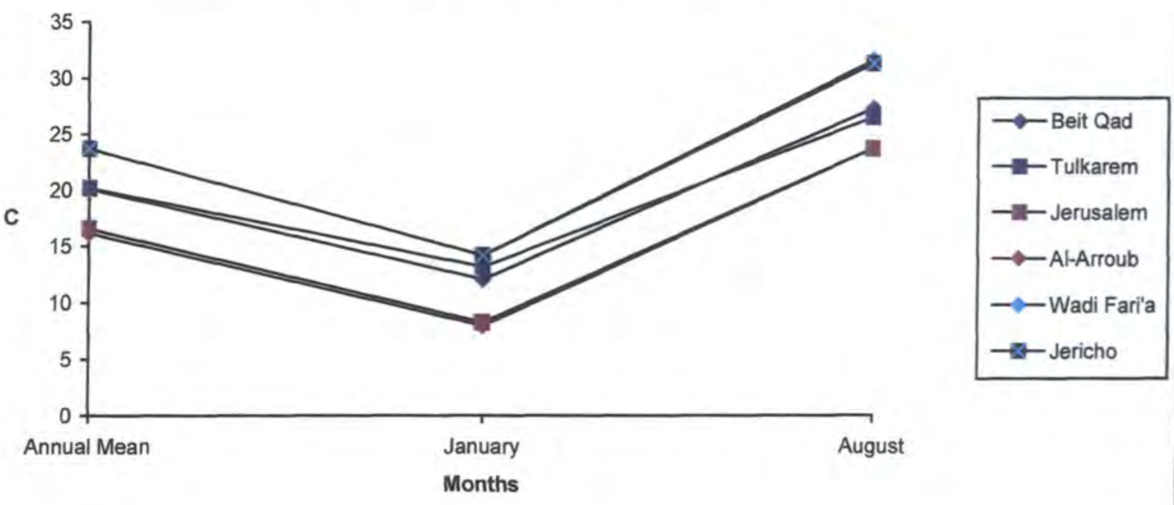


Figure (2:6): Water catchments in The West Bank

Source: Palestine Ministry of Planning and International Co-operation, 1996

Figure (2:7) : Annual mean temperature and the mean of the coldest and the hottest months between the years 1923-1965



It can be seen from the figure above that there are three temperature zones in the WB: the semi-coastal zone, the heights zone and Al-Ghour zone. The annual mean of the semi coastal zone represented by the climatic stations of Tulkarm and Beit Qad is around 20°C. In the area of the heights it is 16.6°C for the Jerusalem station and 16.2°C for Al-'Arroub which lies to the north east of Hebron and that of Al-Ghour rises to around 24°C for both Wad Fari'a and Jericho climatic stations. The difference in temperature between the semi-coastal area and the heights is about 4°C and 8°C between the heights and Al-Ghour.

Topography and distance from the sea play an important role in deciding these variations of temperature. Tulkarm that has an elevation of 80m and also Beit Qad to the north east of Jenin at an elevation of 190m receive more marine effects because they are open to the sea. The climate stations of Jerusalem (The Airport of Qalandya)

2.6 Climate

2.6.1 Elements of climate

The main elements of climate are:- temperature, wind, and precipitation.

a) Temperature: mean annual temperature of the WB refers that it is moderate. The annual mean temperature of Jerusalem for the coldest month is 8.3°C, while it is 23.7 °C for the hottest month. Mean annual temperature of the WB varies seasonally and spatially as shown in table 2.3.

Table (2:3): The annual mean temperature and the mean of the coldest and the hottest months between the years 1923-1965 (°C)

Station	Annual mean	January	August
Semi-coastal:			
a) Beit Qad	20.1	12.1	27.3
b) Tulkarm	20.2	13.2	26.5
Heights:			
a) Jerusalem	16.6	8.3	23.7
b) Al-'Arroub	16.2	8	23.2
Al-Ghour:			
a) Wad Fari'a	23.7	14.2	31.6
b) Jericho	23.7	14.2	31.3

Source: The climatological information of Jordan, Dept. of Meteorology, 1968, Amman which has an elevation of 755m and Al-'Arroub at 960m result in lifting and cooling of air- masses over the western slopes. But in Al-Ghour, topography plays a remarkable role firstly by raising its temperature: the heights prevent sea effects and cold air-masses from reaching this zone. Secondly, there is the low level of its land, and thirdly, the role of descending air from tops of heights in rising temperature for it is being heated.

Temperature in Winter: January is the coldest month all over the WB having mean temperature of 8°C. Mean temperature varies from one zone to another: It is not less than 14 °C for Al-Ghour, 12-13 °C for the semi coastal zone and 8 °C for the heights. It can be seen that the mean temperature of both the semi-coastal and Al-Ghour regions in January is almost the same, while considerable difference exist between the mean annual temperature of the heights and that of Al-Ghour (6°C).

Temperature in summer: The mean temperature for this season is not less than 23°C all over the WB. August is the hottest month for the three regions with variations among them. It is 31.3-31.6°C for Al-Ghour, 26.5-27.3°C for the semi-coastal area, and 23.2-23.7°C for the heights region. It can be seen that the difference in temperature between the semi-coastal and the heights for August is 3.4°C, 4.6°C between the coastal and Al-Ghour and 8°C between the heights and Al-Ghour.

The absolute minimum temperature (a.min.t): Its importance is to determine the areas suitable for trees, field crops, and vegetables because it is not the same for these crop types. The lowest (*a.min.t*) occurs in January for all areas of the WB. It was -3.5 °C for the semi coastal region, -6 °C for the heights and 0 °C for Al-Ghour.

The highest (*a.min.t*) recorded are 14.6-17°C for the semi coastal region, 9.5-12.6°C, for the heights and 20°C for Al-Ghour.

The absolute maximum temperature (a.max.t) has bad effects on crops, trees, and vegetables. The highest (*a.max.t*) recorded all over the WB in the period 1923-1965 was in July. It was 47.2°C for the semi-coastal region, 41°C for the heights, and 50.5°C for Al-Ghour. For the same period, the lowest (*a.max.t*) of January was between 29-31.7°C for the coastal region, 26°C for the heights, and 27°C for Al-Ghour.

b) Wind: Wind system in the WB is affected by a number of factors: First, centers of high and low pressure. Secondly, the passage of cyclones over the area, and lastly, relief of the area. In winter, the area is affected by the high pressure over Siberia, the Azores and its extension over the North Africa Desert, and the high pressure over Saudi Arabia Peninsula and parts of the Syrian Badia. In this season, the Mediterranean Sea is considered to be a center of low pressure for its relatively warm water. In summer, the WB is affected by the Azori high pressure extends northward, even the Mediterranean becomes part of it. It is affected also by the monsoon depression of India extends to reach the Arabian Peninsula, In addition to the monsoon depression of Sudan.

It can be seen that the WB is affected by two main wind systems. The north westerly dominates the area in summer, and the south westerly dominates it in winter.

In winter, the dominant direction of the wind over the heights is the south westerly, and sometimes the north westerly. These winds are usually associated with cyclones and results in climatic instabilities and rainy clouds because these clouds come from cold humid areas since they pass over the Mediterranean Sea. The direction of these winds in summer is south- western to north western. The air masses in summer are calm and results in a calm, clear and dry weather. By the end of spring and the beginning of summer, dry warm winds (Sharav) blow from south- east and last for about three days. These winds have bad affects on agriculture, especially on olive trees being in the flowering stage at that time. It also effects rain-fed vegetables by reducing soil moisture content very rapidly. In Al-Ghour, the dominant wind direction in winter is the northern and sometimes the southern. While in summer, the northern wind is the dominant especially at night and early morning, while at day the wind direction is south- eastern.

c) Precipitation: rain in the WB fall in winter as a result of cyclones coming from the west direction and passes over the area. Rain is restricted to winter because cyclones only appear in this season.

In winter, the westerly and the north westerly are the dominant winds blowing from the Azori high pressure center in the Atlantic Ocean towards the low pressure center in south west Asia. When these air masses pass over large areas of water, they reach the south- eastern shore of the Mediterranean Sea saturated with water vapor. Water vapor saturated clouds deposit most of their load on the coastal plain and the western slopes, while eastern slopes and the Jordan Valley receive a small amount of rain.

The north to south direction of the WB heights being perpendicular at the air masses direction coming from the Mediterranean Sea divide the WB into two rain zones:

1) The western slopes and summits with 500 to 800 mm of annual mean of precipitation.

2) The eastern slopes and Al-Ghour with 400 mm for the slopes and 100mm for Al-Ghour figure (2.8).

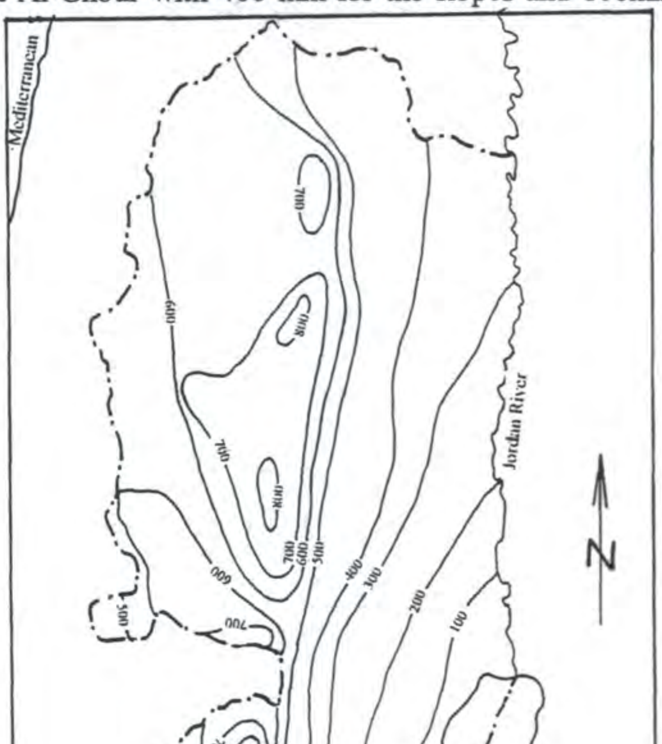


Figure (2:8): Annual average rainfall of the West Bank (mm)

Source: Atlas of Israel, 1974

In addition to the heights direction effect on the rain distribution over the WB, topographic passages also affect this distribution. These passages such as Marj Iben 'Amer and its extension to Beisan area northern Al-Ghour allowed marine effects to reach the northern part of Al-Ghour and increase the annual mean of precipitation there to 300 mm. While that of the southern part, and because of the absence of topographic passages, it is only 100 mm.

Rainfall in the WB usually starts in late September and October with low rates, then these rates increase to the maximum in December, January and February. Thereafter, it falls down in March, April and May. In June, July and August, the WB receives no rain at all (summer months).

Table (2:4): Annual and seasonal average of precipitation (mm) between 1923-1965 recorded in climate stations in the West Bank

	Summer	Autumn	Winter	Spring	Annual Average
Beit Qad	-	73.9	290.9	73.3	438
Tulkarm	-	110.2	449.3	111.5	671
Jerusalem	-	84.3	409.7	133.1	627
Al-'Arroub	-	87.8	407.4	145.5	640.6
Wad Fari'a	-	37.9	157.6	44.2	239.7
Jericho	-	22.2	93.1	34.5	149.8

Source: The climatological Information of Jordan, The Meteorological Dept., 1968, Amman

It can be seen from table 2.4 that most rain falls in winter (about 70%) and the rest percentage falls in autumn and spring. This seasonal distribution of rain is not constant and fluctuates considerably, especially for autumn and winter.

The amount of rain also varies from one year to another and from one region to another. For example, in 1968, the climate station of Al-Fari'a recorded 135% of the annual average in. On the other hand, the station of Tulkarm recorded 49% of the annual average in 1974.

2.6.2 Climate Regions of the West Bank

The WB has been divided into three climate regions according to Kopen classification, figure 2.9. These regions are (Y. Fayed, 1971):

a) The Mediterranean System; rain in winter and hot and dry in summer (Csa). This system covers most of the WB.

b) The Semi-Arid Climate (BS), it includes the area which looks over the Jordan Valley, particularly, the northern part of Al-Ghour.

c) The Desert-Arid climate (BW): This region dominates the southern part of the Jordan Valley. The drought conditions here are due to the scarcity of rainfall (100 mm) and high temperature.

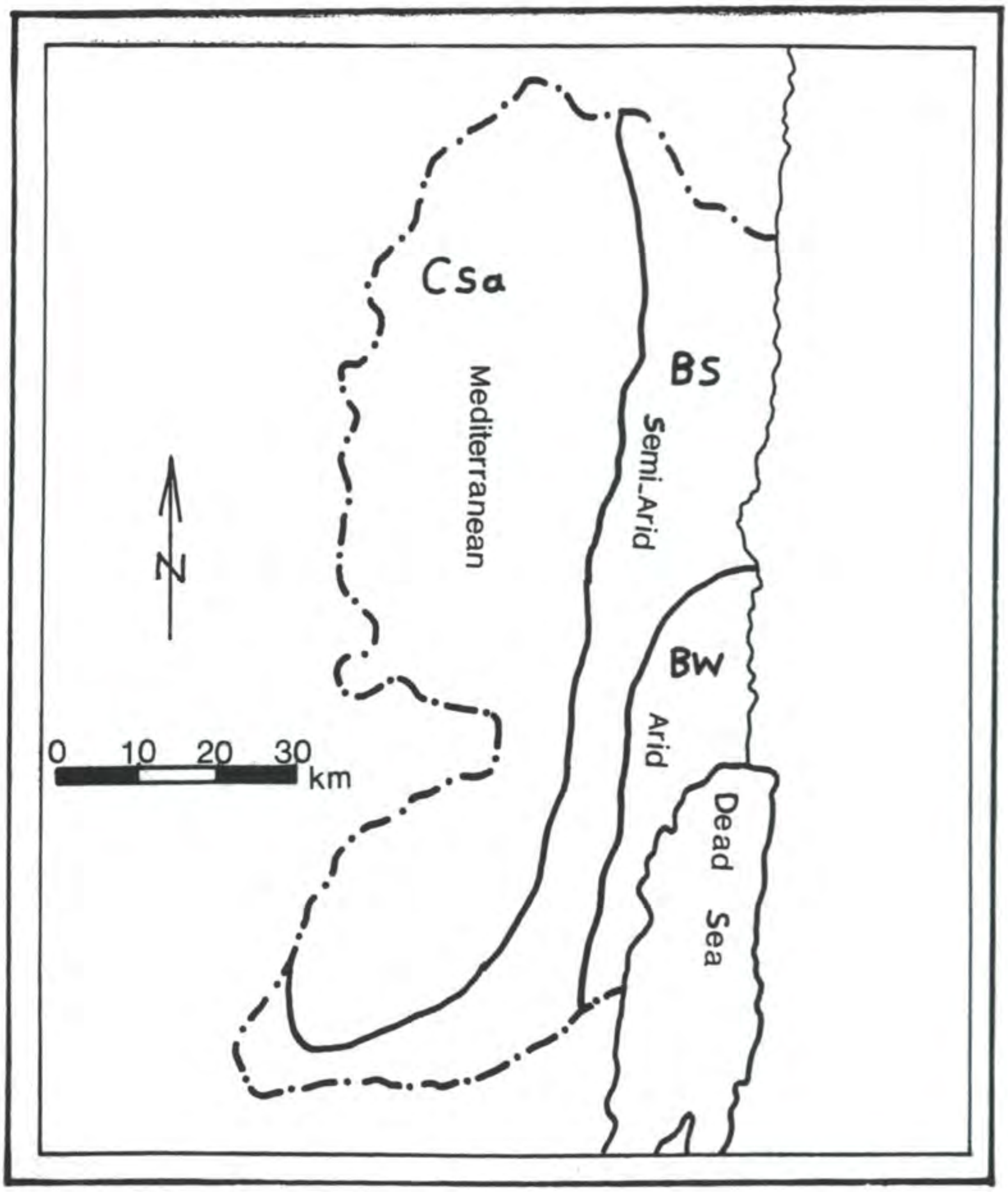


Figure (2:9): Climate regions of the West Bank according to Kopen classification

Source: Atlas of Israel, 1974

2.7 Soil

The geology of the WB played a principal role in soil formation. Soil in the WB contains a high percentage of calcium because the geology of the WB is mainly limestone and dolomite. Spatial variations of geological structure are reflected in rock and soil characteristics. Areas of domes and anticlines are mainly formed of limestone and dolomite, while topographic depressions are mainly formed from soft limestone and chalks. The dolomite and limestone evolved and developed a soil which is usually classified as a terra rossa, although it has poor drainage (Karmon, 1969).

Topography has a strong effect on soil formation. This can be seen clearly if a comparison is made between steep areas on the one hand, and low plain areas on the other hand. Soil of low plain areas is thick and smooth, while that of the steep areas is thin and unsuitable for all sorts of agriculture. Topography also has an effect on water distribution. In plane areas, water goes deeply in soil and is equally distributed in the area, while for steep areas, most of water flows rapidly in wadis and does not penetrate deeply and equally along slopes. Ground water has no effect on the tops of slopes, but for bottoms of slopes, and because ground water is close to surface, it sometimes forms marshes such as the salty soils of the eastern parts of Al-Ghour (the badlands).

Climate of the WB with its major elements (humidity, temperature and wind) shares effectively in soil formation. Firstly, in humid and semi- humid areas, minerals in soil such as CaCO3 are dissolved and deposited again. Secondly, soils of steep areas are eroded by heavy rain to be deposited in low areas and depressions causing desertification of these heights on one hand, and enriching depressions with soil on the other hand. The effects of accidental floods on the eastern flanks of the WB heights are clear. Apart from some depressions there, these flanks are almost barren and have no agricultural land cover. In arid areas where evaporation rate exceeds rainfall, soil is dry and salty.

High temperature in humid environment increases chemical and biological activity in soil and consequently organic matters is dissolved rapidly. Dry winds increase the rate of water evaporation on the soil surface and carry it from dry zones to other areas.

Biological elements do play a principal role in soil formation mainly through vegetation that causes soil chemical and mechanical weathering. While dead vegetation enriches soil with humus giving it the brown color, live vegetation deepens the level of soil by dissolving rocks and preventing erosion.

In addition to the previous factors, time is an important factor for soil formation: the process of rock solution is slow and so the formation of soil pedology needs a long time.

2.7.1 Types of Soil in the West Bank

It can be seen in figure 2.10 that there are main types of soils spread in the WB. These soils are:

1) Terra Rossa: This soil constitutes most of the area under the central highlands around Jenin, Nablus and Jerusalem (Bender, 1974). 50% of the Terra Rossa soil is silica (Si), 10-15% is iron (Fe) and Aluminum (Al), while Calcium (Ca) represents only 5% (Orni, 1973).

2) Yellow Mediterranean Soils: This soil exists in narrow strips around the Jordan Valley. It is mainly formed of limestone, semi deposits of loess and basalt.

3) Yellow Steppe Soils: It covers an area to the east of the Yellow Mediterranean soils in the semi-arid climate region, from the extreme north to the south. It also exists on both sides of the Jordan Valley such as Ghour Al-Fari'a. Its structure is similar to that of the Yellow Mediterranean Soils.

4) Grumusols: This soil is mainly exist in the northern and central part of the West Bank. It is a mixture of Terra Rossa, Yellow Mediterranean and Yellow Steppe Soils. Its transmittance to water is low because of a high clay content.

5) Chernozem-Like Soils: It is of volcanic rock origin. It exists south Wad Al-Malih in the Jordan Valley and in Ghour Al-Katar to the east and the north west of Jenin. It also exists to the south- west and to the east of Nablus. It occures in small areas because volcanic activities in the area are rare. It has a grey color.

6) Soil Associations of the Jordan Valley: It accumulated in the alluvium plain of the Jordan Valley and are composed from different kinds of soils mainly rich humus, red-brownish, gray-brownish, white gray marl soils, and the dark gray soils.

In addition to these main types of soils, there are small areas of local distributed soils such as the Sierosem, Rendzinas, Marl Soils, Solonchaks and the Alluvial Soils.

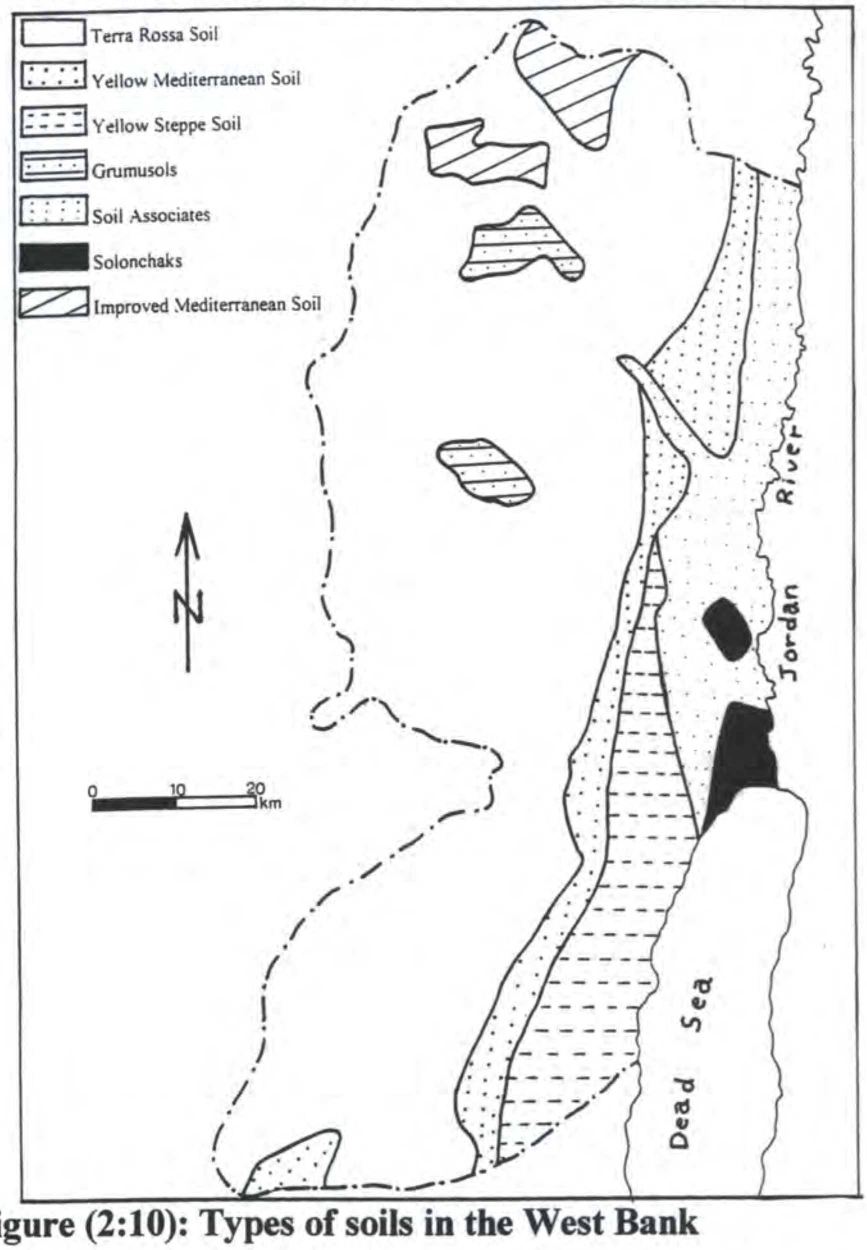


Figure (2:10): Types of soils in the West Bank

Source: Palestine Ministry of Planning and International Co-operation, 1996

2.8 Agriculture

During the time of the Ottoman and the British occupation, agriculture had been primitive and the land productivity was low. Despite the fact that agricultural activities were limited to fertile and plain lands, more than 60% of the population worked in this economic sector.

In the Jordanian period (1950-1967), progress occurred in agriculture. The area under cultivation increased from 301.7 thousand ha in 1952 to 324.5 thousand ha in 1966 and the number of agricultural tractors and agricultural engines also increased considerably. Moreover, the structure of many crops changed. On one hand, the area of some crops increased while on the other hand the area of others decreased. Table 2.5 shows this change.

Table (2:5): Agriculture in the West Bank Between 1952-1967 (area in 000 ha)

Crop Type	Area for the year 1952	Area for the year 1967	Change%
Fruit Trees	12.35	32	159
Olive Trees	50	59.05	18
Vegetables	18.7	22.65	42.5
Cereal Crops	122.5	81.7	-33.3
Total Area	203.55	199.4	-2

Source: General Statistics Department, 1952, 1967, Amman-Jordan

It can be said that agriculture is the most productive sector in the WB. The gross national product was 29.2% in 1980 (this ratio is not constant because of unstable climate conditions). The increase of agricultural production between 1968 and 1981 was 9.6% and the productivity per worker between 1967 and 1981 was doubled. This progress is illustrated by the changes in methods of cultivation, the increase of mechanization and the replacement of low-value crops with high-value cash crops (Benvenisti, 1983).

2.8.1 Factors Affect Agriculture

Agriculture in the WB is affected by a number of physical and human factors. The physical factors can be summarized as follows:

1) Geomorphology: About 86% of the WB including a number of intermediate plains concentrated in the north part of the WB (District of Nablus) is mountainous. While the remaining 14% represents the Jordan Valley (Al-Ghour) (Ennab, 1979). The north to south extension of the WB mountains prevents marine influences of the Mediterranean Sea. This situation made the western slopes receive much more rain than the eastern slopes, because it is situated in rain shadow conditions. On the one hand, the spread of the intermediate basins increased the thickness of their soil and became good agricultural lands. On the other hand the steepness of heights resulted in severe soil erosion reducing their agricultural capability. The scarcity of rain on the eastern slopes resulted in barren unvegetated surface appearance and decided cultivation system in Al-Ghour to an irrigated one.

2) Climate: Temperature of the heights region is suitable for the cultivation of most crop types because it does not descend to less than 5 °C at any time of the year. In Al-Ghour temperature is not less than 14 °C that is suitable for cultivating irrigated vegetables. In summer, and because of high temperatures, different types of crops need to be irrigated. Strong winds during the spring season (the time of plants flowering) cause the flowers of the olives to fall off and consequently reduce their production. Rain and its uneven spatial distribution controlled agricultural distribution. Therefore, the eastern slopes are nearly out of any kind of rain-fed crops.

Most of agricultural activities in the WB depend on rainfall because the water resources are limited and the Israeli Authorities do not allow a free use of water in the WB. This affected the land productivity and the cultivation of only one crop a year.

3) Soil: Soil of the WB is poor in its organic matter and contains much salt and chemicals. The development of soil differs from one site to another: on the slopes, soil is developed very slowly while in the basins and plains it is developed more rapidly. Terra Rossa Soil that exists in plain areas is suitable for the cultivation of citrus trees and vegetables, while that of the mountainous areas are mostly planted with olive trees and some almonds and grapes. The Yellow Steppe soil which exist in the semi-arid climate region is suitable for grazing and the production of barley, while soil of the Jordan Valley is suitable for the cultivation of various types of crops (Bender, 1974).

4) Water Resources: in 1968, about 97.2% of the lands under cultivation in the WB were dependent on rain and the rest area (2.8%) was irrigated crops. The main source of water used in crop irrigation is the ground water such as wells and springs.

Running water of some wadis such as Al-Fari'a, Bathan and Al-Malih was used to irrigate some lands in Al-Ghour. Water of River Jordan was used to irrigate citrus, vegetables and some beans by pumping water from the river. There were more than 200 pumps along the river before 1967, but a few months later those pumps had disappeared because Israel closed the area and it is considered as a military area. The amount of water used for irrigation was estimated to be around 100 M m^3 in 1970 of which 60% came from the springs of Al-Ghour and the perennial wadis and the rest came from the artisian wells (The Israeli Military Administration of the WB, 1970).

The limited area of land suitable for high-value crops under irrigation is a major constraint on development. Some of these lands are situated in the Jordan Valley and taken over from the Palestinians for Israeli agricultural production. Water consumption for agriculture had been frozen at a level 20% higher than in 1967. Of some 50,000 ha of land potentially irrigable for agricultural use, fewer than 10,000 ha are irrigated (77% of which lies in the northern part of the WB). The problem is that Israeli settlements (colonies) in the WB consume as much as the total Palestinian population of the WB. According to a strict policy, licences for drilling in the WB are refused (Benvenisti, 1983).

Agriculture in the WB is also affected by a number of human factors. These factors can be summarized as follows:

1) Labour: in 1967, about 63% of the Palestinians in the WB lived in rural areas (villages) and 37.7% of workers worked in agriculture. This availability of workers made the Palestinian farmer take care of his land and reclaim it.

After 1967 (the Israeli occupation of the WB), large numbers of the Palestinians were forced to leave their homes to the neighboring Arab countries. Therefore, the percentage of people working in agriculture declined to about 29% of the total workers. In 1970 the percentage of people worked in agriculture increased to about 39.2% because Israel offered loans and encouraged the farmers to cultivate their lands. The aim of Israel was to cover the shortage of some vegetables in the Israeli market and to link the Palestinian farmers with the targets of the Israeli Ministry of Agriculture. In 1971, the percentage of people worked in agriculture was reduced to 34.2% because many Palestinian workers preferred to work in Israel for the Israeli factories which offered good payments to workers. In 1973, workers in agriculture became less than 26.5% because more workers joined the work in Israel. After October 1973 (The Arab-Israeli war), many Palestinians returned to their farms and the percent of workers in agriculture rose to 29.6% (Ennab 1977). Despite this decline in the workers percentage, the spread of agricultural machines compensated for the lack of labour.

2) Farm Size: size of farms in the WB is becoming smaller. More than half the farms of the WB are less than 1 hectare especially in the western and the northern borders (ARIJ 1994). The reason for that is that the people living on the borders lost their lands in the war of 1948. Size of farms is not the same all over the WB; for example, it is smaller in the area of Tulkarem and Qalqilia (north west of the WB) compared with that in the eastern area of Nablus. In general, the small area of agricultural land, the high increase of population and the socio-economic system are behind the severe splitting of the agricultural land.

3) Mechanization: Before 1967, farmers rarely used tractors and other agricultural machinery and most of the work in the field was being done manually, however, the number of tractors increased 9 times between 1968-1974 (The Israeli Military Administration of The West Bank, 1974). Farmers decided to improve the agricultural system and use modern methods for two reasons. First, Israeli merchants started to buy a considerable amount of the Palestinian agricultural production, and second, Israeli banks offered some facilities and loans to the Palestinian farmers. These Israeli facilities aimed at covering shortages of some agricultural crops in the Israeli market.

4) Markets: The area under cultivation increased throughout the1950s,1960s and 1970s to meet the increasing needs of Palestinian refugees in Jordan and some other Arab countries, which became their main market. But by the end of the 1980s the agricultural economy of the WB had been severely affected by the disconnection of the two banks of the River Jordan and the frequent military closure of the WB. This resulted in the fall in price of agricultural production.

After the Israeli occupation of the WB, Israel put restrictions on the exportation of the Palestinian production to the Arab markets in order to meet their needs with cheaper prices. In 1972, 70% of the exports went to Arab markets, 23% went to Israeli markets and 7% to the European market (Hilal, 1974). In 1975, the exports to the Arab countries fell to about 45.4%, increased to 42.6% for the Israeli market and 12% for the European market.

5) Internal and External Migration: It is the most important social factor that affected the agricultural sector of the WB. Before 1967, both internal and external migration

was economic. But after 1967, farmers were forced to leave their lands because Israel took on large areas for security claims.

2.8.2 Agricultural Crops

The most important agricultural areas in the WB lie on the western slopes region and the Jordan Valley (Al-Ghour). These two areas belong to two different climates. Four main agricultural crop types can be recognized in the WB: -

1) Olive and fruit trees: this category includes olive trees, citrus trees and grape trees. Before 1967, the WB produced about 67% of the total production of Jordan from this category (Agricultural Atlas of Jordan 1973). Due to rainfall fluctuations, area and production of this category is also fluctuated. For example, between 1967 and 1974 the total area of this category decreased by 12%. Table 2.6 shows the contribution of each district in the production of this category.

Table (2:6): Production of the three districts of olives and fruit trees for the year 1966 (%)

District	Production %
Nablus (northern the WB)	**49.2**
Jerusalem (mid the WB)	26.3
Hebron (southern the WB)	24.5

However, in 1966 **District of Nablus** (northern the WB) produced 80% of the total production of the WB from olives and citrus, District of Hebron produced 67% of the total production of the WB from grapes and District of Jerusalem produced 17.8% of citrus and olives.

The concentration of olives, fruit and citrus trees in the **District of Nablus** results from the fertile soil, the spread of intermediate basins and the availability of springs, see table 2.7.

Table (2:7): Hectare area of fruit trees for the three districts for the year 1966

District	**Area (000 ha)**	**%**
Nablus	**46**	**57**
Jerusalem	26.3	32.5
Hebron	8.5	10.5

Source: Agricultural Atlas of Jordan, 1973

The olive tree is the most important crop in the WB for its use as food, production of soap and heating in winter. The area of this crop reduced down between the years 1967 and 1968 from 59,000 ha to 51,000 ha because Israeli authorities closed and rooted out certain areas for settlement building. But after 1968, the area increased to 60,000 ha because of the high demand on this crop. Because this crop is totally dependent on rainfall, its production has fluctuated considerably. For example, the production for 1962 represented only about 6% of that of 1961.

Grapes are mainly planted in the district of Hebron and Jerusalem. About 90% of this crop are planted in these two districts for the colder weather (Agricultural Atlas of

Jordan, 1973). While in the district of Nablus, Palestinian farmers plant a few trees of this crop among olive trees. So, pure grapevine planting in fields in the district of Nablus is very limited.

The citrus crop is almost stable in area and production. The main areas planted with this crop are the Jordan Valley (Ghour), Tulkarem and Qalqilia. This crop is an irrigated one so it exists where water exists.

2) Vegetables: This crop is mainly cultivated in the plain and semi-plain lands, especially Al-Ghour and the intermediate basins that mainly spread in the northern part of the WB. Most these crops are rain-fed crops and very limited areas are irrigated. District of Nablus occupies the first place in area and production among other districts. It produces about 86% of the total production of this crop. The main vegetables are tomatoes, onion cucumber, pepper, potatoes, okra, and egg plant.

3) Cereals: Although the area cultivated with cereal crops reduced after 1967, area unit production has increased because of the use of modern techniques and chemical fertilizers. Apart from limited irrigated areas of cereals near Jericho, this crop is a rain-fed one, so its production has recorded wide annual variations.

The **District of Nablus** occupies the first place in area and production among other districts. In 1966, it contributed with about 75% of the total production and 50% of the total area of cereals.

The main cereal crops are Wheat and Barley. Between the years 1961-1966, 65% of the total area of cereals had been cultivated with wheat. In 1966, District of Nablus produced about 78% of the total production of this crop, although the area represented only 54% of the total area. This illustrates the high productivity of land in this district compared with the other districts of the WB (Agricultural Atlas of Jordan, 1973). Barley comes in the second place after wheat. The area cultivated with barley for the same period was 26%. This district also occupies the first place in area and production of barley compared with other districts. It contributed 74% of the total production and 46% of the total area.

4) Beans: It includes all types of beans including chickpeas and lentils. This crop is mainly cultivated as rain-fed crop in the plain and semi-plain lands. Due to fluctuations of rain quantity from one year to another, production of this crop is also unstable and exposed to fluctuations. The **District of Nablus** also occupies the first place for this crop compared with other districts. It contributed with about 69% of the total production before 1967 and 56% of the total area.

Table (2:8): Field Crop Area of the West Bank for Different Years (000ha)

Year/Crop	Wheat	Barley	Beans	Sesame	Tobacco	Watermelon	Total
1966	45.98	19.58	14.38	2.25	2.75	4.7	89.64
1968	46.49	23.10	14.16	1.8	0.45	4.3	90.30
1975	33.00	20.00	10.50	1	0.4	0.5	65.40
1981	22.40	17.40	5.30	0.93	0.4	3.5	49.96
1985	19.00	15.40	-*	1.02	-*	4.02	47.00

Note: - statistics are not available*

Sources: West Bank Agriculture, 1974/ 1976/ 1981.Unpublished Statistics

Table 2.8 shows that wheat and barley occupy more than 70% of the total area of the field crops in the WB for all dates. It also shows a continuous decline in the area of the majority of crops. Watermelons declined to their lowest point in 1975 or 12% of the average. The reason for this sharp decline could be the uneven distribution of rain over the year.

Table (2:9): Changes in the field crop (cereals and beans) type in the West Bank

Year	Total Area (000ha)	Total Production (000tons)	Yield/ha (ton)
1967/68	89.85	23.5	0.26
1979/80	45.86	71.8	1.57
1984/85	49.57	23.0	0.46
1967/85 (% growth)	-44.8	-2.2	

Source: Judea, Samaria, and Gaza Area Statistics; Agricultural Branch Accounts 1986, Central Bureau of Statistics.

It can be seen from table 2.9 that although the area of field crops decreased between 1967 and 1985 by 44.8%, the total production remained almost the same. It can also be seen that the total yield in 1979/80 was three times that of the other dates. Fluctuations of production can be explained by the unstable climatic conditions especially rainfall, while increase of productivity can be explained by the use of developed methods and chemical fertilizers.

2.9 Summary

It can be seen that a mixture of physical and human factors affects agriculture in the West Bank. Climate and geomorphology have a central role in the distribution and productivity of agricultural crops. The north-south extension of the West Bank mountains divided the West Bank into two main regions: the western slopes and the eastern slopes. The average annual rainfall of the western slopes is between 500-700 mm (500 mm for the semi-coastal areas represented by Tulkarem and Jenin and 700 mm for the central part of the mountains). While it is between 200-400 mm for the eastern slopes (400 mm for the upper sloes and 200 mm for the Jordan Valley). These rainfall spatial variations resulted in variations in agricultural activities.

The existence of topographic hollows or intermediate fertile plains among the mountains allowed for horticultural, arable and citrus tree cropping, while mountainous areas were given over to olive and fruit tree cropping. The steep topography of the West Bank caused severe soil erosion of the heights but enriched the plains with soil. These topographic and climatic variations strongly influence the spatial distribution of agriculture in the study area. The amount of land in agricultural production decreases when moving from the west to the east and crop type changes when moving from mountainous lands to fertile plains. Therefore, these agro-spatial variations are taken into consideration in the field sampling. The study area is divided into five strata to ensure a good coverage and representation of the agro-spatial variations of the area (see chapter 6).

The political situation particularly the Israeli water use restrictions created difficulties for agricultural development in the West Bank. Apart from limited areas of Tulkarem sub-district and the Jordan Valley, most agricultural lands of the West Bank are rainfall dependent.

It can be seen also that northern the West bank (District of Nablus) contributes with more than 75% of the overall crop production. This agricultural importance of the northern part of the West Bank is the main reason for selecting it for this study.

The previous review of agriculture in the West Bank shows that the data available are mostly either from Jordanian or Israeli sources. This is due to the political situation in the study area. Today, the Palestinian National Authority (PNA) through its institutions, particularly the Ministry of Agriculture and the Ministry of Planning, is trying to create its own agricultural data-base rather than being dependent on others for data. This process is facing many difficulties. First, the PNA has not yet full control over the West Bank particularly the agricultural lands. Therefore, a comprehensive field survey is not possible. Secondly, any comprehensive field survey will be costly and time consuming, and thirdly, large- scale maps necessary for field data collection are not available.

Remote sensing imagery could be a good solution for the previously mentioned difficulties (see chapter 1). This study is an attempt to contribute in creating a Palestinian agricultural database through the use of satellite remote sensing and limited field survey methods.

CHAPTER THREE

PREVIOUS AGRICULTURAL REMOTE SENSING STUDIES

3.1. Introduction

3.2. Major Agricultural Remote Sensing Programs

3.2.1. The Large Area Crop Inventory Experiment (LACIE)

3.2.2. The Corn Blight Watch Experiment

3.2.3. Crop Identification Technology Assessment for Remote Sensing (CITARS)

3.2.4. Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS)

3.2.5. Agricultural Resources Investigations in Northern Italy and Southern France (AGRESTE)

3.2.6. Determinazione e Utilizzo di Telerilevamento in Agricoltura (DUTA) Project

3.2.7. Monitoring Agriculture by Remote Sensing (MARS)

3.3. Agricultural Remote Sensing Studies

3.4. Conventional Agricultural Studies

3.4.1. Agricultural Studies in Neighboring Arab Countries

3.4.2. Agricultural Studies in the West Bank

3.5. Discussion of Previous Studies

3.6. Summary

3.1: Introduction

Since the launch of earth resources satellites in early 1970s, the importance and the role of remote sensing technology has significantly increased. The Landsat MSS and Landsat TM satellite programs systems enabled more precise and effective study of agricultural land use/ land cover types and crop area estimation from their multispectral sensors.

As agriculture (food) is a basic necessity for mankind, a number of large programs and individual studies using remote sensing or conventional methods have been devoted for monitoring and evaluating the status of agriculture at both small and large scales. These programs and studies can be divided into three types:

- Major agricultural remote sensing programs,
- Agricultural remote sensing studies, and
- Conventional agricultural studies

3.2 Major Agricultural Remote Sensing Programs

The major remote sensing programs exist in the United States of America and Europe. The general common aim among these programs is to use remote sensing technology for monitoring, evaluating, and estimating agricultural land use/ land cover types at different scales (local, regional, continental and global levels). The major agricultural remote sensing programs are:

3.2. 1 The Large Area Crop Inventory Experiment (LACIE)

The LACIE project was designed in the USA in the years 1973-1974 following the success of preliminary agricultural investigations conducted with Landsat-1 data and the progress made in developing of appropriate data processing techniques. LACIE was established by the United States Department of Agriculture (USDA), the National Aeronautics and Space Administration (NASA) and The National Oceanic and Atmospheric Administration (NOAA). In 1977 LACIE estimated the Soviet Union's wheat production within 6% of the official figures released in 1978. A year later, satellite based estimates varied only 1% from the official figures. This experiment established the techniques for estimating area, yield and production of wheat in the USA and other major wheat production regions of the world mainly the former USSR, India, China, Australia, Argentina and Brazil. The major objectives of LACIE were to develop and test techniques for using Landsat MSS data to study, evaluate and estimate wheat area, yield and production at global levels. LACIE reported that the experiment produced accurate results (LACIE, 1978a). They also improved the regression models for estimating wheat yields and statistical methods assessing the accuracy of predictions based on satellite data.

3.2.2 The Corn Blight Watch Experiment

This experiment was established in the United States by the USDA and NASA in 1971. The objective of this program was to detect and recognize the infected corn areas in some states of America during the growing season across the Corn Belt region. The results of the experiment has established the possibility of using remote sensing to detect the corn leaf blight (Meyers, 1983).

3.2.3 Crop Identification Technology Assessment for Remote Sensing (CITARS)

This experiment was designed to look for better techniques to improve crop classification and identification using Landsat MSS. It was conducted between the years 1973-1975. The main objectives of this project (Meyers, 1983) were to study first, the effects of Landsat data acquisition during the corn and soybean growing season on crop identification, and second, the effects of crop environment such as soil, weather, and field sizes on crop identification. It proved that the multi-temporal data improves image classification accuracy and crop area estimation.

3.2.4 Agriculture and Resources Inventory Surveys Through Aerospace Remote Sensing (AgRISTARS)

This program was established in the United States in 1980. The major aim of this long-term program is to investigate the use of remote sensing in agriculture at the national and international levels to provide information about the food situation in the world. Within this program eight projects were designed to fulfill its aims (AgRISTARS, 1981 and 1982). These projects are:

1. Inventory Technology Development (ITD)
2. Early Warning and Crop Condition Assessment (EW/ CCA)
3. Yield Model Development (YMD)
4. Supporting Research (SR)
5. Soil Moisture (SM)
6. Domestic Crops and Land Cover (DCLC)
7. Renewable Resources Inventory (RRI)

8. Conservation and Pollution (CP)

The aim of each project is linked with its name. For example, the main aim of DCLC was to obtain more accurate crop area estimates for the winter wheat, corn and soybeans. The Statistical Reporting Services (SRS) provided estimates with reduced sampling errors by using ground data coupled with Landsat data (Mergerson *et al.* 1982).

AgRISTARS has increased the efficiency and accuracy of the area, yield and production estimation methods. It has also clarified and ranked the problems that continue to exist in the technology and shortcomings in an understanding of certain aspects of underlying phenomena.

3.2.5 Agricultural Resources Investigations in Northern Italy and Southern France (AGRESTE)

This was the first European Commission agricultural remote sensing project. It was established between the years 1973 and 1977 and carried out by the Joint Research Center at Ispra in Italy and the National French and Italian Institutes. Unlike the previously mentioned programs which have global interests, this project was designed to investigate the potential of remote sensing applications to agriculture and forestry under European conditions. To meet the climatic variations and consequently the land use patterns; the areas chosen for this purpose were Northern Italy and Southern France.

In this project, rice and forestry resources (mainly beech forest) were to be identified and classified by remote sensing. In addition, estimation of yield and biomass of crops was to be carried out. Landsat MSS data, aerial photographs, and field data were used in this project. The project succeeded in the identification and classification of beach forest better than that of rice. The reason is that rice is spectrally overlapped with other vegetation types when the Landsat MSS data was classified.

3.2.6 Determinazione e Utilizzo di Telerilevamento in Agricoltura (DUTA) Project

This agricultural program was established in Italy in 1980. The aim of this project was to integrate satellite remote sensing data in operational procedures for the estimation of the production of important economic crops and getting useful information for managing water resources (Angelis and Gizzi, 1984).

DUTA used a combination of field and satellite data to improve accuracy of area estimation and image classification. The DUTA project developed statistical remote sensing techniques to evaluate the effects of stratification schemes in terms of increased estimation of accuracy (Angelis and Gizzi, 1984). It also developed a cost benefit analysis of stratification procedures.

In 1985 DUTA was renamed as AGRIT-1 and has been implemented each year using more advanced data mainly Landsat TM data which is better suited to agricultural mapping than Landsat MSS in terms of the spatial, spectral, radiometric and temporal resolutions.

3.2.7 Monitoring Agriculture by Remote Sensing (MARS)

MARS is a European remote sensing project initiated in late 1980s by the EU countries. The main aim of this project is to derive crop acreage estimates and crop yield estimates at a European level (Genovese, 1995). MARS project provides crop yield forecasts using a large network of data. These data can be summarized as follows:

- EUROSTAT series: this data comes from first historical production area and yield time series and second from the AGROMET model which uses some meteorological data (rainfall and temperature) for crop yield forecasts.
- Meteorological Data: It includes rainfall, temperature, radiation, potential evapotranspiration, and climate water balance. These data are obtained from ground meteorological stations spread in Europe. The data are used for a direct alarms situations or meteorological analysis and integrated with crop analysis systems.
- Crop Growth Monitoring System data (CGMS). This system uses a number of parameters for crop growth monitoring. The main parameters used are weight of dry matter, weight of the storage organs, the leaf area index (LAI), the development stage and the soil moisture.
- Low resolution data (NOAA-AVHRR): This remote sensing system has a spatial resolution 1.1 km^2. It provides MARS with a day by a day Normalized Difference Vegetation Index (NDVI) profiles and estimations of surface temperatures which in turn are used in crop assessment.

- High resolution satellite data (Landsat TM and SPOT HRV XS images): These remote sensing data are used for crop acreage and yield estimates at the European, and regional scales.
- In addition to the above mentioned data, auxiliary data such as contextual data, documents, maps, aerial photographs and field data are used in MARS.

The main agricultural crops targeted in this project are wheat, barley, maize grain, rice, sugar beet, potatoes, soya, sunflower, and rape seed. In addition to EU countries, the project covers the northern parts of Algeria, Tunisia and Morocco.

Results of the MARS project performance, showed that the methodology applied can provide crop yield and area estimation forecasts at earlier stage than official sources. For example, the error committed in crop yield forecasts for the year 1994 in France, Italy, and the UK varies from 1% to 3% and errors in areas estimates varies from 3% to 6% for the same regions.

3.3. Agricultural Remote Sensing Studies

In addition to these main universal agricultural remote sensing programs, many national and local projects have used satellite data from different times in the growing season to monitor crop growth and predict levels of production.

Logica plc with co-operation from the British National Space Center (BNSC) and some British universities is conducting a project for monitoring sugar beet from space.

The purpose of the project is to develop a computer-based model to improve the prediction of sugar beet yield. The project uses SPOT, Landsat, and ERS-1 satellite data together with meteorological, soil and crop data in a sugar beet yield prediction model. Results of this project may achieve earlier and more accurate yield predictions and reduce the pre-season sampling efforts. Logica with co-operation of British universities also is undertaking a project for mapping uncharted regions of the world using radar data. These regions are frequently cloudy and difficult to be imaged by optical sensors most times of the year. Digital terrain models are generated from SAR images to be used by natural resources explorations.

Carton (1990) described the performance and results of a pilot study carried out by SOGREAH using two SPOT XS scenes. The project aimed at the inventory of small and medium size irrigation schemes in Algeria. The study showed that it is necessary to make agro-climatic zoning to group the periods of the ordered scenes and the subsequent verification missions in the field.

Congalton *et al.* (1998) conducted a crop mapping and monitoring study for the Lower Colorado River Basin in America. The objective of their study was to develop a digital GIS data base of crops, vegetation and water situation a long the Lower Colorado River using remotely sensed data. Landsat TM images, SPOT images, aerial photographs and field data were used in this study. These data were used in a model prepared by the USGS and the Bureau of Reclamation called the Lower Colorado River Accounting System (LCRAS). The combination of different types of data for crop mapping increased and improved the performance of this model.

Redondo *et al.* (1984) used Landsat MSS data for developing a method for the estimation of wheat in Argentina. Results of this study gave high accuracy and enough to be used as a crop estimation system. He also used Landsat-MSS data in 1980 for the estimation of cereal crops areas and production. Results proved that it is possible to get accurate results when a combination of satellite data and ground truth information is made.

Rondeaux *et al.* (1995) investigated the sensitivity of the Normalized Difference Vegetation Index (NDVI) to soil background. Twenty six samples of different types of soil were tested in the laboratory. A number of soil adjusted vegetation indices were investigated in this study. They found that soil background is a major surface component that controls the spectral behavior of vegetation canopies.

Running (1995) introduced a new logic for global vegetation classification using remote sensing techniques mainly the AVHRR (NDVI). This classification logic was derived from combinations of three primary attributes of plant canopy structure. These attributes are permanence of above ground live biomass, leaf longevity and leaf type (broadleaf or needle leaf). This logic came to overcome the problems and difficulties that traditional methods faced; such as the inconsistency of vegetation cover, the ambiguity in global vegetation maps.

Vyas *et al.* (1996) conducted a comparative study of Sugar Beet canopy cover in East Anglia-UK. They used Synthetic Aperture Radar (SAR) data acquired by ERS-1 and SPOT HRV XS data. Radiometric measurements of sugar beet were taken. The Optimized Soil Adjusted Vegetation Index (OSAVI) was used for SPOT measurements and the Leaf Area Index (LAI) was used for SAR data. The study showed that SPOT is sensitive to land cover, while SAR is more sensitive to LAI. The study also showed that optical data are more sensitive to water stress than radar data. They suggested that radar data may be able to provide useful estimates of canopy cover for crop production modeling, especially in the case of the absence of optical data due to cloudy weather.

Townshend *et al.* (1991) suggested to use remote sensing capabilities for global land cover classification with suitable spatial, spectral and temporal resolutions to overcome the significant deficiencies of information derived from conventional ground based data. He suggested that remote sensing techniques may overcome the problem of dissimilarities of data sources that conventional methods used for vegetation type area estimates. The dissimilarities of data sources and the variation of criteria used in classification result in considerably different area estimation results.

Corves and Place (1994) studied the central Brazilian Amazon basin using Landsat TM data for two dates (1988 and 1991). They mapped the reliability of satellite-derived land cover maps. This study investigated the problems which may rise when using traditional methods for assessing satellite-derived land cover map accuracy based on samples; especially when those samples are unfeasable. They suggested a solution for such a problem based on the production of reliability maps which can be derived from the probability files (distance from the mean). They found that reliability maps help to reduce thematic map error due to mislabeling and aid in the identification of missing classes as well as improved training site selection in supervised classification.

Rasolofoharinoro *et al.* (1998) studied mangrove trees in certain areas of Madagascar using SPOT images acquired in 1986 and 1995, aerial photographs and intensive field survey. The purpose of the study was to use remote sensing technology to assess conspicuous change of mangrove geographical expansion. Results of the study were good enough to be used for conservation and management purposes.

Thenkaball (1999) conducted research on the slash-and-burn agriculture in the Congolese basin of central Africa southern Cameroon using near-real-time SPOT-HRV data. The objective of this study was to map the deforested rain-forest areas, impact of deforestation, analyze cultivation patterns and suggest alternatives to slash-and-burn. Mapping accuracy was about 83% and some land cover types were highly overlapped. It is recommended that the use of MIR and TIR bands are useful in such studies.

Moreira *et al.* (1986) conducted a study to evaluate the production of wheat in Brazil using Landsat MSS data and aerial photographs separately. Results of the two methods were very close, but when the two sets of data were used together, accuracy of wheat area estimation was improved.

INPE (Brazilian Institute for Space Research) designed a program which developed a reliable, accurate and timely forecasting system for several crops based on satellite remote sensing data. INPE with cooperation of China (CSAT) are developing a series of remote sensing satellites for agricultural and forest monitoring. One of the main aims of these satellites is to monitor deforestation in the Amazon basin and forest burning. The under canopy burnings are the most difficult to detect by optical remote sensing. So, thermal sensors may help in the detection of such burnings.

Abdel Hady *et al.* (1983) used Landsat-MSS images for the estimation of irrigated agricultural areas in the Delta and Nile Valleys in Egypt. An inventory of irrigated agricultural lands has been produced from this study.

In 1978 the Commonwealth Scientific and Industrial Research Organization (CSIRO) started a pilot study project to investigate the role of Landsat MSS in crop identification for the wheat belt in Western Australia. In 1981 a project was established by a number of CSIRO divisions to evaluate the potential of Landsat data to first estimate crop cultivated area, secondly to discriminate between these crops, and thirdly to estimate yield in the wheat belt of Western Australia (Campbell *et al.* 1982). The study proved that Landsat MSS can provide planners, researchers and users with powerful and useful information, especially in areas characterized with relatively large fields.

In 1987, the World Bank in agreement with the Philippine Department of Environment and Natural Resources (DENR) executed a land use study using Spot satellite imagery (Lus Combe, 1990). The Swedish Space Corporation (SSC), part owners of the SPOT program, was contracted by the bank to carry out the technical work and the image interpretation and analysis. The SPOT study primarily used visual interpretation of the imagery with some digital classification. Because the Philippines is located in a tropical area, cloud cover is a major concern for collecting satellite imagery. So the collection of about 190 needed scenes took about 11 months (from March 1987 to February 1988). Forty three land use map sheets at a scale 1/ 250 000 were produced. This study demonstrated that SPOT data can be used for land use mapping quickly and inexpensively at a national, regional and provincial land use statistics. It also demonstrated some of the problems such as the difficulty of getting complete image coverage of acceptable quality for large areas characterized with excessive cloud cover. Another limitation of using remote sensing technology is its ability to discriminate among certain types of vegetation land cover.

Buttner and Csillage (1989) conducted a comparative study of crop and soil mapping of the Great Hungarian Plain using multi-temporal SPOT XS and Landsat TM imagery. They found that soil-vegetation discrimination was very accurate with both Spring and Summer images. The Spring image was appropriate to map winter crops and the summer image, however, found unfavorable to separate maize and sunflower. Spectral separability and classification accuracy was better with Landsat TM owing to its MIR band compared with Spot XS. The relatively large field size (10-25 ha) minimized the advantage of the better spatial resolution of Spot XS over Landsat TM data.

Buechel *et al.* (1989) studied the effects of the complex environment of New York State on crop separability using Landsat TM data. Six crops were the target of this study (wheat, corn, hay, cut-hay, pasture, and oats). Unsupervised classification accuracy and divergence of spectra were determined for these crop types from early season Landsat TM scenes for 31 sites across New York State. Twelve environmental variables were considered in the determination of crop separability. Results of the study showed that statistically significant models were found for individual crops, but no significant relationship was found to characterize general separability. This is due to regional variation in an early season TM-based inventory of areas as complex as New York State.

Campbell and Browder (1995) described a field data collection strategy used to study agricultural land uses in Rondonia, Brazil. In addition to multi-temporal SPOT Imagery and aerial photographs, a large variety of field data were used in the study. The field data include careful positioning of samples, ground photographs, maps, field sketches, notes, farmer interviews, and video imagery. The use of such very well organized data and the exchange of information among the different sources of data developed other dimensions that have a more general significance for remote sensing field data collection.

Grignetti *et al.* (1997) conducted a study of the Mediterranean vegetation in the southeast of Rome, Italy. The complexity of vegetation cover in such Mediterranean environment, which is mainly governed by season and local climatic conditions, is reduced by two ways. First using multi-temporal satellite sensor data. Secondly, merging Landsat TM data with SPOT P data to improve both the spatial and spectral resolution.

Benedetti *et al.* (1994) used the Normalized Difference Vegetation Index (NDVI) time series (1986-1989) derived from NOAA data in the Local Area Coverage 1.1 Km format (LAC format) to map and classify vegetation in the middle Mediterranean area centered on Italy. This work confirmed the importance of NDVI for vegetation and land cover mapping at regional and national scale.

Gao (1998) used SPOT XS data to map mangroves in Auckland, New Zealand. Two methods were used, the first dealt with mangrove cover as one class apart from considerable variations of its density. The second method divided the mangrove cover into two categories: dense mangrove and sparse mangrove. Results of the study showed that the two-tiered mangrove classification scheme achieved better accuracy of 9% than the one-tiered mangrove classification scheme. Merging the two mangrove classes after classification improved the classification accuracy.

Fuller and Parsell (1990) conducted a study on mapping major crops, semi-natural, and natural vegetation in lowland Britain using multi-temporal Landsat TM images. Objectives of the study were first, to measure and map the distributions of land use/ land cover types with emphasis on semi-natural habitats. The second objective of this study was to assess the potential for detecting areas of changed land use through time for the purpose of accurate mapping. The authors recommended that the image analyst should well understand first, characteristics of target features, second, characteristics of images to be analyzed, and last, techniques of image analysis. This requires a close collaboration between scientists and the remote sensing specialists.

Turner and Congalton (1998) conducted a crop mapping study for part of the Niger Delta flood plain of Mali-West Africa. The objective of the study was to establish a methodology for accurate mapping of rice fields. Images of this area are characterized by the high spectral heterogeneity of some land cover types (ploughed and unploughed surfaces prior to flood entry). This spectral overlapping between these two cover types affects very much the accuracy of rice fields mapping. To reduce this effect, multi-temporal SPOT XS data were classified using a stepwise hybrid classification approach (supervised, stratification, and unsupervised classification). This approach improved the ability to distinguish spectrally heterogeneous rice fields when compared with principal component reduction methods.

Ayanz and Biging (1997) studied land cover types of a part of Spain using Landsat TM and SPOT imagery. Different approaches of classification were used to improve image classification accuracy. These approaches were based on i), band selection with spectral separability, ii), band selection with spectral analysis, iii), band selection with spectral separability and prior probabilities, iv), unsupervised classification, and v), iterative classification with band selection with spectral separability indices. Results of the study showed that:- a) the overall accuracy of both SPOT and Landsat TM images were so close when the single stage classification was used, b) the overall accuracy of both Landsat TM and SPOT images was better when the iterative classification (multi-stage classification) was used, and c) the overall accuracy of Landsat TM images was better than that of SPOT when the iterative classification was used. Since this classification approach is heavily influenced by the band selection process, which is performed for each iteration, the higher spectral information content of TM allowed a better separability of the classes and therefore produced classifications with higher accuracy.

Lenney and Woodcock (1997) conducted a multi-temporal monitoring of agricultural lands in Egypt using Landsat TM data. The objective of their study was to investigate the effect of the use of multi-temporal data sets on the accuracy of area estimation of productive and non-productive lands on one hand and the reclaimed lands in the Western Desert on the other hand. This study proved that multi-temporal data of different dates highly improve the accuracy of area estimation in such areas characterized with high temporal variability.

3.4 Conventional Agricultural Studies

Apart from Israeli studies, this study is the first academic study of agriculture for parts of the West Bank using remote sensing and GIS technology. The majority of agricultural studies in the Arab countries used traditional methods based on heavy field survey. Such studies are laborious, expensive and time consuming, especially for large geographical areas. In this study, conventional agricultural studies (non-remote sensing studies) are divided into two categories:

- Agricultural studies in neighboring Arab countries
- Agricultural Studies in the West Bank

3.4.1 Agricultural Studies in Neighboring Arab Countries

A number of conventional agricultural studies have been conducted in the Arab neighbouring countries as Jordan, Iraq and Syria. Most of these research studies were conducted for higher education degrees.

An-Na'eem (1981) studied crop types in Balqa District, Jordan. The objective of this study was to serve the agricultural and regional planning of the district. Two agricultural patterns were recognized in the study area; 1) irrigated pattern: in this pattern which exists in the Jordan Valley part of the district, vegetables, bananas, and citrus trees are grown. 2) rain-fed pattern: in this pattern which exists in the hilly lands of the district, field crops (mainly cereals), and fruit trees are grown.

Ali (1988) conducted an economical study of the greenhouses vegetables production in Al-Baq'a Basin, Jordan. The objective of this study was to recognize the relationship between farm size, costs and production income. Results showed that the production income of the greenhouses is relatively high and the ideal size of the farm is between 51-60 houses.

Bino (1993) studied changes of economic activities in Dhulail Valley, Jordan. The impact of agricultural pattern change on the socio-economic conditions of the area was investigated. The study showed that a change in the agricultural pattern from field cropping (mainly cereals) to vegetables and fruit trees cropping has taken place.

Abed (1989) studied the agricultural potentials of Anbar District, Iraq. Results of the study showed the big influence of both physical and human factors on agricultural production and variability from one place to another. The author suggested the use of modern technology in agriculture such as irrigation, fertilizers and sowing to develop agriculture in the district.

Kazkouz (1990) studied the spatial variations of agricultural production in the Upper Furat River Region. The study proved that the agricultural policy has a big effect on production. The agricultural reclamation laws of 1983 resulted in expanding the agricultural lands. The study also showed that certain changes in cultivated areas and production has taken place between 1980-1988.

Abu-Rhail (1989) studied the agricultural production in Al-Musayab Sub-District, Iraq. The objective of the study was to investigate the role of soil type in crop production and the spatial distribution of crop types. The study showed that horticultural cropping existed close to main rivers where good drainage soils existed. On the other hand, field cropping (cereal crops) existed in river basins. The study also showed that intensive horticultural cropping areas are highly populated, while the field cropping areas are sparsely populated.

Al-Yasseen (1979) conducted a study on the potentials of agriculture in Ninawa District, Iraq. The study recommended that the cultivated land can be expanded and the district has good agricultural potentials.

As-Saqqa, A. N. (1995) studied the agricultural developments in Al-Baq'a Basin, Jordan through the past four decades. Historical statistics, maps, aerial photographs, and field survey have been used in this study. The study proved that a lot of agricultural changes took place in the area such as the spread of new types of agriculture mainly recreational agriculture, the plantation of greenhouses twice a year, the vertical agricultural expansion, the intensive farming, and the change from rain-fed cropping to irrigated cropping.

3.4.2 Agricultural Studies in the West Bank

The agricultural sector in the West Bank was completely controlled by Israel between 1967 and 1993. After the Oslo transition agreement between Israel and the Palestine Liberation Organization (PLO), some of agricultural responsibilities were transferred to The Palestinian National Authority (PNA). The PNA through its organizations started an emergency plan for natural resources protection in the West Bank. The main organizations, which have some capabilities to use agricultural geographical data, are: The Palestine Geographic Center, Ministry of Planning, Ministry of Agriculture, and the Palestine Central Bureau of Statistics. There are also non-governmental organizations that have some capabilities in this field.

Al-Khayyat (1997) conducted a study on the Palestinian agricultural advisory systems in Tulkarem and Qalqilia areas during the last ten years of Israeli occupation. The study showed that the advisory centers and educational programs were not enough and not efficient. So, there is a need for more comprehensive and well-established advisory centers.

The Palestine Ministry of Planning and International Cooperation (MOPIC) (1996) divided the West Bank agriculturally into three categories: 1) lands of high agricultural value:- this category was given grade 1 and it includes agricultural plains and topographic hollows, 2) lands of intermediate agricultural value are given grade 2, and include hilly lands which are covered with different types of trees, bushes, rough grass, and natural vegetation, and 3) lands of low agricultural value are given grade 3 and include non-vegetated lands which lie in the Jordan Valley and eroded mountainous lands.

Kahan (1983) studied agriculture and water in the West Bank and Gaza Strip for the period 1966-1981. He found that first, the total cultivated lands in the West Bank decreased from 208 thousand ha in 1966 to 167 thousand ha in 1981, second, the total irrigated lands remained the same.

Some attempts are going on in the West Bank to use remote sensing data for land use studies including agriculture. But these attempts face many difficulties (see chapter one). In 1994, The Palestine Geographic Center with the cooperation of the Institute Geographic National (IGN) of France produced 1/ 50000 false color composite maps for the West Bank and Gaza Strip using SPOT XS images. These maps were distributed to different educational organizations. The limitation of these maps is that they are not classified and difficult for ordinary people to understand.

The Applied Research Center in Bethlehem (1994) conducted a study of rain-fed agriculture in the West Bank using the available agricultural statistics in the Rural Development Center of An-Najah National University and the Israeli statistics.

The Arab Studies Center in East Jerusalem with cooperation of some academics of the Palestinian universities and organizations tried to put forward a remote sensing land use/ land cover system for Palestine. This project faces a lot of technical and financial problems mainly the lack in remote sensing and GIS specialists. At the same time, the Palestinian Central Bureau of Statistics is also trying to set up their own land use/ land cover system for Palestine. These efforts from governmental and non-governmental organizations should work together to produce a uniform land use system and avoid confusion.

Many countries in the Middle East suffer the lack of accurate and up to date topographic and thematic maps (Harris, 1981). Petrie (1979) found that the existing maps in some Middle East countries were inaccurate and compiled by field work. He also found that the aerial photographs go back to the Second World War. He concluded that there is a need in the developing countries such as Sudan with its large area and relatively limited resources for reliable and accurate mapping. Petrie found that Landsat MSS imagery for Sudan was useful in identifying the general patterns of topography and agricultural areas, but was not effective in identifying roads and small villages.

Parry (1978) in a project aimed at identifying land systems in Darfur in Sudan in connection with Food and Agricultural Organization (FAO) was able to identify the main linear features (roads and railways) from Landsat imagery. He came to the same conclusion as Petrie that the existing maps are insufficient, but it was possible to identify and map general land systems in that area.

Bowen-Jones (1980) in a study aimed at improving local agricultural in Oman found that there is a need for land use mapping to identify areas of agricultural potential and compensate for the lack of topographic and thematic maps. Landsat image has been used for the agricultural mapping of the area.

The main reason for the lack of topographic and thematic maps in some of the Middle East countries is the colonial occupation of these countries that lasted for many decades. After these countries got their independence, they started different conventional mapping surveys based on the surveys made by the colonial powers that ruled the area for a long time. Some of the Middle East countries mainly the Arab Gulf States and after the Gulf War in 1990, started to establish geographic centers which use the remote sensing the GIS technology for different applications. European experts mainly assist these centers. For example, the mapping project in Qatar started in early nineties uses the remote sensing and GIS technology.

Also the West Bank suffers from the lack of reliable and accurate thematic and topographic maps for it is still under the Israeli occupation. The Israeli topographic maps which are available (1:50 000) are not suitable for detailed and accurate mapping of some types of crops especially the arable and the horticultural crops (see chapter 5 and 6). In addition, it is difficult for individuals to get the appropriate Israeli aerial photographs for research work.

3.5 Discussion of Previous Studies

It can be seen from the previously reviewed agricultural remote sensing projects that:

- Landsat MSS was the first remote sensing system to be used by these programs for agricultural monitoring. They started with single aim work and developed to multi-purpose work. They also developed their work from general to more accurate, specialized and detailed purposes. For example, the major aim of LACIE (1973) was to estimate wheat production at a global level. While AgRISTARS (19800) aimed at using remote sensing for agricultural monitoring at both national and international levels. Also, eight projects were designed within this program to fulfill its aims. Remarkable development in remote sensing occurred after the launch of Landsat TM satellite. This satellite carries better spatial, spectral, radiometric and temporal resolution sensors. In 1985 DUTA stated using the TM data and so renamed to AGRIT-1. While the American Programs targeted agriculture of the globe, the European programs targeted agriculture in regions of the continent.

- Landsat TM data has advantage over the Landsat MSS data for its better spatial, spectral, radiometric and temporal resolution and gives better crop estimation especially in areas characterized by medium field size (see chapter 4).

- SPOT data has advantage over the Landsat data for its better spatial resolution, on the other hand Landsat data especially the TM is spectrally better than the SPOT (see chapter 4). Therefore, SPOT data are suitable for mapping areas characterized by small and medium size and may produce better cartographic maps than Landsat when the targeted crops are of good spectral separability.

- Optical remote sensing data such as SPOT and Landsat are not suitable for cloudy regions. Active and Passive Radar systems which uses or senses microwaves (long waves) may be the alternative for it is not affected by cloudy weather. Radar remote sensing systems such as the Synthetic Aperture Radar (SAR) can sense the ground surface any time and season.

- Low spatial resolution data such as the NOQA data (1.1km resolution) may give acceptable accuracy for large homogeneous areas inventories. Such low- resolution data are not suitable for small fields regions and detailed classifications.

- The use of multi-temporal remote sensing data may increase the accuracy of crop area estimation especially in areas characterized by large temporal variability. Data exchange between images increases the understanding of the spectral, thematic and temporal properties of the crop under study.

- Remote sensing can be used successfully in developing countries and for large areas inexpensively (see chapter one).

- Field data collection programs, the availability of ancillary data and documents, and the good understanding of target features characteristics are important determinants of image analysis accuracy.

3.6 Summary

Since agriculture is a vital sector at global, regional, and national levels, it is paid great attention by different countries, organizations and individuals. Developed countries mainly the United States and Europe achieved rapid progress in agricultural satellite remote sensing and established large scale research programs and experiments. These programs used a variety of remote sensing systems such as Landsat and SPOT. The objective of these programs and experiments was to investigate the capability of using satellite remote sensing techniques for crop identification, crop production, and crop area estimation. Results of these experiments proved that satellite remote sensing can provide valuable agricultural information at different levels and in turn help in better understanding of agriculture in the world and put forward plans to meet future requirements. These programs have developed techniques and methods for better, quicker, and more efficient satellite image analysis.

The use of agricultural satellite remote sensing in the developing countries including the West Bank (the study area) still in its infancy. This is due to the severe shortage of specialists in this field. At present, most agricultural studies in these countries use traditional survey methods.

CHAPTER FOUR

DATA SOURCES

4.1. Introduction

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4.8. Why SPOT Multispectral Data?

4.9. Image Environmental and Cultural Conditions

4.10. Summary

4.1 Introduction

The data used in this study are from a variety of sources because the West Bank has experienced and is still living under unusual political conditions. The West Bank has been ruled over by different foreign powers: the Ottomans, the British, (the Jordanians) and the Israelis. After the Oslo agreement between the PLO (The Palestine Liberation Organization) and Israel in 1993, some areas of the WB and Gaza Strip became under the rule of the Palestinian National Authority (PNA).

During the British Mandate the Ordnance Survey carried out a topocadastral survey of Palestine including the West Bank in 1933. The survey was updated from time to time between 1933 and 1942. So, The Survey of Palestine compiled this survey in 1942 producing different maps at a scale of 1: 20 000. The British surveys became the base used in other surveys. Israel also carried out its own surveys of the West Bank from 1977 to the present day. Jordan used the British maps as base maps but did not carry out a separate comprehensive survey.

The Palestinian National Authority (PNA) in cooperation with some European countries is trying to carry out an urgent limited survey of certain areas of the WB using the surveys mentioned and satellite images supplied by international institutions. This limited survey is not efficient and faces many technical difficulties and does not meet the required needs of geographical management. The reason for these difficulties is firstly the lack of specialists in remote sensing and GIS in these institutions. For example, the Palestine Geographic Center distributed unclassified SPOT XS false color image maps to schools of the West Bank, which are difficult for ordinary people to understand. At the moment the remote sensing lab of this center is unemployed. Secondly, the overlapped responsibilities among the Palestinian institutions and thirdly, an absence of cooperation and coordination among them.

As the purpose of this research is to develop techniques for crop area estimation in the northern part of the West Bank with reasonable cost and time, the most suitable data is the digital satellite imagery because it covers large geographical area. In addition to satellite imagery, two stages of field data collection were carried out, the first stage was carried out in May and June 1998 and was devoted to the collection of training data and interviewing farmers. The second stage is a stratified random sampling (conducted in April and May 1999) and devoted to field crop area estimation. In order to get more accurate results, ancillary data such as maps and aerial photographs are used.

The data sources can be summarized as follows:

4.2 Field Survey

Field data were collected through a field survey carried out in two stages:

Stage one: in this stage; the actual land use\ land cover at the time of the field survey (May-June, 1998) was recorded on maps and aerial photographs. Farmers were interviewed and asked to complete a questionnaire about their agricultural activities (see chapter 5).

Stage two: This stage was carried out between July and October 1999. In this stage a stratified sampling strategy was set up to collect field data for crop type area.

The field data are used for the following purposes:

a) to produce crop type area estimates derived from both field sampling and satellite imagery.

b) to select training data of known characteristics for supervised image classification.

c) to help understand the environmental conditions of agricultural crops (soil color, topography, crop density, under canopy vegetation) in each stratum which can be taken into consideration in image classification to improve classification accuracy.

d) to help understand the problems faced by Palestinian farmers and difficulties of agricultural development in the WB.

e) to assess the accuracy of image classification.

4.3 Aerial Photographs

Aerial photographs are still the most widely used type of remotely sensed data for large scale mapping, because of their spatial resolution availability, time freezing, and stereo capability (Curran 1985). Aerial photographs have been widely used for agricultural purposes such as area estimation, production of agricultural land use maps, and identification of crop disease (Myers 1983, Lillesand & Kiefer 1987 and Lo 1986). Most agricultural remote sensing programs use aerial photography to support ground data (Shueb, 1990). The special advantage of aerial photographs for the study area is that they show field boundaries in areas characterized by small sized fields.

In this research, panchromatic Israeli aerial photographs covering limited areas of the study area have been used. These aerial photographs were taken in December 1995, October 1997 and October 1998 at a scale of 1: 15000 and 1: 20000. They cover some areas of Tulkarem, Jenin sub-districts and a part of Nablus city, see figure 4.1. The acquisition date of the aerial photographs is not ideal because most of the fields will be freshly sown at that time of the year (December). Despite their inappropriate date, they provided one of the major sources for the first stage of the field work, that is the selection of training sites. These aerial photographs are not adequate for field sampling because they only cover limited parts of the study area.

Figure (4:1): 1: 15, 000 Scale Aerial photograph (December 1995) used for the research study. It covers part of Sha'rawiyya Plain Northern Tulkarem

4.4 Maps

The main map data used for this research was the 1: 50,000 Israeli maps dated 1992. The study area is covered by 9 sheet maps each grid square represents an area of 1 km^2 (figure 4.2). The Israeli maps were used to help to assign the training areas especially the relatively constant land use/ land cover types such as olive trees, citrus and woodlands because these types cover relatively large fields in the WB. These maps do not show field boundaries in the plains where intensive agriculture exists. The absence of field boundaries on these maps could be justified by:

a) Field size: most fields in the WB are small. About 50% of the total land ownership in the northern part of the WB is less than 1 ha. Only 6% of the land is held in parcels of more than 10 ha in size (Ennab 1977 and ARIJ 1994). The small size of fields is partly due to the limited extend of good agricultural land and the fragmented of ownership determined by the social system.

b) Field boundaries: most of the Palestinian farmers do not build clear boundaries such as walls and hedges around their lands as those in Britain for instance. They only mark the boundaries by a number of large paced stones. So, boundaries of these fields disappear under the crop canopy.

c) Field use: the Palestinian farmer is used to growing more than one crop type in the same field and season. For example, tomatoes, okra and cucumber are grown in an area of less than 1 hectare. This kind of farming is more common in the irrigated areas than the rain-fed farming areas. This situation creates difficulties in deciding real field boundaries.

In order to try to resolve field boundaries, CORONA large scale satellite photographs are used in conjunction with maps to design the sampling frame for the study area.

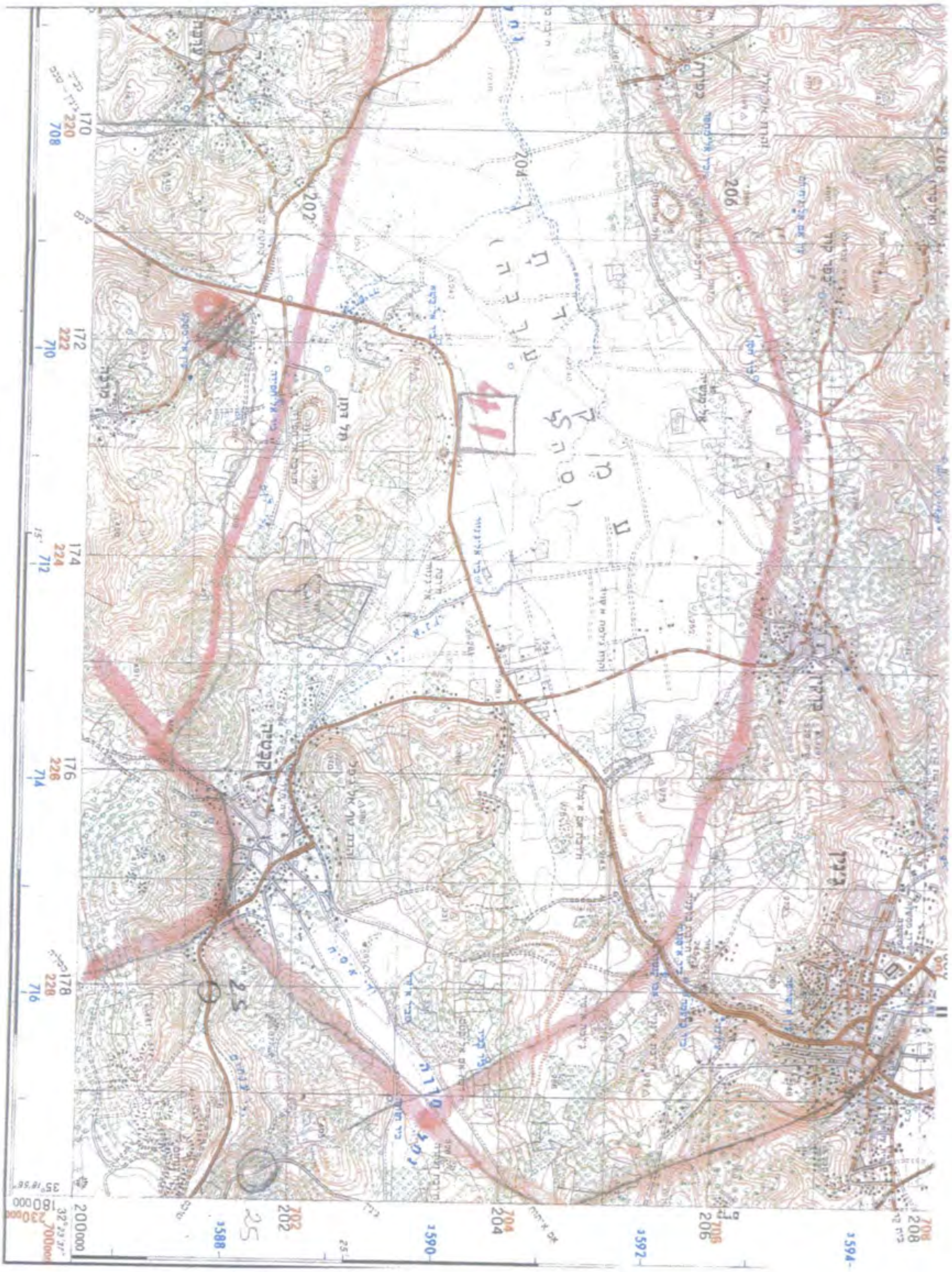


Figure (4:2) 1: 50,000 topographic map used for the research study

4.5 CORONA Data

CORONA panchromatic satellite photographs acquired in June 1970 were used in this research study to try to resolve field boundaries in the upland areas which are mostly planted with olive and fruit trees. The data consists of four 16 km wide strips selected to cover the study area. The data are scanned to a CD, then prints at scale 1: 40 000 are produced in the photography room of the Department of Geography of Durham University. The spatial resolution of the data is 4 meters. The data were geometrically corrected on PCI remote sensing software. Twenty five ground control points (GCPs) from the 1: 50,000 Israeli topographic maps were selected for the rectification of each of the four strips. The 1: 40 000 CORONA prints were only used in the field for overview while the digital data used for the allocation of field sample units at 4 m resolution. The sample units were enlarged on the Arcview GIS software and printed out at a large scale showing fields boundaries to be used in the field survey in conjunction with the Israeli topographic maps (see chapter 6). As mentioned, the main aim of these photographs is to show the boundaries between olive and fruit trees and non-agricultural land (see chapter 5). As mentioned earlier in section 4.4, Palestinian farmers do not build walls or hedges around their fields, and boundaries disappear under the canopy. Therefore, the identification of field boundaries is achieved from grey tone contrast between olive and fruit trees and non-agricultural lands. Olive and fruit trees look dark on the CORONA imagery while the non-agricultural areas look light except areas covered with dense bushes. Confusion from the photograph may occur between some areas of specific types of bushes and olive trees.

4.6. SPOT Satellite Data

4.6.1. Introduction

Section 4.6.2 will discuss the SPOT satellite program and its development and its subsections will give a brief description of the French SPOT series and describe the data from the SPOT HRV XS sensor. Also a comparison between SPOT HRV Multispectral (XS) and Panchromatic SPOT data on the one hand, and Landsat TM sensor on the other hand will be made because these two sensors are the two most commonly employed for agricultural studies. The reasons for choosing the SPOT HRV XS data for this project are also discussed.

4.6.2 SPOT Satellite Program

The idea of this satellite came from France in 1978 to provide geographical data from sensors giving high resolution images and repetitive coverage of the earth. The acronym SPOT is an abbreviation of the French words; System Pour l'Observation de la Terre (SPOT). Sweden and Belgium were co-sponsors of the program. SPOT was designed by the French Center National d'Etudes Spatiales (CNES) as a commercially orientated program to be operational rather than experimental in character. It has 22 direct ground receiving stations worldwide (figure 4.3). Four SPOT satellite missions have been launched since 1986 until 1998 (SPOT 1, SPOT 2, SPOT 3 and SPOT 4). Section 4.6.3.1 describes these satellites systems.

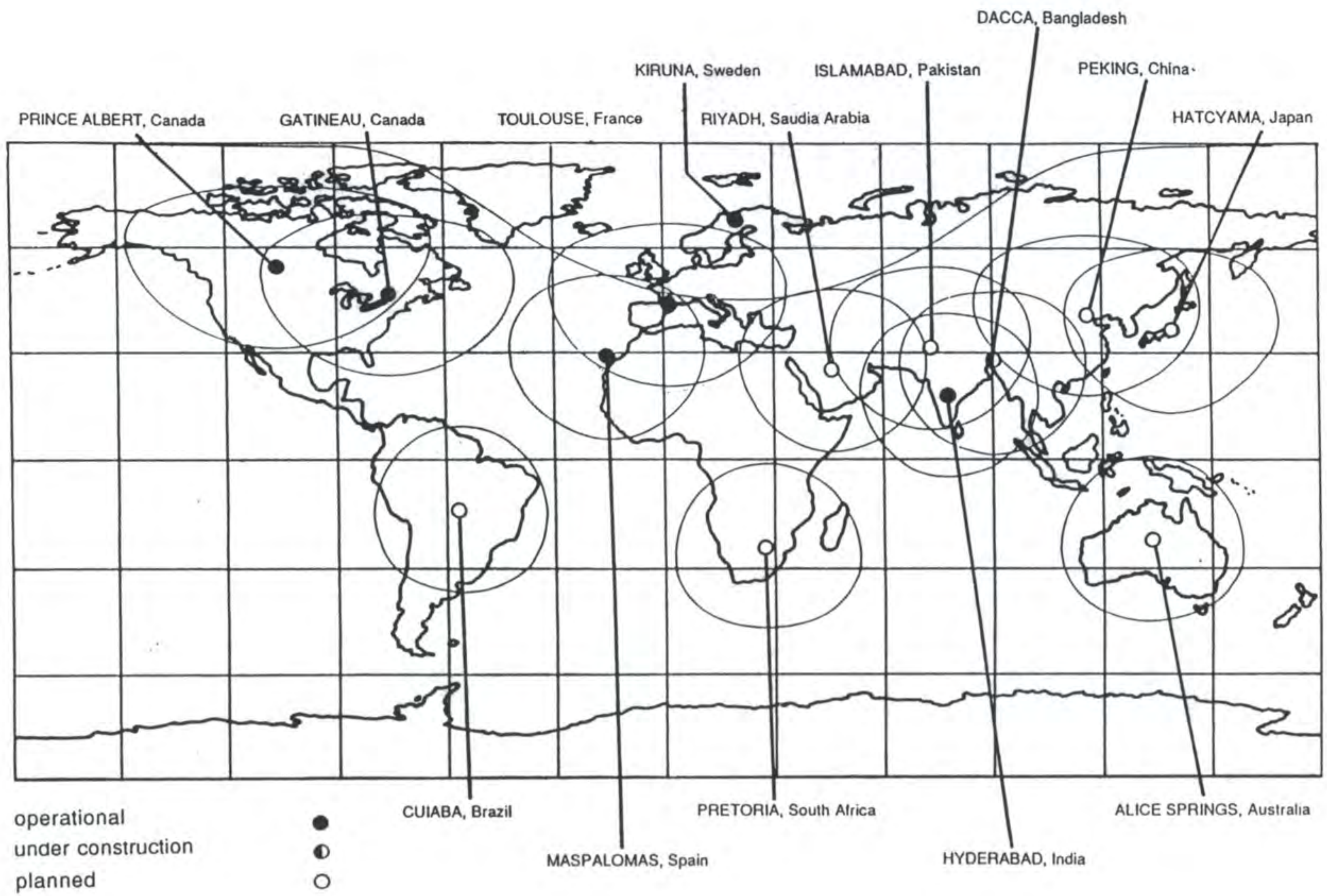


Figure (4:3): Ground receiving stations of SPOT

Source: National Remote Sensing Centre (NRSC), 1987

4.6.2.1 SPOT 1-3

Several authors, including Lillesand & Kiefer 1987 and Jensen 1996, provide a detailed description of SPOT data. These satellites were launched from the Kourou Launch Range in French Guiana on February 21, 1986, 22 January, 1990 and 26 September, 1993 respectively. SPOT 1 was withdrawn from active service on 31 December, 1990, but SPOT 2 is still operational. SPOT 3 stopped functioning on 14 November, 1997 after a malfunction . These satellites' programs can be considered as a start of a new era in remote sensing for (a) it is the first earth resources satellite system to include a linear array sensor and employ a push-broom scanning techniques (b) it is also the first system to have pointable optics. This enables side-to-side off-nadir viewing capabilities, and it offers full-scene stereoscopic imaging from two different but overlapping satellite tracks.

These satellites have a near polar, sun-synchronous orbit at an altitude of 832 km and inclination of 98.7°. SPOT crosses the equator at 10:30 A.M. local solar time. The orbit pattern repeats every 26 days. This means that any point on the earth can be imaged using the same viewing angle at this frequency. However, the pointable optics of the system enable off-nadir viewing during passes separated alternatively by 1 and 4 days, depending on the latitude of the area viewed. This revisit capability is important in two respects. First, it increases the potential frequency of coverage of areas where cloud cover is a problem. Second, it provides an opportunity for viewing a given area at frequencies ranging from successive days to several days, to a few weeks. Many applications particularly within agriculture and forestry, require repeated observations over these types of time scales.

The sensor for SPOT 1-3 consists of two identical high resolution visible (HRV) imaging systems and auxiliary tape recorders:

1) Panchromatic mode (black and white): this imaging system operates in the visible broad waveband 0.51 - 0.73 μm (the green and the red wavebands). Its spatial resolution is 10 m.

2) Multispectral mode: It operates in three spectral wavebands; the green (0.50 - 0.59 μm), the red (0.61 - 0.68 μm) and the near infrared (0.79 - 0.89 μm). Its spatial resolution is 20 m.

4.6.2.2. SPOT 4

This satellite was successfully launched on 24 March 1998. It is more spectrally developed than the previous SPOT remote sensing satellite systems. The High Resolution Visible (HRV) imaging instruments operate in two modes:

1) Panchromatic mode (black and white): this imaging system is different from the previous panchromatic system used in SPOT 1-3 by operating in a narrower panchromatic waveband which is the red (0.61 - 0.68 μm) with the same spatial resolution (10 m).

2) Multispectral mode: a short-wave infrared waveband (1.58 - 1.75 μm) has been added to the existing three spectral wavebands of SPOT 1 - 3. So, this system works in four spectral bands instead of three with the same spatial resolution (20 m).

France in co-operation with Belgium, Sweden and Italy funded another sensor for SPOT 4 called SPOT 4- VEGETATION. This sensor is expected to make a significant advance in the ability to monitor crops and the continental biosphere. The

VEGETATION instrument on SPOT 4 provides global coverage on an almost daily basis at a resolution of 1 km. Thus it is suitable for long-term environmental observation on a regional and global scale. Spectral bands used in VEGETATION are the blue band (0.43 - 0.47 μm), the red band (0.61 - 0.68 μm), the near infrared (0.78 - 0.89 μm) and the short-wave infrared (1.58 - 1.75 μm). The blue band is used for atmospheric and oceanographic applications and the rest of the bands are used for vegetation studies. Daily coverage; with a swath width of 2.250 km, the VEGETATION instrument covers almost all the globe's land masses while orbiting the earth 14 times a day.

4.6.2.3 SPOT 5

This future satellite is expected to be launched late in 2001. It will include a new imaging instrument High Resolution Geometry (HRG). It will be placed in the same orbit as SPOT 1, 2, 3 and 4. It is expected to deliver the following improvements compared with SPOT 4:

- higher resolution in multispectral mode: 10 m (instead of 20 m) in all 3 spectral bands in the visible and the near infrared (NIR) ranges. The spectral band in the short-wave infrared is maintained at a resolution of 20 m.
- higher ground resolution in panchromatic mode, 5 m and 2.5 m instead of 10 m.
- the swath width of each instrument is 60 km, the same as SPOT 1 - 4.
- the oblique viewing capability of each instrument is maintained providing rapid revisit capability to a given area.
- possibility of a dedicated instrument for along track stereo data acquisition.

Spectral bands of SPOT 5 are expected to be the same bands as SPOT 4 except the panchromatic which will return to the values used for SPOT 1-3 (0.51 - 0.73 µm). Table 4.1 summarizes the principal characteristics of SPOT satellites.

Table (4:1): Main properties of SPOT satellite data

	SPOT 1 - 3	SPOT 4	SPOT 5
Launch Date	22 Feb, 1986, 22 Jan 1990, 26 Sept 1993 respectively	24 March, 1998	not launched yet. expected to be launched late 2001
Altitude	832 km	832 km	832 km
Type	Sun-Synchronous	Sun-Synchronous	Sun-Synchronous
Repeat Coverage	26 days	26 days VEGETATION (1 day)	26 days
Inclination	98.7° (nadir viewing)	98.7 (nadir viewing)	98.7 (nadir viewing)
Imaging Instruments	HRV in two modes: P and XS	- HRV in two modes: P and XS - VEGETATION	- HRV in two modes: P and XS - HRG
Spectral Bands (µm)	P (0.51 - 0.73) XS (0.50 - 0.59), (0.61 - 0.68), (0.79 - 0.89)	P (0.61 - 0.68) XS (the same as SPOT 1-3 plus a short-wave IR (1.58 - 1.75) VEGETATION bands: (0.43 - 0.47), (0.61 - 0.68), (0.78 - 0.89), (1.58 - 1.75)	P (0.51 - 0.73) XS (the same as SPOT 4)
Spatial Resolution	P (10 m) XS (20 m)	P (10 m) XS (20 m) VEGETATION (1 km)	P(5, 2.5 m) XS (10 m)
Status	SPOT 1 and 3 are not operational, SPOT 2 is operational.	operational	Not operational yet

Source: Lillesand & Kiefer 1987, Jensen 1996, SPOT-Image Company 1999

notes: P (panchromatic), XS (Multispectral), HRV (High Resolution Visible), HRG (High Resolution Geometry)

Table (4:2): SPOT Multispectral Bands and Their Applications

Band No.	Band	Width µm	Application
1	Green (G)	0.50 - 0.59	Designed to measure green reflectance peak of vegetation for vegetation discrimination and vigor assessment. Also useful for cultural feature identification
2	Red (R)	0.61 - 0.68	Designed to sense in a chlorophyll absorption region aiding in plant species differentiation. Also useful for cultural feature identification and helps in defining iron rich rocks.
3	Near Infrared (NIR)	0.79 - 0.89	Useful for determining vegetation types, vigor, and biomass content, for delineating water bodies, and for soil moisture discrimination. Reconnaissance mapping and geobotanical studies

Source: Lillesand & Kiefer 1987, Townshend et al 1988, Jensen 1996

4.7 Comparison between SPOT and Landsat data

SPOT and Landsat data have the following important differences:

1) The spatial resolution. This can be defined as the pixel size or the smallest separation value between two objects that can be resolved by the remote sensing instruments. For satellite images, the spatial resolution is the dimension in a measurement unit such as meter (m) and kilometre (km) of the earth projected instantaneous field of view (Jensen 1996). For SPOT, the spatial resolution is 10 m in the P mode and 20 m in the XS mode as mentioned in the previous sections of this chapter. For Landsat, the spatial resolution is 80 m in the Multispectral Scanner (MSS) system and 30 m in the Thematic Mapper (TM) system. High spatial resolution is more appropriate for areas characterized by small field sized as this study area. Plains that represent the valuable agricultural lands in the West Bank are characterized by such small field size.

2) Spectral resolution. This refers to the number and width of specific wavelength intervals in the electromagnetic spectrum to which a sensor is sensitive. The width of band may be large (coarse), as with panchromatic aerial photography (0.40 - 0.70 μm) or relatively small (fine) as band 3 of Landsat TM sensor (0.63 - 0.69 μm). In the first example, the sensor records all the reflected blue, green and red radiant flux incident on it. In the second case, the sensor records a very specific range of the red radiant flux (Jensen 1996). As mentioned in the previous sections of this chapter, SPOT P mode is sensitive to one wide spectral band in the visible portion of the spectrum (0.51 - 0.73 μm). Therefore, it records all the reflected green and red radiant flux incident on it

from different objects on the ground. But SPOT XS mode is sensitive to 3 spectral bands; in the green, the red and the near infrared.

Landsat MSS carries sensors that record data on 4 spectral wavebands. These bands are; the green, the red and two near infrared bands. Landsat TM carries sensors record data on 7 spectral wavebands; the three visible bands, 1 near infrared, 2 middle infrared (short infrared) and 1 thermal infrared band (Curran 1985). The two middle infrared wavebands of the Landsat TM sensors increase its ability for better spectral differentiation among different land use types. On the other hand, the absence of these two wavebands from the SPOT XS sensors decrease its capabilities in spectral analysis.

3) Temporal resolution. It refers to how often the sensor system records imagery of a particular region. Temporal resolution is important for discriminating characteristics of features under study. For example, agricultural crops have different calendars in different regions, so it is essential to acquire remotely sensed data at suitable dates in the phenological cycle. Feature change information provides insight and better understanding of processes influencing the development of the crops (Steven 1993).

As mentioned, both SPOT P and XS modes have a 26 days repeat cycle in addition to pointable system with a repeatable cycle of 2 - 3 days. For Landsat, it has an 18 days repeatable cycle for MSS system and 16 days for the TM.

From the previous comparison between SPOT and Landsat remote sensing systems, the following points can be recorded:

- SPOT provides better spatial resolution data than Landsat and it is possible to fuse the Panchromatic and the XS data.
- Landsat, especially Landsat TM provides a better spectral resolution than SPOT.
- SPOT provides better temporal resolution than Landsat with the pointable system.

So, for spectral analysis, Landsat TM data are preferred to SPOT data because firstly, it gives the possibility of selecting the bands that maximize contrast between the objects of interest. Secondly, it can be used for a larger number of applications, and lastly, careful selection of the spectral bands may improve the probability of more accurate feature detection and identification. For some land use mapping and crop type area estimation, SPOT data are preferred to Landsat data especially in regions characterized by small field size. The reason is that the relatively high spatial resolution of SPOT imagery compared with that of Landsat imagery may reduce the number of mixed pixels and so improve crop type area estimation results. Secondly, better spatial resolution in areas characterized by small field size may reduce the salt and pepper appearance of classified images and produces more readable cartographic maps. Better image geometric correction results may be produced from higher spatial resolution imagery.

4) Radiometric resolution. It describes the range number of brightness values of the different wavebands of the sensor. The radiometric resolution is often expressed in terms of the number of binary digits or bits necessary to represent the range of available brightness values (Richards & Jia 1999). For example, the data such as SPOT and Landsat TM with 8 bits have 256 levels of brightness, while Landsat MSS has a lower radiometric resolution (128 levels of brightness for bands 1, 2, 3, and 64 brightness levels for band 4).

4.8 Why SPOT HRV Data ?

Successful utilization of remotely sensed data for different applications requires careful selection of a suitable data and image processing techniques. Selection of remotely sensed data is linked with a number of variables: sensor characteristics, subject or application, availability and costs of data. Spatial, spectral, temporal, and radiometric characteristics of sensors to a great extent determine the type and quality of information that could be extracted from images (Phinn 1998). The environmental composition of a certain geographical area under investigation, the subject to be investigated and the targets of investigation are also important factors that determine the appropriate remotely sensed data.

On the basis mentioned above, SPOT XS data have been selected for this research. Spectrally, several authors and studies have shown that the green, the red and the near infrared spectral bands are suitable for agricultural studies.

Atkinson *et al* (1985) in the UK used TM bands to differentiate among different land use classes in Reading area of the UK. They found that the best bands for separating all classes are band 2 (the green band), band 3 (the red band), band 4 (the near infrared) and band 5 (the short-wave infrared). They also found that band 1 (the blue) and 2 on one hand and band 5 and band 7 (short-wave infrared) were highly correlated.

Shueb (1990), used TM bands 2, 3, 4, and 5 for the calculation of crop area estimates in County Durham. Ghodieh (1994), found that TM bands 2, 3, and 4 are the best bands for agricultural studies in the lowland regions of County Durham and bands 3, 4, and 7 are the best for the uplands.

May, Pinder III, and Kroh (1997) carried out a comparison of Landsat TM and SPOT XS imagery for the classification of shrub and meadow vegetation in northern California. They found that TM data were more effective than SPOT data in separating shrubs from meadows because of the additional short-wave infrared bands in the TM data. But it is possible to improve the relative performance of SPOT data by extracting additional information concerning texture or pattern from greater spatial resolution of SPOT images.

SPOT XS bands are almost identical to the best Landsat TM bands for agricultural studies (band 2, 3, and 4). Table 4.3 illustrates this similarity

Table (4:3): Similarities between SPOT XS bands and the best TM agricultural bands

SPOT XS Bands (μm)	**Landsat TM Bands (μm)**
Band 1 (0.50 - 0.59)	Band 2 (0.52 - 0.60)
Band 2 (0.61 - 0.68)	Band 3 (0.63 - 0.69)
Band 3 (0.79 - 0.89)	band 4 (0.79 - 0.90)

Previous studies show that, for general agricultural image classification; SPOT HRV XS and Landsat TM have similar capabilities.

As mentioned in previous sections, one of the major aims of this study is to produce crop type area estimates for the northern part of the WB. Therefore, the spatial resolution of the sensor to be utilized is vital to achieve the most accurate results possible. The West Bank is characterized by small agricultural field sizes, especially in the plain areas that represent the main agricultural land in the WB, see section 2.8.1. The SPOT HRV XS data used in this research are resampled to 10 m spatial resolution maintaining the 3 usual SPOT HRV XS bands of the Jordan Valley images. While the red band is substituted with the panchromatic band of the rest study area (panchromatic sharpened images).

4.9 Image Environmental and Cultural Conditions

Spectral reflectance of agricultural crops is decided by a highly complicated and interrelated network of environmental and cultural conditions. Most of agricultural remote sensing studies and remote sensing literature in general have investigated these conditions (Curran 1985, Lillesand 1987, Harris 1987, Jensen 1996, and Gao & Skillcorn 1997). The dynamic and changeable conditions of crops present difficulties for making direct and automatic land use \ land cover area estimation. In other words, the crop properties and the environment in which the crop exists have a great effect on its spectral reflectance. A good qualitative and quantitative understanding of these conditions could result in considerable improvement of data performance and analysis. The main environmental conditions that decide the spectral reflectance of agricultural crops are:

-Solar angle

- Climatic conditions (clouds, seasonality, winds, haze, and temperature)

- Geomorphology (elevation, slope and aspect)

- Soil moisture

- Crop background (soil and vegetation)

Solar angle has important effects on the spectral reflectance of agricultural crops. When the sun is high in the sky (noontime), its rays penetrates the crop canopy effectively and so the spectral signal that the sensor receives will be affected by the canopy environment such as the shadow of the crop canopy and the under canopy features (soil and vegetation). But when the sun is low, (in the morning and the afternoon) the sun rays is reflected by the crop canopy itself resulting in a higher reflectance especially on the ear infrared spectral band (Curran 1985).

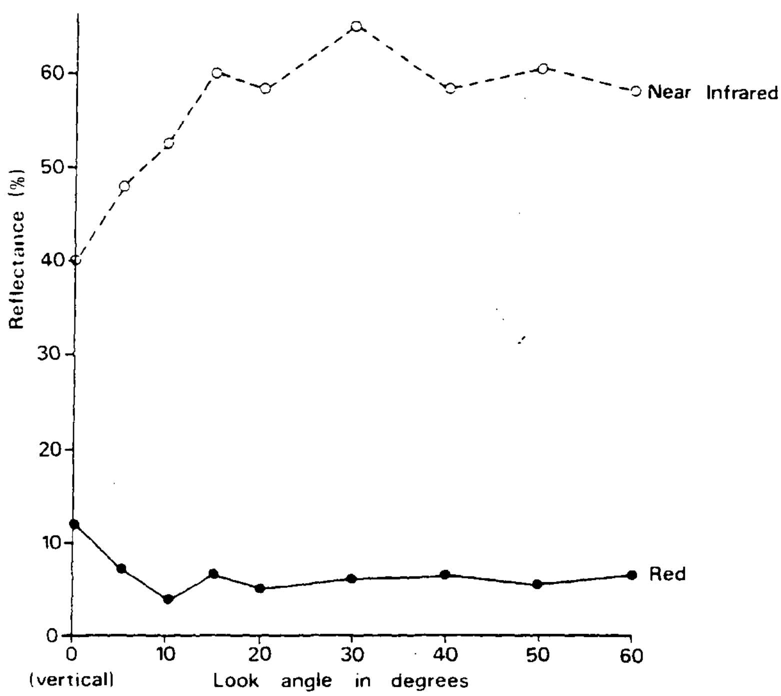


Figure (4:4): Effects of solar angle on reflectance measurements of agriculture

Source: Curran, 1985

Clouds represent a major problem to optical remote sensing systems which use reflecting spectral wavebands (the visible, the near and the short-wave infrared). SPOT XS use the visible and the near infrared wavelengths, so this remote sensing system can not work successfully in cloudy weather conditions. Fortunately, the West Bank as a Mediterranean region enjoys clear skies for most of the year. It stays sunny from mid-spring until mid-autumn (April - October). Image of the study area was acquired in May or mid-spring and is completely cloud-free.

Seasonality is a very important factor that affects the spectral reflectance of agricultural crops. It is also important for crop type discrimination and differentiation and consequently affects mapping accuracy and crop type area estimation. To maximize the benefits of remote sensing, the date of imagery should be selected carefully.

Gao and Skillcon (1997) studied the capability of SPOT HRV XS data in producing land cover maps at the urban-rural periphery for two seasons (winter and summer). A higher mapping accuracy is achieved for the summer image because of the distinctiveness of particular vegetation types in this season.

Mid-spring does achieve good differentiation among the major types of crops. At this time of the year most lands would be under cultivation (rain-fed and irrigated lands) (see chapter 5).

Haze, water vapor, aerosols and gases affect image quality through absorption and scattering of electromagnetic radiation. The sensor does not record only the radiation reflected by different objects on the ground, but also it records radiation scattered by different contents of the atmosphere and consequently affects the accuracy of image analysis and classification results (Mather 1987). Haze usually appears over the western flanks of the WB mountains, intermediate plains and depressions, and bottoms of valleys in early morning. It disappears very rapidly after it is exposed to sunshine. At the time of SPOT imaging of the West Bank (10:30 AM), haze would disappear. Therefore, SPOT HRV XS data used in this research study is free of haze.

Wind affects the spectral reflectance of crops by changing the canopy geometry and plant leaf orientation. This effect varies with crop type, wind speed and direction, and the spectral bands used. Temperature has an indirect effect on the spectral reflectance of crops. Its effect is on the plant leaf geometry and the crop Leaf Area Index (LAI), especially for the rain-fed agricultural crops. The relatively high temperature averages of the WB in summer reduces the soil moisture and crop leaf water content. This results in changes in the leaf geometry and a reduction of leaf area index. This effect is highest in the middle of the day.

Geomorphology not only affects the spectral reflectance of agricultural crops, but also the spatial distribution of these crops. Areas with high elevations and steep slopes are exposed to severe soil erosion. Consequently, the agricultural capability of these areas is reduced and the underneath rocks are exposed changing the reflectance characteristics of the subsurface. Agricultural areas with a southern aspect in the Northern Hemisphere have higher spectral reflectance than areas with northern aspect for the same crop types. This affects the accuracy of image classification. Topographic shadowing also influences the spectral characteristics of crops. It reduces the spectral reflectance of crops in all spectral channels and reduces the ability to differentiate among some land cover types.

Rough terrain and considerable spatial variations of elevation, slope and aspect (see chapter 2) characterize the study area.

Soil moisture affects reflectance of agricultural crops through the preferential absorption of electromagnetic radiation in certain spectral bands, especially in the near infrared. These effects have been investigated by several authors (Curran 1985, Bauer *et al* 1981a), see figure 4.5.

Soil moisture depends on many variables such as location, site, soil type thickness, rate of infiltration, drainage, slope and aspect, cultivation system (irrigated or rain-fed) and time of irrigation. These variables affect soil moisture in the WB considerably and consequently affect the spectral signatures of crops.

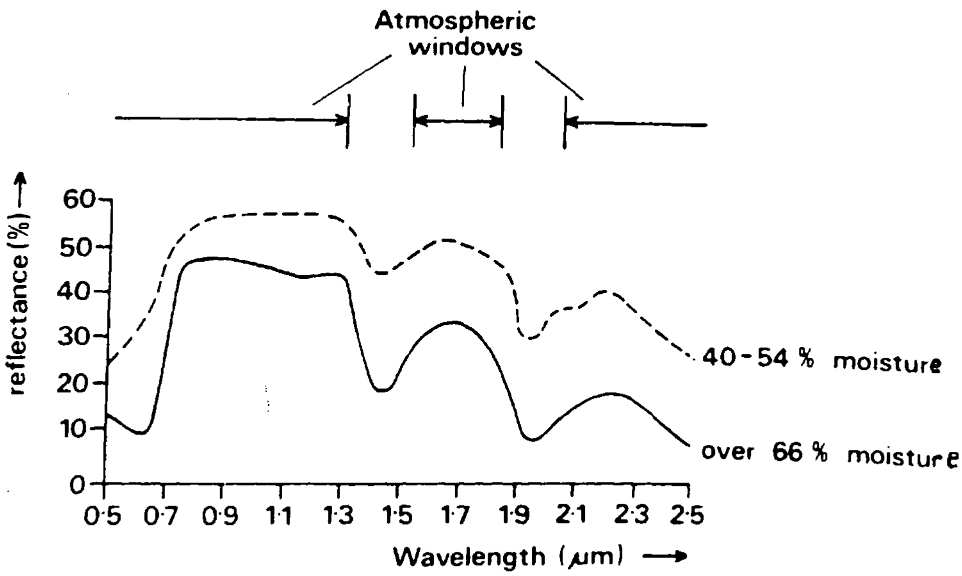


Figure (4:5): Effect of soil moisture on the spectral reflectance of crops

Source: Curran, 1985

Crop background or subsurface includes soil type and vegetation. The effect of crop background on its spectral reflectance varies from one crop type to another and from one spectral band to another also. Light color soil such as the limestone increases the spectral reflectance of crops on all channels. While dark color soil decreases it on all channels also. Vegetation background of crops reduces the spectral reflectance of crops on the red spectral waveband because this waveband is affected by plant chlorophyll content. On the other hand, the type of the subsurface vegetation decides the spectral reflectance for the infrared spectral band.

Agricultural crops in the WB have different types of background or subsurface: in the mountainous areas which are mainly planted with olive and fruit trees, the background is either rough grass and bushes or bare light limestone rocks. This is due to soil erosion, thin dry soil, and rough terrain. In the flat plain areas because of the relatively thick moist soil and the clean crop subsurface, the crop background or subsurface is a dark color soil.

The cultural conditions that affect the spectral reflectance of agricultural crops can be summarized in the following points:

- Crop calendar
- Row spacing and row direction
- Fertilization

Crop calendar determines the appearance of land for the different growing stages of crops (date of ploughing, sowing, tillering, flowering, ripening and harvesting). For each of these stages, the crop may have different reflectance characteristics in different wavebands (see chapter 5).

In the WB the crop calendar of a rain-fed system is different from that of the irrigated cultivation. Irrigated crops (mainly vegetables) in the WB are grown by two methods: open and sheltered farming. Apart from root crops, crops which are grown in open fields are planted in spring and summer (beans, tomatoes, cucumber etc) to avoid the frost of the cold months. Sheltered irrigated crops (mainly vegetables) are grown in greenhouses and plastic tunnels at any time of the year. The greenhouses are normally cultivated two or three times a year. Rain-fed crops such as wheat and barley are basically planted in November, while dry farming crops (spring crops) such as tomatoes, okra, cucumber and chickpeas are planted in February and March.

Row direction has a significant influence on the reflectance of agricultural crops. Suits (1972), Curran (1985), Lillesand & Kiefer (1987) concluded that the reflectance factor increases as the sun elevation increases. This is because of the effect of shadow within the canopy. The effect of row direction on crop reflectance is wavelength dependent.

The effect of crop row direction in the WB appears only in the plain areas where it is possible to plant in rows. While in the rough terrain areas that are mainly planted with trees, regular plantation is not possible. Spacing between rows affects the soil-vegetation ratio and consequently affects reflectance of crops in different spectral bands. Crop type usually determines spacing between rows. Some crops such as cucumber and melons require a large row spacing because they grow horizontally. Other crops such as okra do not require large row spacing because it grows vertically.

Fertilization affects the spectral reflectance of crops and this depends on the type of fertilizer (chemical or organic). Chemical fertilizers such as nitrogen increase chlorophyll representation raising the peak green reflectance of crops and decreasing the reflectance of the red. Organic fertilizers both darken soil color and activate the chlorophyll. In the rain-fed agricultural areas, Palestinian farmers add both types of fertilizers to the land before the start of the rain season. But in the irrigated areas, fertilizers can be added at any time.

4.10 Summary

It can be seen from the sources of data that these sources are of different types and uses. The data can be summarized as follows:

- Field data obtained from the field survey used for crop type area estimation, image classification and accuracy assessment.
- Large scale Israeli aerial photographs used for field data collection, especially in the plain valuable agricultural lands.
- Israeli topographic maps (1: 50 000) used for sampling, image geometric correction, measurement of plain lands, overviewing and training of the relatively constant land use types.
- CORONA satellite photographs used for the field data collection to resolve field boundaries in the uplands.
- SPOT HRV XS images used for agricultural classification and crop type area estimation.
- Due to the difficulty of getting satellite data, only single date imagery is used.

CHAPTER FIVE

CROP AREA ESTIMATION USING SPOT HRV DATA

5.1 Introduction

This chapter describes the methods used to obtain estimates of main crop area and land use/ land cover in the northern part of the West Bank using SPOT HRV data. The following sections show the steps followed for the production and analysis of the crop area estimates.

5.2. Pre-Classification Data Processing

This process includes all the pre-processing techniques applied to the SPOT XS data. Errors and distortions occur in the data acquisition process and can affect the quality of the remotely sensed data. These errors which are caused by different factors can be in the spatial, spectral, temporal and radiometric resolution (Duggin and Robinove, 1990; Lunetta *et al.*, 1991).

In this study, the following processes were applied to the three spectral channels of the SPOT HRV data before the data were analyzed. These were:

1) Merging SPOT panchromatic (PAN) data with SPOT XS data of the study area,

2) Geometric Correction,

3) Contrast Stretching,

4) Digitization of the study area boundaries, and

5) Image stratification.

5.2.1 Merging SPOT (PAN) data with SPOT-XS data

Merging different types of remotely sensed data is usually done by analysts to achieve the following purposes:- a) to obtain more effective visual display, b) improve the spatial resolution of the data, c) improve the spectral resolution and d) increase classification accuracy. SPOT PAN (10 m resolution) can be merged with SPOT XS (20 m resolution) data (Jensen *et al.*, 1990). SPOT-PAN can also be merged with Landsat TM data (30 m resolution) (Hallada, 1986; Welch and Ehlers, 1987; Chavez and Bowell, 1988). Multispectral data can also be merged with active microwave (Sabins, 1987; Harris *et al.*, 1990). Digitized aerial photographs can be merged with SPOT-XS or TM data (Chavez, 1986; Grasso, 1993).

Elhers *et al.* (1990) merged SPOT XS 20 m and SPOT-PAN 10 m data. The resulting multi-resolution image retained the spatial resolution of the 10 m, yet provided the spectral qualities (hue and saturation values) of the SPOT XS. The enhanced detail available from merged images was found to be important for visual land use interpretation (Elhers *et al.*, 1990).

Sunar and Musaoglu (1998) merged multi-resolution SPOT-PAN and Landsat-TM data. Landsat TM data provided distinct spectral patterns in various hues, while the SPOT-PAN data provided high resolution data in which surface textural patterns are revealed.

SPOT-PAN images of the study area have been geometrically rectified to the UTM projection at 10 m and merged with a geometrically rectified SPOT XS data of the same geographic area. The SPOT-PAN data span the spectral region from 0.51-0.73 μm. Therefore, it is a record of both green and red energy. It can be substituted directly for either the green (SPOT XS1) or red (SPOT XS2) bands. In this study, the PAN band is substituted for the red SPOT XS band for the sub-scenes 1, 2, 4, and 5. While for the sub-scenes 3 and 6 the SPOT XS bands remained without substitution keeping the original spectral coverage of SPOT XS. The result is a display that contains the spatial detail of the SPOT-PAN data (10 m) and the spectral detail of the 20 m SPOT XS data. This method has the advantage of not changing the radiometric characteristics of both the SPOT-PAN and SPOT XS data (Jensen, 1996).

5.2.2. Geometric Correction

Remotely sensed images contain both systematic and unsystematic geometric distortions. Systematic errors are due to sensor characteristics, and so can be corrected using data from platform ephemeris data and knowledge of sensor distortions. Unsystematic distortions cannot be corrected satisfactorily without a sufficient number of ground control points (GCPs). These distortions are caused by two factors: altitude; when the sensor departs from its normal altitude or terrain increases in elevation, and secondly, attitude; when the sensor axis departs its normal attitude to earth's surface (Jensen, 1996).

These geometric distortions change the geometric properties of the image to correct for systematic pixel positional errors or to perform image rectification (Schowengerdt, 1984). Although for some applications these errors are not important, in many applications geometric transformation is necessary. Some of the applications for which image geometric correction is necessary are:

1) locate common points in different scenes of the same area.

2) perform multi-temporal analysis of the same area.

3) mosaicing a number of adjacent images and

4) overlay different images of the same area (Davison 1986).

There are two common geometric correction methods usually used by researchers:

1) image-to-map rectification. 2) image-to-image registration.

Image to map rectification is used when accurate measurements from images are required, while image to image rectification is usually used when it is not necessary to have each pixel assigned to a unique x, y coordinate in a map projection. In this study and for accurate measurements from images, image to map rectification method is used.

5.2.2.1. Ground Control Points Selection

To transform satellite imagery geometrically to the local map coordinate system, a number of ground control points (GCPs) are selected. These are features that can be readily identified on both the image and the map. The GCPs are selected from SPOT XS (RGB) stretched false color composite data since the imagery of the study area are haze free. The most suitable control points are those which have high contrast such as land-water boundaries that appear clearly on both maps and images and are relatively constant (must not change with time) such as road conjunctions, river and wadis conjunctions, corners of forests, and bends in rivers. Examples of the GCPs used are shown in figure 5.1.

Ground co-ordinates were taken from maps of the Israeli Survey at 1: 50 000 scale which are ideal for this purpose. The satellite imagery is completely cloud and haze free (a common phenomenon in this region). This helped in the selection of the desired number of GCPs for each sub-scene.

Each SPOT XS sub-scene of the study area measured approximately 24 x 28 km for which the x, y, and z coordinates for 12 - 16 GCPs were selected (i.e. one every 6 - 8 km). The points were distributed nearly evenly throughout the image with slightly denser sampling in the mountainous areas. The three coordinates including altitude (z) were used to increase the accuracy of rectification especially in the highly rugged terrain. The selected GCP's from the maps were located and recorded on image using the PCI image processing software. This procedure is a three- stage process: first, the SPOT XS image is sub-sampled to fit the screen, and the cursor is used to indicate the approximate location of the GCP. A full resolution sub-image is then displayed and the cursor is again used to indicate the GCPs position. A several times magnified sub-image is then output to the screen and the control point accurately located, then the coordinates of the control point in x, y, and z are recorded. At this point the pixel coordinates (columns and rows) with respect to the top left-hand corner of the image are automatically stored, and the map coordinates (northing and easting), altitude (in meters) are input from the keyboard. The wrongly registered GCPs were easily identified by looking to the root mean square error for each point. These points were deleted and registered again correctly. A Root Mean Square (RMS) of between 0.4 -

1.5 pixel is obtained or (4 - 15 meters). Sources of these errors could be map errors, rough terrain, and point positioning errors.

When the transformation matrix for each sub-scene was determined, it was used to rectify the image to the local map coordinate system. This involves the use of an interpolative resampling process. Three methods are commonly used:

1) Nearest-neighbor interpolation: This preserves the radiometric quality of the original image.

2) Linear interpolation: This corrects the geometric distortions but introduces radiometric errors.

3) Cubic convolution: This assigns values to output pixels in much the same manner as linear interpolation, except that the weighted values of 16 input pixels surrounding the location of the desired pixel coordinates are used to determine the value of the output pixel. This method is computationally expensive.

The nearest-neighbor interpolation method was used to transform the SPOT XS images of the study area for it preserves the radiometric quality of the original image, see figure 5.2.

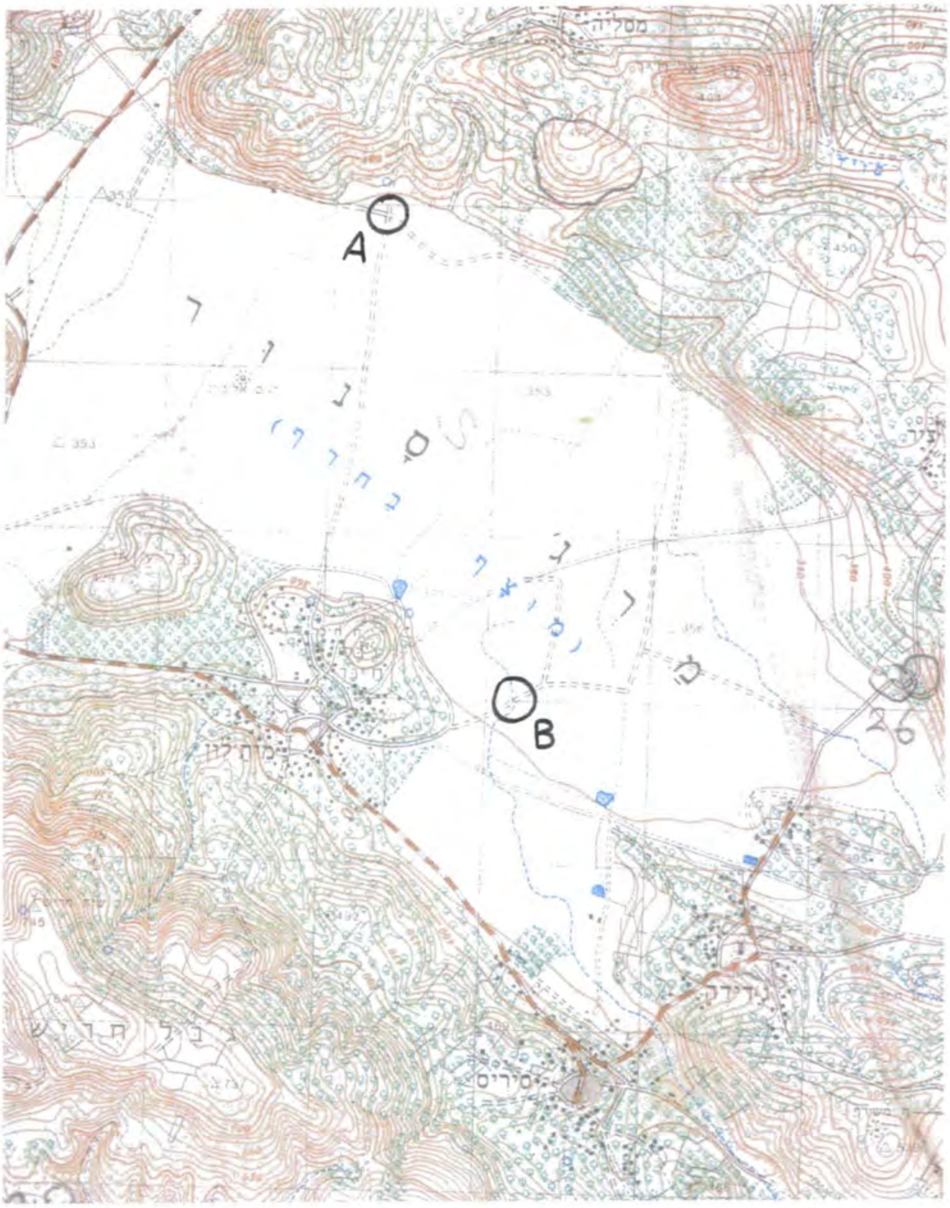


Figure (5:1): Examples of GCPs Used for Image Rectification

The point **A** is roads junction and the point **B** is wadis and roads intersection

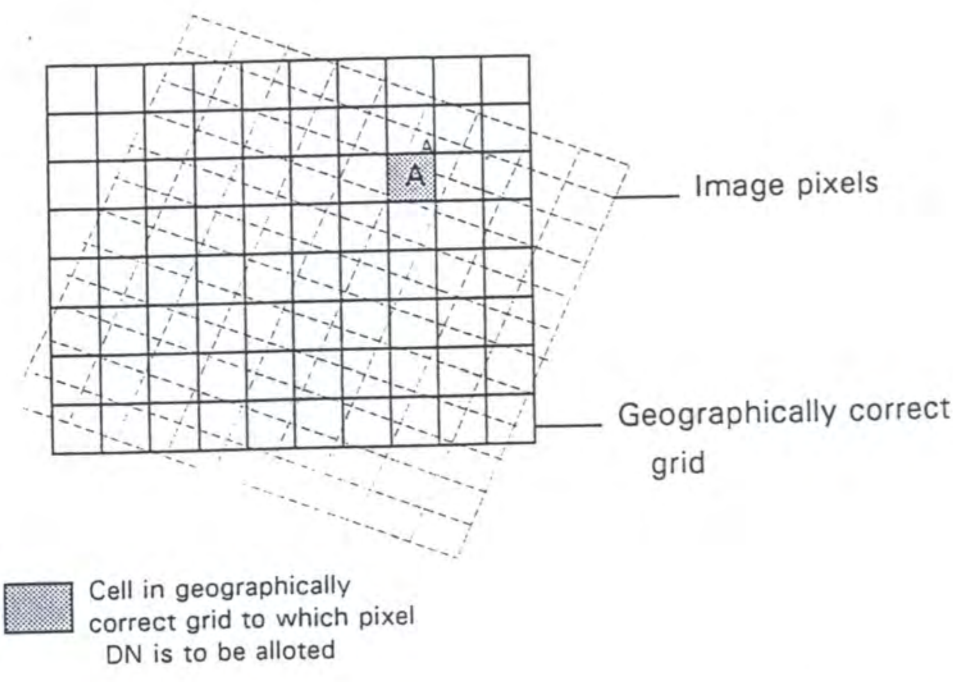


Figure (5:2): Image Rectification Using the Nearest-Neighbor Interpolation Method

Source: Ghodieh, 1994

5.2.3. Image Contrast Stretching

The aim of this pre-processing procedure is to improve the appearance of an image for visual analysis and the subsequent image processing work. Remote sensing systems record the reflected and emitted energy of different materials. The amount of this energy varies from one feature to another and from one waveband to another. This results in contrast between different types of materials. Contrast between materials at the visible, near-infrared and mid-infrared wavelengths is relatively low especially in homogeneous environments. For example, people in developing countries build their houses from wood and soil. This results in low contrast imagery for such areas compared with urban areas in developed countries where houses are built of concrete and asphalt. This situation reduces the interpretability of the image. Another factor that affects image contrast is the sensitivity of the sensors. For example, if the sensor sensitivity is insufficient to record the full range of intensities of reflected or emitted energy from different objects, the resultant image will be of low contrast. To improve the image contrast, the intensity range should be increased and the brightness values should be stretched to utilize the entire range of sensor's intensity. There are two main contrast stretching techniques, see figure 5.3.

1) Linear contrast stretching: this process aims to increase the visual and digital image interpretation by expanding the range of the original brightness values to use the full range of the radiometric intensity of the sensors.

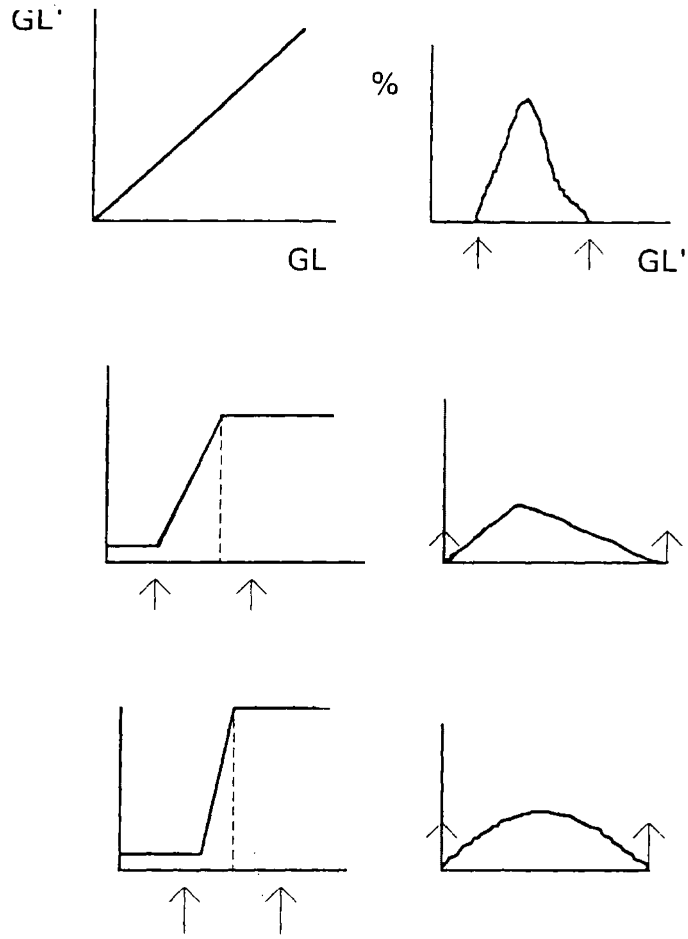
2) Nonlinear contrast stretching: The most common nonlinear contrast stretching technique is *histogram equalization.* This technique is dramatically different from any other technique because the original data have been redistributed according to the cumulative frequency histogram of the data. So, while this technique may improve the

visibility of the detail in an image, it also changes the relationship between brightness values and image structure (Russ, 1992).

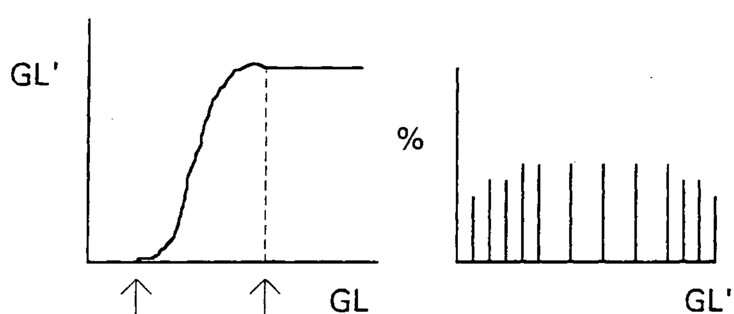
Both linear and histogram equalization techniques were used to enhance the visual interpretation of the SPOT XS images. Histograms of SPOT images have been examined and experiments have been carried out until good visual appearance of images is obtained. The linear contrast stretching technique is mostly used in the heavily cultivated areas where texture analysis is important mainly for the discrimination between horticulture and citrus trees. While the histogram equalization technique was used in the rocky barren areas and mainly in the images covering the eastern slopes of the West Bank.

5.2.4. Digitization of the Study Area Boundaries

The boundaries of the study area (northern the West Bank) were digitized using the Arc/Info GIS software. Limits of the strata were also digitized to work out crop area estimates on both the total study area and on an individual stratum basis. The digitized map is edited, exported and imported in the Unix Arc/Info GIS software to be incorporated in image analysis and crop area estimation procedure, see figure 5.4.



Linear contrast enhancement with variable saturation



Histogram Equalisation

Where GL is the original grey level, and GL' is the grey level after image stretching

Figure (5:3): Comparison between Contrast Stretching Techniques

Source: Ghodieh, 1994

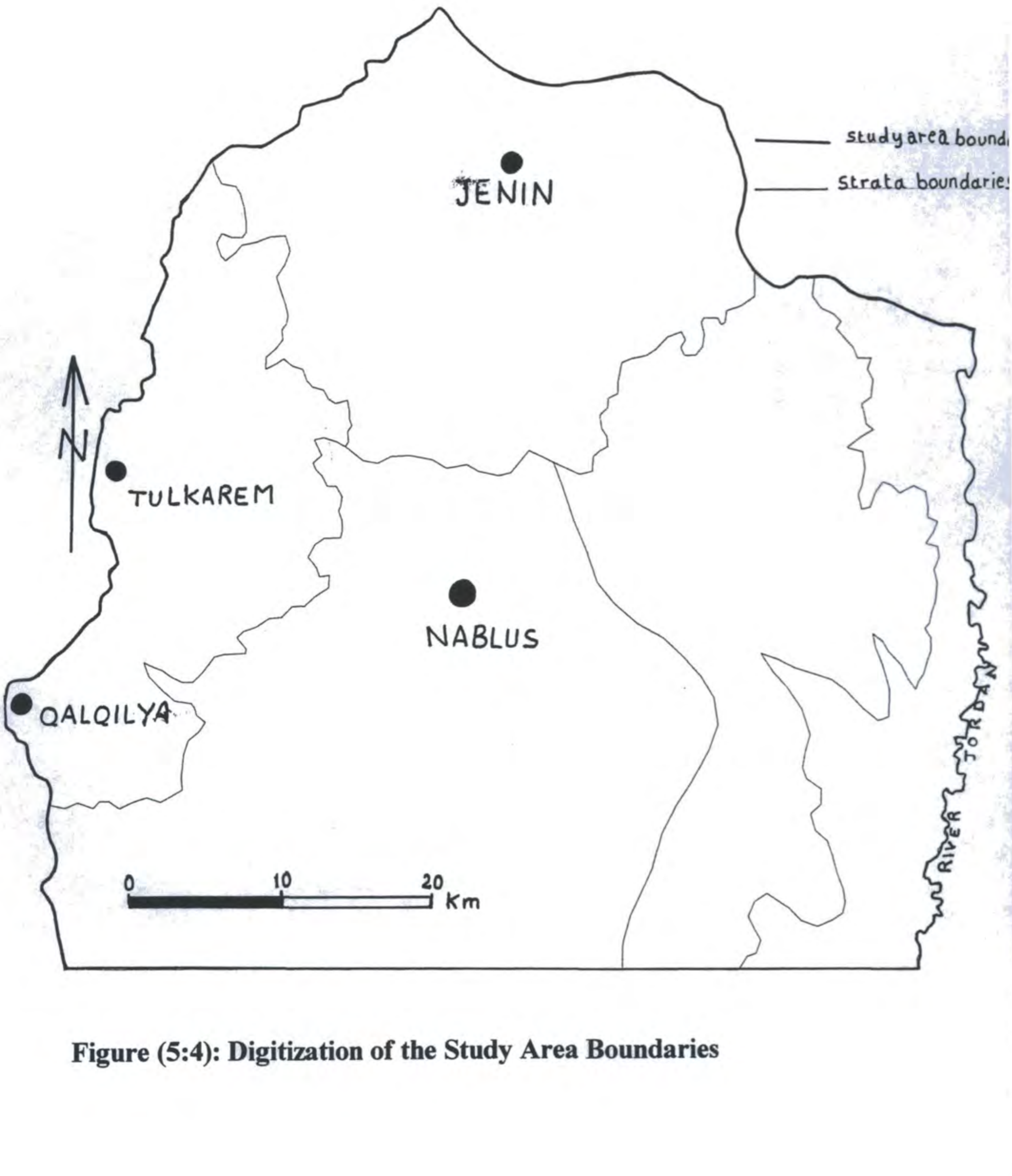


Figure (5:4): Digitization of the Study Area Boundaries

5.3. Image Classification

5.1. Introduction

Digital image classification is a remote sensing technique which groups features and objects of an image according to their spectral characteristics where those having similar spectral characteristics are located in one group or class. Multispectral classification in one of the most common methods used in the transformation of image data into information (Jensen, 1996).

In this study, a multispectral classification method is used. The SPOT HRV XS sensor has three bands: SPOT XS1 (0.50 - 0.59μm), SPOT XS2 (0.61 - 0.68μm), SPOT XS3 (0.79 - 0.89 μm). SPOT HRV PAN (0.51 - 0.73μm) is used instead of the red band for the purpose of the classification of four of the six sub-scenes.

There are two image classification techniques that have been widely used for agricultural land cover mapping. New techniques such as artificial neural networks have been tested for agricultural applications but these are still experimental methods. For a study of a new area it is important to select a classification method that is well tried and tested.

1) Supervised classification

2) Unsupervised classification

A third method can be recognized called the *hybrid approach* which involves a combination of supervised and unsupervised classification.

5.3.2. Supervised Classification

In this classification method, type and location of a set of land cover types such as agricultural, urban or water are well known through fieldwork, maps, aerial photographs and personal experience (Mausel *et al.*, 1990). This set of land cover types is called the ***training classes*** or ***training sites.*** The spectral characteristics of these training sites are used to train the computerized classification technique to classify the whole image. Each pixel in the image is assigned to the training class which has the highest probability of being a member. If all the land cover types existing in the image are not included in the training classes, those missed will be assigned to unclassified or unknown. So, for having the whole image area classified, the training classes should include all land cover types. Supervised classification is also called ***hard classification*** because a pixel is assigned to one class, despite the fact that it is a mixture of biophysical materials with different percentages of contribution (Foody *et al.*, 1992).

There are three frequently used supervised classification algorithms:

1) The Parallelpiped Classifier

2) The Minimum Distance Classifier, and

3) The Maximum Likelihood Classifier

The choice of a certain classifier depends on the data and the aim of classification. The parallelpiped (Box) classifier is sensitive to class variance, but it is not sensitive to class correlation. Therefore, it does not take into consideration the problem of overlapped classes. The minimum distance to mean classifier classifies each pixel to the nearest mean DN of a class in the training areas. It is insensitive to variance of the spectral properties of each class. So, for images having classes close to each other such as intensive vegetation, this classifier is inappropriate. The last main supervised classification method which is the maximum likelihood classifier is the most popular one for it addresses the shortcomings of the previous methods; it calculates the mean vector of each class in each band, it also calculates variance and correlation for each class in the training set. These calculations assume that the data are normally distributed. So, it is described as ***Guassian Classifier.*** The principle of this classifier is that it delineates ellipsoidal and equal-probability contours in the n-dimensional space (Curran 1985, Lillisand and Kiefer 1987, and Jensen 1996). Each pixel is assigned to the class which has the highest probability of membership. For example, the highest probability of pixel p2 membership in the figure 5.5 is the class soil. 'as every spectral response has a probability, however low, of representing a class, no pixels are left out in the cold' (Curran, 1985). For example, the lone pixel p1 in the figure below would be classified as urban.

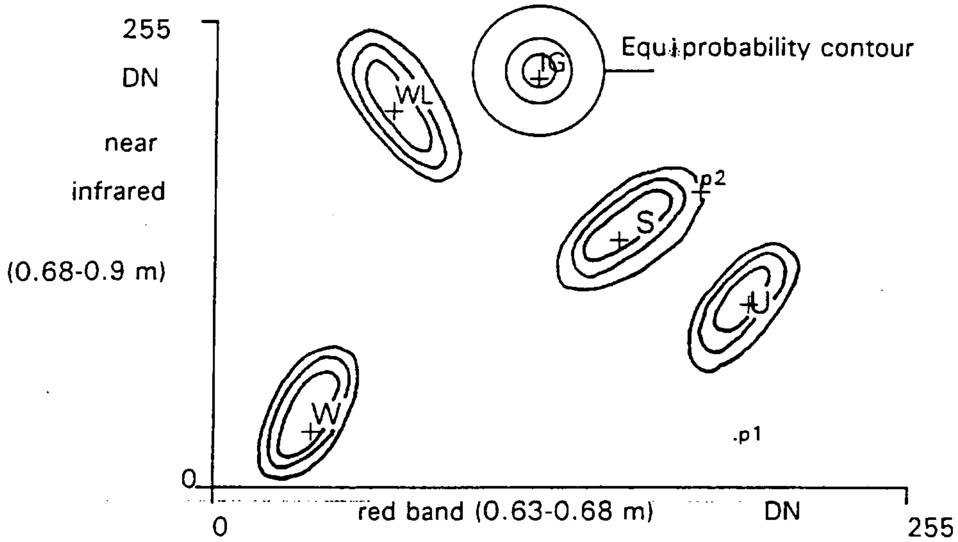


Figure (5:5): Principle of the Maximum Likelihood Classifier

Source: Curran, 1985 in Ghodieh's M.Sc. thesis

Where W is water, WL is woodland, IG is improved grass, S is soil, U is urban, + is the mean vector, and p1 and p2 is pixel number.

5.3.3. Unsupervised Classification

While supervised classification requires a set of training sites representing all land cover types within the scene, unsupervised classification allows the computer to choose the class means and covariance matrices to be used in the classification. So, this method produces spectral classes rather than thematic classes. These classes are meaningless to the analyst unless they are transformed into information classes and this requires awareness of the spectral characteristics of different materials (Schowengerdt, 1984). Unsupervised classification can be applied when the analyst has no prior knowledge of the study area and no field data collection program is carried out. The advantage of this technique over the supervised one is that it does not require field work and can be done quickly.

It can be seen that the main difference between the supervised and unsupervised classification is whether the analyst trains the classifier or allows it to select its own classes. It is possible to combine both methods to obtain better classification accuracy (Davis and Swain, 1978). It is also possible to add the visual interpretation to help in image analysis especially for high spatial resolution images such as SPOT HRV imagery.

5.3.4. Adopted Approach

A supervised classification approach named the Maximum Likelihood Classifier was applied to the SPOT HRV data for the study area. A set of training sites representing 23 land cover classes was selected from the whole study area (the northern West Bank).

The applied land cover classification scheme was taken directly from the field survey, maps, and aerial photographs (environmental classes) before studying the different world classification schemes. There are different classification schemes developed compatible with remotely sensed data. The most common schemes are:

- United States Geological Survey Land Use/ Land Cover Classification System (USGS).
- United States Fish and Wildlife Service Wetland Classification System.
- NOAA Coast Watch Land Cover Classification System.
- The World Land Utilization Survey Classification (WLUS).
- The Second Land Utilization Survey Classification.
- Department of Environment (DoE) Developed Area Classification.
- The National Land Use Classification (NLUC).
- The National Gazetteer Pilot Study (NGPS).

These classification schemes do not concentrate on the same issues. Some of them emphasize resources (land cover), others emphasize human activity on land (land use). For example, the USGS is resource oriented (land cover) in contrast with various human activity (land use) oriented systems (Anderson *et al.*, 1976). On the other hand, the SLUC (Standard Land Use Coding Manual) is land use oriented and dependent on *in situ* observation of land use information (Rhind and Hudson, 1980).

As remote sensing deals directly with environment (land cover) more interest and details of USGS need to be discussed. This system includes different types of remote sensing analysis techniques such as visual photo interpretation and digital multispectral classification at various scales and resolutions. The USGS includes nine broad land use/ land cover categories and each of these categories into finer levels of classification as seen below:

Table (5:1): The USGS Remote Sensing Land Use/ Land Cover Classification

Main Categories (Level I)	Secondary Categories (Level II)
1. Urban or Built Up Land	11. Residential 12. Commercial and Services 13. Industrial 14. Transportation, Communications and Utilities 15. Industrial and Commercial Complexes 16. Mixed Urban or Built Up 17. Other Urban or Built Up Land
2. Agricultural Land	21. Crop Land and Pasture 22. Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas 23. Confined Feeding Operations 24. Other Agricultural Land
3. Range Land	31.Herbaceous Range Land 32. Shrub-Brush Land, Range Land 33. Mixed Range Land
4. Forest Land	41.Deciduous Forest Land 42. Evergreen Forest Land 43. Mixed Forest Land
5. Water	51.Streams and Canals 52. Lakes 53. Reservoirs 54. Bays and Estuaries
6. Wet Land	61. Forested Wet Land 62. Non-forested Wet Land
7. Barren Land	71. Dry Salt Flats 72. Beaches 73. Sandy Areas Other Than Beaches 74. Bare Exposed Rock 75. Strip Mines, Quarries, and Gravel Pits 76. Transitional Areas 77. Mixed Barren Land
8. Tundra	81.Shrub and Brush Tundra 82. Herbaceous Tundra 83. Bare Ground Tundra 84. Wet Tundra 85. Mixed Tundra
9. Perennial Snow or Ice	91.Perennial Snow-field 92. Glaciers

Source: Anderson *et al.*, 1976

Table (5:2): Levels of the USGS Land use/ land cover Classification System and the Type of Remotely Sensed Data

Classification Level	Typical Data Characteristics
I	Landsat-MSS (79x79 m), TM (30x30 m), and SPOT-XS (20x20 m)
II	SPOT-PAN (10x10 m) data or high-altitude aerial photography acquired at 40, 000 ft (12400 m) or above; results in imagery that is ≤ 1: 80 000 scale
III	Medium-altitude data acquired between 10 000 and 40 000 ft (3100 and 12400 m); results in imagery that is between 1: 20 000 to 1: 80 000
IV	Low-altitude data acquired below 10 000 ft (3100 m); results in imagery that is larger than 1: 20 000 scale

These classification systems insist on a hard boundary between the classes despite the fact that remote sensor data records signatures of a mixture of different types of features, especially at the edges of these features. This means that when adopting one of these existing nationally recognized classification systems, this fact should be taken into consideration.

It can be seen from the above table that the higher the spatial resolution is, the better the classification level becomes. Field size is another factor that affects the classification level; small fields result in more mixed pixels while large ones result in relatively purely classified pixels. Farming customs and traditions is a third factor that affects the classification level. For example, in developing countries such as Palestine, farmers cultivate more than one type of crops in one field to fulfill household needs of different crops (potatoes, cabbage, tomatoes, and so on). Therefore, the resultant spectral signatures of such fields represent a mixture of completely different crops. This is a frequent occurance, especially in the irrigated crop areas. Spectral resolution is also an important consideration but not as critical parameter as spatial resolution.

The USGS Land Use/ Land Cover classification system has been designed for use with remote sensing to meet the following criteria (Anderson *et al.*, 1976):

- a minimum level of interpretation accuracy of at least 85 per cent,
- equal accuracy for the interpretation of the different categories,
- repeatable results,
- applicability over large areas,
- it should permit vegetation and other types of land cover to be used as surrogates for activity, and
- it should be possible to be used with remotely sensed data acquired at different times.

In order to develop a suitable land use/ land cover system to be used with remote sensing techniques, the training sites were selected directly from the fieldwork, aerial photographs and maps were adapted to the USGS classification system. The training sites represent the actual environmental and functional situation in the field at the time of the field work (May and June, 1998). For example, ploughed fields are labeled as *ploughed land* because the crop type is not known at the time of the survey. The environmental and functional classes are then compared with the USGS classification system where every field class fell in the appropriate USGS classification level. For example, olive trees are located in **class2** (agricultural land, cropland) and so on. The resultant classification scheme derived from both the training sites and the USGS system is seen in table 5.3.

Table (5:3): Land Cover Classification System Used in the Study

Main Categories (Level I)	**Level II**	**Level III**	**Level IV**
1. Urban or Built-up Land			
2. Agricultural Land	21. Crop Land and Pasture	211. Field Crops 212. Tree Crops	2111. Cereals 2112. Horticultural Crops (Vegetables) 21121. Rain-fed Horticulture 21122. Irrigated Horticulture 2113. Ploughed Land 2114. Greenhouses 2121. Olive Trees 2122. Citrus Trees 2123. Fruit Trees; Bushes 2124. Mixed Trees
3. Forest Land	31. Mixed Forest Land		
4. Range Land	41. Bare Soil; Bushes 42. Bare Soil; Rough Grass 43. Natural Vegetation 44. Natural Vegetation, Rocks 45. Rough Grass, Bushes		
5. Barren Land	51. Rocky Land, Quarries 52. Flat Bad Land		
6. Wet Land	61. Nonforested Wet Land		

5.3.5. Training Area Selection

This stage of supervised image classification is a fundamental one because it is the main difference between the supervised and the unsupervised classification. Training sites must be representative of the land cover types that exist in the image. Before training data were collected, the following factors that may affect land cover/ land use in the study area were taken into consideration:

1) Terrain characteristics and elevation,

2) Slope and aspect and,

3) Type of farming practice.

Terrain Characteristics and Elevation: As mentioned in chapter two, about 86% of the total area of the West Bank is mountainous and the plain (14%) lies in the Jordan Valley. Within the hills and mountains, many topographic hollows or intermediate plains are characterized by field cropping and irrigated trees. These areas represent the *food basket* of the Palestinians in the West Bank (almost all vegetables, arable crops including cereals, citrus trees, and a part of olive and fruit trees are produced in these plains). On the other hand, the hilly and mountainous areas are characterized by rain-fed farming, mainly olive trees. Because of the special economic importance of these intermediate plains, they were identified on 1: 50,000 scale maps and on some 1: 15,000 aerial photographs. The following observations can be recorded on these maps and aerial photographs:

- field boundaries are not shown on the maps

- the aerial photographs were acquired at an inappropriate season (December, 1995), because at this time of the year, the fields would be either freshly sown or just prepared for cultivation

- the aerial photographs do show field boundaries

- both maps and aerial photographs show areas cultivated with trees

neither maps nor aerial photographs show the crop type

- aerial photographs show the greenhouses clearly

- the 1: 50,000 maps do not show the environmental conditions of the area directly

- aerial photographs provide useful information about environmental conditions of the area such as tree density, slope and aspect, soil color, and sub-canopy vegetation. This information helps to better understanding and interpret the satellite data.

Slope and Aspect: This factor has a crucial effect on land use/ land cover characteristics. As mentioned in chapter two, two completely different environments can be identified in the study area; the eastern slopes which includes the upper eastern slopes (Shafa el-Ghour) and the western slopes which include the area of Nablus, Tulkarem and Jenin (see chapter 2).

Type of Farming: Two main types of farming can be identified in the northern West Bank: a) dry farming and b) irrigated farming. The spatial distribution of these two types is dependent on both environmental and human factors:

- The environmental factors that effect topography are slope, soil, and the availability of water resources.

- The human factor is mainly the Israeli water policy in the West Bank.

A third type of farming can be recognized in the study area; it is mainly dry farming supported by some irrigation when required. In drought periods, farmers bring water in tanks from neighboring artesian wells to rescue their crops. The field work shows that the spatial distribution of farming types is as follows:

Irrigated systems of field and tree crops exist mainly in the plains of Tulkarem and the Jordan Valley (Al-Ghour). Dry field crop farming exists in the plains of the upper eastern slopes. Both dry and irrigated field and tree cropping exist in the plains of Nablus and Jenin. The eastern slopes are nearly out of rain-fed tree cropping because the low annual average rainfall in this area (less than 300mm) does not allow such cropping. The relatively steep areas of the western slopes region are cultivated by rain-fed tree cropping mainly olive trees and mixed fruit trees.

On the above mentioned basis, five different semi-regions or strata can be recognized in the study area:

1) stratum one or area of Tulkarem

2) stratum two or area of Jenin

3) stratum three or area of Nablus

4) stratum four or the upper eastern slopes (Shafa el-Ghour) and,

5) stratum five or the Jordan Valley (Al-Ghour)

Administratively, stratum one represents the semi-district of Tulkarem, stratum two represents the semi-district of Jenin, and the other three strata are included in the semi-district of Nablus (figure 5.6).

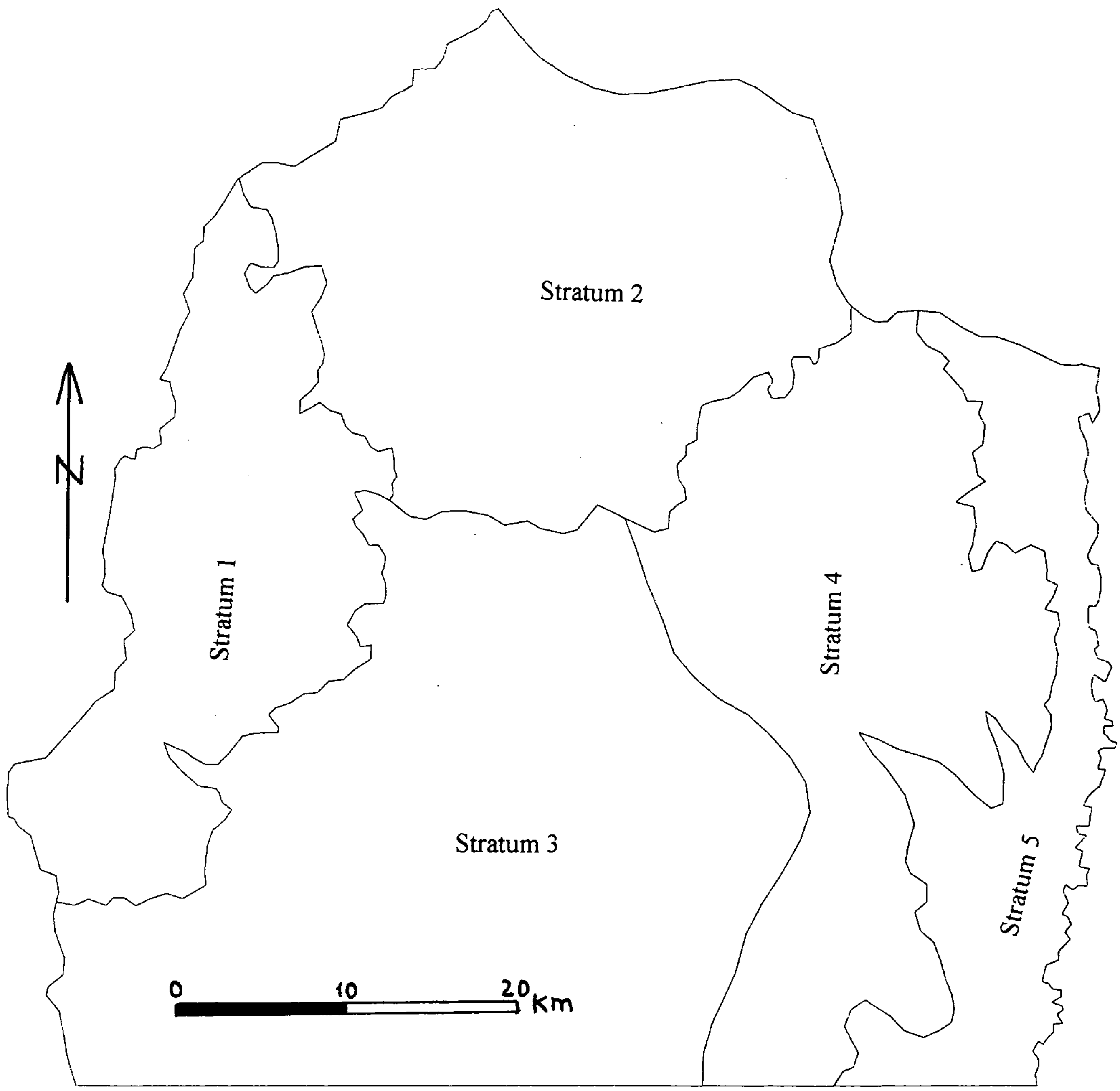


Figure (5:6): Division of the Study Area into Five Strata

In order to overcome environmental variations, training areas for different land cover types were (when possible) selected to represent all these environments. For example, olive trees on the steeply sloping lands would not have the same spectral signatures of that on the relatively flat lands because density of the different crop densities and surface illumination. So, training sites are selected from both sloping and flat environments. Another serious problem arose during the training stage; it is that farmers do not keep records of their agricultural activities in previous years. When farmers were asked about the type of crop that they grew in their fields in the image acquisition data, they did not give precise answers. To solve this problem, it was necessary to have a full cultural and environmental understanding of the agricultural status in each region or stratum. This problem is serious for the dramatically changeable land use/ land cover types, mainly horticultural and cereal crops.

The training data were obtained from the following sources:

1) Israeli maps. These maps were used to determine the land cover types that have a relatively static status such as built-up areas, woodland, olive trees, citrus trees, rough vegetation and fruit trees.
2) Aerial photographs. Stereoscopic aerial photographs were used for the selection of both static and changeable land cover types. These photographs are better than the maps because i) they show field boundaries in the plain area and ii) they provide the analyst with better understanding of environmental conditions of the different land cover types, and so improve accuracy of interpretation. In order to get accurate information about cultivation, sketches of the field boundaries were drafted and labeled with the proper land use type in addition to some descriptive environmental

conditions of the fields such as soil color, texture, row spacing and crop growth stage.

3) Interviewing farmers. Farmers were interviewed in their fields and asked about their activities in the field. The questions included in the questionnaire are:

a) What type of crop existed in your field in May 1994?

b) What type of crops you usually cultivate?

c) When do you start preparing your field for cultivation?

d) What preparations do you make in the field before cultivation?

e) When do you plough your field for cultivation?

f) What do you use to plough the land, animals or tractors?

g) Do you add any fertilizers to your field?

h) What type of fertilizers do you add? (chemical or organic)

i) When do you add these fertilizers?

j) How many kilograms of fertilizers do you add for one hectare area?

k) When do you harvest the crop?

l) Where do you sell the production?

m) Do you follow a clear crop rotation?

n) What problems do you face in your work?

o) How can these problems be solved?

The farmers did not give precise answers about the type of crop grown their fields in May 1994 because none of them kept records for that year or for any other year and the long period between the field data collection date and the image acquisition data. This problem is likely to affect the quality of training data. It was also found that in the irrigated areas (Tulkarem and Al-Ghour), farmers do not follow any clear crop calendar. They sometimes plant the same crop type three times a year. The reason for that is because they use chemical fertilizers very intensively. Secondly, in the purely dry farming areas (stratum four), they follow a very distinct crop calendar: winter crops (wheat or barley), spring crops (okra or sorghum; these crops resist drought), winter crops. Thirdly, in the mixed farming areas (Jenin and Nablus), they mainly plant winter cereals (wheat and barley) and spring crops (okra, tomatoes, onion, chickpeas, courgettes, and cucumber). Fortunately, the image acquisition season (May) is suitable to differentiate between two main types of crops; cereals and horticulture (vegetables). So, the land cover type at the time of the field work is considered appropriate.

5.3.5.1. Training Classes Included in Classification and their Annotation Key

1. **Supervised Training Classes:** Table 5.4 shows the classes chosen from the previously mentioned sources (field, aerial photos and farmers interview) for the supervised classification of the northern part of the West Bank.

Table (5:4): Land cover classes chosen for the supervised image classification

No.	Class	Key	Notes
1	Arable Crops	AC	Particularly wheat and barley
2	Horticulture	H1	It includes spring dry farming crops (relatively low leaf area index crops) such as okra and tomatoes
3	Horticulture	H	It includes irrigated crops (relatively high leaf area index crops) such as cabbage, cauliflower, tomatoes, egg-plants and potatoes
4	Greenhouse	GH	Mostly planted with vegetables
5	Olive Trees 1	OT1	It includes densely planted areas existing in the relatively flat land or the margins of the plains
6	Olive Trees 2	OT2	It includes sparsely planted olive land mixed with some fruit trees mainly almonds, apricots, figs and vineyards
7	Olive Trees 3	OT3	It includes sparse olive land mixed with rough grass and bushes. It exists in the mountainous areas
8	Citrus Trees	CT	It includes orange, clementine, and some lemon and grapefruit
9	Fruit Trees & Bushes	FT;B	It includes fruit trees such as figs, apricots, and grapes mixed with bushes and some olive trees
10	Mixed Forest	MF	It includes both coniferous and deciduous woodland (the coniferous woodland is the dominant)
11	Rough grass & Bushes	RG;B	It includes unmanaged grass and bushes existing in the mountainous land
12	Rocks & Natural Vegetation	R;NV	It includes rocky land partially covered with natural vegetation. It mainly exist on the eastern slopes
13	Rocky Land	RL	It includes rocks and quarries
14	Badland	BL	It includes bare salty land. It exists in the Jordan Valley
15	Built-up Areas	BUA	

2. **Unclassified Areas:** These classes represent the areas that are not considered in the supervised training set. In other words, the supervised classification left some **areas** of the image unclassified. These areas are treated as independent classes because they occupy areas (not discrete pixels). Identification of the informative classes of these areas is achieved by:

a) spatial recognition: a comparison of each unclassified area with the available reference data such as large scale aerial photographs and maps is made, then given a grade of probability.

b) spectral recognition: a statistical report including the minimum, the maximum, the mean, the standard deviation and a variance/ covariance matrix for each unclassified area is produced. This statistical report is compared with the statistical report of each supervised training area and given a grade of probability.

c) textural recognition: texture or roughness of these unknown areas is compared with those of supervised training areas, then given a grade of probability.

d) Grade average probability of the three probabilities is calculated for each unknown area, then assigned to the class it fits best or create a new class for it. Table 5:5 illustrates the idea. Conditions of the unknown area are:- the area is large, it is located in mountainous topography, and it has irregular boundaries.

e) The weight of each factor can be decided according to its importance in the study area.

Table (5:5): Methodology of unknown areas class detection

Class	Spatial Probability	Spectral Probability	Textural Probability	Average Probability %
Olive Trees	8	5	5	60
Citrus Trees	0	6	6	40
Rough Grass & Bushes	5	5	5	50
Mixed Forest	5	2	2	30
Fruit Trees and Bushes	8	6	6	66.7

In this example, the three factors are given equal weight, so calibration of the result is required. It can be seen from the average probability of this unknown area class that there is a competition on this area between olive trees class (60%) and the fruit and bushes class (66.7%). But details of both percentages can give the decision; first, the spatial probability is the same for the two classes. Second, the spectral and textural probability indicates that this area is a mixture of different types of trees and vegetation (50% for olive class, 60% for citrus, 50% for rough grass and bushes, and 60% for fruit and bushes class). So, this area is assigned as mixed trees area. Despite the high spectral and textural probability of citrus class, this class is excluded because the spatial probability provides a strong indication that it is not a citrus trees area. The same procedure is applied to all unknown areas. The detected training classes included in image classification are:

1. Ploughed Land (PL)
2. Mixed Trees (MT)

3. Bare Soil; Rough Grass (BS; RG)
4. Bare Soil; Bushes (BS; B)
5. Natural Vegetation (NV)
6. Bad land2 (BL2) and
7. Bad Land3 (BL3)

5.3.5.2. Allocation of Training Areas on Image

As mentioned in chapter 3, a mosaic of 6 SPOT HRV sub- scenes covers the study area. To reduce environmental variation effects on classification accuracy, each sub-scene is classified separately. The radiometric quality of each sub-scene is studied before the allocation of training areas on image to obtain a rough idea of the main land cover components contained in each image.

To represent each class effectively, an adequate number of pixels must be chosen from different sites throughout the image (Davis and Swain 1978, Mather 1987, and Jensen 1996). Environmental variations such as tree density, slope and aspect, and soil color for some land cover types are taken into consideration. For example, the olive tree class is divided into three secondary classes; olive1, olive2, and olive3 because the crop exists in different environments.

5.3.5.3. Bands Used for Image Classification

It is important to use appropriate spectral bands for agricultural and land cover classification. The bands used should achieve the optimum spectral discrimination between different land cover types, especially those of similar spectral properties. Previous studies of optical remote sensing showed that for agricultural studies, broad band sensors such as AVHRR, Landsat MSS, Landsat TM, and SPOT HRV XS and panchromatic data have good spatial resolution and it is often possible to make a visual interpretation of land cover using textural information.

The data available for this study are three bands (green, SPOT-PAN, and the near infrared, sharpened image) from SPOT sub- scenes that cover the two middle and western parts of the study area. The Jordan Valley region was covered by SPOT HRV XS sub-scenes. The rest of the study area is covered by SPOT HRV XS that has been fused with the SPOT-PAN band. In practice this is achieved by substituting the red band by the panchromatic band which has the effect of improving the visual interpretability. To investigate the effect of the fusion of SPOT HRV XS data with the SPOT-PAN data correlation between bands of the two data has been studied. Tables 5.6 and 5.7 show that correlation between the three spectral bands of the pan-sharpened SPOT HRV image is still lower than that of the SPOT HRV XS image. This can be explained by the higher scattering of the visible bands in the Jordan Valley for its low altitude.

Table (5:6): Correlation matrix for SPOT XS wavebands in the study area

	IR	R	G
IR	1.00	0.71	0.82
R	0.71	1.00	0.97
G	0.82	0.97	1.00

Table (5:7): Correlation matrix for the pan-sharpened SPOT XS wavebands in the study area

	IR	PAN	G
IR	1.00	0.686	0.73
PAN	0.69	1.00	0.93
G	0.73	0.93	1.00

To understand the efficiency of the SPOT XS wavebands in image classification, the training statistics for each band have been studied and analyzed both statistically and graphically. The aim of this analysis is to determine degree of between-class separability in the training data. Using statistical methods, combinations of bands are normally ranked according to their potential ability to discriminate each class from all others using *n* bands at a time (3 bands). The more the bands are analyzed in the classification, the more the cost and perhaps the greater the amount of redundant spectral information being used (Jensen, 1996). ***Divergence*** is one of the widely used statistical methods for band selection and analysis (Swain and Davis, 1978) when only two training area statistics are analyzed. But when there are more than two classes, the ***average divergence*** is computed. This involves computing the average over all possible pairs of classes, while holding the subset of bands constant. Divergence is computed using the mean and covariance matrices of the class statistics collected in the training phase of the supervised classification.

In this study, the average divergence is used to check the separability among different land cover classes. For non-overlapping distributions a value of 2 was given to *Bhattacharrya distance* and the *transformed divergence* (Rees, 1999). The Bhattacharrya method assumes that the two classes are normally distributed and the means and the covariance are available. This method calculates distance between each pairs of classes. The best bands are whose sum of *Bhattacharrya distance* between the classes is highest. The *transformed divergence* decreases the effect of the outlying easily separable classes on the average divergence. The following figures illustrate the average separability among the different land cover classes over the 6 sub-scenes of the study area:

Table (5:8): Divergence Statistics for the Tulkarem (sub-scene1) Land Cover Classes Evaluated Using the Green, the Panchromatic, and the Near Infrared SPOT Band Combinations at One Time

	CT	OT3	OT2	RL	GH	PL	H	MF	BUA	OT1
OT3	1.81									
OT2	1.59	0.66								
RL	1.99	1.84	1.96							
GH	1.82	1.64	1.65	1.69						
PL	1.94	1.94	1.91	1.99	1.96					
H	1.92	1.98	1.99	1.88	1.46	1.99				
MF	1.98	1.67	1.96	1.95	1.92	1.16	1.99			
BUA	1.97	1.67	1.84	1.61	1.28	1.98	1.89	1.84		
OT1	1.65	0.79	**0.24**	1.98	1.65	1.75	1.98	1.89	1.83	
RG; B	0.70	1.4	1.02	1.96	2	1.95	1.86	1.99	1.87	1.26

Average Divergence* = 1.73, Minimum = 0.24, Maximum = 2, values range = 0-2

Table (5:9): Divergence Statistics for Jenin (sub-scene2) Land Cover Classes Evaluated Using the Green, the Panchromatic, and the Near Infrared SPOT Band Combinations at One Time

	BUA	MF	OT1	OT2	OT3	WS	RG; B	BS; B	RL	CT	AC	H1	H
MF	1.95												
OT1	1.96	1.11											
OT2	1.90	1.39	1.33										
OT3	1.90	1.79	1.64	**0.80**									
WS	2	2	2	2	2								
RG; B	1.98	1.97	1.97	1.86	1.92	2							
BS;RG	1.89	1.99	1.99	1.99	1.93	2	1.89						
RL	1.99	1.99	1.99	1.99	1.99	2	1.60	1.79					
CT	1.99	1.99	1.98	1.86	1.89	2	1.04	1.99	1.97				
AC	1.99	1.99	1.99	1.98	1.95	2	1.69	1.98	1.67	1.94			
H1	1.99	1.99	1.99	1.98	1.74	2	1.92	1.99	1.98	1.96	1.1		
H	1.99	1.99	1.98	1.96	1.95	2	1.33	1.99	1.95	1.08	1.2	1.56	
PL	1.98	1.62	1.35	1.85	1.93	2	1.97	1.99	2	1.99	2	1.99	1.98

Average Divergence = 1.85, Minimum = 0.80, Maximum = 2, Divergence Range = 0-2

* Above 1.5 is good, 1-1.5 is intermediate, and below 1 is poor

Table (5:10): Divergence Statistics for Eastern Slopes and the Jordan Valley (sub-scene3) Land Cover Classes Evaluated Using the Green, the Red, and the Near Infrared SPOT Band Combinations at One Time

	BUA	MF	AC	H	CT	RNVL	OT2	RL	RG;B	BS;RG	PL	BL1	BL2	BL3	OT1
MF	1.99														
AC	1.95	1.82													
H	1.99	1.99	1.69												
CT	1.99	1.99	1.98	1.13											
RNVL	1.98	1.99	1.99	1.99	1.99										
OT2	1.95	1.68	0.80	1.97	1.99	1.99									
RL	1.95	1.99	1.88	1.87	1.99	1.89	1.99								
RG;B	1.99	1.99	1.74	1.47	1.63	1.99	1.93	1.84							
BS;RG	1.73	1.99	1.92	1.98	1.99	1.90	1.90	1.89	1.94						
PL	1.99	1.98	1.08	1.99	1.99	1.99	1.45	1.99	1.99	1.99					
BL1	1.25	1.99	1.93	1.99	1.99	1.99	1.94	1.99	1.98	1.63	1.99				
BL2	1.92	2	1.99	2	2	1.99	2	1.99	2	1.99	1.99	1.55			
BL3	1.28	1.99	1.98	1.99	1.99	1.74	1.98	1.90	1.99	1.45	1.99	1.79	1.78		
OT1	1.99	1.77	1.23	1.99	1.99	1.99	**0.51**	1.99	1.99	1.99	1.48	1.99	2	1.99	
H1	1.99	1.99	1.19	1.98	2	1.94	1.73	1.99	1.99	1.99	1.20	1.99	1.99	1.99	1.81

Average Divergence = 1.86, Minimum = 0.51, Maximum = 2, Divergence Range = 0-2

Table (5:11): Divergence Statistics for the Qalqilia (sub-scene4) Land Cover Classes Evaluated Using the Green, the Panchromatic, and the Near Infrared SPOT Band Combinations at One Time

	BUA	MF	RG;B	BS;RG	BS;B	CT	H	AC	PL	RNVL	OT1
MF	1.79										
RG;B	1.89	1.59									
BS;RG	1.42	1.77	1.92								
BS;B	1.58	1.08	1.54	1.22							
CT	1.97	1.76	1.0	1.99	1.89						
H	1.97	1.76	1.59	1.98	1.89	1.29					
AC	1.99	1.98	1.99	1.99	1.98	1.99	1.88				
PL	1.91	**0.55**	1.65	1.99	1.72	1.67	1.75	1.98			
RNVL	1.89	1.55	1.89	1.72	1.41	1.97	1.77	1.59	1.84		
OT1	1.91	0.86	1.88	1.96	1.60	1.93	1.84	1.99	0.97	1.78	
RL	1.97	1.99	1.99	1.97	1.95	1.99	1.99	1.99	1.99	1.95	1.99

Average Divergence = 1.76, Minimum = 0.55, Maximum = 1.99, Divergence Range = 0-2

Table (5:12): Divergence Statistics for the Nablus (sub-scene5) Land Cover Classes Evaluated Using the Green, the Panchromatic, and the Near Infrared SPOT Band Combinations at One Time

	BUA	MF	RL	RG;B	FT;B	BS;RG	RNVL	MT	OT1	CT	H	AC	PL
MF	1.95												
RL	1.92	1.98											
RG;B	1.99	1.99	1.89										
FT;B	1.99	1.98	1.99	1.87									
BS;RG	1.49	1.93	1.94	1.99	1.94								
RNVL	1.84	1.86	1.97	1.99	1.99	1.89							
MT	1.94	1.70	1.96	1.99	1.99	1.97	1.47						
OT1	1.98	**0.82**	1.99	2	1.99	1.99	1.99	1.99					
CT	1.99	1.96	1.97	1.79	1.18	1.96	1.97	1.94	1.99				
H	1.99	1.98	1.99	1.84	1.88	1.99	1.98	1.88	1.99	1.02			
AC	1.98	1.99	1.95	1.96	1.99	1.99	1.99	1.98	1.99	1.99	1.97		
PL	1.98	1.93	1.99	1.99	1.99	1.99	1.75	1.96	1.89	1.99	1.99	1.99	
OT2	1.79	1.73	1.99	2	1.99	1.39	1.89	1.96	1.84	1.98	1.99	1.99	1.99

Average Divergence = 1.90, Minimum = 0.82, Maximum = 2, Divergence Range = 0-2

Table (5:13): Divergence Statistics for Eastern Slopes and the Jordan Valley (sub-scene6) Land Cover Classes Evaluated Using the Green, the Red, and the Near Infrared SPOT Band Combinations at One Time

	BL1	AC	BUA	CT	BL2	BS; RG	BL3	H	OT1	H1	PL	RL	RNVL
AC	1.97												
BUA	1.02	1.98											
CT	1.99	1.83	1.99										
BL2	1.38	1.99	0.60	1.99									
BS; RG	1.25	1.93	1.81	1.99	1.96								
BL3	0.94	1.97	**0.27**	1.99	0.94	1.69							
H	1.86	1.77	1.83	1.53	1.91	1.95	1.87						
OT1	1.99	1.96	1.99	1.99	2	2	1.99	1.99					
H1	1.99	1.86	1.99	1.99	1.99	1.99	1.99	1.99	2				
PL	1.99	1.89	1.99	1.99	1.99	1.98	1.99	1.99	1.93	1.93			
RL	1.94	1.38	1.93	1.99	1.99	1.92	1.87	1.93	1.98	1.98	1.96		
RNVL	1.83	1.67	1.93	1.99	1.99	1.39	1.88	1.97	1.99	1.84	1.65	1.68	
RG; B	1.99	1.69	1.99	1.97	1.99	1.99	1.99	1.89	1.99	1.99	1.99	1.84	1.99

Average Divergence = 1.84, Minimum = 0.27, Maximum = 2, Divergence Range = 0-2

It can be seen from the above tables (tables 5.8 to 5.13) that the average separability of all the training classes for the six sub-scenes is between 1.73-1.90 when a ***Bhattacharrya Divergence*** is used and between 1.85-1.95 when a ***Transformed Divergence*** is used. It can be seen also that the spectral separability varies from one scene to another for the different land cover/ land use types. The lowest separability with different levels is recorded between the following classes:

- Olive Trees1 (OT1), Olive Trees2 (OT2), Olive Trees3 (OT3)
- Olive Trees1 (OT1), Mixed Forest (MF) in stratum 3.
- Badland classes (BL1, 2 and 3), Built-up Areas (BUA) in stratum 5.

- Rough Grass and Bushes (RG; B), Citrus Trees (CT) is stratum 2.
- Olive Trees (OT), Rough Grass and Bushes (RG; B)

This overlap between these classes may result in either overestimation or underestimation of these land cover types, and so influence the final classification accuracy.

To further investigate the degree of separability between classes the mean and the standard deviation of DN values for each class were plotted for the SPOT bands 1, 2, and 3.

Figure (5:7): Mean Reflectance of Agricultural Classes of the Study Area

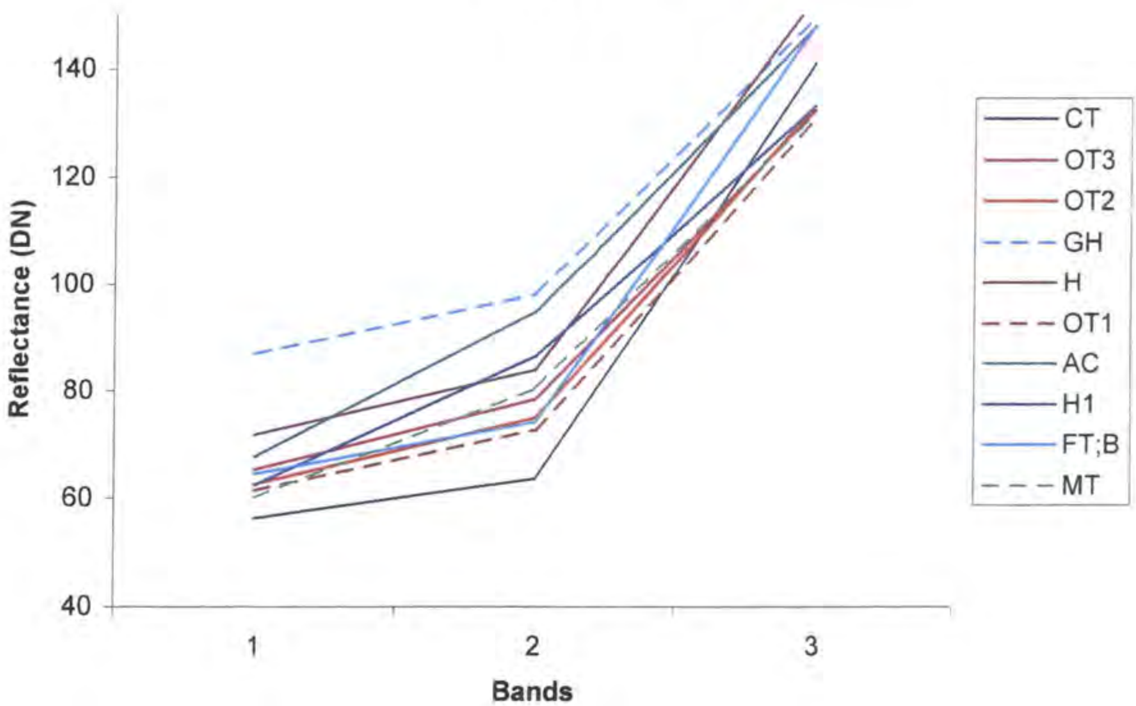
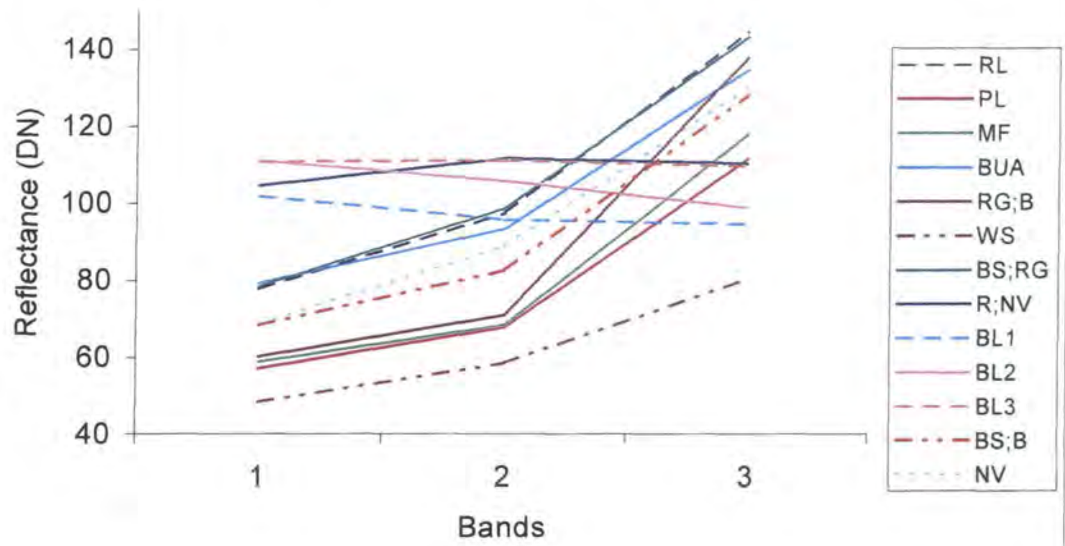


Figure (5:8): Mean Reflectance of Non-Agricultural Classes of the Study Area



It is clear from the above figures that olive tree classes, badland classes, and bushes and rough grass are difficult to separate spectrally. Moreover, each group of these classes has nearly the same thematic meaning. So, it was thought to have these classes generalized as follows:

- OT1, OT2, and OT3 classes became OT class
- BL1, BL2, and BL3 classes became BL class
- BS; RG, B; RG, and BS; B classes became B; RG class
- H; H1 classes became H class

Each group is given the same color in the final map and the total area of each group is considered. For example, area of olive trees = area of olive1, olive2 and olive3.

The resultant land cover classes after the training data analysis and development are shown in table 5.14.

Table (5:14): Land Cover Classes After Development

No.	Land Cover Class	Annotation Key
1	Unclassified	UC
2	Arable Crops	AC
3	Horticulture	H
4	Citrus Trees	CT
5	Olive Trees	OT
6	Fruit Trees; Bushes	FT; B
7	Mixed Trees	MT
8	Greenhouse	GH
9	Wet Soil	WS
10	Ploughed Land	PL
11	Mixed Forest	MF
12	Built-up Areas	BUA
13	Bad Land	BL
14	Rocky Natural Vegetation Land	RNVL
15	Rough Grass; Bushes	RG; B
16	Rocky Land	RL

5.4. Image Mosaicing and Clipping

As the study area lies in 6 sub-scenes, the classified sub-scenes need to be mosaiced to form one continuous image. The classified sub-scenes were transferred from the PCI remote sensing software to the Arc/ Info software, then merged in one image containing the whole study area. The resultant image mosaic is converted to a grid and the dimension of each grid is 10.036 x 10.036 m or 100.72 m². In order to obtain number of pixels for each land cover type on both the study area and individual stratum levels, the mosaic is clipped to the boundaries of the study area as well as the boundaries of each individual stratum producing a land use map for the study area (figure 5.9). By multiplying the number of pixels in each land cover class by its area (100.72 m²), the area for each land cover class is obtained on both the stratum and the whole study area levels as shown in tables 5.15 to 5.19.

Table (5:15): Land Cover Area Estimation of Stratum One

No	Land Cover Class	Hectare Area (ha)[1]	% of Total Area
1	UC	3206.4	9.10
2	AC	442.9	1.26
3	BUA	1352.8	3.86
4	CT	1060.9	3.03
5	FT; B	55.1	0.16
6	GH	604.8	1.73
7	H	1271.4	3.62
8	MF	3168.6	9.04
9	R; NV	5313.8	15.16
10	OT	8762.4	25.00
11	MT	105.9	0.30
12	PL	655.5	1.87
13	RL	2432.1	6.94
14	RG; B	6609.9	18.86
	TOTAL	**35043**	**100**

Table (5:16): Land Cover Area Estimation of Stratum Two

No	Land Cover Class	Hectare Area (ha)	% of Total Area
1	UC	3674.5	6.64
2	AC	4613.7	8.34
3	H	7424.1	13.42
4	BUA	861.5	1.56
5	CT	2635.6	4.76
6	BL	74.1	0.13
7	FT; B	82.7	0.15
8	GH	80.4	0.15
9	MF	1388.7	2.51
10	OT	16701.7	30.19
11	MT	88.9	0.16
12	PL	3953.6	7.15
13	RL	3202.5	5.79
14	R; NV	131.1	0.24
15	WS	194.6	0.35
16	RG; B	10205.4	18.45
	TOTAL	**55313**	**100**

Table (5:17): Land Cover Area Estimation of Stratum Three

No	Land Cover Class	Hectare Area (ha)	% of Total Area
1	UC	9911.2	13.20
2	AC	1539.8	2.05
4	BUA	1641.0	2.19
5	CT	2271.7	3.03
6	RG; B	8877.7	11.83
7	BL	4.0	0.04
8	FT; B	1276.6	1.70
9	H	1849.2	2.46
10	MF	9270.9	12.35
11	OT	13360.7	17.92
12	MT	6361.0	8.47
13	PL	1881.4	2.51
14	RL	7040.8	9.38
15	R; NV	9798.6	13.05
	TOTAL	**75085**	**100**

one hectare = $10000 m^2$

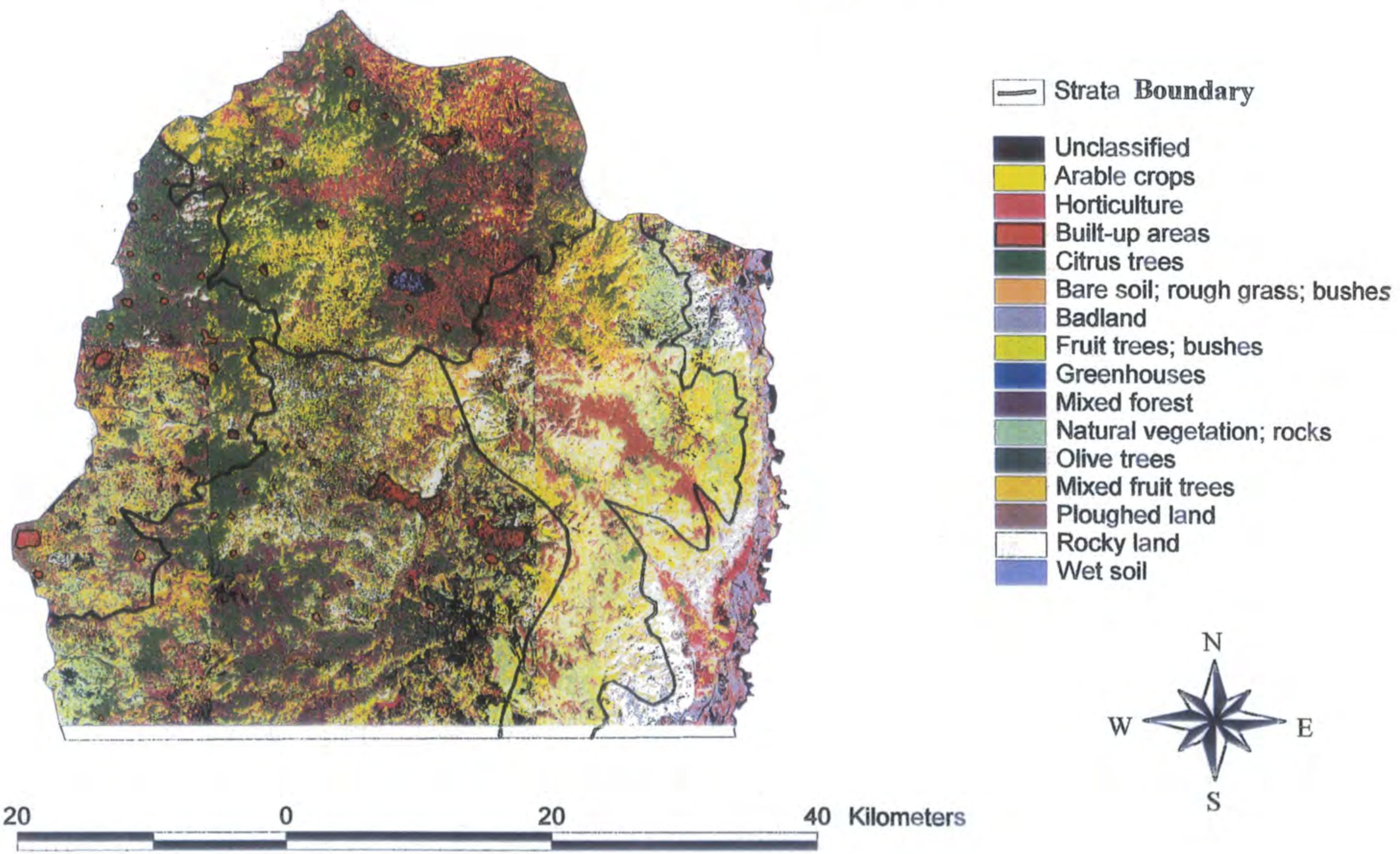
Table (5:18): Land Cover Area Estimation of Stratum Four

No	Land Cover Class	Hectare Area (ha)	% of Total Area
1	UC	3106.8	6.39
2	AC	3268.8	6.73
3	H	1740.9	3.58
4	BUA	388.2	0.79
5	CT	686.1	1.41
6	RG; B	7130.8	14.70
7	BL	1552.4	3.19
8	FT; B	21.7	0.04
9	MF	196.1	0.40
10	OT	1680.4	3.45
11	MT	461.7	0.95
12	PL	6049.7	12.45
13	RL	9518.2	19.59
14	R; NV	12784.4	26.31
	TOTAL	**48586**	**100**

Table (5:19): Land Cover Area Estimation of Stratum Five

No	Land Cover Class	Hectare Area (ha)	% of Total Area
1	UC	2241.9	9.64
2	AC	993.9	4.27
3	H	1888.0	8.11
4	BUA	958.3	4.12
5	CT	259.2	1.11
6	RG; B	1879.9	8.08
7	BL	6283.6	27.10
8	MF	1.3	0.01
9	OT	33.0	0.14
10	PL	107.8	0.46
11	RL	6780.7	29.14
12	R; NV	1841.2	7.91
	TOTAL	**23268**	**100**

Figure (5:9): Land Use Classification of the Study Area for the Year 1994



5.5 Development of Land Cover\ Land Use Class Area Estimation From SPOT HRV Data

It can be seen from the above tables that the classes included in image classification are a mixture of land use and land cover classes. This means that some of these classes have no specific thematic meaning such as the classes of the PL, WS, GH. This is because remote sensing does not provide direct information about human activity on the land (Lillesand & Kiefer, 1987). These classes need to be inserted into meaningful classes. For example, what type of crops is a certain ploughed land more likely to be planted with? What are the main crops that farmers plant in their greenhouses? Why is that piece of land wet? What type of crops is this wetland farmers likely to be planted with at that time of the year?

Pre-knowledge of the agricultural status in each stratum is needed to have these environmental classes translated into meaningful classes. The sources of this pre-knowledge are:

- the crop calendar in the area
- interviewing farmers
- field visit, and
- the study of the physical and human characteristics of the area such as soil, topography, and water availability.

In general, the ***ploughed land*** is prepared either for cereal cropping or horticulture depending on characteristics of each stratum:

- In stratum one (area of Tulkarem and Qalqilia), ploughed land and greenhouses were given to horticultural crops (vegetables). The reason for that is, first, in this stratum cereal cropping has almost disappeared since the mid-eighties. Secondly, the availability of water from artisan wells in this stratum and thirdly, during the field visit cereal fields are hardly observed.

- In strata two, three and four (area of Jenin, Nablus and Shafa El-Ghour), ploughed land is given proportionally to both cereal and horticultural crops proportionally because in these strata both types of crops can be cultivated.

- In stratum five (Al-Ghour), ploughed land is given to horticulture because cereals can not be grown there because of the dry weather (see chapter 2).

Greenhouse land cover class is assigned to horticulture (vegetables) because during the fieldwork, all greenhouses are planted with vegetables mainly cucumbers, tomatoes and peppers.

Wet soil land cover class is restricted to a limited area in region two. The land here stays wet from November until April or May. It is usually planted with spring crops mainly vegetables depending on the remaining soil moisture. Therefore this land cover class is given to horticulture. The resultant classes after development are shown in tables 5.20 to 5.26.

Table (5:20): Development of classes of the study area

No.	Class	Annotation
1	Unclassified	UC
2	Arable Crops	AC
3	Horticulture	H
4	Olive Trees	OT
5	Citrus Trees	CT
6	Fruit Trees & Bushes	FT;B
7	Mixed Trees	MT
8	Mixed Forest	MF
9	Built-up Areas	BUA
10	Badland	BL
11	Rocks &Natural Vegetation	R;NV
12	Rough grass & Bushes	RG;B
13	Rocky Land	RL

Table (5:21): Developed Land Cover Class Area Estimation of Stratum One

No	Land Cover Class	Hectare Area (ha)[1]	% of Total Area
1	UC	3206.4	9.10
2	AC	442.9	1.26
3	BUA	1352.8	3.86
4	CT	1060.9	3.03
5	FT; B	55.1	0.16
6	H	2532.1	7.22
7	MF	3168.6	9.04
8	R; NV	5313.8	15.16
9	OT	8762.4	25.00
10	MT	105.9	0.30
11	RL	2432.1	6.94
12	RG; B	6609.9	18.86
	TOTAL	**35043**	**100**

Table (5:22): Developed Land Cover Class Area Estimation of Stratum Two

No	Land Cover Class	Hectare Area (ha)	% of Total Area
1	UC	3674.5	6.64
2	AC	6129.0	11.08
3	H	10137.4	18.33
4	BUA	861.5	1.56
5	CT	2635.6	4.76
6	BL	74.1	0.13
7	FT; B	82.7	0.15
8	MF	1388.7	2.51
9	OT	16701.7	30.19
10	MT	88.9	0.16
11	RL	3202.5	5.79
12	R; NV	131.1	0.24
13	RG; B	10205.4	18.45
	TOTAL	**55313**	**100**

Table (5:23): Developed Land Cover Class Area Estimation of Stratum Three

No	Land Cover Class	Hectare Area (ha)	% of Total Area
1	UC	9911.2	13.20
2	AC	2395.0	3.19
3	BUA	1641.0	2.19
4	CT	2271.7	3.03
5	RG; B	8877.7	11.83
6	BL	4.0	0.04
7	FT; B	1276.6	1.70
8	H	2875.5	3.83
9	MF	9270.9	12.35
10	OT	13360.7	17.92
11	MT	6361.0	8.47
12	RL	7040.8	9.38
13	R; NV	9798.6	13.05
	TOTAL	**75085**	**100**

one hectare = $10000m^2$

Table (5:24): Developed Land Cover Class Area Estimation of Stratum Four

No	Land Cover Class	Hectare Area (ha)	% of Total Area
1	UC	3106.8	6.39
2	AC	7217.8	14.86
3	H	3841.6	7.90
4	BUA	388.2	0.79
5	CT	686.1	1.41
6	RG; B	7130.8	14.70
7	BL	1552.4	3.19
8	FT; B	21.7	0.04
9	MF	196.1	0.40
10	OT	1680.4	3.45
11	MT	461.7	0.95
12	RL	9518.2	19.59
13	R; NV	12784.4	26.31
	TOTAL	**48586**	**100**

Table (5:25): Developed Land Cover Class Area Estimation of Stratum Five

No	Land Cover Class	Hectare Area (ha)	% of Total Area
1	UC	2241.9	9.64
2	AC	993.9	4.27
3	H	1995.8	8.57
4	BUA	958.3	4.12
5	CT	259.2	1.11
6	RG; B	1879.9	8.08
7	BL	6283.6	27.10
8	MF	1.3	0.05
9	OT	33.0	0.14
10	RL	6780.7	29.14
11	R; NV	1841.2	7.91
	TOTAL	**23268**	**100**

Table (5:26): Developed Land Cover Class Area Estimation of The Study Area

No	Land Cover Class	Hectare Area (ha)	% of Total Area
1	UC	22068.4	9.30
2	AC	17178.6	7.24
3	H	21382.4	9.01
4	OT	40530.0	17.08
5	CT	6905.3	2.91
6	FT; B	1447.5	0.61
7	MT	7023.9	2.96
8	MF	14000.4	5.90
9	BUA	5196.8	2.19
10	BL	7901.9	3.33
11	R; NV	29875.4	12.59
12	RG; B	34597.6	14.58
13	RL	28973.7	12.21
	TOTAL	**237295**	**100**

Further development of the previously mentioned classes was done to:

a) Meet the main purpose of the study which is crop type area estimation,

b) Make the final classes produced from the SPOT HRV XS image comparable to the classification scheme used in the field sampling survey,

c) Combine the estimates obtained from image classification with the estimates obtained from the field sampling survey and apply the double sampling technique to improve the estimates, and

d) Make the final estimations applicable and useful for decision-makers.

In the field sampling survey, five broad land use categories were investigated, olive and fruit trees, citrus trees, horticulture (vegetables), arable crops, the and non-agricultural land category. Thus, to derive these classes from image classification, further development of the classes was developed as follows:

- Olive trees (olive1, olive2 and olive3), fruit and bushes, and mixed trees were merged into one class named olive and fruit trees (OT, FT). The reason for that is the fruit trees and the mixed trees classes are always mixed with olive trees, and during the field sampling it was difficult to delineate large fields of these classes clearly (see chapter 6).

- Citrus trees
- Arable crops including areas of the ploughed lands as mentioned earlier in this section.
- Horticulture including horticulture class, horticulture1, greenhouses, wet soil, and areas of the ploughed lands.
- The other classes (built-up areas, bare soil and rough grass, rough grass and bushes, bare soil and bushes, mixed forest, badland1, 2, and 3, natural vegetation, rocky land, and the rocks and natural vegetation) were merged into one class called the non-agricultural lands class. Table 5.27 shows the final SPOT HRV area estimates of the developed agricultural land use classes.

Table (5:27): Final SPOT HRV XS Area Estimates for Agricultural Crops Northern West Bank (ha)

Stratum	Olive and Fruit trees	Citrus Trees	Horticulture	Arable Crops	Non-Agricultural
1	8923.3	1060.9	2532.1	442.9	18883.2
2	18173.2	2635.6	10137.4	6128.9	15863.3
3	20998.0	2271.7	2875.5	2394.9	27371.8
4	2163.7	686.1	3841.6	7217.6	31570.1
5	32.6	259.1	1995.8	993.8	17745.0

5.6 Image Classification Accuracy Assessment

Classification accuracy assessment of derived land use/ land cover maps from remotely sensed data is important especially when these maps and statistics are to be used by decision makers. Accuracy assessment is also important to identify the sources of errors. There are two main types of accuracy assessment for crop classification (Mead & Szajgin, 1982):

1) site specific assessment, and, 2) non-site specific assessment.

The first method involves a comparison of the classification results of remotely sensed data with reference information and statistics. This method is effective because it gives the accuracy of each class and the spectral overlap among different classes (inclusion and exclusion errors). It also gives an insight into how the data derived from the remotely sensed data compared with the ground truth data on a locational basis. The second method (non-site specific) ignores the spatial and locational relationships. It only compares the total coverage of a class with its coverage obtained by other methods and sources. Therefore, the non-site specific accuracy assessment method may be a misleading one (Congalton & Green, 1998).

In this study, the site specific method is preferred because location is fundamental in geographical studies. To get reference information to compare with the remote sensing classification map and fill the error matrix with values, the test reference information is collected before and after the classification. As time and cost are important in using remote sensing for large geographical areas, a stratified random sample was used to collect the appropriate number of samples for each agricultural category.

In this study, the time and cost were considered in implementing the assessment method of image classification accuracy. Accuracy testing was carried out on fields in the sampling units during both phases of field data collection. To minimize time and cost, Mead and Szajgin (1982) suggest that the collection of the assessment data could be carried out simultaneously with training data. In the first phase (training areas collection), field data were collected for image classification and for accuracy assessment using large scale Israeli aerial photographs. These test data were used in accuracy assessment of the plain agricultural lands. In the second phase (the field data sampling phase), the field data were used for area estimates and accuracy assessment of the uplands using the CORONA satellite photography (see chapters 3 & 6). Therefore, the SPOT HRV image classification accuracy assessment was done by using the ground field data obtained during the training phase by selecting independent test sites and the sampling units visited during the second phase of the fieldwork.

In previous studies, the optimum sample size used to assess the accuracy of individual categories in remote sensing classification map varied considerably. Hay (1979) and Congalton (1991) suggest that a minimum of 50 samples for each category could be a good rule, while Gurney (1981) suggests 400 pixels for each class. The size of the study area, number of classes included in classification, the relative importance of certain categories and variability of different categories should also be taken into consideration (Jensen, 1996).

In this study, special care is paid for the most valuable categories. These categories are:

1) Olive Trees (OT)
2) Horticultural Crops (H)
3) Citrus Trees (CT) and
4) Arable Crops (AC)

Taking into consideration the previous studies as well as time, cost, and the field characteristics, test pixels and test areas in this study were determined as follows. First, crops existing in plain land mainly horticulture, arable crops, and citrus trees were assessed on a polygon basis. This means that the whole polygon is taken for assessment what ever the size of it is. The relatively large fields were selected (more than 1 ha or 100 pixels because most fields are relatively small). Secondly, crops existing in the upland mainly olive trees and fruit trees in addition to the non-agricultural categories were assessed on a cluster basis. 200 pixels were selected for each land use category to be assessed. Finally, because the number of pixels selected for accuracy assessment is not the same for all classes, results were converted to become percentages.

There are three types of accuracy assessments that can be made for a classified image, the overall classification accuracy, the producer's accuracy and the user's accuracy. The overall accuracy is the sum of the major diagonal divided by the total number of the sample units in the entire error matrix. The producer's accuracy refers to the number of pixels which have been correctly identified as a land use type, while the user's accuracy refers to the actual number or percentage of pixels of a certain class on the classified image that exists on the ground (Congalton & Green, 1998). Tables 5.27 to 5.31 show classification accuracy assessment results.

Table (5:28): Classification Accuracy Assessment for Stratum One

	AC	H	CT	OT;FT	MF	R;NV	RG;B	RL	BUA	GH	PL	T
AC	**89**	3	0	0	0	6	2	0	0	0	0	**100**
H	0	**52**	22	8	10	0	8	0	0	0	0	**100**
CT	0	0	**93**	2	0	0	2	0	0	3	0	**100**
OT;FT	0	0	1	**71**	8	0	9	0	3	8	0	**100**
MF	0	0	0	0	**87**	0	0	0	0	0	13	**100**
R;NV	2	0	0	10	20	**52**	15	0	0	1	0	**100**
RG;B	0	0	0	0	5	18	**77**	0	0	0	0	**100**
RL	0	0	0	0	0	0	0	**85**	15	0	0	**100**
BUA	0	0	0	2	0	0	6	5	**87**	0	0	**100**
GH	0	0	0	5	0	0	0	1	6	**88**	0	**100**
PL	0	0	0	0	30	0	0	0	0	0	**70**	**100**
T	**91**	**55**	**116**	**98**	**160**	**76**	**119**	**91**	**111**	**100**	**83**	**1100**
UA%	**97**	**94**	**80**	**72**	**54**	**68**	**65**	**93**	**78**	**88**	**84**	

* reference data in rows and classified data in columns
AC = Arable Crops, H = Horticulture, CT = Citrus Trees, OT;FT = Olive and Fruit Trees, MF = Mixed Forest, R;NV = Rocks and natural vegetation, RG;B = rough grass and Bushes, RL = Rocky Land, BUA = Built-up Areas, GH = Greenhouses, PL = Ploughed Land, T = Total, UA% is the User's Accuracy. Producer's accuracy are shown in diagonal.

OVERALL ACCURACY = (89+52+93+71+87+52+77+85+87+88+70)/1100 = 851/1100 = **77%**

Table (5:29): Classification Accuracy Assessment for Stratum Two

	AC	H	BUA	CT	OT;FT	MF	RL	RG;B	PL	T
AC	**74**	26	0	0	0	0	0	0	0	**100**
H	4	**84**	0	3	8	0	0	1	0	**100**
BUA	0	0	**86**	0	2	0	9	3	0	**100**
CT	0	2	0	**90**	3	0	0	5	0	**100**
OT;FT	0	4	0	6	**68**	8	0	5	9	**100**
MF	0	0	0	0	8	**92**	0	0	0	**100**
RL	2	0	0	0	0	0	**81**	17	0	**100**
RG;B	0	9	0	23	6	0	0	**60**	2	**100**
PL	0	0	0	0	5	2	0	0	**93**	**100**
T	**80**	**125**	**86**	**122**	**100**	**102**	**90**	**91**	**104**	**900**
UA%	**92**	**67**	**100**	**74**	**69**	**90**	**90**	**66**	**89**	

* reference data in rows and classified data in columns

AC = Arable Crops, H = Horticulture, BUA = Built-up Areas, CT = Citrus Trees, OT;FT = Olive and Fruit Trees, MF = Mixed Forest, RL = Rocky Land, RG;B = rough grass and Bushes, PL = Ploughed Land, T = Total, UA% is the User's Accuracy. Producer's accuracy is shown in diagonal.

OVERALL ACCURACY = (74+84+86+90+68+92+81+60+93)/900 = 728/900 = **81%**

Table (5:30): Classification Accuracy Assessment for Stratum Three

	AC	BUA	CT	RG;B	PL	OT;FT	H	MF	RL	R;NV	T
AC	**84**	0	0	4	0	0	7	0	5	0	**100**
BUA	0	**89**	1	6	0	3	0	1	0	0	**100**
CT	2	0	**82**	6	0	1	9	0	0	0	**100**
RG;B	0	0	15	**58**	0	17	3	4	2	1	**100**
PL	0	0	0	0	**84**	12	0	4	0	0	**100**
OT;FT	0	0	4	1	6	**61**	1	26	0	1	**100**
H	0	0	29	1	0	0	**70**	0	0	0	**100**
MF	0	1	2	3	0	8	0	**78**	3	5	**100**
RL	0	0	0	0	0	0	0	0	**100**	0	**100**
R;VN	0	5	1	3	0	16	0	0	1	**74**	**100**
T	**86**	**95**	**134**	**82**	**90**	**118**	**90**	**113**	**111**	**81**	**1000**
UA%	**97**	**94**	**61**	**71**	**93**	**52**	**78**	**69**	**90**	**91**	

*reference data in rows and classified data in columns

AC = Arable Crops, BUA = Built-up Areas, CT = Citrus Trees, RG;B = rough grass and Bushes, PL = Ploughed Land, OT;FT = Olive and Fruit Trees, H = Horticulture, MF = Mixed Forest, RL = Rocky Land, R;NV = Rocks and Natural Vegetation , T = Total, UA% is the User's Accuracy. Producer's accuracy is shown in diagonal.

OVERALL ACCURACY = (84+89+82+58+84+61+70+78+100+74)/1000 = 780/1000 = **78%.**

Table (5:31): Classification Accuracy Assessment for Stratum Four

	AC	H	BUA	CT	RG;B	BL	OT;FT	RL	R;NV	PL	MF	T
AC	**92**	1	0	0	3	0	1	3	0	0	0	**100**
H	0	**94**	0	6	0	0	0	0	0	0	0	**100**
BUA	1	0	**89**	0	5	0	3	2	0	0	0	**100**
CT	0	7	0	**89**	4	0	0	0	0	0	0	**100**
RG;B	6	13	0	9	**67**	0	2	3	0	0	0	**100**
BL	0	0	18	0	4	**74**	0	2	2	0	0	**100**
OT;FT	11	4	0	3	3	0	**68**	1	2	8	0	**100**
RL	4	0	0	0	0	0	0	**90**	6	0	0	**100**
R;NV	4	0	0	0	8	3	0	5	**77**	3	0	**100**
PL	7	0	0	0	0	0	5	0	0	**88**	0	**100**
MF	0	0	0	0	0	0	6	0	0	0	**94**	**100**
T	**125**	**119**	**107**	**107**	**94**	**77**	**85**	**106**	**87**	**99**	**94**	**1100**
UA%	**74**	**79**	**83**	**83**	**71**	**96**	**80**	**85**	**89**	**89**	**100**	

*reference data in rows and classified data in columns

AC = Arable Crops, H = Horticulture, BUA = Built-up Areas, CT = Citrus Trees, RG;B = rough grass and Bushes, BL = Badland, OT;FT = Olive and Fruit Trees RL = Rocky Land, R;NV = Rocks and Natural Vegetation, PL = Ploughed Land, MF = Mixed Forest, T = Total, UA% is the User's Accuracy. Producer's accuracy is shown in diagonal.

OVERALL ACCURACY = (92+94+89+89+67+74+68+90+77+88+94)/1100 = 922/1100 = **84%.**

Table (5:32): Classification Accuracy Assessment for Stratum Five

	AC	H	BUA	CT	RG;B	BL	R;NV	RL	T
AC	**91**	0	0	0	0	0	0	9	**100**
H	3	**96**	0	1	0	0	0	0	**100**
BUA	0	0	**82**	0	4	12	0	2	**100**
CT	0	16	0	**84**	0	0	0	0	**100**
RG;B	5	3	0	0	**92**	0	0	0	**100**
BL	0	0	20	0	4	**73**	0	3	**100**
R;NV	2	0	0	0	10	1	**79**	8	**100**
RL	0	0	0	0	0	0	3	**97**	**100**
T	**101**	**115**	**102**	**85**	**110**	**86**	**82**	**119**	**800**
UA%	**90**	**83**	**80**	**99**	**84**	**85**	**96**	**82**	

*reference data in rows and classified data in columns

AC = Arable Crops, H = Horticulture, BUA = Built-up Areas, CT = Citrus Trees, RG;B = rough grass and Bushes, BL = Badland, R;NV = Rocks and Natural Vegetation RL = Rocky Land, T = Total, UA% is the User's Accuracy. Producer's accuracy is shown in diagonal.

OVERALL ACCURACY = (91+96+82+84+92+73+79+97)/800 = 694/800 = **87%**

Table (5:33): SPOT HRV XS Classification Accuracy Assessment of the Study Area (Northern West Bank)

Land Use	Producer's Accuracy (%)	User's Accuracy (%)	Overall Accuracy (%)
AC	86	90	86
H	79	80	79
CT	88	79	88
OT;FT	67	68	67
MF	88	77	88
GH	88	88	88
R;NV	71	86	71
RL	91	88	91
BUA	87	88	87
PL	84	89	84
RG;B	71	71	71
BL	74	91	74

OVERALL CLASSIFICATION ACCURACY OF THE STUDY AREA = (86+79+88+67+88+88+71+91+87+ 84+71+74)/1200 = 974/1200 = 81%

5.6.1. Discussion of Classification Accuracy Assessment Results

In this study, the classification accuracy assessment is carried out at different levels; the stratum level, the crop type level in each stratum. Tables 5.27 to 5.31 show that:

1) The overall accuracy in stratum five is the highest (87%). Accuracy ranges from 73 to 97%. The lowest accuracy is for the Badland class because it is spectrally overlapped with the Built-up Areas class. The relatively high accuracy achieved for this stratum is probably due to the relatively small number of classes existing in the area and the good spectral separability among land cover types. Citrus trees and horticulture in this stratum are overlapped and 16% of the citrus pixels are assigned as horticulture and so the user's accuracy of horticulture is decreased from 96% to 83%. This may mean that the classification overestimated horticulture at the expense of citrus trees.

2) In stratum four, the overall accuracy comes in the second highest place among the five strata (84%). The lowest accuracy in this stratum is for the Rough Grass & Bushes and Olive &Fruit Trees classes. Olive trees are confused with arable crops which is unreasonable because these two categories at this time of the year (May) are spectrally different. The reason for this error is the land use change between the image acquisition date (1994) and the field data collection (1998). Some arable lands in the plain areas were planted with olives (young trees). These fields were labeled as olives at the time of the field survey (1998). Rough grass and bushes are also confused with horticulture in this stratum. 13% of the rough grass pixels were assigned to horticulture. This is due to the increasing land cover complexity when

moving from the east to the west (from the Jordan valley to the center of the Nablus mountains).

3) The overall accuracy in stratum three which represents the core or the center of the Nablus mountains is 78%. The lowest accuracy is for the Olive & Fruit trees and Rough Grass & Bushes classes. These two categories in this area are confused. Where 17% of the rough grass pixels mainly *Sarcopoterium Spinosum* is assigned to olives and fruits, only 1% of olive pixels assigned as rough grass and bushes. The complex land cover, the mountainous landscape (topography), slope and aspect, and the impurity of land cover types may explain the relatively low accuracy of these classes in this stratum.

4) In stratum two, the overall accuracy is 81%. The lowest level of accuracy was also for Olive & Fruit Trees and Rough Grass & Bushes classes. In addition to the reasons mentioned in the previous point, certain types of bushes existing in this stratum are responsible for the spectral overlapping between these two categories on the one hand, and between citrus trees and bushes. Some areas of this stratum are covered with *Tistacia Lentiscus* and *Quercus Calliprinos* bushes. *Tistacia Lentiscus* is a kind of bush about two meters tall with evergreen waxy leaves, while Quercus Calliprinos is an oak tree.

5) Finally, the overall accuracy of stratum one is 77%. The lowest accuracy was for Horticulture and Rough grass & Bushes classes. Horticulture is confused with citrus trees. The reason for such overlapping is the relatively high leaf Area Index (LAI) of both classes in such an irrigated area. The rough grass is overlapped with the natural vegetation class that mainly covers the south eastern part of this stratum.

Sources of errors and the relatively low accuracy of some land use types in certain areas can be investigated through viewing the different sources of data and the steps followed in image classification and assessment, the classification scheme, and the characteristics of the study area.

a) The reference data used in this study were the ground data, aerial and satellite photographs, and Israeli topographic maps.

- The ground data collection for image classification (1998) and assessment was far from the image acquisition date (1994). This time separation affected and complicated the field data collection process, especially because farmers do not keep records of their previous activities in the field. They hardly remember the type of crop they grew at the image acquisition date.

- The season and the date of the Israeli aerial photographs used were not ideal for agricultural data collection. They were acquired in autumn and Winter where the fields are prepared for cultivation or freshly sown. Although the possibility of getting agricultural data on seasonal crops was limited, these photographs were useful for training and testing the relatively constant agricultural types much as olives and citrus trees. CORONA satellite photographs were also useful for collecting agricultural data in the uplands regions where olive trees are the dominant land use, however they are old photographs acquired in 1970. For more efficient field data collection, aerial photographs for the same season and the year of the satellite image are vital for detailed accuracy assessment.

- The 1: 50 000 Israeli topographic maps were used along with the 1: 40 000 CORONA prints for overviewing only, while the large scale CORONA prints were used for field data labeling. So, these maps were of a limited use in the field data collection. Large scale maps showing field boundaries are also recommended for field data collection and labeling because even vertical aerial photographs can contain considerable errors especially away from the nadir point.

b) The classification scheme used in this study is for land cover. On the other hand, the reference data used for accuracy assessment is for land use data (thematic data). This difference between the applied classification and the reference data affected the accuracy of a certain classes such as the olive trees class and the rough grass class. It was not possible to make field measurements of percentages of crop crown closure to solve this problem.

c) Despite the relatively high spatial resolution of SPOT HRV XS data, the limited spectral resolution and the absence of the middle or the short-wave infrared reduced spectral separability especially in the rough textured areas (the uplands).

d) The complex topography of the study area may have affected the classification accuracy. The area is characterized by large topographic variations (elevation, slope and aspect). This situation increased the effect of topographic shadowing on the spectral separability of a certain land use types mainly olives, mixed forest and the ploughed land in the strata 1 to 4.

CHAPTER SIX

CROP AREA ESTIMATION BY FIELD SAMPLING

6.1 Introduction

This chapter discusses the field sampling methodology for estimating the major crop type areas in the study area (northern West Bank). Results of field area estimation will be compared with crop type area estimation by satellite remote sensing to improve the final area estimation results.

It is necessary to study the idea of sampling, its purposes, and methods before selecting the proper sampling technique. Sampling is a procedure that is based on the selection of a subset of data (in any form) representing as much as possible the characteristics of the total population under study.

Sampling is justified for the following reasons: 1) when the population under study is large. This is particularly applicable in geographical studies. For example, in this study the geographical study area is large (2373 km^2) and would be difficult to survey fully on the ground. Such a large area of an agricultural survey would need a large numbers of skilled surveyors and would take long time and be very costly, 2) Sampling may save effort, time and cost, 3) it allows more effective, comprehensive and accurate collection of information on a limited number of samples, 4) it enables researchers to meet with a selected number of farmers to better understand the cultural environment of the area and, and 5) in many cases such as this case, it is impossible to reach all the population sites, sampling reduces the effect of this constraint on the results of the study. It is only through the use of samples that inferential statistics allows to draw conclusions regarding the population in which we are interested.

6.2. Sampling Methods

Before selecting an appropriate sampling method for the field data collection program, it is necessary to review the most commonly used sampling methods. The aim of the review is to understand their characteristics, advantages and limitations to be able to decide on the most suitable method for this study.

In spite of the advantages of sampling, there are also problems associated with it. **Sampling error and bias.** When the selected samples are not representative of the population, sampling error exists. Unrepresentative samples will produce an erroneous estimate of the parameter and result in sampling error. There are two basic sources of sampling problems; the first is the overestimation, or underestimation of the real characteristics of the population that may result from the sample draw. The second source of sampling problems is sampling bias. Bias results from the tendency to favor the selection of some elements over others in the collection of the sample. It is therefore necessary to ensure that the collection of sample data follows a prescribed method which has been shown to minimize such error. A brief statement focusing on proper sampling procedures is warranted at this point. Four main sampling methods are discussed here:

- **simple random sampling**
- **systematic sampling**
- **stratified sampling**
- **cluster sampling**

The **simple random sampling** method involves a method by which each possible sample has the same likelihood or probability of being selected from the total population under study. In this method every individual or object in the population of interest has an equal chance of being chosen for study. The choice of any individuals is in no way affected by the researcher in any stage of the sampling process. A random sampling process should satisfy the following criteria:

1) every individual should have an equal chance of inclusion in the sample throughout the sampling procedure.
2) the selection of any particular individual should not affect the chance of selection of other individual (the probability of inclusion in the sample should be equal and independent of each other).

In this method each drawn individual is removed from the population for all subsequent draws. So, it is called simple random sampling without replacement.

In the **systematic sampling** method, the sample is chosen in a regular way. For example, taking every 10^{th} individual from the population under study. Selection of the first sample in this method is done randomly, then the subsequent samples are selected regularly or systematically. If the first selected sample was the 4^{th} one, then the second sample would be the 14^{th} and the third is 24^{th}, and so on.

This method seems to produce an even coverage of the population in the sense that sample members are selected evenly from the population avoiding the bunching that can often occur with random sampling. Also, in this method, no individual can be selected more than once. The systematic sampling does not give every individual in a population the same probability of selection because once the first selection has been made, all samples of the population except the sample size (the decided number of samples from the population) have lost all chance of representation in the sample. So, it may not be possible to make reliable inferences about the population on the basis of the sample.

In the **stratified sampling** method, the population under study is divided into small subsets of population called strata before the selection of samples. Stratified sampling is usually used when the whole population includes considerable spatial variations that may reduce the accuracy of any estimation if other methods such as the simple random and systematic sampling are used. In this case, stratification of the population into smaller homogeneous groups may reduce variability within an individual stratum. Also, stratification is useful in spatial sampling such as the study of land cover/ land use patterns. The advantage of stratified spatial random sampling is that it ensures an equal degree of representation of sub-areas, producing a more representative spatial coverage without completely sacrificing the randomness necessary for subsequent statistical testing (Ebdon, 1976). Dealing with smaller aerial units is easier and facilitates the data management especially when the area under study is large as is often in remote sensing studies. Dealing with smaller units enables us to make more precise, detailed and effective statistical and illustrative observations, which is essential in remote sensing studies.

In the conventional stratified sampling method, each stratum is represented in proportion to its size. This means that the number of sampling units in each stratum depends on its size compared with the total population size, unless it is seen that a certain stratum should be represented differently.

Stratification should be based on subjective elements, which serve the objectives of the study, and this differs from one subject to another. For agricultural remote sensing studies, the following elements or some of them could be taken into consideration:

- administrative boundaries,
- topographic characteristics (elevation, slope and aspect),
- climate characteristics (precipitation, temperature...etc),
- soil types,
- farming system (irrigated, rain-fed),
- vegetation density,
- geology,
- socio-economic characteristics,
- the general land use characteristics, and
- other environmental considerations

The **cluster sampling** method is based on dividing the entire population into clusters or groups then selecting a sample of these groups (Webster 1992). All observations in those selected clusters are included in the sample. For example, the study area is divided into five strata, these strata are considered to be clusters or groups. According to cluster sampling, a stratum is selected from the five to represent the study area. This technique is easier and quicker than the previously mentioned techniques. But results of such sampling technique may be biased, especially when the area under study is characterized by considerable spatial variability. Moreover, small unit sample gives more precise results than a large unit (Cochran 1977).

It can be seen from the sampling methods illustrated above that they suffer the following limitations:

a) The simple random sampling method may not cover the population of study well.

b) In the systematic sampling method, the samples are not selected independently from each other. Once the first sample is selected the rest needed samples are determined.

c) Cluster sampling method may not represent the population of study well, especially when considerable spatial variations exist.

6.3. Adopted Sampling Method

The view of the main sampling methods shows that the simple random sampling and the cluster sampling may not give good representation of the population. Samples in the systematic sampling method are not selected independently because the first selected sample determines the rest needed samples.

Lo *et al.*(1998) studied and evaluated the effectiveness of five sampling methods empirically to decide the thematic accuracy of vegetation maps of two study areas in Georgia and Florida (USA). The study showed that the stratified random sampling produced best results for thematic accuracy evaluation.

Alfred de Gier *et al.* (1992) estimated the timber volume in a part of Norway using two methods of double sampling. The first was the simple random sampling without stratification and the second method was the stratified random sampling. They found that when variances of the mean estimates for the two methods compared, the stratified random sampling was better.

Shueb (1990) studied agricultural crops in County Durham, UK. A stratified random sampling was used in this study. The study area was divided into five strata because it includes considerable environmental variations. He concluded that the stratified random sampling is the most appropriate for area characterized by such spatial variations.

To avoid the disadvantages of the previously mentioned sampling methods, a combination is made among these methods to produce a hybrid method. That method is called a stratified random sampling. The study area (northern West Bank) is relatively large (2373 km^2) and includes considerable spatial variations. Ignoring these variations (topographic, climatic and land use) in any sampling of the area may result in considerable sampling error and bias. For example, the valuable agricultural lands in the WB lie in relatively small plains, and if those areas are ignored, crop area estimation could not reflect the real agricultural situation in the study area. As seen earlier in this section, the simple random sampling, the systematic sampling and the cluster sampling methods may ignore these vital spatial variations. The stratified spatial random sampling method may achieve the following two objectives:

1) better coverage and distribution of the study area by selected samples, especially when the study area is characterized by considerable spatial variations, and

2) more accurate analysis and estimates.

As mentioned in chapter 5, the study area was divided into five main strata (figure 6.1). Stratification was based on the following considerations:

- administrative boundaries (the Jordanian administrative boundaries were used because that of the Palestinian Authority is still unstable),

- topographic characteristics (mainly elevation, slope and aspect),

- soil type,

- agricultural intensity and field size,

- climatic characteristics (mainly precipitation and temperature),

- farming system (irrigated and rain-fed), and

- land cover density.

These environmental considerations were taken into account when the study area was stratified.

As seen in chapter two, the study area nearly covers the district of Nablus according to the Jordanian administrative division or 40% of the total surface area of the West Bank. The District of Nablus consists of three sub-districts (Jenin, Tulkarem, and Nablus). The Sub-District of Nablus includes severe environmental variability (see figure 6.1), so it is divided into three strata taking into account the previously mentioned environmental considerations. By doing this, the study area is divided into five strata (figure 6.2). These strata are:

1) The Sub-District of Tulkarem or stratum one

2) The sub-District of Jenin or stratum two

3) The Sub-District of Nablus or stratum three, four, and five

Furthermore, and to ensure adequate coverage of the vital and extremely valuable agricultural lands, each stratum has been divided into two sub-strata, see figure 6.3.

- plain agricultural lands

- other lands

These plain agricultural lands are scattered through the study area. They are characterized by their relatively small areas on the one hand. On the other hand, type of farming in the plain lands is completely different from other lands. So, ignoring these lands in stratification may result in considerable sampling error.

Topographic characteristics of the study area including elevation, slope and aspect are the most important considerations taken into account when stratification was made. The topography of the West Bank has a large influence on the agriculture of the West Bank.

Climate, mainly rainfall and temperature, has a large effect on farming systems and land vegetational cover density. The eastern slopes of the Nablus mountains including the Jordan Valley lie in a rain shadow and do not receive large amounts of rain. So, on one hand, plain lands here are unsuitable for rain-fed farming. On the other hand, areas of rough terrain are sparsely vegetated.

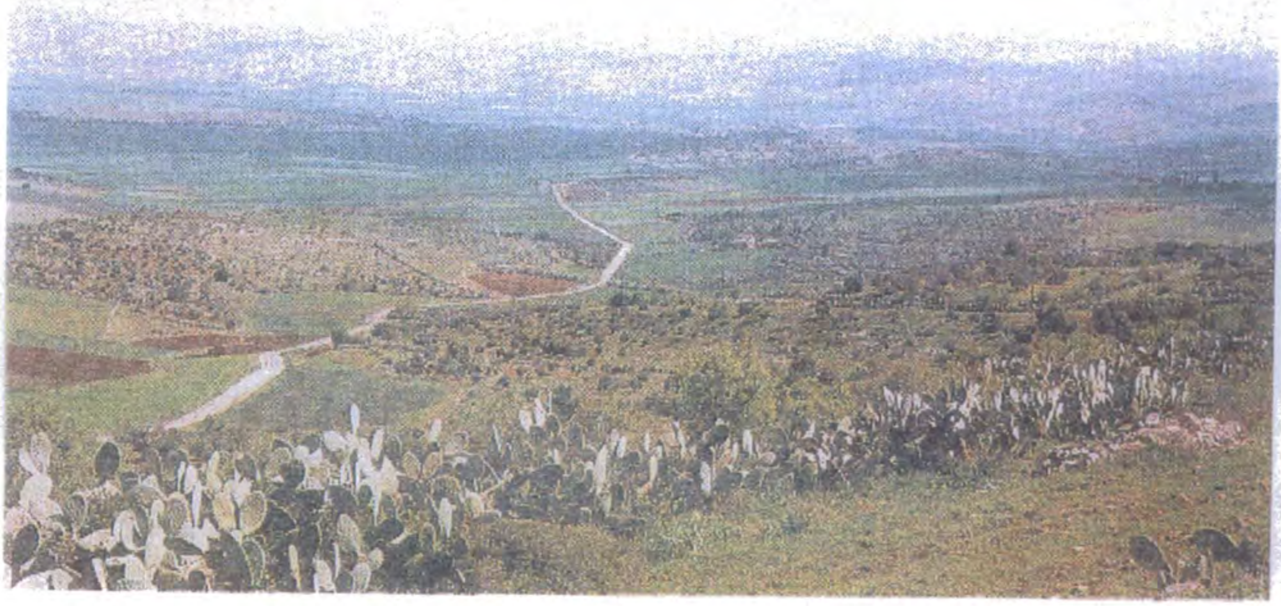
Field size in the study area is affected by the following factors:

- type of farming; areas of intensive or irrigated farming are characterized by smaller fields, while areas of rain-fed farming are characterized by larger fields.
- topography; it is difficult to determine field limits in the hilly and rough areas, for these areas are mostly planted by trees. Field limits in these areas are lines of stones which can not be seen through the canopy. The hilly lands in the study area represent the majority of the total area.
- the socio-economic system where the fields are fragmented by this system and their size becomes smaller and smaller.

These previously mentioned factors were the main reasons for using the stratification methodology. Application of this methodology can be summarized as follows:

1) The study area was divided into five main strata.
2) Each stratum was divided into two sub-strata (agricultural plain lands and other lands). Area of the plain agricultural lands is 280 km^2 or about 11.8% of the study area (table 6.2). The rest of the study area is called **other lands** rather than hilly or mountainous lands, because the plain badlands existing in the Jordan Valley are included in this category.
3) The proportional size of each stratum was determined.
4) The number of samples, which had to be selected from the whole population, was determined to be 3% for the five strata as a whole. The sample size in each stratum was obtained according to its proportional size to the whole population. Then areas of agricultural plain lands were determined and given a number of samples proportional to their size of each stratum size (table 6.1).
5) The random sampling approach without replacement was applied in each stratum separately to select the sample units.

Figure (6:1): Environmental Variations of the Study Area



a) Environment of Stratum One

b) Environment of Stratum Two

c) Environment of Stratum Three

d) Environment of Stratum Four

e) Environment of Stratum Five

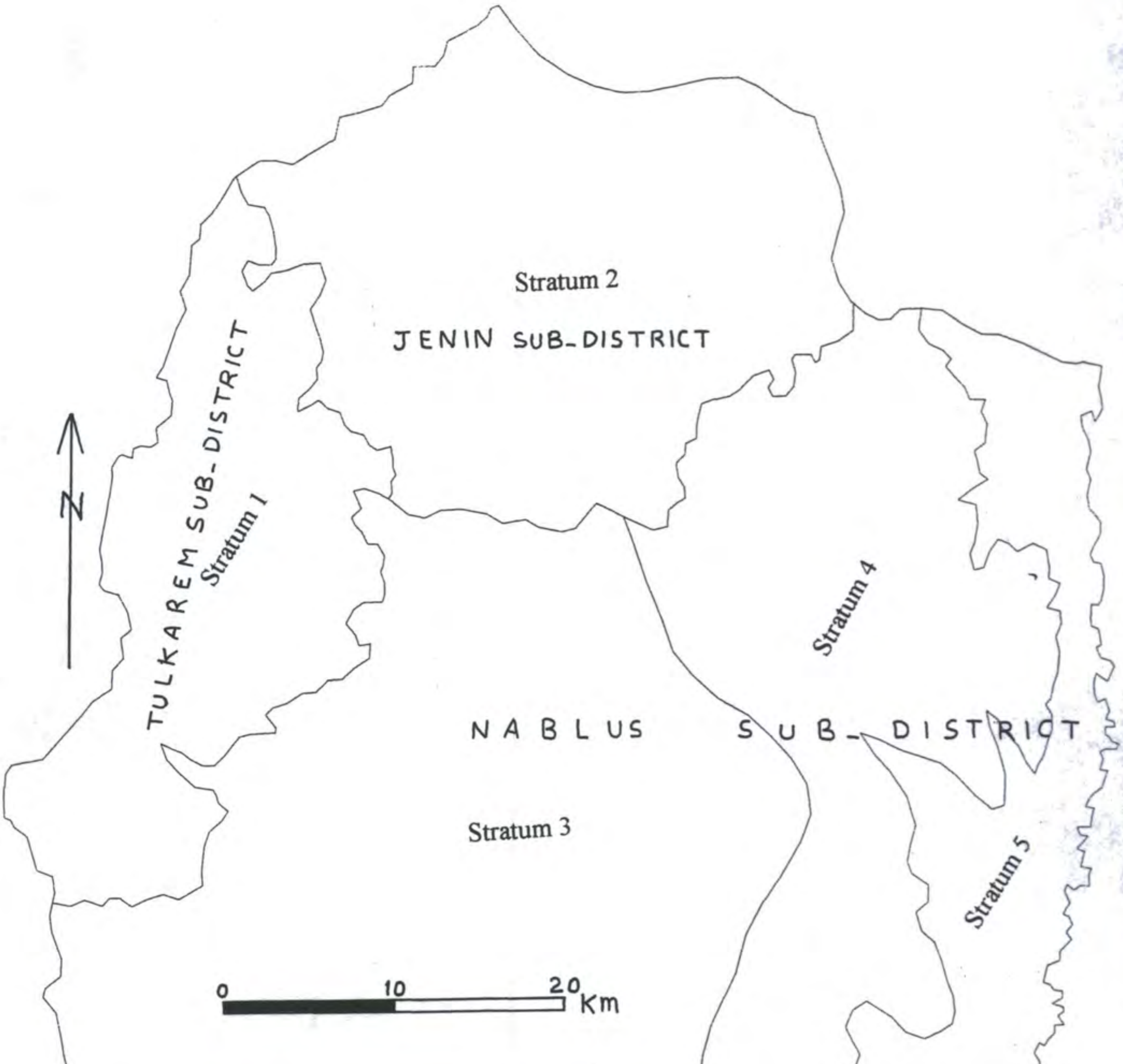


Figure (6:2): Division of the Study Area into Five Strata

6.4. Selection of Sample Unit Size

There are no clear rules in remote sensing which determine sample unit size. In the European Union, an approximate size for sample units is suggested to be between 25 and 100 ha depending on the homogeneity of land use and the average field size (Deppe, 1998). Alonso *et al.* (1991) investigated the use of the sample units with square segments (700x700m), and sample units with irregular segments (approximately 50 ha). But in general, for agricultural studies, each sample unit should include enough fields to ensure the coverage of different agricultural crops in the area. A number of considerations should be taken into account before selection of sample unit size when agricultural remote sensing techniques are used. These considerations which are strongly interrelated are:

- the average field size in the study area,
- homogeneity of land use,
- purpose of the study,
- spatial resolution of the used remote sensing system,
- characteristics of the study area,
- characteristics of reference data available for the field survey,
- size of the total population,
- detailed characteristics of individual units within the population,
- the ease with which the sample units can be surveyed, and
- the adopted classification scheme.

In this study, the most important considerations which determined the sample unit size are: the homogeneity of land use, the detailed characteristics of individual units within the population, the adopted classification scheme, the grid square of the available maps, and the average field size.

Depending on the above mentioned considerations, the sample unit size was determined to be equal to 1 km^2 or 100 hectares which is equal to the grid square of the Israeli 1:50,000 scale maps. Also the use of such relatively large sample unit size reduced the number of samples and facilitated the field survey in such an insecure area. In other words, when the sample unit is small, the number of samples becomes larger and the probability of having sample units close to the Israeli settlements becomes higher which may affect the field survey.

As seen in chapter 5, there are four main agricultural crop types grown in the study area. These crops are:

1) Arable Crops, mainly cereals.

2) Horticultural Crops or vegetables.

3) Olive Trees.

4) Citrus Trees.

These four crop types represent more than 90% of the total cultivated land in the study area, while the rest (10%) is a mixture of different types of trees such as almonds, olives, apricots, figs, vineyard (complex agricultural land). These two categories (mixed trees, fruit trees and bushes) can not be delineated in the field clearly, so it could be wise to be added to olive trees category and renamed (olive trees and fruit trees).

As the principal aim of this study is to estimate the crop type areas, the field data collection was concentrated in the agricultural lands. The non-agricultural lands mainly exist in stratum 4 and stratum 5. These two strata represent the eastern slopes and the Jordan Valley respectively. Only the samples of the plain agricultural lands in these two strata were considered in the fieldwork because the rest area of them is non-agricultural.

6.5. Field Data Collection (The Second Phase)

As mentioned in chapter five, the fieldwork consisted of two phases. The first was devoted to the collection of ground training data. The training data were used for satellite image classification or land use/ land cover area estimation (image sampling). The second phase of field data collection was devoted to field sampling to produce crop area estimation to be compared with those produced by satellite image sampling. Then the two crop area estimation results by image sampling and field sampling techniques are used to enhance the crop area estimation in the study area.

The field survey of the second phase was carried out between July and October 1999. Before visiting the field, the following preparations were made:

a) projection of strata boundaries on the Israeli 1:50,000 scale maps and SPOT HRV image prints: it was necessary to transfer the five strata boundaries from the rectified SPOT HRV digital images to these maps and prints to be able to apply the adopted sampling methodology (the stratified random sampling technique). The grid of coordinates appears on these maps which help in allocation of sample units.

b) delineation of agricultural plains and calculation of their areas: the 1:50,000 scale Israeli maps and unclassified SPOT image prints were used to delineate these agricultural plains in each stratum. It was easy to identify these areas on both maps and false color image prints. The main guide for the identification of these plains on maps was the contour line spacing. Contour lines in these areas are relatively distant from each other. While the identification of these plains on the SPOT false color image prints was based on the high contrast of land use\ land cover between these plains and the surroundings. The regular and clear field limits of these plains in addition of the author's pre-knowledge of the study area gained from the first phase of the field survey also helped in the delineation of the plains, see figure 6.3. A planimeter was used for area calculation.

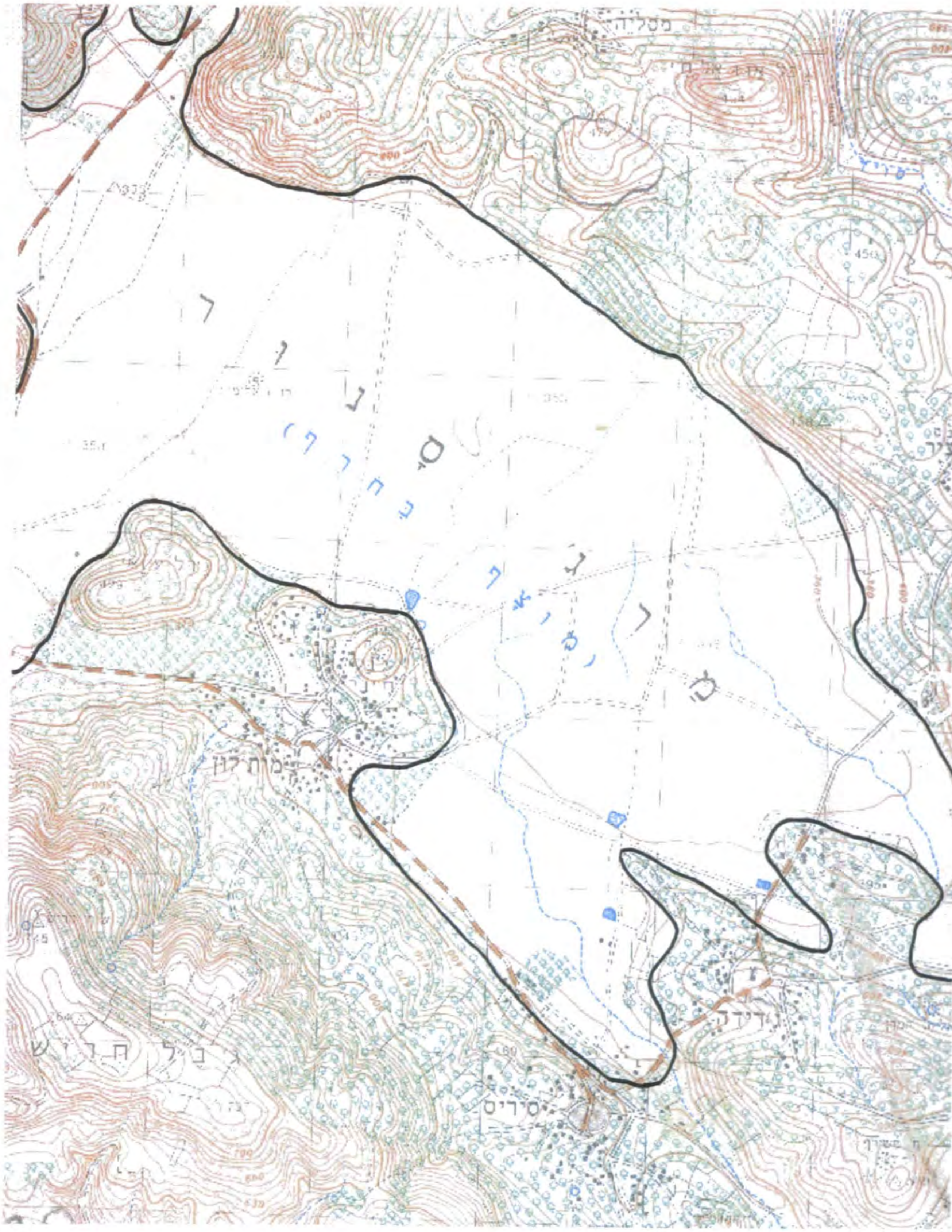


Figure (6:3): Delineation of agricultural plains on maps

c) allocation of sample units on reference data: The reference data used for sample unit allocation were the 1:50,000 Israeli maps (figure 6.3), SPOT-XS satellite image prints and 1:20,000 and 1:15,000 aerial photographs when available (figure 6.5). The Israeli 1:50,000 maps already have a 1km^2 grid. The simple random sampling for each stratum was applied twice on 3% of the study area. This sample size may achieve good representation of the study area at a reasonable cost. Cochran (1977) sees that a sample of 3% may be suitable to give acceptable precision. The first sampling was for the ***agricultural plains***, and the second was for the ***other lands*** (see table 6.2). The sample units (nc) were selected at random from the total units in each stratum (Nc), within which the variable of interest was measured (y_i). The number of the sample units (nc) in the whole frame ranged from 7 to 23 (table 6.1). Agricultural plains in each stratum were represented according to their proportional size of the stratum. For example, in stratum two, those plains were presented by 4 sample units out of 17 (23.5%) because the size of these agricultural plains is 23.5% of the total stratum area (see table 6.2). The total sample units were 73 or 3% of N.

Table (6.1): Distribution of Samples over the Five Strata

Stratum No. c	Area (km^2)	% of Population	Sample Units Nc	SU Allocation nc
1	350.43	14.77	350	11
2	553.13	23.31	553	17
3	750.85	31.64	751	23
4	485.86	20.47	486	15
5	232.68	9.81	233	7
Total	**2372.95**	**100**	**2373**	**73**

Table (6:2): Distribution of Sample Units over Agricultural Plains and Other Areas of the Five Strata

Stratum	plains area (km^2)	plains proportion (%)	other lands area (km^2)	other lands proportion (%)	SU allocation for plains	SU allocation for other lands
1	23.33	6.7	327.10	93.3	1	10
2	133.92	23.5	419.21	76.5	4	13
3	32.19	4.3	718.66	95.7	1	22
4	48.53	10.0	437.33	90.0	2	13
5	42.05	18.0	190.63	82.0	1	6
Total	**280.02**		**2092.93**		**9**	**64**

Allocation of sample units started with the identification of the exact location of a SU from its coordinates on the mentioned base maps. Then the SU of agricultural plains were transferred from the 1:50,000 scale maps to the aerial photographs which were considered as a basis for the field survey of these plains. The air photos were acquired during December 1995, October 1997, and October 1998. The main advantage of these air photos is that they show field boundaries, especially in the plains. The season of these aerial photographs was inappropriate to differentiate among seasonal crops such as horticultural crops and cereals, because at this time of the year the fields would be either ploughed or freshly sown. However, they were useful for the identification of the relatively permanent crops such as olive trees and citrus trees. Then boundaries of the fields within each sample unit were transcribed to be used in the field data collection. Stratum number, sample unit number, and coordinates of the sample unit were recorded on each transcription. Maps and aerial photographs were used as the base for the field survey of other cultivated lands (olive trees and fruit trees). Out of cropping sample units were not surveyed, but identified on maps and images. These areas exist mainly in the eastern slopes and the Jordan Valley (stratum 4 and 5).

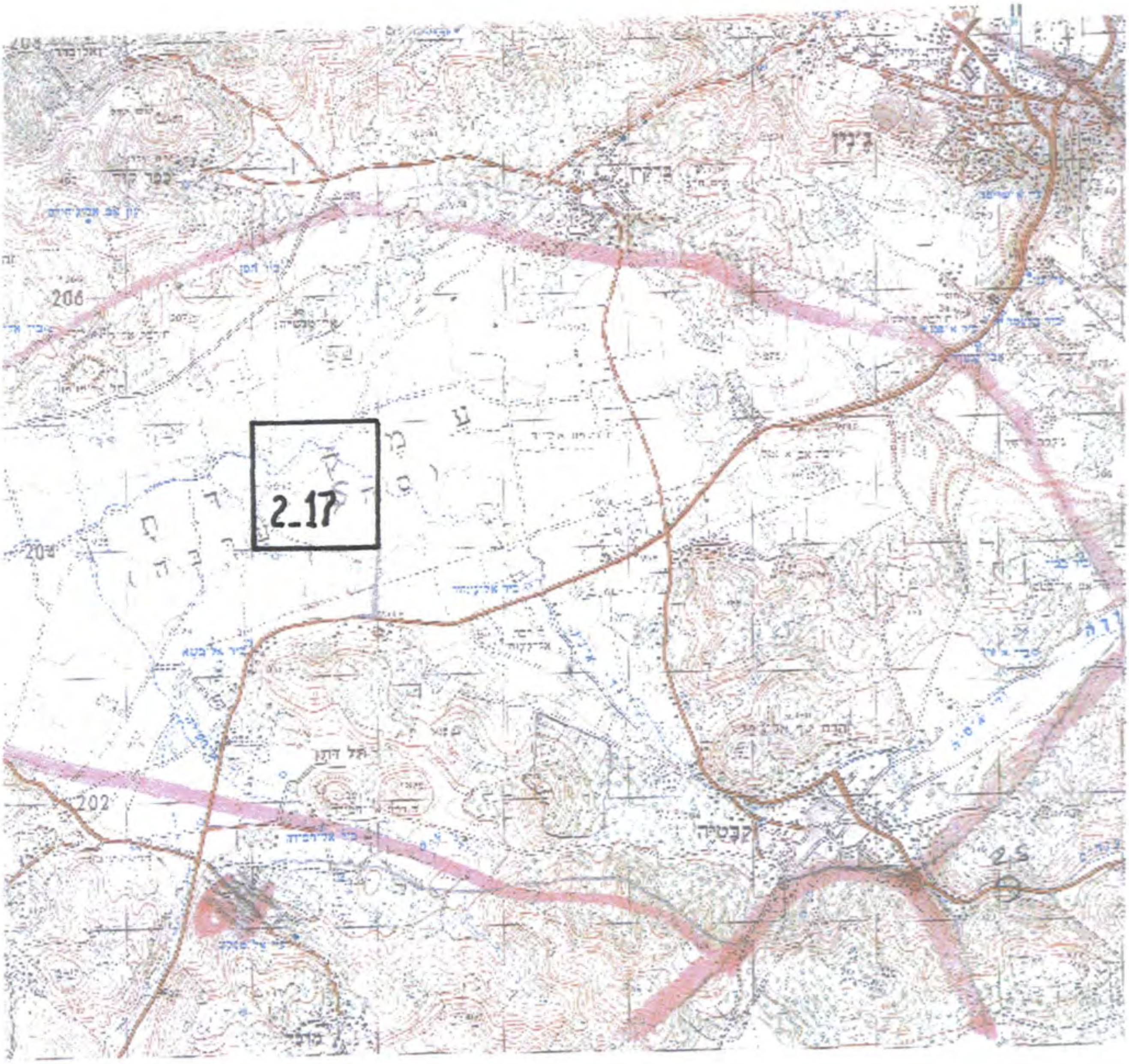


Figure (6:4): Allocation of Sample Units on the 1:50,000 maps

Figure (6:5): Allocation of Sample Units on Aerial Photographs

d) Determination of agricultural land use classes existing in the study area: The important agricultural classes to be surveyed were determined in the first phase of the field data collection program. The annotation key for writing the collected data which has been used in the first phase of the field survey (image sampling phase) was used again in the second phase:

- Arable Crops mainly cereals (AC).
- Citrus Trees (CT).
- Olive Trees and Fruit Trees (OT; FT).
- Horticulture or vegetables (H).

6.5.1. Field Visit

As mentioned in section 6.5 of this chapter, the field data collection of the second phase was carried out between July and October 1999. The field survey began with the plain agricultural lands in stratum 2 in the sub-district of Jenin for the following reasons. First, these agricultural plains are mainly cultivated with seasonal crops (cereals or horticulture) and it would be difficult to monitor the actual land use in these plains after the end of August because farmers start to plough fields for the next season. Secondly, most agricultural plains in stratum 2 or the Sub-District of Jenin are rain-fed lands and the two targeted crops are cereals and horticulture, so the best time to discriminate between them is June, July and August. In these three months cereal crops would be either dry or cut (stubble), while horticultural fields would be either green or soil (the remainders of the crop were removed from the field by the end of the growing season). Four sample units in of this stratum were surveyed field by field using aerial photographs. Land use type at the time of the field survey (summer 1999) was recorded. It was not possible to know precisely from the farmers the type of crop existed in the field in the date of images used for this study because they do not keep any records of their activities in the field. Agronomic understanding and the crop calendar in the study area helped in to address this issue (see chapter 5, section 3.5). This situation on the one hand, would to a great extent determine the appropriate methodology for image classification accuracy assessment in these areas. On the other hand, it would affect results of regression estimation of both image and field sampling results. In the same way, 2 sample units were surveyed in the plains of stratum 4 and 1 sample unit in stratum 3. Strata 1 and 5 were left to the last stage of surveying the agricultural plains, because in these two strata, the plains are mostly cultivated with horticultural crops and citrus trees. There is no problem to differentiate between these two crop types at any time of the year. One sample unit for each of these strata was surveyed. Aerial photographs were used as a basis for the survey of all agricultural plains in the study area. Surveying these 9 sample units was completed by the end of July 1999.

Other lands were surveyed using mainly the 1:50,000 scale Israeli maps and prints of CORONA photographs (figure 6.6) acquired in June 1970 (see chapter four, section 4.5). It was not possible to get a full coverage of aerial photographs of appropriate scale for all sample units. Moreover, scales of both maps (1:50,000) and CORONA prints (1:40,000) were inappropriate to carry out the field survey because both do not show the boundaries of land cover types existing in the sample units. To overcome this problem, the digital CORONA data were used. In order to identify land use\ land cover boundaries clearly, the sample units were displayed on the computer screen at a large scale using the Arcview GIS software version 3.1, then allocated on the Corona image, see chapter 4. Prints of the sample units were produced and used in the field survey.

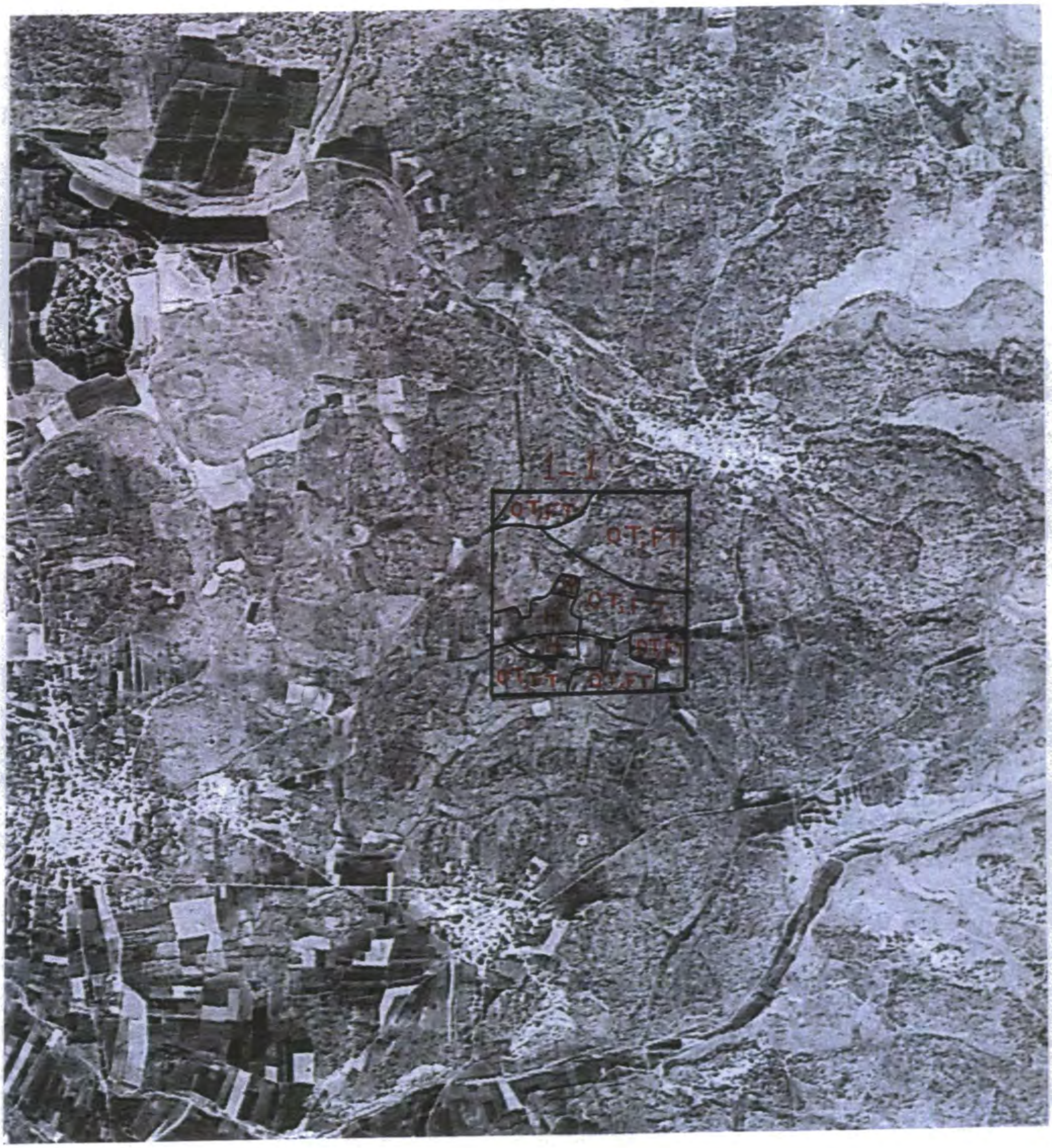


Figure (6:6): Allocation of sample units on CORONA photographs

In these areas (other lands), two main land cover categories can be recognized; olive and fruit trees class and out of crops class. The latter class includes all non-agricultural land cover classes identified and used for image classification, such as rocky lands, badlands, rough grass, bushes, woodland and so on (see chapter five section 5.3.5.1). Therefore, the targeted agricultural land use class here is mainly the olive trees and fruit trees (OT; FT).

6.6. Area Measurement of Land Use Categories

Once the fields in each sample unit are labeled with the correct land cover type, they are ready to be measured on the crop type basis. The pinpoint crop area for each sample unit for each stratum was estimated using the GIS software of Arcview, version 3.1. The following procedures were applied for this purpose:

1) The sample units including field limits were digitized on the rectified CORONA panchromatic photographs having 4 meter resolution.

2) Fields for **area, ID, and land use** were added in the tables of the Arcview GIS software. The area of each polygon was calculated in m^2 then converted to hectares. A code number including the stratum number and the sample unit number was added to the ID field. For example, the number 110 means that the stratum is 1 and the sample is one also, the number 210 means that the stratum is two and the sample is 1. One ID number was given for all polygons of the same sample in the same stratum whatever the number of polygons are. The third field added to the table was the land use. Each polygon was given an annotation symbol according to its land use type. For example,

polygons of olive trees were given the letter "OT", while polygons of horticulture were given the letter "H", and so on.

6.6.1. Statistical Analysis of the Field Data

As one of the main aims of this study is to produce crop area estimation using field sampling technique in addition to satellite imagery sampling technique, data collected from the field were statistically processed as follows:

a) crop type area in each sample for each stratum was calculated, then the average area $\bar{y}c$ for each crop for each stratum was calculated using the equation:

$$\bar{y}c = \frac{\sum_{i=}^{n} y_i}{nc} \qquad 6.1$$

where $\bar{y}c$ is the average field area (ha) in the stratum c, y_i is the field measurement and nc is the number of selected sample units in each stratum.

b) variance of each crop area in each sample and for each stratum (s^2c) population mean was also estimated using the equation:

$$V(\bar{y}c) = \left(\frac{Nc - nc}{Nc}\right)\left(\frac{s^2c}{nc}\right) \qquad 6.2$$

where s^2c is variance for each stratum c.

c) standard deviation of each stratum (sc) population mean was estimated using the equation:

$$sc = \sqrt{\frac{\Sigma (y_i - \bar{y})^2}{(nc-1)}} \quad 6.3$$

where sc is the standard deviation for each stratum c, nc is the number of selected samples in each stratum c, Nc is the total sample size for each stratum, and $\bar{y}c$ is the mean of the field area measurement in stratum c.

The difference between the variance and the standard deviation is that variance is the square of the standard deviation. The standard deviation gives measurements of the same units used in area estimation, so it is easier and more meaningful to deal with than the variance. The amount of variance is affected by the sample size. For example, if the sample size n is equal to the population size N, then the variance would necessarily be equal to 0 because the mean of the field area measurement in each stratum ($\bar{y}c$) would be equal to the mean field area measurement of the population of the stratum ($\bar{Y}$). In other words, all sample units are included in the field survey.

d) variance of the sample units s^2x_i in each stratum and the standard deviation syi were calculated using equations:

$$s^2y_i = \sum (y_i - \bar{y}c)^2 \quad 6.4$$

$$sy_i = \sum (y_i - \bar{y}c) \quad 6.5$$

where s^2y_i is the variance of the field area measurement of a certain land use type in the sample unit, and sy_i is the standard deviation.

e) from the equations variance of the stratum mean $s^2\,c$ and the standard deviation sc were obtained using the equations:

$$s^2c=\frac{\sum(y_i-\bar{y})^2}{(nc-1)}$$ 6.6

$$sc=\sqrt{\frac{\sum(y_i-\bar{y})^2}{(nc-1)}}$$ 6.7

f) the standard error (*SE*) of the mean area of each land use type for each stratum was obtained :

$$SE(\bar{y}c)=\frac{sc}{\sqrt{nc}}$$ 6.8

The standard error *SE* (ha) was estimated as a percentage of the population to facilitate the evaluation of the results for each crop area estimation in each stratum. Percentage of the *SE* is called the coefficient of variation (*CV*). The coefficient of variation *CV* for each stratum was obtained using the equation:

$$CVc=\frac{SE(\bar{y}c)}{\bar{y}c}\times 100$$ 6.9

g) The total field area of land use types in each stratum ($\hat{y}c$) was obtained using the equation:

$$\hat{y}c=Nc\hat{y}c$$ 6.10

h) variance $V(\hat{y}c)$ and standard error $SE(\hat{y}c)$ of the total area of land use types in each stratum was estimated using the variance of the selected sample units of the stratum:

$$V(\hat{y}c)=N^2c(\frac{s^2c}{nc})$$ 6.11

where $(\frac{s^2c}{nc})$ is the sample units variance of the stratum.

$$SE(\hat{y}c) = Nc(\frac{s^2c}{nc}) \qquad 6.12$$

where $(\frac{s^2c}{nc})$ is the standard error of the sample units in the stratum.

i) after these statistical operations have been applied to each stratum for each agricultural crop type, results of these statistical analysis were applied on the entire study area as follows:

- the population mean of each crop type $(\bar{Y})$ was estimated:

$$\bar{Y} = \frac{1}{N}\sum_{c=1}^{5} Nc\bar{y}c \qquad 6.13$$

- the mean population variance $V(\hat{Y})$:

$$V(\hat{Y}) = (\frac{1}{N})^2 \sum_{c=1}^{5} N^2c(\frac{s^2c}{nc}) \qquad 6.14$$

- the standard error of the population mean $SE(\bar{Y})$:

$$SE(\bar{Y}) = \frac{1}{N}\sqrt{\sum_{c=1}^{5} N^2c(\frac{s^2c}{nc})} \qquad 6.15$$

- crop area estimation over the five strata $(\hat{Y})$ was achieved from:

$$\hat{Y} = \sum_{c=1}^{5} Nc\bar{y}c \qquad 6.16$$

- variance of estimated crop area over the entire study area $V(\hat{Y})$:

$$V(\hat{Y}) = \sum_{c=1}^{5} N^2cV(\bar{y}c) \qquad 6.17$$

- the square root of the variance is taken as the standard error of the estimated crop area:

$$SE(\hat{Y}) = \sqrt{\sum_{c=1}^{5} N^2 c (\frac{s^2 c}{nc})} \qquad 6.18$$

6.7. Final Crop Area Measurement By Field Survey

Using the previously mentioned statistical method, area estimation for each crop in the selected samples has been calculated. Results were applied at the stratum level and then at the entire study area level. Sample variance for each stratum was obtained from the computation of the sample mean $\bar{y}c$ and the sum of the squared deviation of $(y_i - y)$ in each stratum. The following tables show in details the statistical method applied:

Table (6:3): Area Estimation of Olive and Fruit Trees in the Five Strata (ha)

Stratum c	nc	Mean $\bar{y}c$	$\sum(y_i - \bar{y}c)^2$	Variance s^2c	St. Deviation sc
1	11	46.976	10324.301	1032.430	32.131
2	17	20.589	17634.512	1102.157	33.199
3	23	36.055	18941.758	860.989	29.343
4	15	5.953	3341.548	238.682	15.449
5	7	0.217	1.980	0.330	0.575

Table (6:4): Area Estimation of Citrus Trees in the Five Strata (ha)

Stratum c	nc	Mean $\bar{y}c$	$\sum y_i-\bar{y}c)^2$	Variance $s^2 c$	St. Deviation sc
1	11	2.990	444.010	44.401	6.663
2	17	–	–	–	–
3	23	–	–	–	–
4	15	1.594	553.656	38.111	6.174
5	7	0.903	34.236	5.706	2.389

Table (6:5): Area Estimation of Horticulture in the Five Strata (ha)

Stratum c	nc	Mean $\bar{y}c$	$\sum(y_i-\bar{y}c)^2$	Variance $s^2 c$	St. Deviation sc
1	11	7.636	5464.170	546.417	23.376
2	17	12.381	8742.800	546.425	23.376
3	23	–	–	–	–
4	15	5.553	3689.364	263.526	16.233
5	7	11.120	5193.486	865.581	29.421

Table (6:6): Area Estimation of Arable Crops (Cereals) in the Five Strata (ha)

Stratum c	nc	Mean $\bar{y}c$	$\sum(y_i-\bar{y}c)^2$	Variance s^2c	St. Deviation sc
1	11	–	–	–	–
2	17	16.923	8092.704	505.794	22.490
3	23	4.426	7749.698	352.259	18.769
4	15	12.059	8977.542	641.253	25.323
5	7	2.263	215.064	35.844	5.987

Table (6:7): Area Estimation of Non-Agricultural Lands in the Five Strata (ha)

Stratum c	nc	Mean $\bar{y}c$	$\sum(y_i-\bar{y}c)^2$	Variance s^2c	St. Deviation sc
1	11	43.378	10515.320	1051.532	32.427
2	17	50.106	26646.112	1665.382	40.809
3	23	59.257	22744.128	1033.824	32.153
4	15	74.841	16932.006	1209.429	34.777
5	7	85.497	8529.978	1421.663	37.705

The standard error SE of the stratum mean $\bar{y}c$ [$SE(\bar{y}c)$], and SE of the total population of each stratum $SE(\hat{y}c)$ were calculated using the standard error equations mentioned in section 6.6.1. The pinpoint crop area estimation in each stratum was obtained using the mean $\bar{y}c$ and the number of sample units in the stratum *Nc*. The Tables below illustrate these calculations.

Table (6:8): The Standard Error (*SE*) for Olive and Fruit Trees Over the Five Strata

Stratum	*Nc*	$SE(\bar{y}c)$	$N[SE(\bar{y}c)]$	$[N(SE(\bar{y}c)]^2$	$Nc\bar{y}c$
1	350	9.68786	3390.75135	11497194.72	16441.60
2	553	8.05194	4452.72282	19826740.51	11385.72
3	751	6.11844	4594.94693	21113537.29	27077.31
4	486	3.98891	1938.61026	3758209.74	2893.16
5	233	0.21733	50.63766	2564.17	50.56
Sums	2373		14427.66902	56018246.43	57848.34

Table (6:9): The Standard Error (*SE*) for Citrus Tree Over the Five Strata

Stratum	*Nc*	$SE(\bar{y}c)$	$N[SE(\bar{y}c)]$	$[N(SE(\bar{y}c)]^2$	$Nc\bar{y}c$
1	350	2.00897	703.13950	494405.16	703.15
2	553	—	—	—	—
3	751	—	—	—	—
4	486	1.59412	774.68000	600160.09	774.68
5	233	0.90296	210.38901	44263.54	210.40
Sums	2373		1688.23000	1138820.79	1688.23

Table (6:10): The Standard Error (SE) for Horticulture Over the Five Strata

Stratum	Nc	$SE(\bar{y}c)$	$N[SE(\bar{y}c)]$	$[N(SE(\bar{y}c)]^2$	$Nc\bar{y}c$
1	350	7.04813	2466.84515	6085324.99	2672.60
2	553	5.66951	3135.24014	9829730.71	6846.69
3	751	—	—	—	—
4	486	4.19134	2036.99221	4149337.27	2698.76
5	233	11.12009	2590.98144	6713184.80	2590.96
Sums	2373		10230.05893	26777577.78	14809.01

Table (6:11): The Standard Error (SE) for Arable Crops Over the Five Strata

Stratum	Nc	$SE(\bar{y}c)$	$N[SE(\bar{y}c)]$	$[N(SE(\bar{y}c)]^2$	$Nc\bar{y}c$
1	350	—	—	—	—
2	553	5.45463	3016.40818	9098718.30	9358.42
3	751	3.91361	2939.11886	8638419.66	3323.93
4	486	6.53837	3177.64782	10097445.67	5860.67
5	233	2.26200	527.24948	277992.01	527.28
Sums	2373		9660.42433	28112575.64	19070.30

Table (6:12): The Standard Error (SE) for Non-Agricultural Lands Over the Five Strata

Stratum	Nc	$SE(\bar{y}c)$	$N[SE(\bar{y}c)]$	$[N(SE(\bar{y}c)]^2$	$Nc\bar{y}c$
1	350	9.77711	3421.98780	11710000.50	15182.30
2	553	9.89764	5473.39271	29958027.74	27708.18
3	751	6.70436	5034.97436	25350966.81	44502.01
4	486	8.97938	4363.97868	19044309.92	36372.73
5	233	14.25115	3320.51806	11025840.16	19920.80
Sums	2373		21614.85160	97089145.13	143686.01

From the above tables and by applying the equation of CV mentioned in section 6.6.1, the coefficient of variation CV was obtained. The final crop area estimation over the five strata was obtained using a 95% confidence limit. The equation applied for this purpose is:

$$\hat{Y}_{pop} = Nc \pm 1.96 SE(\hat{Y}) \qquad 6.19$$

The tables below show the CV and the final area estimation for each crop (ha) for each crop in the five strata.

Table (6:13): Field Area Estimation (ha) for Olive and Fruit Trees

the northern West Bank, 1994

Stratum	Estimated Area	Standard Error $SE(\hat{y}c)$	Coefficient of Variation $CV\%$
1	16441.6	3390.8	20.6
2	11385.7	4452.7	39.1
3	27077.3	4594.9	17.0
4	2893.2	1938.6	67.0
5	50.6	50.6	100.0

$$SE(\hat{Y}) = \sqrt{\sum_{c=1}^{5}\left[N(SE(\hat{y}c)\right]^2}$$

$$\hat{Y}_{pop} = Nc\bar{y}c \pm 1.96SE(\hat{Y})$$

$$\hat{Y}_{pop} = \mathbf{57848.34 \pm 14669.69}$$

Table (6:14): Field Area Estimation (ha) for Citrus Trees

Northern the West Bank, 1994

Stratum	Estimated Area	Standard Error $SE(\bar{y}c)$	Coefficient of Variation $CV\%$
1	703.1	703.1	100
2	—	—	—
3	—	—	—
4	774.7	774.7	100
5	210.4	210.4	100

$$SE(\hat{Y}) = \sqrt{\sum_{c=1}^{5}\left[N(SE(\hat{y}c)\right]^2}$$

$$\hat{Y}_{pop} = Nc\bar{x}c \pm 1.96SE(\hat{Y})$$

$$\hat{Y}_{pop} = \mathbf{1688.23 \pm 2091.63}$$

Table (6:15): Field Area Estimation (ha) for Horticulture

Northern the West Bank, 1994

Stratum	Estimated Area	Standard Error $SE(\bar{y}c)$	Coefficient of Variation $CV\%$
1	2672.6	2466.8	92.3
2	6846.7	3135.2	45.8
3	—	—	—
4	2698.8	2037.0	75.5
5	2591.0	2591.0	100.0

$$SE(\hat{Y})=\sqrt{\sum_{c=1}^{5}\left[N(SE(\hat{y}c)\right]^2}$$

$$\hat{Y}_{pop}=Nc\bar{x}c\pm 1.96SE(\hat{Y})$$

$\hat{Y}_{pop}=$ **14809.01±10142.42**

Table (6:16): Field Area Estimation (ha) for Arable Crops

Northern the West Bank, 1994

Stratum	Estimated Area	Standard Error $SE(\bar{y}c)$	Coefficient of Variation $CV\%$
1	—	—	—
2	9358.4	3016.4	32.2
3	3323.9	2939.1	88.4
4	5860.7	3177.6	54.2
5	527.3	527.2	100.0

$$SE(\hat{Y})=\sqrt{\sum_{c=1}^{5}\left[N(SE(\hat{y}c)\right]^2}$$

$$\hat{Y}_{pop}=Nc\bar{x}c\pm 1.96SE(\hat{Y})$$

$\hat{Y}_{pop}=$ **19070.3±10392.14**

Table (6:17): Field Area Estimation (ha) for Non-Agricultural Lands Northern the West Bank, 1994

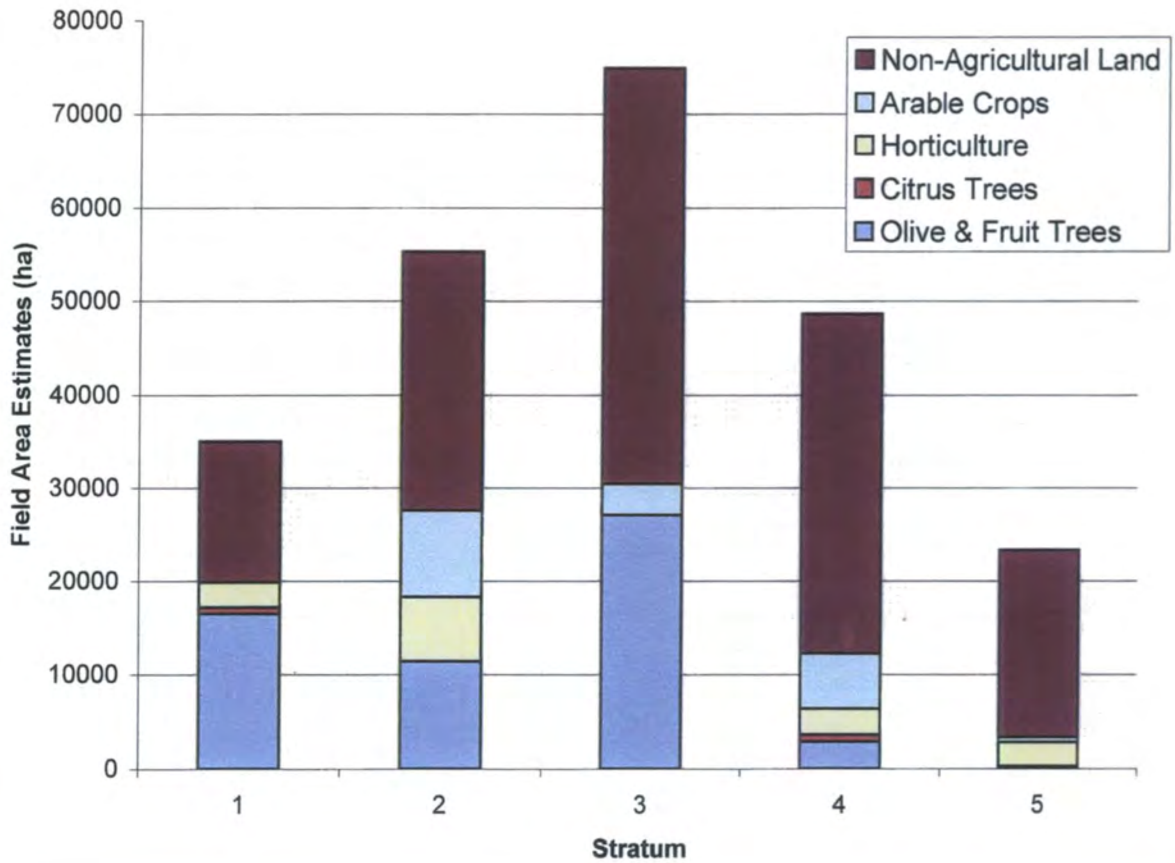
Stratum	Estimated Area	Standard Error $SE(\bar{y}c)$	Coefficient of Variation $CV\%$
1	15182.3	3422.0	22.5
2	27708.2	5473.4	19.8
3	44502.0	5035.0	11.3
4	36372.7	4364.0	12.0
5	19920.8	3320.5	16.7

$$SE(\hat{Y}) = \sqrt{\sum_{c=1}^{5} \left[N(SE(\hat{y}c)\right]^2}$$

$$\hat{Y}_{pop} = Nc\bar{x}c \pm 1.96SE(\hat{Y})$$

$$\hat{Y}_{pop} = \mathbf{143686.0 \pm 19312.66}$$

Figure (6.7): Field Area Estimates (ha) in the Five Strata



6.8. Analysis of Statistical Results

Field area estimation results of the main agricultural crops (Olive and Fruit Trees, Citrus Trees, Horticulture, and Arable Crops) over the five strata the Northern West Bank show the following:

1. Olive and Fruit Trees mainly exist in the first three strata. The main reason for that is that these three strata lie in the western flanks of the Nablus mountains and the semi-coastal regions. These regions are characterized by suitable climate conditions for growing this crop type on one hand, and the suitable soil type on the other hand (see sections 2.6 and 6.7 in chapter 2). Most samples selected in these three strata included this crop type. In stratum 4 olive and fruit trees decrease because climate conditions and soil become less suitable. In stratum 5 this crop type is nearly vanished because of the unsuitable environment in this stratum. Statistical results show that the standard error or the coefficient of variation of area estimation becomes larger when we move from the west to the east in the study area. The coefficient of variation for this crop in stratum 5 is 100%, which means that the *SE* of the estimate is equal to the area estimate itself. The reason for this high value of the *SE* is that only one sample in stratum five has a small area (one field) of this crop. This field lies near an Israeli settlement and it is planted with an irrigated vineyard.

2. Citrus Trees exist in the strata 1, 4, and 5. Only one sample in each of these strata has this crop because it exists in the plain irrigated agricultural plains. In strata 2 and 3, the field survey did not record any area of this crop. This situation resulted in a high standard error of the final area estimation.

3. Horticulture exists in all the strata except stratum 3. This crop exists in the plain agricultural lands. It is irrigated in strata 1 and 5 for the availability of water resources in these strata on the one hand, and it can not be grown as a non-irrigated crop in stratum 5 for the scarcity of rainfall on the other hand. In stratum 2, this crop is a rain-fed one. In stratum 3 the field survey did not record any area of this crop because the main agricultural plains lie at the extreme eastern edge of this stratum. This means that the average rainfall here is insufficient for growing this crop. The standard error for this crop is the least in stratum 2 because not less than 4 sample units have this crop. In stratum 5, the standard error of the estimation is 100% because only one sample has this crop.

4. Arable crops exist in all strata except stratum 1. The reason is that most agricultural plain lands in stratum 1 are irrigated (drip-irrigation), and this crop is a rain-fed one. The standard error is the highest in stratum 5 because this crop exists in limited fields in one sample unit.

5. The non-agricultural lands spread over the five strata with different percentages. The standard error for this category is the least because it exists in most sample units of the five strata.

6.9 Summary

Due to considerable spatial variations of the study area, the stratified random sampling method is applied to estimate crop type area through the field survey. The study area was divided into five strata. The valuable agricultural plains were given special care to ensure their inclusion in the sampling procedure. 3% of the total study area or 73 km^2 were surveyed using maps, aerial photographs, satellite photographs and SPOT HRV image prints. The collected field data were integrated into the Arcview GIS software version 3.1 and area estimates for each crop in each stratum was carried out using the statistical methodology mentioned in section 6.1.1. The field survey results were combined with the satellite data to carry out the double sampling technique (see chapter 7).

CHAPTER SEVEN

CROP AREA ESTIMATION BY THE DOUBLE SAMPLING TECHNIQUE

7.1. Introduction

This Chapter is devoted to introducing and applying the double sampling methodology to produce improved and more accurate area estimation for agricultural crop types. The double sampling technique is mainly based on the combination of two sets of statistical data obtained from two different sources to produce more precise estimations.

In this study, the crop type area estimation measurements obtained from SPOT HRV satellite imagery which are acquired in May 1994, are combined with crop area estimation measurements obtained by field survey in 1999.

Neyman (1938) was the first to propose double sampling for estimating stratum weight in large regional inventories. Cochran (1953) also used the double sampling technique for area estimation describing it statistically.

7.2. What is Double Sampling?

Different authors such as Cochran (1953), Wigton *et al.* (1973), Benson *et al.* (1974), Gonzalez *et al.* (1991, 1993, 1997), Kalkhan *et al.* (1998), Alfred de Gier *et al.* (1992), and Deppe (1998) used and described the double sampling methodology for crop area estimation.

Double sampling is a multi-phase sampling procedure. It combines two sets of data obtained from two different types or sources of surveys. The two-phase sampling requires a pre-knowledge of the population size under study before establishing the sampling frame. In the multi-phase sampling, the sample unit size is the same all over the study area.

The reason for using the double sampling technique for crop area estimation in this study is first, results of direct expansion survey method (ground survey) showed high standard error for most of agricultural crop type estimates. Secondly, the use of more than one source of data may support and improve the accuracy of estimates, and thirdly, the use of crop type area estimates obtained from classified images may reduce the field sampling bias.

In the double sampling technique, the two sets of data or the two variables (in this study x is the field survey variable and y is the SPOT HRV variable) are correlated. As correlation between the two variables becomes larger, the standard error of the estimation becomes smaller; and so area estimation is improved. Correlation between the two variables is used to estimate crop type area in each stratum of the study area.

Two estimation techniques are usually used in the double sampling studies:-

1) **Ratio Estimator, and**
2) **Linear Regression Estimator**

7.2.1. Ratio Estimator

This technique was given this name because data used are in the form of a ratio. Ratio estimate uses two sources of data to estimate the correlation coefficient (r). One of these data sources is called the dependent variable and the other is called the independent or the auxiliary variable. The auxiliary variable is used to improve the estimates of the dependent one. Correlation between the two variables is calculated using the equation:

$$r_{xy} = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2\sum_{i=1}^{n}(y_i-\bar{y})^2}} \qquad 7.1$$

The ratio estimator ($\hat{y}_n$) is calculated using the sample means of the two variables and multiplied by the mean of the total population of the supplementary data $\bar{X}$. The formula that is usually used is:

$$\hat{y}_n = \frac{\bar{y}}{\bar{x}}\bar{X} \qquad 7.2$$

The sample variance of the estimation $V(\hat{y}_n)$ can be calculated using the equation:

$$V(\hat{y}_n) = \frac{1}{n(n-1)}\sum_{i=1}^{n}(y_i-\frac{\bar{y}}{\bar{x}}x_i)^2 \qquad 7.3$$

Yeates (1981) showed that the ratio estimate can be used when the selected number of sample units in each stratum is large enough, otherwise variance and bias resulting from the ratio estimator will be large. To reduce variance and bias of results, the number of samples in each stratum should be increased. In remote sensing applications increasing the number of samples in each stratum will be costly and does not achieve one of the advantages of remote sensing technology over conventional techniques. Therefore, ratio estimates can be used in applications that require large number of samples or in applications where bias is not a crucial problem such as with population studies.

Apart from the above mentioned limitations of the ratio estimate technique, this technique is statistically simple.

7.2.2. Linear Regression Estimator

Linear regression estimator also uses two sets of data obtained from different sources for the estimation of the correlation coefficient (r) to improve the estimate of x and y. In this methodology, it is necessary to calculate the regression coefficient (b). The equation used for this purpose is:

$$b = \frac{\sum_{i=1}^{n}(y_i - \bar{y})(x_i - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad 7.4$$

The linear regression estimator is:

$$\hat{y}_{reg} = N[\bar{y} + b(\bar{X} - \bar{x})] \qquad 7.5$$

Sample variance of $\hat{y}_{reg}$ can be calculated by using the equation:

$$V(\hat{y}_{reg}) = N^2 \left(\frac{s^2}{n}\right)(1 - r^2) \qquad 7.6$$

$$s^2 = \frac{\sum_i^n (y_i - \bar{y})^2}{n-1} \qquad 7.7$$

The advantage of the linear regression estimator is that it does not need as a large number of samples as the ratio estimator. This advantage is fundamental in remote sensing applications. In addition, variance and bias of ratio estimates are larger than of the linear regression estimate when the number of samples used is the same for the two techniques (Williams 1978, Craig 1989 and Gonzalez *et al.* 1991).

Many authors have used the double sampling technique to improve the accuracy of area estimates of agricultural crops. Kalkhan *et al.* (1998) used double sampling to provide a cost efficient estimate of the accuracy for a Landsat TM classification map of a scene located in Colorado (USA). In the first phase of the study, TM image and aerial photos were used for crop area estimates. While in the second phase a ground stratified random sampling was carried out. The field data were used to correct for misclassification errors associated with the first phase samples. The overall accuracy was increased by 10% when the double sampling technique was used.

Gallego (1998) evaluated the suitability of diachronic regression estimators in parts of Spain (in the diachronic regression, the two sets of data used are not obtained for the same year). He found that this methodology can be applied on areas characterised with plants and crops of sufficient stability. He also recommended that the crop rotation in the area under study should be taken into consideration to detect the type of crop planted that year.

Gonzalez *et al.* (1997) estimated the area of barley in Lleida-Spain using Landsat TM data acquired in 1993 and field data collected in the year 1994. Results of regression estimator produced a relative efficiency of 9. This means that the regression estimator can be applied with field data from the current year and a classified image of another year.

Alfred de Gier *et al.* (1994) conducted a research study for timber volume estimation in a part of Austria. Two-phase aerial photo field regression samples and simple random field samples were used. Regression estimations for two periods (1974, 1979) were made. Results of double sampling gave a better and more accurate estimation than the single-phase estimation.

Deppe (1998) conducted a forest area estimation study in the southern part of Brazil. Two methods were used in the study: the direct expansion method (ground survey) and the double sampling method. Landsat MSS and TM imagery were used and classified separately. Aerial photographs were used as a base for the allocation of field samples. Deppe found that the TM data produced better relative efficiency (*RE*) than the MSS data. This is due to the better spatial, spectral, and radiometric resolutions. He also found that the combination of the sample survey data with classified image data increased the accuracy of area estimation. Deppe recommended that the scale of aerial photos to be used in the field sampling should be large enough to show field boundaries.

Gonzalez *et al.* (1993) used Landsat TM imagery and ground data for crop area estimation of Nowarra (Spain). Two methods of regression estimates were used: the standard regression method (the commonly used method), and the regression method using adjusted proportions obtained from the confusion matrix (the conditional probability matrix). Results of the study showed that the adjusted regression method produced a slightly lower value of the squared correlation coefficient (r^2) and the relative efficiency (*RE*) than the standard regression method. On the other hand the coefficient of variance (*CV*) produced by the adjusted regression method was lower than that of the standard regression method.

Hafner *et al.* (1982), Cappelletti *et al.* (1982) and Latham *et al.* (1982) used Landsat MSS, aerial photographs and field survey in a study of agriculture respectively. Results of their studies showed considerable improvement of crop type area estimate when the two-phase sampling was use.

Gonzalez *et al.* (1991) applied two methodologies for crop area estimation in Spain using Landsat TM and ground data. In the first method, square segments or sample units were used, while in the second method, irregular segments were used. In their study, they found that estimation accuracy obtained by direct expansion for both methods (square and irregular segments) were similar. Also, accuracy obtained by regression method in both methods were similar. On the other hand, and from the point of view of the relative efficiency (*RE*), the obtained results show that the use of remote sensing data is more interesting in square segments than the irregular ones.

7.3. Methodology

As mentioned in the previous section (section 7.2), a regression estimator is preferred to a ratio estimator particularly for remote sensing studies. Therefore, a regression estimator is used in this study to investigate the possibility of obtaining better crop area estimation.

Before applying the linear regression estimator, the following calculations have been made:

1) SPOT HRV area measurement (x) based on number of pixels of the classified image were obtained using the sample units used in the field survey. Measurements were obtained using the following procedures:

a) sample units used in the field survey (see chapter 6) were allocated on the geo-referenced classified SPOT HRV image using the Arcview GIS software (version 3.1).

b) the twenty three land cover classes included in the classified image (see chapter 5) were merged into five thematic classes. Merging land cover classes was done as follows:

- classes of olive trees1, olive trees2, olive trees3, fruit trees, and mixed trees were merged into one thematic class Olive and Fruit Trees.

- classes of horticulture, horticulture1, green houses, wet soil, and a part of the ploughed land were merged into the class of Horticulture.

- cereal crops and a part of the ploughed lands were merged into the class of Arable Crops.

- citrus trees

- other land cover classes (built-up area, badland 1, badland 2, badland 3, bare soil and bushes, mixed forest, natural vegetation, rocky land, rocks and natural vegetation, and rough grass and bushes) were merged into one class named the Non-Agricultural Land (for more details see chapter 5)

c) a map of the study area which contains the boundaries of the five strata was overlaid on top of the classified image to identify the sample units in each stratum.

d) polygons around the classified pixels for each of the five land use categories were digitised on a sample unit and stratum basis.

e) statistics (the sum, the range, the maximum, the minimum, the mean, the variance, and the standard deviation) for each category on the sample and the stratum basis were obtained for tables using the Arcview GIS software (version 3.1).

3) means of the total population ($\overline{X}$)of the classified image for each crop type and on stratum basis was calculated from the from image classification results (see chapter 5).

At this stage, the field data (y), the SPOT HRV sample data (x), and the total classified image data ($\overline{X}$) are available to apply the linear regression estimator technique.

7.4. Statistical Analysis and Development

Statistical procedures and analysis used in the study aimed at developing and increasing the precision of crop area estimation through the use of more than one set of data (ground survey data and satellite image data). These estimations have been used by different authors (see section 7.2.2) and institutions that are concerned with agriculture such as the United States Department of Agriculture (USDA).

In this study, the crop type area produced by field survey was combined and correlated with the crop type area produced by SPOT HRV imagery to obtain the coefficient of determination (r^2). The coefficient of determination indicates to the level of agreement between area estimates (ha) of the ground survey and that of the image survey. Correlation results were used in the regression estimates by applying the linear regression equation.

The equation used for the calculation of (r^2) and consequently (r) is:

$$r^2_{xy} = \frac{\sum_{i=1}^{n}\left[(y_i-\bar{y})(x_i-\bar{x})\right]^2}{\sum_{i=1}^{n}(y_i-\bar{y})^2\sum_{i=1}^{n}(x_i-\bar{x})^2} \qquad 7.8$$

Where y is the crop area (ha) measured from the field, x is the crop area (ha) measured from the classified SPOT HRV image.

$\sum_i^n(x_i-\bar{x})^2$ is obtained from the equation,

$$\sum_i^n(x_i-\bar{x})^2 = V(\bar{x}c)(n-1) \qquad 7.9$$

Where $V(\bar{x}c)$ is the variance of the average sample classified crop pixels for the stratum, sample classified pixels divided by the sample units, and n is the number of sample units for the stratum. The regression estimate was obtained from the linear regression equation,

$$\bar{y}c_{reg} = \bar{y}c + bc(\bar{X}c - \bar{x}c) \qquad 7.10$$

where $\bar{y}c$ is the average area (ha) of field sample in the stratum, bc is the slope of the regression line between y and y or between the ground dependent variable and the SPOT HRV independent variable, $\bar{X}c$ is the average sample classified crop pixels for the stratum (the proportion of pixels classified as a certain crop type in the whole stratum divided by the total units in the stratum), and $\bar{x}c$ is the average proportion of pixels classified as a certain crop type in the ground survey samples.

The slope of regression bc between the ground data and the SPOT HRV data can be calculated from the equation,

$$bc = \frac{\sum_{i=1}^{n}(y_i - \bar{y})(x_i - \bar{x})}{\sum_{i=1}^{n}(x_i - \bar{x})^2} \qquad 7.11$$

The area regression estimate of a crop for the whole stratum is obtained by applying equation 7.10 multiplied by the total number of units in the stratum (Nc). Therefore the equation becomes,

$$\hat{y}c_{reg} = Nc\left[\bar{y}c + bc(\bar{X}c - \bar{x}c)\right] \qquad 7.12$$

Standard error (SE) for the total regression estimate of each crop in each stratum was obtained using the equation,

$$SE(\hat{y}_{reg}) = \sqrt{N^2c\frac{s^2c}{nc}(1 - r^2)bc} \qquad 7.13$$

where s^2c is the variance of field sample units in the stratum, N^2 is the square of the total sample units in the stratum, and r^2 is the coefficient of determination between the field survey and the image survey.

For comparing results of estimations obtained from the regression methodology with estimations obtained from the field survey, the coefficient of variance (*CV*) was calculated as a percentage of the population for each stratum. The equation used is,

$$CVc = \frac{SE(\hat{y}c_{reg})}{\hat{y}c_{reg}} \qquad 7.14$$

7.4.1. Statistical Processing and Results of Regression Estimator

Once the detailed data for both the ground survey and the SPOT HRV classified image on the unit sample and stratum level are obtained, these data are now ready to be processed, combined and correlated. Further analysis and evaluations of the statistical results will be carried out in the following sections of this chapter. Tables below show the statistical processing of both the ground and satellite data.

Table 7.1: Statistics used for Regression estimation of olive and fruit Areas in stratum one (ha)

SU	y_i	x_i	$y_i - \bar{y}$	$x_i - \bar{x}$	$(x_i-\bar{x})(y_i-\bar{y})$	$(y_i - \bar{y})^2$	$(x_i - \bar{x})^2$
1	93.90	52.11	46.92	12.91	605.737	2201.486	166.668
2	-	8.36	46.98	-30.84	-1448.863	2207.120	951.106
3	54.30	42.80	7.32	3.60	26.352	53.582	12.960
4	78.80	57.50	31.82	18.30	582.306	1012.512	334.890
5	96.40	39.90	49.42	0.70	34.594	2442.336	0.490
6	25.45	45.35	-21.53	6.15	-132.409	463.541	37.823
7	62.34	89.10	15.36	49.90	766.464	235.930	2490.010
8	27.36	75.70	-19.62	36.50	-716.130	384.944	1332.250
9	24.50	2.67	-22.48	-36.53	821.194	505.350	1334.441
10	28.67	9.10	-18.31	-30.10	551.131	335.256	906.010
11	25.02	8.63	-21.96	-30.57	671.317	482.242	934.525
Sum	**516.74**	**431.22**	**0**	**0**	**4659.419**	**10324.301**	**8501.200**

where *SU* is the sample unit, x_i is the SPOT HRV measurement (ha), and y_i is the field measurement (ha).

This statistical methodology used in table 7.1 was applied on the five land use categories in the five strata for regression estimation. The following tables (tables 7.2 to 7.6) show regression area estimation of the five agricultural land use categories for the five strata of the study area.

Table (7:2): Regression Area estimates of olive and fruit Areas for the five strata (ha)

Stratum(c)	1	2	3	4	5
$\bar{y}c$	46.98	20.58	36.05	5.95	0.22
$\bar{x}c$	39.20	31.91	31.31	5.36	—
$\sum(y-\bar{y})^2$	10324.30	17634.51	18941.758	3341.548	1.98
$\sum(x-\bar{x})^2$	8501.20	11969.76	7706.82	3127.60	—
s^2	1032.43	1102.16	860.99	238.68	0.33
Nc	350	553	751	486	233
$\bar{X}c$	25.49	32.86	27.96	4.45	0.14
r_{xy}	0.5360	0.3641	0.6168	0.9276	—
bc	0.5481	0.4419	0.9669	0.9588	—
$\hat{y}_{reg}$	13813.9	11618.6	24644.7	2470.1	—
$SE(\hat{y}_{reg})$	1612.29	1832.55	3497.13	174.10	—

Table (7:3): Regression Area estimates of citrus Areas for the five strata (ha)

Stratum(c)	1	2	3	4	5
$\bar{y}c$	2.01	—	—	1.59	0.90
$\bar{x}c$	2.72	2.89	3.45	2.07	0.75
$\sum(y-\bar{y})^2$	444.01	—	—	86.44	34.24
$\sum(x-\bar{x})^2$	200.90	256.00	1065.68	761.32	23.63
s^2	44.40	—	—	6.17	5.71
Nc	350	553	751	486	233
$\bar{X}c$	3.031	4.77	3.02	1.41	1.11
r_{xy}	0.8911	—	—	0.9962	—
bc	1.3247	—	—	0.8324	—
$\hat{y}_{reg}$	847.4	—	—	508.3	—
$SE(\hat{y}_{reg})$	240.2	—	—	22.5	—

Table (7:4): Regression Area estimates of horticulture for the five strata (ha)

Stratum(c)	1	2	3	4	5
$\bar{y}c$	7.64	12.38	___	5.55	11.12
$\bar{x}c$	4.80	18.96	3.21	5.81	8.46
$\sum(y-\bar{y})^2$	5464.17	8742.80	___	3689.36	5193.48
$\sum(x-\bar{x})^2$	717.10	7876.16	1043.24	1337.14	2418.06
s^2	546.42	546.42	___	263.52	865.58
Nc	350	553	751	486	233
$\bar{X}c$	7.23	18.33	3.82	7.90	8.56
r_{xy}	0.9420	0.8208	___	0.8196	0.9987
bc	2.6003	0.8648	___	1.3695	1.4636
$\hat{y}_{reg}$	4887.8	6546.4	___	4093.1	2627.1
$SE(\hat{y}_{reg})$	2152.4	1548.5	___	1598.2	195.2

Table (7:5): Regression Area estimates of arable crops for the five strata

Stratum(c)	1	2	3	4	5
$\bar{y}c$	___	16.92	4.42	12.05	2.26
$\bar{x}c$	0.87	15.49	6.14	13.62	4.33
$\sum(y-\bar{y})^2$	___	8092.70	7749.69	8977.54	215.06
$\sum(x-\bar{x})^2$	29.50	5796.96	7913.84	7762.86	731.10
s^2	___	505.79	352.25	641.25	35.84
Nc	350	553	751	486	233
$\bar{X}c$	1.26	11.08	3.18	14.85	4.26
r_{xy}	___	0.9427	0.9724	0.9649	___
bc	___	1.1121	0.9622	1.0376	___
$\hat{y}_{reg}$	___	6648.2	1119.5	6481.4	___
$SE(\hat{y}_{reg})$	___	1119.6	660.2	866.1	___

Table (7:6): Regression Area estimates of non-agricultural land for the five strata (ha)

Stratum(c)	1	2	3	4	5
$\bar{y}c$	43.37	50.10	59.25	74.84	85.49
$\bar{x}c$	52.41	30.75	55.84	73.00	87.01
$\sum(y-\bar{y})^2$	10515.32	26646.11	22744.12	16932.01	8529.97
$\sum(x-\bar{x})^2$	5861.40	13797.44	8847.74	13366.50	5999.28
s^2	1051.53	1665.38	1033.82	1209.42	1421.66
Nc	350	553	751	486	233
$\bar{X}c$	53.95	28.68	36.44	64.95	76.15
r_{xy}	0.4331	0.4468	0.6875	0.9467	0.9991
bc	0.5802	0.6208	1.1023	1.0655	1.1914
$\hat{y}_{reg}$	15495.4	26567.2	29937.9	32208.9	17392.5
$SE(\hat{y}_{reg})$	1789.6	3039.9	4030.2	1497.4	163.1

In order to analyse and evaluate the efficiency of the double sampling technique a comparison between the single-phase area estimation (the field survey) and the double sampling method (regression estimate) is carried out. This comparison will clarify whether the double sampling using a regression estimate is a successful method for improving and increasing the precision of the ground estimates. It will clarify whether the use of SPOT HRV data as another independent and auxiliary source increased the efficiency of agricultural area estimates for the Northern West Bank.

The comparison procedure is made in terms of,

a) area estimate,

b) standard error (*SE*),

c) coefficient of variation (*CV*),and

d) relative efficiency (*RE*)

Table (7:7): Field Area Estimates versus Regression Area Estimates of Olive and Fruit Areas (ha) Northern West Bank

Stratum	Ground Survey Estimate			Regression Estimate		
c	Area	*S.E*	*C.V*(%)	Area	*S.E*	*C.V* (%)
1	16441.6	3390.8	20.6	13813.9	1612.3	11.7
2	11385.7	4452.7	39.1	11618.6	1832.6	15.8
3	27077.3	4594.9	17.0	24644.7	3497.1	14.2
4	2893.2	1938.6	67.0	2470.1	174.1	7.0
5	50.6	50.6	100.0	—	—	—

Table (7:8): Field Area Estimates versus Regression Area Estimates of Citrus Areas (ha) Northern West Bank

Stratum	Ground Survey Estimate			Regression Estimates		
c	Area	*S.E*	*C.V*(%)	Area	*S.E*	*C.V* (%)
1	703.2	703.1	100.0	847.4	240.2	28.3
2	—	—	—	—	—	—
3	—	—	—	—	—	—
4	774.7	774.4	100.0	508.4	22.5	4.4
5	210.4	210.4	100.0	—	—	—

Table (7:9): Field Area Estimates versus Regression Area Estimates of Horticulture (ha) Northern West Bank

Stratum	Ground Survey Estimate			Regression Estimate		
c	Area	*S.E*	*C.V*(%)	Area	*S.E*	*C.V* (%)
1	2672.6	2466.8	92.3	4887.8	2152.4	44.0
2	6846.7	3135.2	45.8	6546.4	1548.5	23.7
3	—	—	—	—	—	—
4	2698.8	2037.0	75.5	4093.1	1598.2	39.5
5	2590.9	2591.0	100.0	2627.1	195.2	7.4

Table (7:10): Field Area Estimates versus Regression Area Estimates of Arable Crops (ha) Northern West Bank

Stratum	Ground Survey Estimate			Regression Estimate		
c	Area	*S.E*	*C.V*(%)	Area	*S.E*	*C.V* (%)
1	—	—	—	—	—	—
2	9358.4	3016.4	32.2	6648.2	1119.6	16.8
3	3323.9	2939.1	88.4	1119.5	660.2	58.9
4	5860.7	3177.6	54.2	6481.4	866.1	13.4
5	527.3	527.2	100.0	—	—	—

Table (7:11): Field Area Estimates versus Regression Area Estimates of Non-Agricultural Land (ha) Northern West Bank

Stratum	Ground Survey Estimate			Regression Estimate		
c	Area	*S.E*	*C.V*(%)	Area	*S.E*	*C.V* (%)
1	15182.3	3422.0	22.5	15495.4	1789.6	11.5
2	27708.2	5473.4	19.8	26567.2	3039.9	11.4
3	44502.0	5035.0	11.3	29937.9	4030.2	13.5
4	36372.7	4364.0	12.0	32208.9	1497.4	4.6
5	19920.8	3320.5	16.7	17392.5	163.1	1.0

Tables 7.12 to 7.16 show crop type area estimation of Northern West Bank obtained from the field survey, regression estimate, and the SPOT HRV classified image for the year 1994. Relative efficiency (RE) is also included in these tables. As mentioned earlier in this section, the relative efficiency was calculated on the crop type and stratum basis to evaluate the performance of the regression estimator applied in this study.

The relative efficiency (*RE*) can be described as the ratio between the variance produced from the field survey and that produced from the application of the double sampling. The higher the ratio is, the better the regression estimate performance becomes. For example, a relative efficiency of 2 means that the same precision would have been obtained if the ground data sample size had been doubled and the satellite image had not been used (Gonzalez *et al.* 1997). On the other hand, if the relative efficiency is 1, this means that variance for the two estimates is the same, and no improvement in precision is achieved. But if the relative efficiency is less than 1, this means that accuracy of estimation has been decreased.

In this study, variance produced from the double sampling area estimates is calculated from the coefficient of determination r^2 and the field variance. The equation used for this purpose is,

$$V(\hat{y}c_{reg}) = 1 - r^2(s^2c) \qquad 7.15$$

where s^2 is the variance of the field estimates. So, the equation used for the calculation of the relative efficiency is,

$$RE = \frac{V(\hat{y}c)}{V(\hat{y}c_{reg})} = \frac{1}{1-r^2} \qquad 7.16$$

Table (7:12): Area estimate (ha) for olive and fruit Areas Northern West Bank, May 1994

Stratum *c*	Field Estimate Area	*SE*	Regression Estimate Area	*SE*	*RE*	SPOT HRV Area
1	16441.6	3390.8	13813.9	1612.29	1.33	8923.2
2	11385.7	4452.7	11618.6	1832.6	1.15	18173.2
3	27077.3	4594.9	24644.7	3497.1	1.6	20997.9
4	2893.2	1938.6	2470.1	174.1	7.16	2163.6
5	50.6	50.6	—	—	—	32.6

Table (7:13): Area estimate (ha) for citrus Areas Northern West Bank, May 1994

Stratum *c*	Field Estimate Area	*SE*	Regression Estimate Area	*SE*	*RE*	SPOT HRV Area
1	703.2	703.1	847.4	240.2	4.9	1060.9
2	—	—	—	—	—	2635.6
3	—	—	—	—	—	2271.7
4	774.7	774.4	508.4	22.5	133.3	686.1
5	210.4	210.4	—	—	—	259.1

Table 7.14: Area estimate (ha) for horticulture Areas Northern West Bank, May 1994

Stratum c	Field Estimate Area	SE	Regression Estimate Area	SE	RE	SPOT HRV Area
1	2672.6	2466.8	4887.8	2152.4	8.9	2532.1
2	6846.7	3135.2	6546.4	1548.5	3.1	10137.4
3	—	—	—	—	—	2875.5
4	2698.8	2037.0	4093.1	1598.2	3.0	3841.6
5	2591.0	2591.0	2627.1	195.2	370.4	1995.8

Table (7:15): Area estimate (ha) for arable crops Northern West Bank, May 1994

Stratum *c*	Field Estimate Area	*SE*	Regression Estimate Area	*SE*	*RE*	SPOT HRV Area
1	—	—	—	—	—	442.9
2	9358.4	3016.4	6648.2	1119.6	9.0	6128.9
3	3323.9	2939.1	1119.5	660.2	18.3	2394.9
4	5860.7	3177.6	6481.4	866.1	14.5	7217.6
5	527.3	527.2	—	—	—	993.8

Table (7:16): Area estimate (ha) for non-agricultural land Northern West Bank, May 1994

Stratum	Field Estimate		Regression Estimate		*RE*	SPOT
c	Area	*SE*	Area	*SE*		HRV Area
1	15182.3	3422.0	15495.4	1789.6	1.2	18883.2
2	27708.2	5473.4	26567.2	3039.9	1.2	15863.3
3	44502.0	5035.0	29937.9	4030.2	1.9	27371.8
4	36372.7	4364.0	32208.9	1497.4	9.6	31570.1
5	19920.8	3320.5	17392.5	163.1	588.2	17745.0

Table (7:17): Summary of the coefficient of determination and the relative efficiency for different crops in the study Area

Stratum	OT;FT		CT		H		AC		Non-A	
	r^2	*RE*	r^2	*RE*	r^2	*RE*	r^2	*RE*	r^2	*RE*
1	0.2474	1.3	0.7940	4.9	0.8874	8.9	—	—	0.1876	1.2
2	0.1326	1.2	—	—	0.6738	3.1	0.8886	9.0	0.1996	1.2
3	0.3804	1.6	—	—	—	—	0.9455	18.3	0.4727	1.9
4	0.8604	7.2	0.9925	133.3	0.6718	3.0	0.9310	14.5	0.8963	9.6
5	—	—	—	—	0.9973	370.4	—	—	0.9983	588.2

Once the area for each crop type was calculated from both the field sampling survey and the SPOT HRV classified image sampling, regression lines ($y = a + bx$) between the two estimates at the sample unit level for each stratum were drawn. Where y is the dependent variable or the field measurement, x is the independent variable or the SPOT HRV measurement, b is the slope between the two variables, and a is the intercept ($y - bx$).

The regression line is drawn to show the level of agreement between the field area measurement and the SPOT HRV area measurement. Distance between sample plots and the line refers to the variance of these plots. The closer from the line the plots are the higher the correlation between the two measurements is and the lower the variance is. In other words, when the area plots of the field and the image estimates are close to the regression line, this means that better agreement between the two measurements is achieved. Figures 7.1 to 7.18 show the regression lines for the different crops.

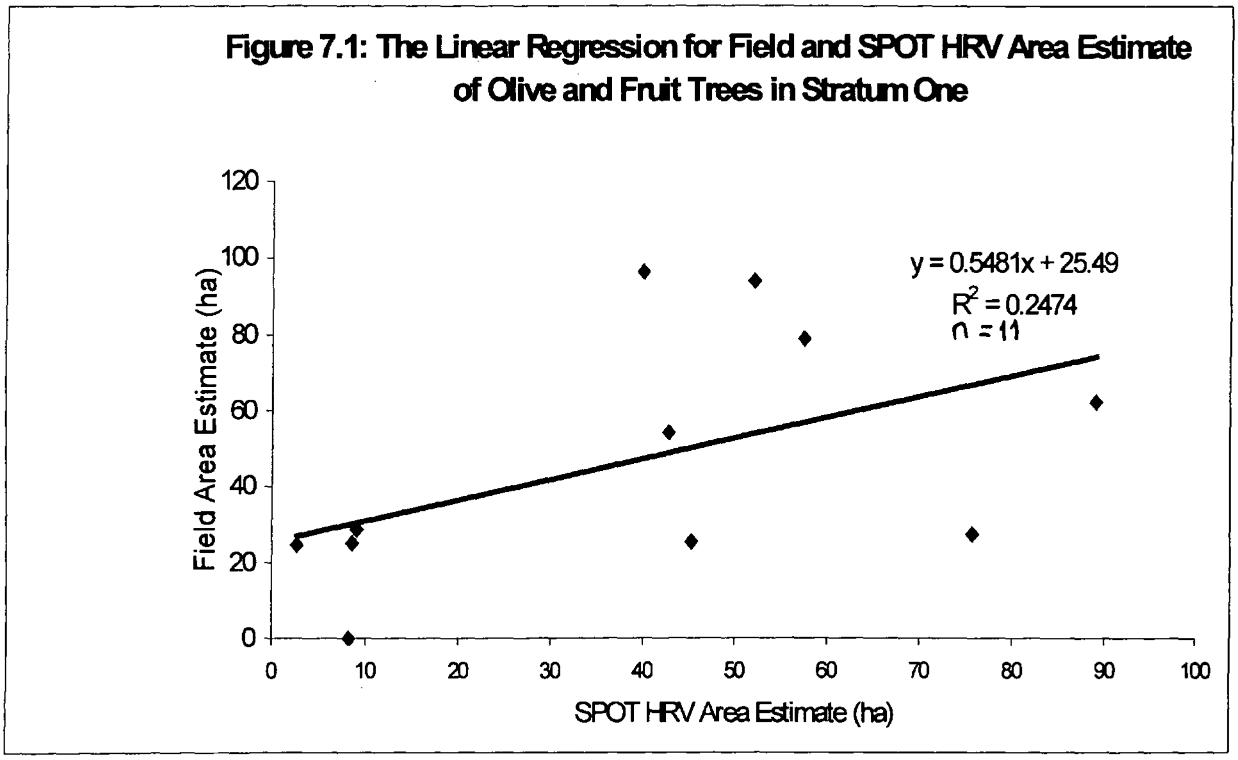


Figure 7.1: The Linear Regression for Field and SPOT HRV Area Estimate of Olive and Fruit Trees in Stratum One
y = 0.5481x + 25.49
R² = 0.2474
n = 11
Field Area Estimate (ha)
SPOT HRV Area Estimate (ha)
0
20
40
60
80
100
120
0
10
20
30
40
50
60
70
80
90
100

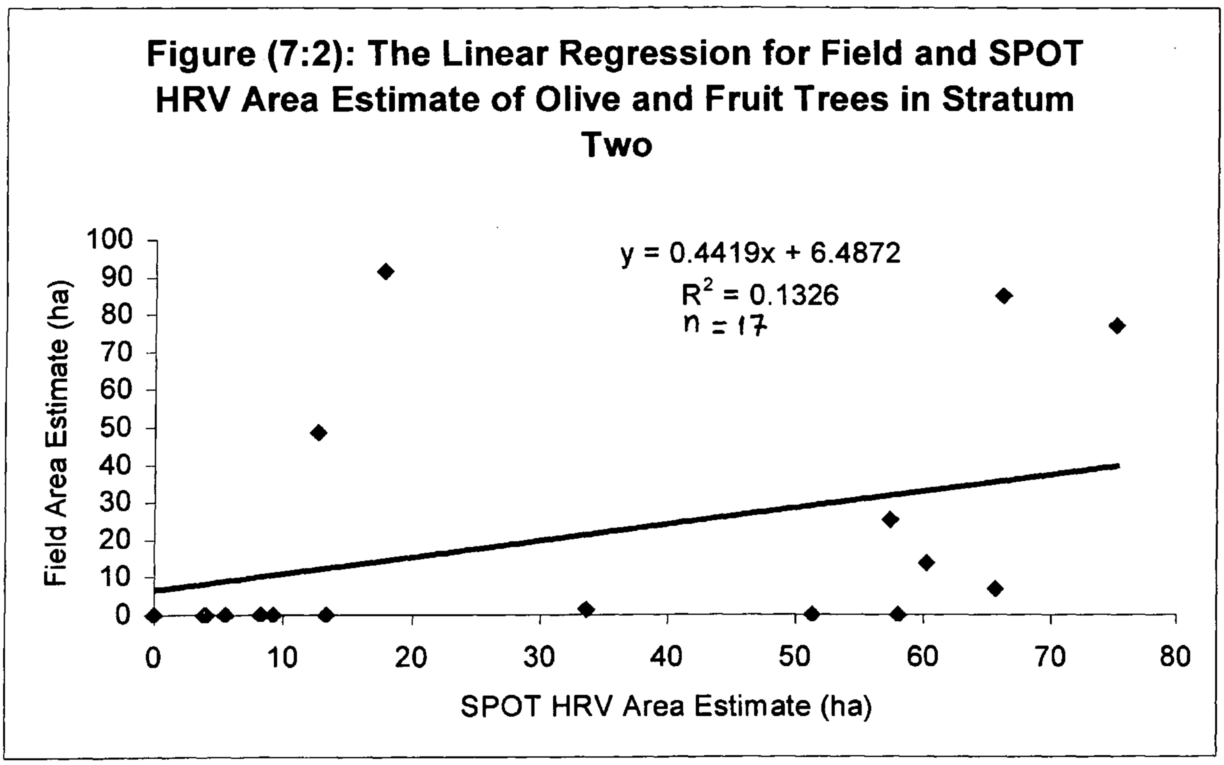


Figure (7:2): The Linear Regression for Field and SPOT HRV Area Estimate of Olive and Fruit Trees in Stratum Two
y = 0.4419x + 6.4872
R² = 0.1326
n = 17
Field Area Estimate (ha)
SPOT HRV Area Estimate (ha)
0
10
20
30
40
50
60
70
80
90
100
0
10
20
30
40
50
60
70
80

Figure (7:3): The Linear Regression for Field and SPOT HRV Area Estimate of Olive and Fruit Trees in Stratum Three

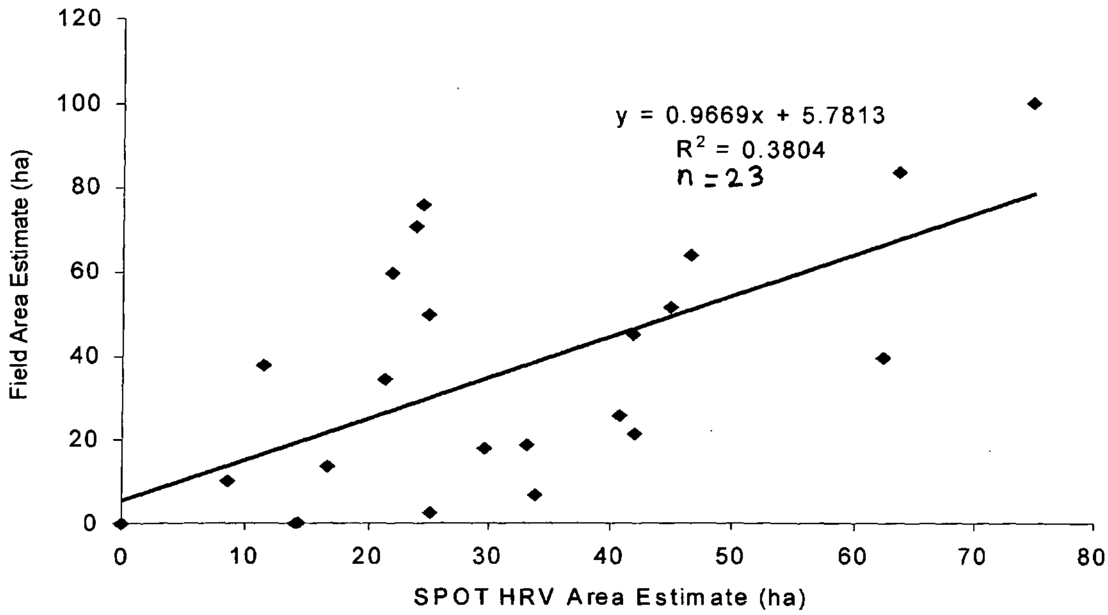


Figure (7:4): The Linear Regression of Field and SPOT HRV Area Estimate of Olive and Fruit Trees in Stratum Four

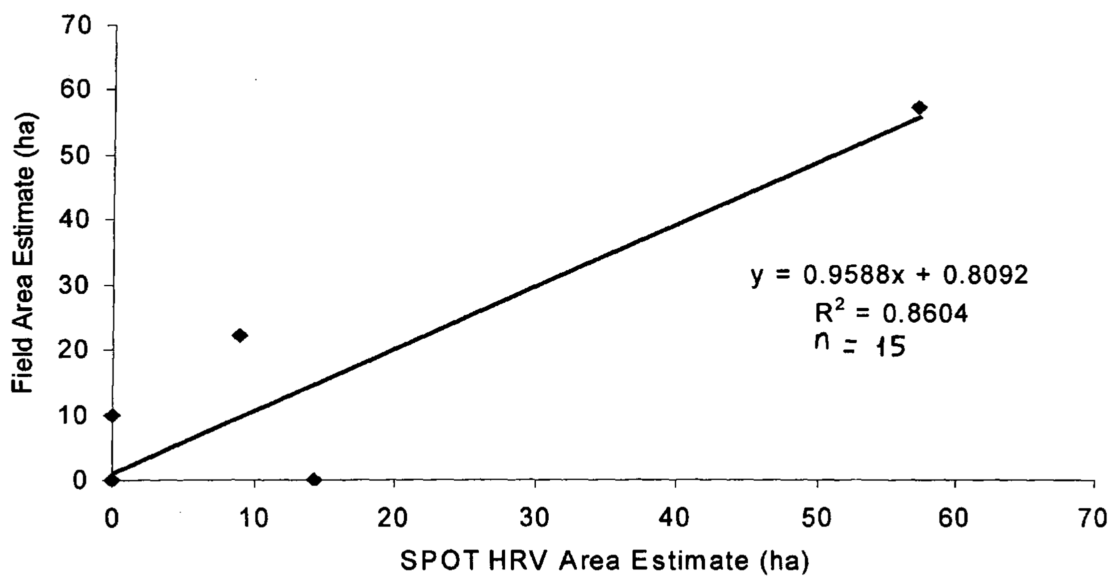


Figure (7:5): The Linear Regression for Field and SPOT HRV Area Estimate of Citrus Trees in Stratum One

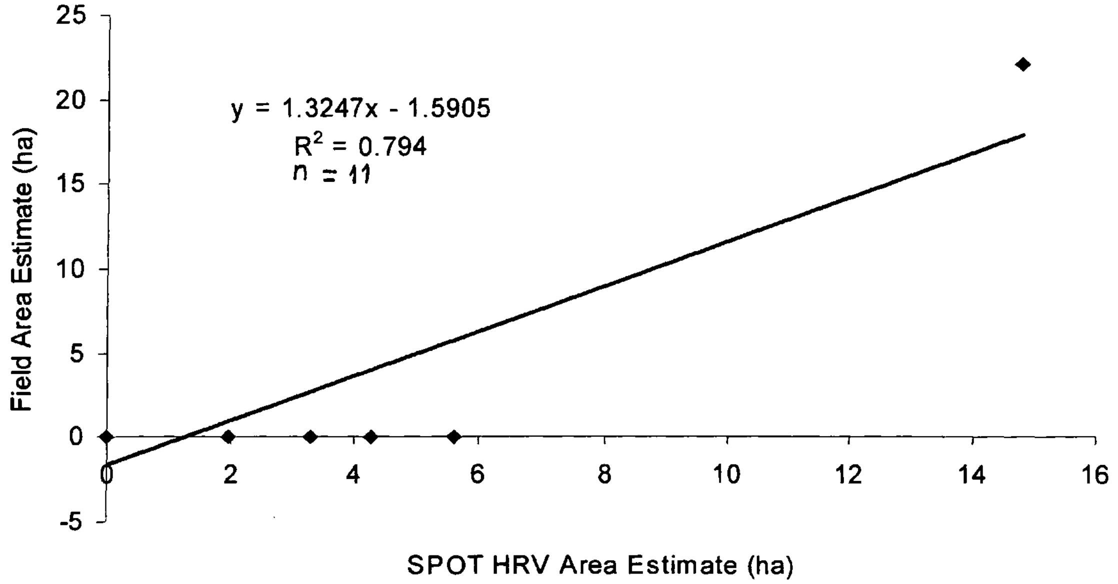


Figure (7:6): The Linear Regression for Field and SPOT HRV Area Estimate of Citrus Trees in Stratum Four

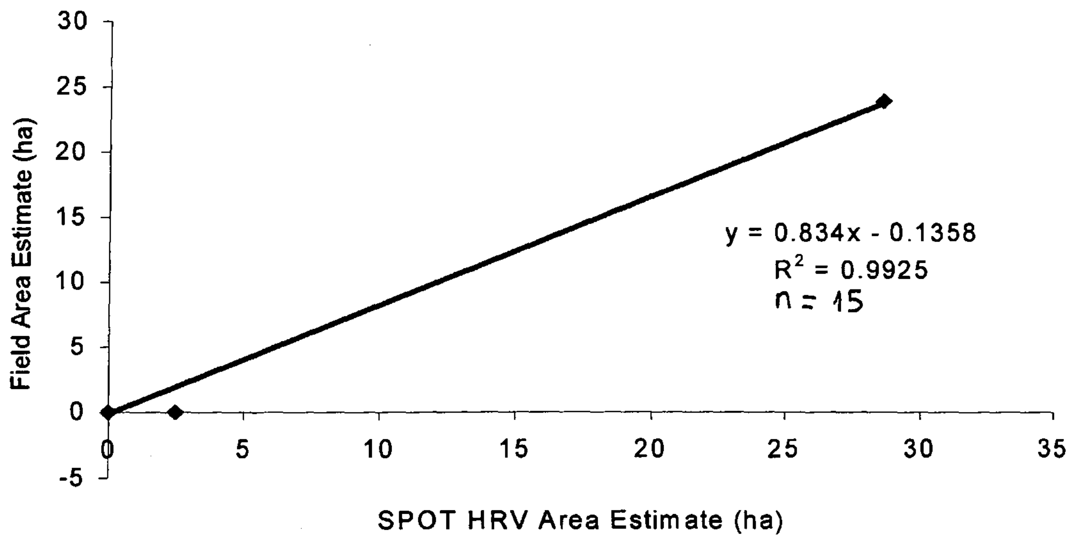


Figure (7:7): The Linear Regression of Field and SPOT HRV Area Estimate of Horticulture in Stratum One

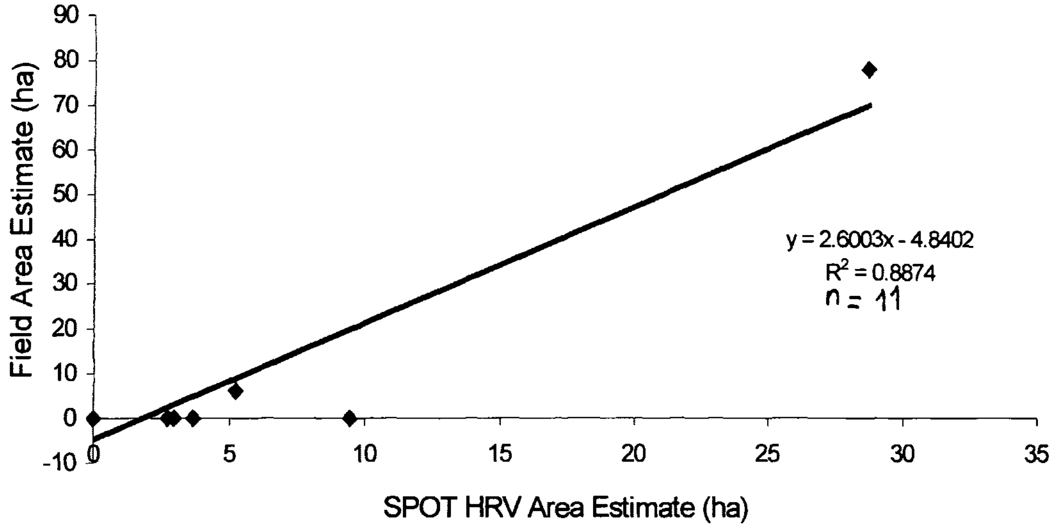


Figure (7:8): The Linear Regression for Field and SPOT HRV Area Estimate of Horticulture in Stratum Two

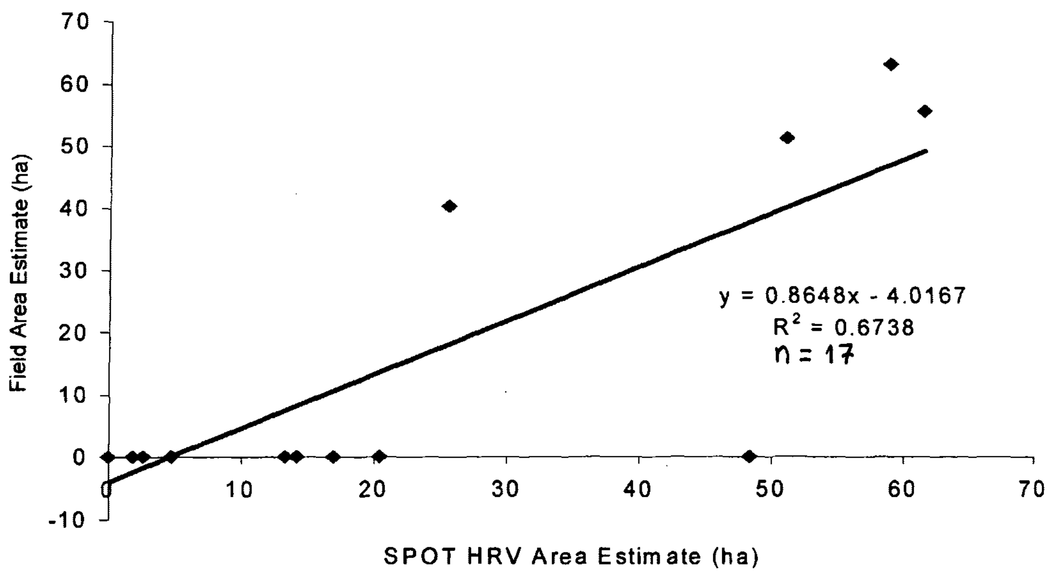


Figure (7:9): The Linear Regression for Field and SPOT HRV Area Estimate of Horticulture in Stratum Four

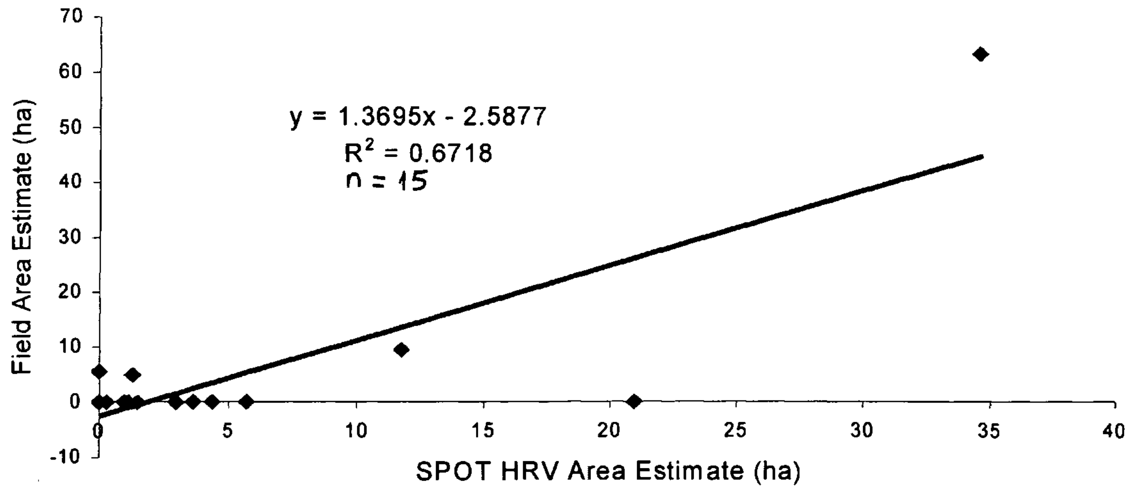
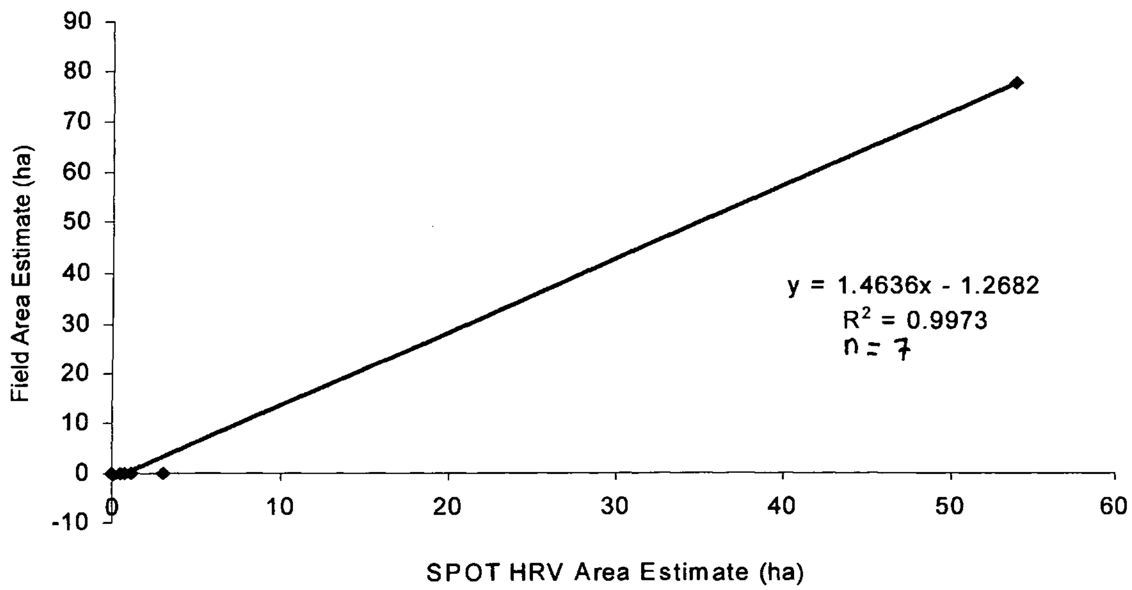


Figure (7:10): The Linear Regression for Field and SPOT HRV Area Estimate of Horticulture in Stratum Five



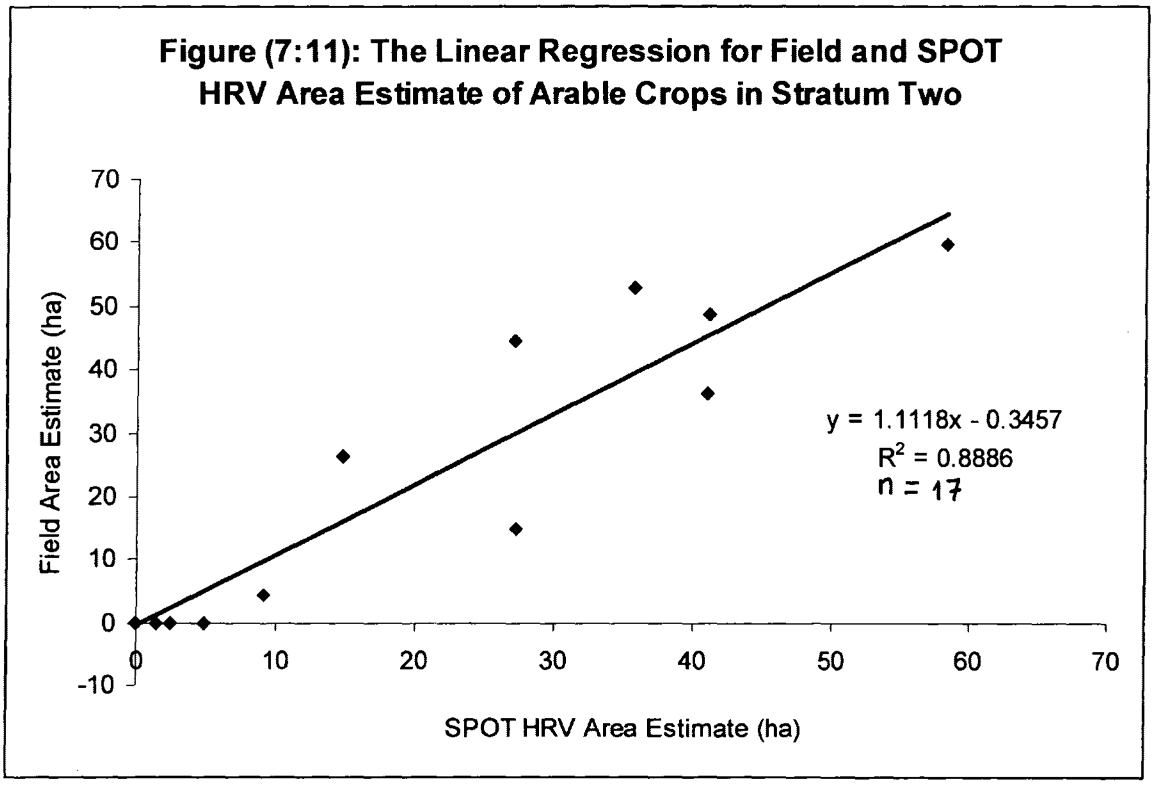


Figure (7:11): The Linear Regression for Field and SPOT HRV Area Estimate of Arable Crops in Stratum Two
y = 1.1118x - 0.3457
R2 = 0.8886
n = 17
Field Area Estimate (ha)
SPOT HRV Area Estimate (ha)

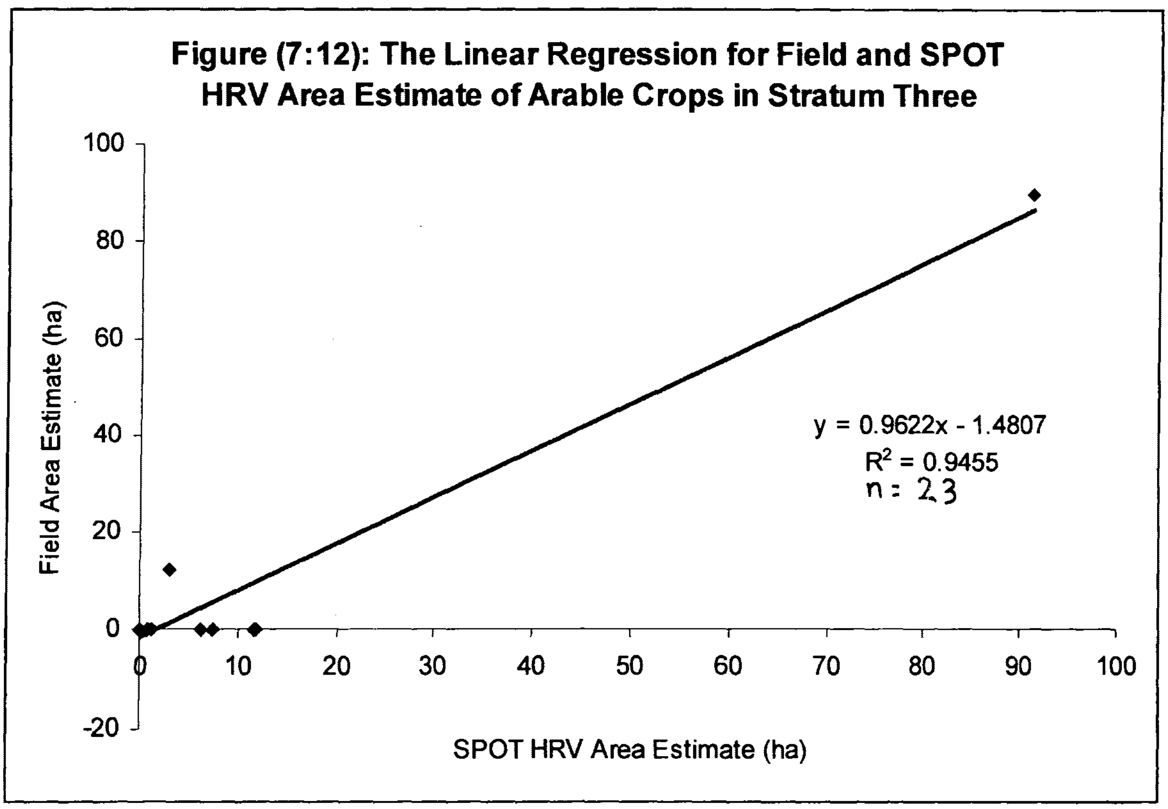


Figure (7:12): The Linear Regression for Field and SPOT HRV Area Estimate of Arable Crops in Stratum Three
y = 0.9622x - 1.4807
R2 = 0.9455
n: 23
Field Area Estimate (ha)
SPOT HRV Area Estimate (ha)

Figure (7:13): The Linear Regression for Field and SPOT HRV Area Estimate of Arable Crops in Stratum Four

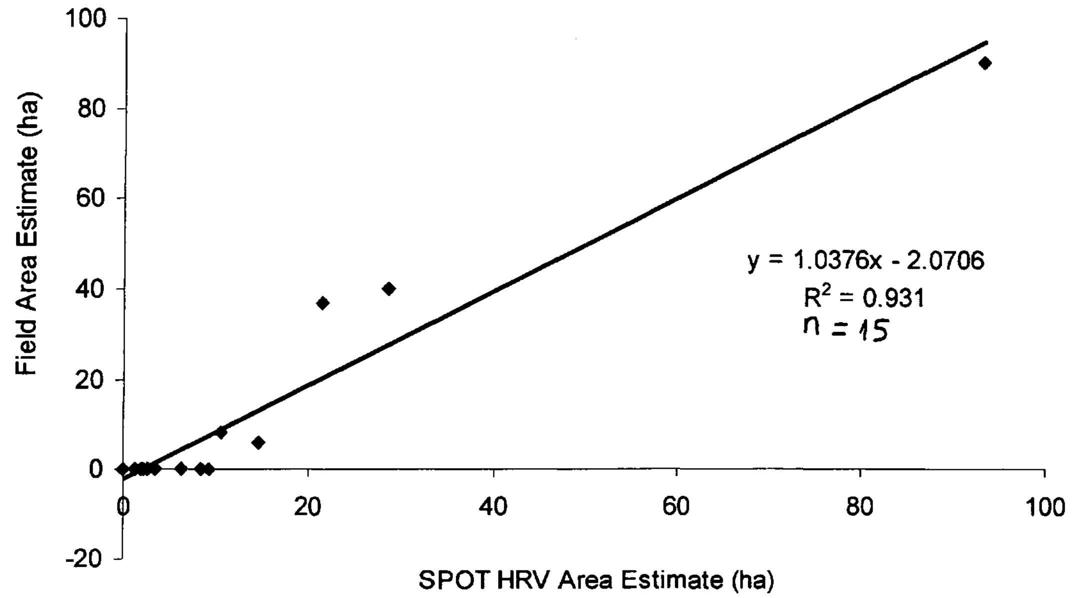


Figure (7:14): The Linear Regression for Field and SPOT HRV Area Estimate of Non-Agricultural Land in StratumOne

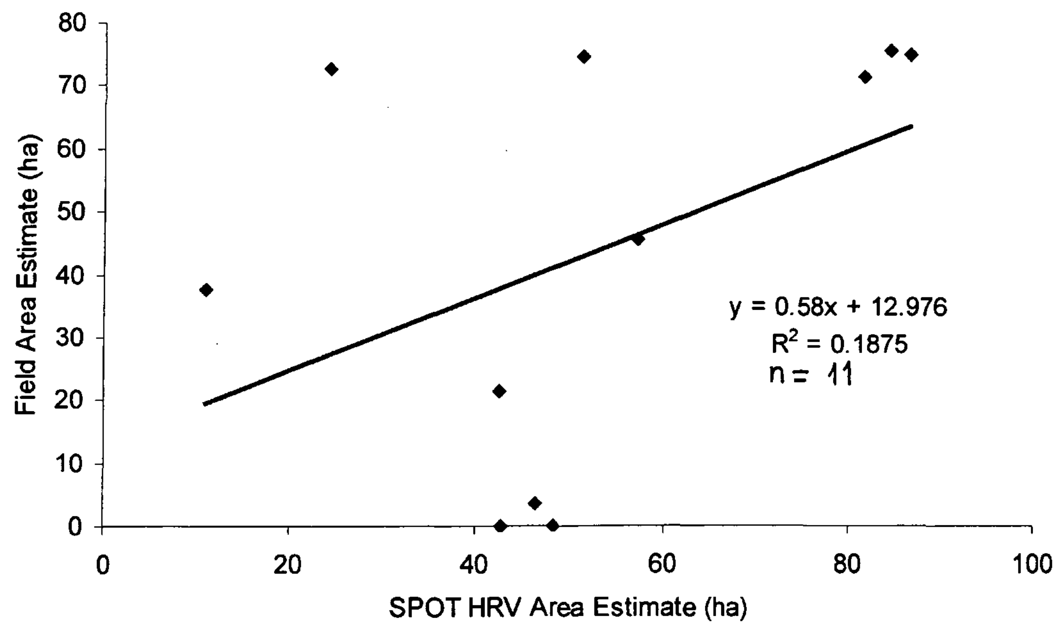


Figure (7:15): The Linear Regression for Field and SPOT HRV Area Estimate of Non-Agricultural Land in Stratum Two

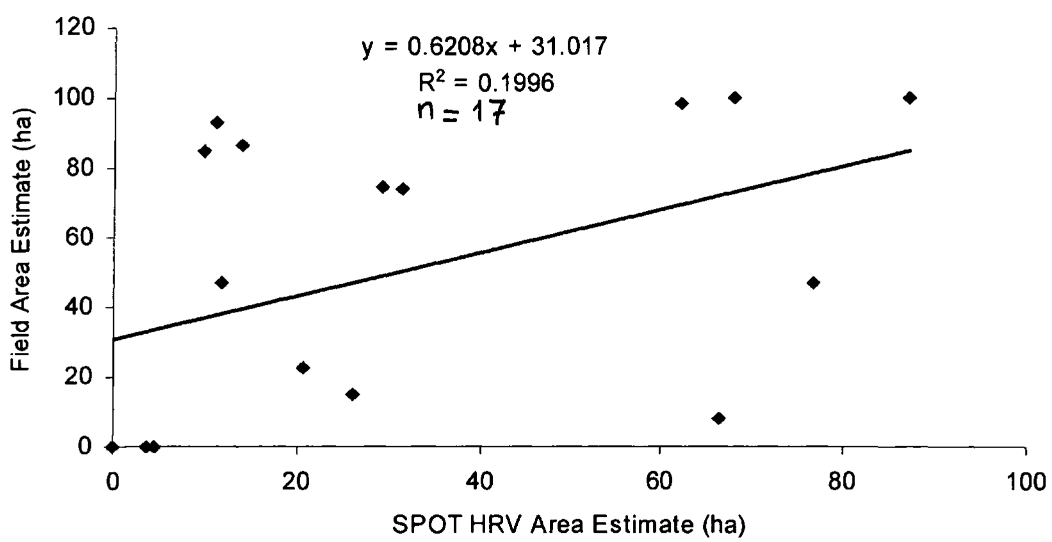


Figure (7:16): The Linear Regression for Field and SPOT HRV Area Estimate of Non-Agricultural Land in Stratum Three

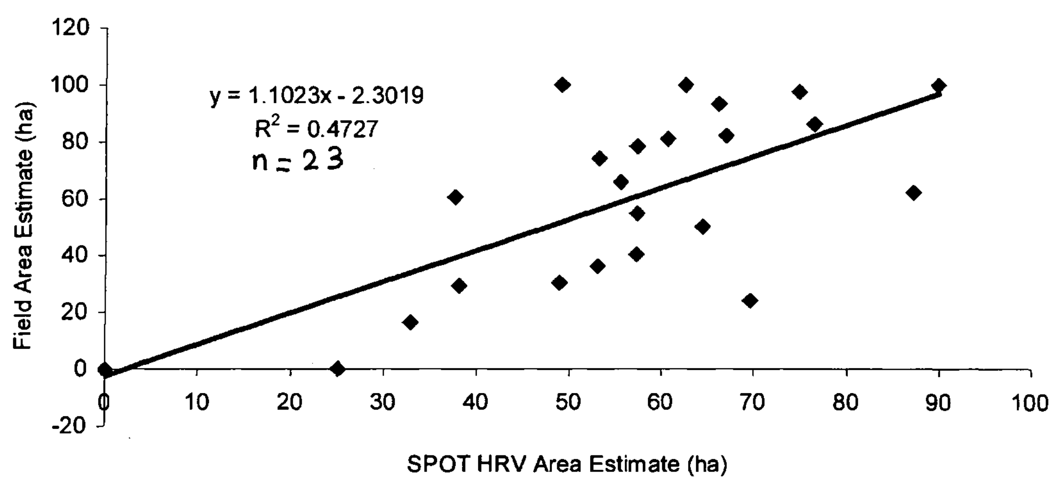


Figure (7:17): The Linear Regression for Field and SPOT HRV Area Estimate of Non-Agricultural Land in Stratum Four

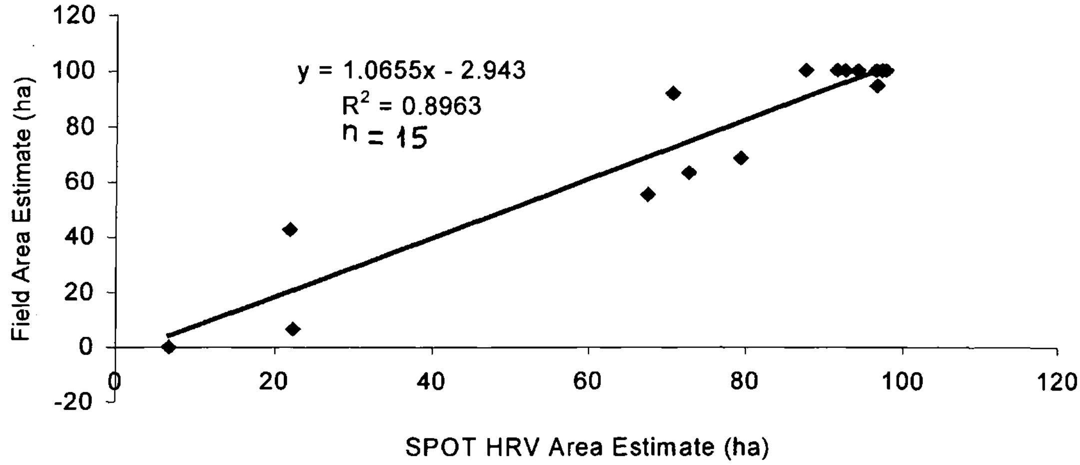
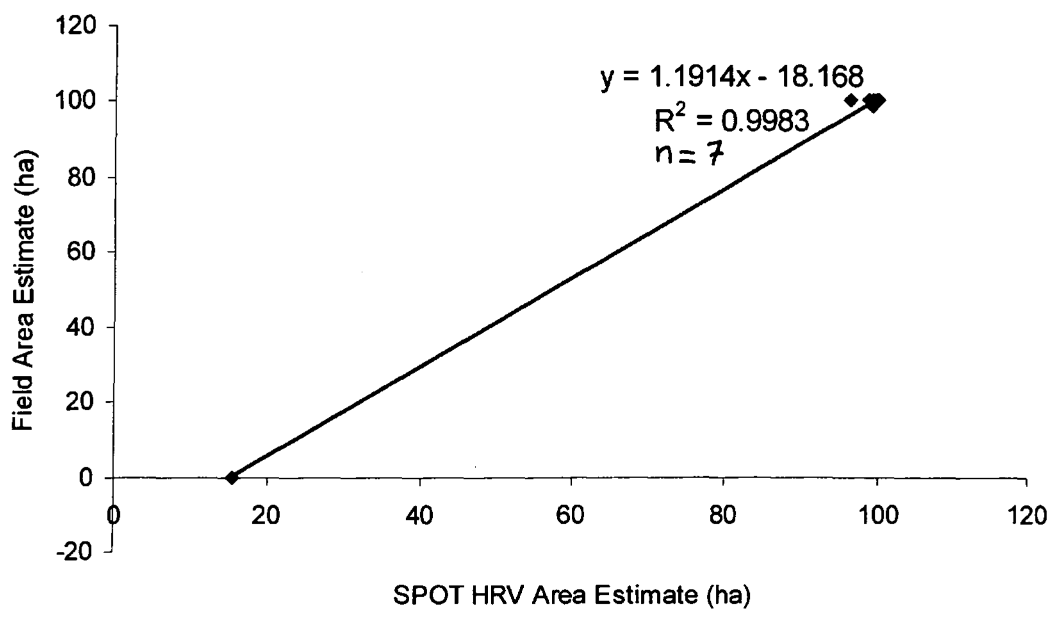


Figure (7:18): The Linear Regression for Field and SPOT HRV Area Estimate of Non-Agricultural Land in Stratum Five



7. 5 Discussion of Results

Evaluation of results can be obtained from the previous tables. These tables summarise results of the double sampling technique that has been used for the crop type area estimation in the northern part of the West Bank.

1) Table 7.17 shows that: First, the arable crop class which is mainly cereal crops scored the best coefficient of determination (more than 0.8886). The reason is because this crop in this time of the year (late May) is in the yellowing stage, which allows it to be easily identified by the SPOT HRV sensor in the three spectral bands. There is no confusion between it and other crop types investigated in the area. Errors in this case came from the development of classes introduced to get thematic classes rather than land cover ones. For example, all ploughed lands in stratum one were given to horticulture because in this stratum, arable crops are nearly out of cultivation. On the other hand, the ploughed land in stratum two was given to both arable and horticulture crops proportionally because both arable and horticulture crops are grown in this stratum (see chapter 6). The second source of error is the uncertain information given by farmers when they were asked about the type of crops grown in the field at that date. Secondly, the horticultural crops in the strata 1 and 5 scored higher coefficients of determination than the strata 2 and 4. The reason is that this crop in the strata 1 and 5 is irrigated and the classes development did not affect its accuracy, while in strata 2 and 4 the class development (see chapter 5) affected its accuracy. Thirdly, the lowest coefficient of determination was scored by both olive and fruit trees class and the non-agricultural class in the strata one, two and three (between 0.13 and 0.47). While in the strata four and five, the coefficient of determination is high (more than 0.85). Figures 7.1 and 7.14 show the clear disagreement between the image area

estimates and the field estimates for some sample units. The reason is that olive & fruit trees class is spectrally overlapped with some vegetational non-agricultural classes included in this broad category, see figure 7.19. The main type of vegetation which is overlapped with olive trees is *Tistacia Lintiscus (it is a kind of evergreen bush, two meters height with a waxy coated leaves).* This type of bush exists in certain areas of the three mentioned strata (south eastern stratum one, north western stratum two, and south western stratum three). For example, field measurement of sample 1 in stratum 1 is 93.9 ha for olive and fruit trees and 0 ha for non-agricultural land, while SPOT HRV measurement of the same sample is 52.1 ha for olive and fruit trees and 42.6 ha for the non-agricultural land. In stratum four and five, the non-agricultural classes are non-vegetated ones; mainly rocky land, badland and sparsely vegetated lands which do not overlap spectrally with the olive trees class.

2) Table 7.13 shows that the field survey did not record any fields of citrus trees in the selected sample units in strata 2 and 3. This is due to the scarcity of this crop in these two strata. The Palestinian official statistics show that the area of this crop is only 250 ha in stratum 2 and 170 ha in stratum 3 (Ministry of Planning and International Co-operation-MOPIC, 1996). SPOT HRV data produced a relatively large error in the area estimate of this crop. The first reason for this misclassification is that citrus trees is spectrally overlapped with *Quercus Calliprinos* which exists in some areas these two strata and SPOT HRV sensors could not discriminate between these two types. The *Quercus Calliprinos* tree is an oak that exists in the north western part of stratum 2 and the south western part of stratum 3. For example, SPOT HRV data produced 15.7 ha of citrus trees in sample 2 of stratum 2 and 28.7 ha in sample 3 of stratum 3. Under these conditions it was not possible to apply regression analysis of this crop type in these two strata.

3) Table 7.13 shows that the field survey did not record any fields of horticulture in the selected sample units in stratum 3. Palestinian official statistics show that the area of this crop in this stratum is 600 ha (MOPIC, 1996). SPOT HRV data produced 2410 ha of this crop. The reason for this disagreement between the field and image data is first, farmers do not keep records of their activities in the field and the uncertain answers they gave. Most lands in the selected sample unit which represented the plain agricultural lands if the stratum were given to arable crops. Secondly, the development (see chapter 5) of land-use/ land cover classes used in image area estimation. For example, a proportion of the ploughed lands were given over to horticulture.

4) In terms of the relative efficiency (*RE*), it can be seen that regression estimate increased the estimate efficiency for all crop types in the strata. None of the *RE* for all crops is lower than 1: that means that area estimation is improved for all crop types when the double sampling was applied. The lowest relative efficiency was for the olive tree class and the non-agricultural land class in the strata 1, 2 and 3 it is between 1.15 to 1.9. The highest relative efficiency achieved for most crops was in strata 4 and 5. The reason is the good spectral separability among the different land cover types in these strata.

5) In terms of the coefficient of variance *CV* of the field and the regression estimates; tables 7.7 to 7.11 show that the *CV* for all crop types in all strata has been considerably reduced. For example, the *CV* of horticulture in stratum 5 has been reduced from 100% when only the field data used to 7.4% when the double

sampling methodology used. This ensures that the use of the double sampling technique produced better results than the field survey or the image survey alone.

The reasons for the large disagreement between the field measurements and the SPOT HRV measurements can be summarised as follows:

a) the Palestinian farmers are not used to keep records of their activities in the field. They hardly remember the type of crop that existed in the field when the image was acquired. The reason is the long time between the image acquisition and the field survey. This mainly affected the arable and horticulture crops (one is overestimated and the other is underestimated).

b) The complex physical and environmental landscape of the West Bank. In other words, there is an extremely big difference between land cover and land use in the study area. For example, most olive and fruit tree land exists in rough mountainous terrain. This situation made it difficult to plough these lands and resulted in fields full of rough grass, bushes and natural vegetation. Therefore, the SPOT HRV sensors were in many cases unable to identify these areas accurately and confusion between olive & fruit trees and non-agricultural vegetation occurred (rough grass, bushes and natural vegetation).

c) In many cases, it was impossible to reach the sample unit to be surveyed when it is close to Israeli settlements. So, the author relied on the 1: 50,000 Israeli maps and aerial photographs.

d) The inappropriate date of the Israeli aerial photographs used for the field sampling (October and December). At this time of the year, all fields will be either freshly sown or prepared for cultivation. So, it is difficult to directly know the crop type in the field especially for the field seasonal crops.

e) Absence of the middle infrared waveband of the SPOT HRV sensing system affected the spectral separability between olive trees and some bushes on one hand, and citrus trees and some non-agricultural trees on the other hand.

6) It can also be seen from figures 7.1 to 7.18 that so many points equal zero. This can be explained by the fact that some crops do not exist in most of the sample units in the study area. For example, in stratum 4 citrus crop exists in one sample unit only and the rest sample units are out of this crop. Also image misclassification results in a bias of regression estimation.

7) In this study the regression data are independent of the training data and so methodology applied is a rigorous one.

Figure (7:19): Complex agricultural land containing olive trees, bushes and rough grass

7.6. Conclusion

Looking at the statistical results and analysis, it is clear that the regression estimator through the double sampling procedure is always better and more efficient than the field sampling alone. The relative efficiency *RE* for all crop types in all strata improved the precision of estimates through the combination of SPOT HRV data with the ground data. Different tables also show that the *CV* for all crops in the study area has considerably improved when the double sampling was applied. It is worth saying that the limited spectral bands of SPOT HRV sensors (particularly the absence of the middle infrared band) associated with the extremely complicated environment of the West Bank affected results of image classification. It is also important to say that the difficult access to some sample units added to the problem.

How accurate is the ground data?

CHAPTER EIGHT

AGRICULTURAL PERSPECTIVE ANALYSIS OF CROP AREA ESTIMATION RESULTS

8.1. Introduction

8.2. Crop Type Area and Importance

8.2.1. Olive & fruit trees

8.2.2. Horticulture

8.2.3. Arable Crops

8.2.4. Citrus Trees

8.1. Introduction

Agricultural analysis of the results for the study area includes the following points:

- The total area of each crop in the study area and its economical importance,
- Comparison of the study statistical results with other sources, and
- The spatial distribution of different crops over the study area

8.2. Crop Type Area and Importance

Table 8.1 summarises the double sampling total area for the major agricultural crops in the northern West Bank. The non-agricultural lands are also included to see the whole picture of agriculture in the study area.

Table (8:1): Total area of agricultural crops Northern West Bank

Crop Type	Area (ha)	%
Olive & Fruit Trees	52547.3	25.3
Citrus Trees	1355.8	0.7
Horticulture	18154.4	8.7
Arable Crops	14249.1	6.9
Non-Agricultural	121601.9	58.4

Figure (8:1): Total Hectarage Estimates Produced for the Study Area

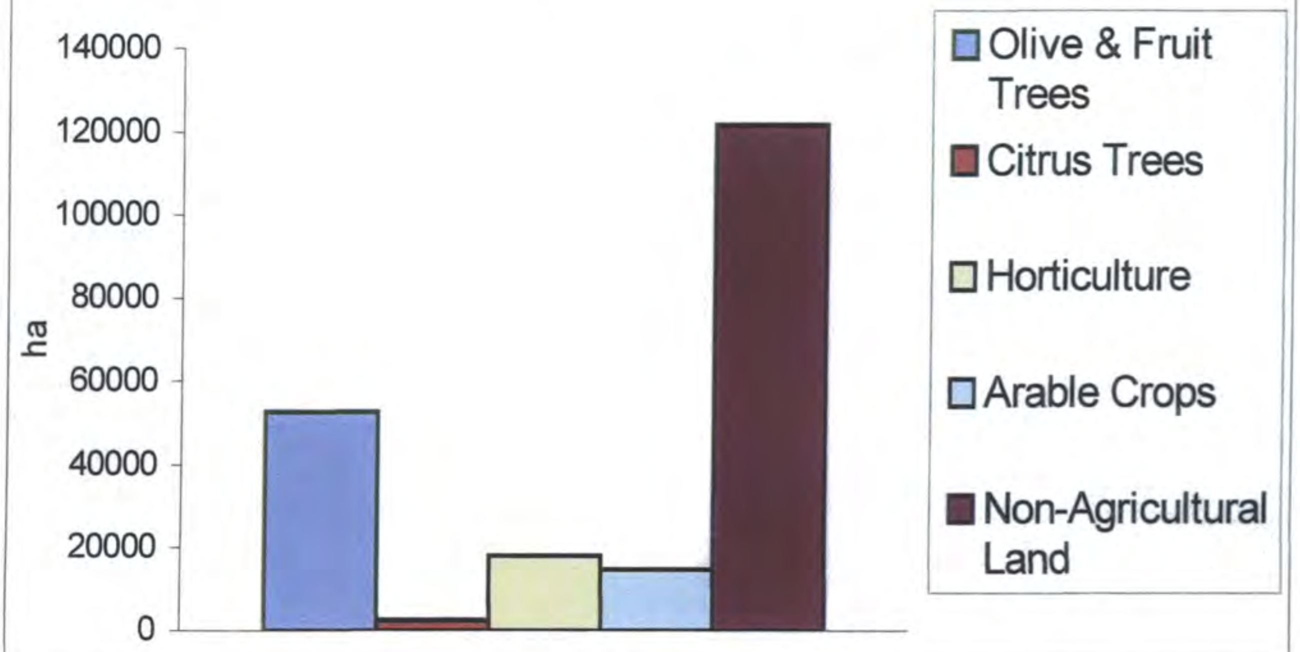


Table 8.1 shows that the total cultivated land occupies 42% of the study area while 58% is non-agricultural. If this percentage is compared with the total cultivated land in the West Bank which is about 30% (Benvenisti 1986, MOPIC 1996, and ARIJ 1994), we realise the relative agricultural importance of the study area. In order to investigate the importance of each crop type in the study area, each crop is analysed separately.

8.2.1 Olive & fruit trees

This crop occupies the first place among other crops in terms of area. It covers 25.3% of the study area or 60% of cultivated land. This area represents more than 60% of the total olive and fruit area existing in the West Bank. Olives is considered to be the most important rain-fed crop in the West Bank. It contributes about 45% of the total agricultural production and with 25% of the agricultural gross national product (Ja'fari & Sawalha 1990).

The Palestinian people have a high respect for the olive tree because it is mentioned in the Koran and cutting it is considered as a crime. The importance of this tree for the Palestinians comes from the fact that olives and olive oil are used in nearly all Palestinian meals and consuming olive oil rather than other oil types is considered a privilege. In the Palestinian traditions, olive oil is spread over the body of the newly born babies because it is believed that the olive oil strengthens their bodies and makes their skin look better. The remains of olives after pressing are used for soap production and heating in winter.

In Palestine the olive tree is a valuable and has a high status because it is evergreen and lives for a long time. Olive production offers the farmer a steady income for a period of time and keeping and marketing the crop is easier than other crops such as vegetables. It also to some extent protects the land from being taken over by the Israeli authorities for colonies building and military training because Israeli authorities are more attracted by the uncultivated areas than the cultivated ones.

The productivity of olive trees extremely fluctuates considerably from one year to another. When the production of one year is relatively high, the production of the next year is expected to be very low. For example, in 1991 the average production was 250 kg per ha of olives, while in 1992, the production rose to 2000 per ha (Sbeih 1993). The main reasons for this severe fluctuation of olive production are the rainfall fluctuations and the olive tree physiology. To investigate these two factors, a comparison for two years is made between olive productivity in the study area where the crop is a rain-fed one and that of Gaza Strip where the crop is an irrigated one (table 8.2).

Table (8:2): Olive productivity in the West Bank and Gaza (kg/ ha)

Year	The Study Area	Gaza
1991	250	2000
1992	2000	5000

Source: Sbeih, 1993

Table 8.2 shows that olive productivity in Gaza Strip is much higher than that of the West Bank because of irrigation. Secondly, although olive crop in Gaza is an irrigated one, its productivity in 1991 is less than that of 1992. This demonstrates the effect of the physiological factor. Thirdly, fluctuation in production in the West Bank is much higher than that of Gaza because irrigation and the use of chemical fertilisers in Gaza reduce the physiological effect. Therefore, Palestinian farmers often stored some of the production to avoid the consequences of the low production of the following year.

Olive production in the northern part of the West Bank is higher than the southern part because the soils are more fertile. In the productive years, the West Bank produces about 170 thousand tons of olives. About 90% of this amount are used to produce 28500 tons of oil and the rest (10%) is tinned. 35% of the production is consumed locally and the same percentage is kept for the next year, while the rest (30%) is sold to the Palestinians in Israel, and Gaza (ARIJ 1994).

Olive tree cropping in the West Bank faces many difficulties. These difficulties can be summarised as follows:

- Image classification showed that olive and fruit tree crop is spectrally overlapped with the bushes and the rough grass. Spectral confusion arised because the under story of many olive tree areas is covered with rough grass and bushes. Therefore, it is difficult to obtain very accurate statistics in mountainous areas using remote sensing because of spectral overlap.

- Mechanical agricultural operations particularly ploughing in these areas are difficult. Therefore, animals are usually used to do this job which cost the Palestinian farmer more than the mechanical ploughing. The price of olive oil is relatively low when compared with prices in other parts of the world such as Europe. The average price in the WB is 4 US$ for 1 kg of oil. The reason for such low price is that most oil is sold locally and the Palestinian market is open for other oil types with lower prices to compete with the local oil. The opening of other markets such as the European Union for Palestinian oil may improve its price.

- With the olive crop, accurate data on crop area does not give an indication of likely crop yield. To estimate yield it is necessary to have a good time series of yield data and to have information on rainfall and soil type.

- In many cases, farmers do not harvest the crop in the correct way. Some farmers hit the branches with sticks to cause the olive to drop but this practice damages the trees and reduces production of the following year. This behaviour also reduces the production quality.

- The Palestinian olive farmer complains that they get little support and advice from the Palestinian National Authority. In other words, farmers do not receive any financial support to improve their agricultural capabilities.

8.2.2 Horticulture

Horticulture is the second most important crop after olives and fruit trees. It covers 8.7% of the study area or 20.7% of the cultivated land. Horticulture (mainly vegetables) is grown in the fertile plains of the study area. Two methods of horticultural cropping are used, open field farming and greenhouse farming. The two methods are used in the irrigated areas, while the open farming is used in the dry farming or rain-fed areas. In the irrigated areas farmers can plant their fields with horticulture at any time of the year. But in the dry farming or rain-fed areas some crops such as onion, cauliflower, garlic and potatoes are planted at the beginning of winter and other crops such as okra, tomatoes, cucumber and courgettes are planted in spring to avoid the danger frost in the cold months.

Irrigated horticulture mainly exists in the strata 1 and 5 and some areas of stratum 4. The reason for that is the availability of artisan water and springs in these areas. On the other hand, the dry hot weather in stratum 5 does not allow for dry or rain-fed farming.

Dry farming or rain-fed horticulture exists in the strata 2 and 4, while in stratum 3 there is virtually no horticulture. The Israeli authorities do not allow any exploration for water that could be used improve the agricultural situation in these areas. Table 7.14 shows that the irrigated horticulture is about 41% and the rain-fed or dry farming horticulture are about 59% of the total horticultural lands in the study area.

Productivity of the irrigated horticultural lands is much higher than that of the rain-fed or dry farming horticulture. The irrigated lands are planted 2 to 3 times a year (mostly in October, April and July). While in the rain-fed or dry horticulture farming, the land is planted only once a year. To clarify this point, the horticulture data produced from this study is analysed.

Cropping Intensity = the crop area/ the agricultural area (Al-Zouka, 1997).

The crop intensity depends on the number of times the land is cultivated per year and the productive portion of the land. The agricultural area is the area of the land on which the crop exists. Because trees are harvested once a year, tree crop intensity usually equals 1 on condition that the agricultural land is completely cultivated. When parts of the land are left without cultivation, the crop intensity becomes less than 1.

In our case, the irrigated land is 7515 ha or 41% of the horticultural land. As these lands are planted 3 times a year, then

Crop Intensity = 7515 × 3 = 22545 ha

This means that the production of 7515 ha in the irrigated lands is equivalent to 22545 ha in the rain-fed or dry farming lands if both areas are equally productive. However, in the study area, the production is not the same for these two areas. Also horticultural production in the rain-fed and dry farming areas fluctuates considerably because of rainfall fluctuations in the study area (see chapter 2). For example one hectare produced about 13 tons of tomatoes in 1990, while in 1991 the same area produced only 4 tons of the same crop. Unlike rain-fed or dry farming horticulture, production of irrigated horticulture is relatively stable unless it is exposed to frost in the cold months (December, January and February). Productivity of **irrigated horticulture** is much higher than that of the **rain-fed horticulture** but the production of **greenhouse horticulture** is much higher than the irrigated open field horticulture. There are three main greenhouse types classified according to their stand height:- the low (2 m height), the medium (2.5 m height) and the high type (3.5 m height). The majority of the greenhouses in the study area are of the medium height type. Table 8.2 compares between tomato production of different horticultural farming types.

Table (8:3): Average tomato production of the different farming types in the study area in one season (tons per ha)

Type of Farming	Production (tons)
Dry Farming	8
Irrigated Open Field Farming	30
Medium Height Greenhouse Farming	100

Source: Rural Research Centre, An-Najah National University, 1989-1991 and the Palestinian Central Bureau of Statistics (PCBS), 1997

SPOT HRV area estimates show that the area of greenhouses in the study area is 605 hectares (the greenhouse class is merged with the horticulture class when the land use classes are developed. See chapter 5). At this stage, areas for the three types of farming in the study area are available. In order to calculate the real agricultural productivity of the three farming types, calibration of the standard crop intensity formula is needed. To simplify the procedure of calculations and build the required formulas, symbols are used.

CA = Crop Area

AA = Agricultural Area

N = Number of time a crop is cultivated per year.

DP = Dry Farming Production

IOP = Irrigated Open Field Farming Production

IOI = Irrigated Open Field Farming Intensity

IOA = Irrigated Open Field Farming Area

MGP = Medium Height Greenhouse Farming Production

MGI = Medium Height Greenhouse Farming Intensity

MGA = Medium Height Greenhouse Farming Area

CC = Calibration Coefficient

DA = Dry Farming Area

GA = Greenhouse Area

HTA = Horticulture Total Area

The following procedures are used to calculate the crop intensity and productivity for each farming type:

- Calibration Coefficient for the three farming types is calculated,

$IOP/\,DP = 30/\,8 = 3.75$

$MGP/\,DP = 100/\,8 = 12.5$

$MGP/\,IOP = 100/\,30 = 3.33$

This means that the production of one hectare of tomato in the irrigated open field farming is equivalent to 3.75 times of that of the dry farming. Secondly, the production of the middle height greenhouse farming is equivalent to 12.5 times of that of the dry farming and 3.33 times that of the irrigated open farming.

- Calibrated farming type crop intensity is calculated as follows:

$$Calibrated\,IOI = \frac{HTA-(DA+GA)\times N}{AA}\times CC$$

$$Calibrated\,IOI = \frac{18154.3-(10639.5+605)\times 3}{6909.8}\times 3.75 = 11.19$$

Calibrated IOA $= 11.19 \times 6909.8 = 77320.7$ ha

$$MGI = \frac{HTA-(IOFFA+DFA)\times N}{AA}\times CC$$

$$MGI = \frac{18154.4-(6909.8+10639.5)\times 3}{605}\times 12.5 = 37.5$$

Calibrated MGA $= 37.5 \times 605 = 22687.5$ ha

- Crop Intensity and Area for the greenhouse farming is also calculated in comparison with the irrigated open field farming,

$$MGI = \frac{HTA-(IOA+DA)}{AA}\times CC$$

$$MGI = \frac{18154.4-(6909.8+10639.5)}{605}\times 3.33 = 3.33$$

Calibrated MGA $= 3.33 \times 605 = 2014.7$ ha

Although the irrigated cropping especially the greenhouse cropping is much more costly than the rain-fed and dry farming types, the calculations above show that the horticultural production of the northern West Bank can be considerably improved if the rain-fed and dry horticultural farming areas are converted to irrigated open field farming type and greenhouse farming. This farming system conversion may also improve the farmers' standard of living and the economy of rural areas in general, which represent about 70% of the Palestinian society in the West Bank.

Horticulture cropping in the West Bank suffers from the lack of markets. This marketing problem results in very low prices especially in spring where the land productivity increases considerably because of the good weather conditions. Certain crop types have almost disappeared from the Palestinian fields because of the problem of marketing. In 1987 the area cultivated with water melon in the West Bank was 1620 ha, but this area was reduced to 150 ha in 1991 (The Rural Research Centre 1991). The reason for this change in the crop type structure is the Jordanian restrictions imposed on the Palestinian agricultural exports to Jordan. The frequent Israeli military closure of the West Bank also has a negative impact on agriculture. In addition, there is a lack of the agricultural advisory services (Al-Khayyat 1997).

8.2.3 Arable Crops

Arable crops, mainly wheat and barley, are the third most important crop type after olive trees and horticulture in terms of area. The total area of these crops in the northern part of the West Bank is 14768 ha covering 6.9% of the study area and representing about 17% of the cultivated lands. The area of this crop is larger than the horticultural area on the whole West Bank because plain lands in the southern part of the West Bank such as the Hebron area is cultivated with cereals. In 1994, the total area of cereals in the West Bank was about 37,000 ha of which 50 % is wheat and 44% is barley and the rest are miscellaneous arable crops mainly chickpeas (PCBS 1997).

The satellite data shows that since the 1980s the area of cereal crops, especially in the northern part of the West Bank, has decreased and has been replaced with horticultural crops and olive trees. Before that date, most fertile plains in stratum one (Tulkarem area) were planted with cereals, but after that date they were cultivated with horticulture. The field survey showed that some arable crop areas especially in stratum three (Nablus area) have recently been given over to olive trees.

This decrease in the area of cereal crops is due to the low income derived from this crop and the fragmentation of field holdings as a result of the socio-economic system. The net income of one hectare of wheat is estimated to be a round 200 US$ (ARIJ 1994). Small-holdings hinder the mechanical agricultural activities and make the farmer depend on animals for the whole cultivation process.

Wheat or bread is a major source of energy in the developing countries and consumption of this crop is relatively high. Production of cereals in the West Bank only covers 10-15% of the local consumption and the shortfall is imported. Productivity of cereals in the West Bank fluctuates from one year to another and from one region to another also according to rainfall. In 1990, the average productivity of wheat in stratum two (Jenin area) was 2500 kg for one hectare, while in Hebron in the southern West Bank productivity for the same year was 1200 kg (Rural Research Centre, An-Najah National University 1991).

It can be seen that cereal cropping in the West Bank faces the problem of low prices and fragmented land holdings. The data from this study when compared with the area of this crop for previous years show that it decreased considerably. More research is needed on suitable cereal varieties suited to the WB environment. Also the Palestinian farmer needs support and advice from the Palestinian National Authority and its institutions.

8.2.4. Citrus Trees

Area of citrus trees is the least important of the main agricultural crops in the northern part of the West Bank. They occupy only 0.7% of the study area or about 2% of the area of the cultivated lands. This area represents 94% of the total citrus trees in the West Bank and the remaining 6% exist in the Jericho area.

Citrus trees are found in strata 1, 4 and 5 while very few can be found in strata 2 and 3. The availability of water in the area of Tulkarem and the Jordan Valley allowed the cultivation of this crop in these two areas. While in the area of Nablus and Jenin, the Israeli authorities apply a more strict water policy. Some of the area of citrus trees are given over to horticulture after 1987 when Jordan stopped importing the surplus of the product of this crop. However, the area of citrus trees is relatively constant if compared with seasonal crops, particularly cereal crops and horticulture.

Unlike olive trees and cereal crops, the productivity of citrus trees in the West Bank is relatively constant because it is an irrigated crop. The average productivity is between 20,000 – 30,000 kg per ha (PCBS, 1997). Citrus cropping in the West Bank as other crops suffers from the lack of markets. This marketing problem results in very low prices and in many cases farmers do not collect the production and leave it for people to take it freely. Citrus cropping can be considerably improved if the marketing problem is solved.

8.2. Comparison of Crop Area Estimation Results with Other Data Sources

Data obtained from this research study is compared with the data of the Palestinian Central Bureau of Statistics (PCBS) for the year 1994. The aim of this comparison is to see the degree of agreement between the two sets of data. It is difficult to consider the PCBS statistics as a reference for accuracy assessment of the crop area estimates produced by this research study. This is due to the lack of confidence in these data because they are derived either from Israeli sources or from farmers' declarations (see chapter one). Also the PCBS advised researchers to be careful when dealing with these statistics because they are not purely of their production. Table 8.4 illustrates this comparison.

Table (8:4): Comparison between the PCBS crop area statistics and the research statistics for the year 1994

	Olive & Fruit Trees	Citrus Trees	Horticulture	Arable Crops
West Bank (PCBS Data)	80669	1773	15289	52559
Study Area (PCBS Data)	55262	1540	10907	26921
Study Area (Research Data)	52547	1355.8	18154	14768

It can be seen from table 8.4 that there is a high agreement between the PCBS statistics and the crop area estimation of the study for tree crops (olive & fruit trees and citrus trees. Agreement between the two sets of statistics for olive & fruit trees is 95% and 88% for citrus trees. On the other hand, agreement between the two statistics for horticulture and arable crops is relatively low. It is 60% for horticulture and 55% for arable crops. The high agreement between the PCBS data and the research study data for tree crops is probably due to the relatively static nature of these crops.

To investigate reasons of disagreement between the PCBS statistics and the research statistics, the author looked at the statistics of the PCBS for the previous year (1993). It was found that these statistics are almost the same as those of the 1994. This indicates that the governmental statistics are not updated.

The field survey and the SPOT HRV imagery showed that there is a transformation in stratum one (Tulkarem area) from cereal cropping to horticulture cropping. The SPOT HRV image classification of stratum one gave 443 ha of arable crops, while the official statistics gave 1606 ha of this crop. This big difference between the two figures demonstrates that the official data are not updated. Confidence of image classification of arable crops comes from the fact that cereal crop at the image acquisition season (late May) can be identified with a high precision because it will be in the yellowing stage of growth (ripening stage) and does not spectrally overlap considerably with other land cover classes.

8.3. Spatial Distribution of Different Crops over the Study Area

As mentioned in chapter six, the study area includes severe physical variations which affects the spatial distribution of agricultural crops over the study area. Results of crop type area estimation emphasised these variations. Table 8.5 illustrates the agricultural spatial distribution of the main crop types and the non-agricultural lands.

Table (8:5): Distribution of crop types over the study area (%)

	OT & FT	CT	H	AC	Non-Agricultural
1	26.3	62.5	26.9	0.0	12.7
2	22.1	0.0	36.1	46.7	21.8
3	46.9	0.0	0.0	7.9	24.6
4	4.7	37.5	22.5	45.5	26.5
5	0.0	0.0	14.5	0.0	14.3
Total	100	100	100	100	100

Table (8:6): Distribution of the cultivated and uncultivated land over the study area (%)

Stratum	Cultivated	Uncultivated
1	55.8	44.2
2	48.7	51.3
3	46.3	53.7
4	29.6	70.4
5	17.0	83.0

Table 8.5 shows that:-

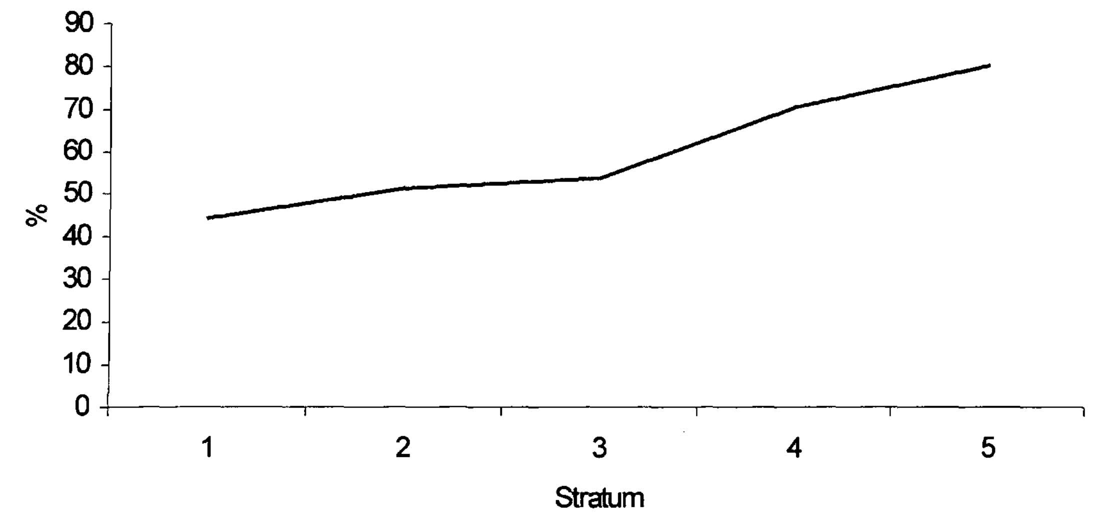
- olive and fruit trees mainly exist in the strata 1, 2 and 3 where about 95% of this crop is grown. While 5% of olive and fruit trees exist in stratum 4 while stratum 5 is out of this crop. This can be explained by the considerable climate conditions variation between the eastern slopes and the western slopes of the Nablus mountains. The climate of the western slopes is Mediterranean (it is well known that the olive tree is a Mediterranean one) while the climate of the eastern slopes is semi-arid to arid, see chapter one.
- about 62.5% of the area of citrus trees exists in Tulkarem area and 37.5% exists on the eastern slopes. But Jenin and Nablus areas are nearly out of this crop. This illustrates the possibility of growing this crop in the Mediterranean and the Arid and Semi-Arid climates when water is available.
- irrigated and non-irrigated horticulture exists in the fertile plains in all strata except stratum 3 because of the unavailability of water in this stratum on the one hand and the small area of fertile plains on the other hand. The western

slopes contribute with about 63% of the area of horticulture and the rest area exists on the eastern slopes and the Jordan Valley.

- about 92% of arable crops exists in the strata 2 and 4. This can be explained by the relatively large fertile plains in stratum 2 (Jenin) and the suitable semi-Arid climate of stratum 4 for growing this crop. The average annual rainfall in stratum 4 is between 250 – 400 mm which is suitable for cereal cropping. Stratum 3 contributes with about 8% of the area of arable crops of the northern part of the West Bank or the total plain fertile lands in this stratum. stratum 5 is nearly out of this crop because of the arid climate of this area.

Table (8:6) shows that the cultivated agricultural land increases when moving from east to west while the uncultivated land increases when moving in from west to east. This can be explained by topographic and climatic variations of the study area. It can be seen from figure 8.2 that the increase of uncultivated land between the strata 1, 2 and 3 is gradual (44.2%, 51.3%, and 53.7% respectively). But this increase of uncultivated land for the strata 4 and 5 is steep (70.4% and 83% respectively). The reason for this steep change is because strata 4 and 5 are situated in the shadow of rain and soil of these areas is not thick. Also, the majority of the eastern slopes are taken over by Israel for military training and security claims (Benvenisti, 1986).

Figure (8:2): Uncultivated Land in the Northern Part of the West Bank



8.4. Summary

This study shows that there is a deficit in wheat production, while production of horticulture (vegetables) citrus trees, and olive & fruit trees exceeds the self-sufficiency level. The problem of crop marketing and fluctuations of the production of olives and cereals underlines the importance of storage and processing of the production. The input of land cultivation for producing existing quantities of wheat, vegetables, olives & fruit, and citrus in the northern part of the West Bank is about 73836 ha. This area can be increased and developed through the co-operation between the Palestinian Governmental and Non-Governmental organisations on the one hand and the international governments and organisations on the other hand. Areas of the eastern slopes that receive more than 300 mm of rainfall can be converted into production but this is dependent on the political and economic situation in the future. As the agricultural area in the West Bank is limited, a strategic framework for future development of agriculture should be outlined by decision makers. Land productivity can be increased considerably if rain-fed and dry farming systems are changed to irrigated systems. Also production surplus of some crops can be used in agricultural industry. Moreover, agricultural land in the West Bank is threatened by soil erosion especially in the mountainous areas, so a land reclamation project in co-operation with the European Union may reduce dangers of this problem on land capability in the future.

CHAPTER NINE

CONCLUSION AND RECOMMENDATIONS

Evaluation and assessment of the Results of the Research study conducted on agriculture northern the West Bank can be carried out in the light of the points that Represent the backbone of the Research study. These points are:

- Objectives of the study,
- Data set used in the study,
- Methodologies and techniques applied,
- Objectives versus results, and
- Recommendations for future studies.

These points will be discussed separately to come out with clear picture and useful recommendations for any future work on the study area.

1) Objectives of the study can be summarised as follows:

i) Investigate the capability of satellite data (in this study SPOT HRV XS and panchromatic-XS fused data are used) to produce reliable statistical land use data on agriculture northern the West Bank,

ii) Investigate the capability of the SPOT HRV XS data to produce reliable area estimate for the main agricultural crop types grown in the study area,

iii) Evaluate the accuracy of crop area estimate obtained from the stratified field sampling, and

iv) Evaluate the crop type area estimate obtained from the double sampling methodology in which the satellite data are combined with the field data and compare it with area estimates obtained from the field survey only.

2) Data sets used in this study are:

i) SPOT HRV XS satellite data acquired in 19, May 1994. The satellite data cover the northern part of the West Bank (40% of the West Bank).

ii) Israeli aerial photographs at scales 1: 15,000 and 1: 20,000 acquired in October and December 1995, 1997, and 1998. These photographs mainly cover the plain agricultural lands in the study area.

iii) CORONA satellite photographs having 4 meters spatial resolution acquired in June, 1970. The data cover all the study area. Prints of the data also used in the study.

iv) 1: 50,000 Israeli topographic maps covering the study area dated 1995.

v) Field data used for image classification and assessment collected in the first stage of the field data collection program (spring 1998). In addition, seventy three 1km² sample units were surveyed in the field in the second stage of the field data collection program (summer 1999). The field data collected in the second stage by the stratified random sampling were used for crop type area estimate.

3) Methodologies and techniques applied to achieve the aims of the study are:

i) SPOT HRV XS data acquired in May, 1994 and resample to 10m spatial resolution used for producing land cover data and area estimates of the main agricultural crops grown in the study area.

ii) Field survey using the stratified random sampling was applied to produce crop type area estimates.

iii) The double sampling technique where the satellite area estimates are combined with area estimates obtained from the field stratified sampling is applied to improve the precision of the final crop type area estimates.

9.1 Image Classification

The overall classification accuracy obtained from the SPOT HRV XS images for the study area was 81%. The best accuracy was for stratum five and four (87% and 84% respectively). The reason for this relatively high accuracy in stratum five is probably the small number of classes used for image classification (8 classes), and the good spectral separability among land cover types. These two strata lie in the eastern slopes of the Nablus mountains where non-agricultural land cover types are mainly rocky land, badlands, and sparsely vegetated areas. Those classes do not highly overlap with agricultural classes.

The relatively low accuracy of olive and fruit trees class (67%) is because this class is spectrally overlapped with the rough grass and bushes. Most olive and fruit trees exist in the uplands where the agricultural mechanical operations such as ploughing are difficult. therefore, olives' under canopies are dominated by rough grass and bushes. Land use change also presents confusion between horticulture (vegetables) and citrus trees existed in stratum one and five because both crops are green on one hand, and the high Leaf Area Index (LAI) of vegetables in these strata because of irrigation on the other hand.

The classification also produced fifteen land cover classes after the development of the first image classification scheme applied (23 classes were merged into 15 classes) with more than 80% accuracy. Despite the spectral overlap of some land use types in some parts of the study area, the results of SPOT HRV image classification northern the West Bank is promising.

9.2. Area Estimates

Area estimates were obtained for the main agricultural crops in the study area using three methodologies:- SPOT HRV XS image classification, field estimates using the stratified random sampling, and the double sampling area estimates using the linear regression estimation where field area estimates are combined with the SPOT area estimates (see chapter 7).

The stratified random sampling methodology was applied on the study area to produce area estimates of the main agricultural crops grown in the Northern West Bank. The reason for applying this type of sampling is the considerable spatial variations existing in the study area. Data obtained from the field were processed and analysed statistically. Results show that the coefficient of variation (*CV*) for some crops in some areas was 100%. To improve the precision of the field estimates, these data were combined with the satellite data.

The double sampling approach using a regression estimation was applied in the study area to produce hectare estimates for crop types and the non-agricultural lands in the Northern West Bank. Field sampling estimates were combined with the SPOT XS estimates. Tables 7.12 to 7.17 show that the regression estimator produced better and more efficient estimates than the field sampling alone. The relative efficiency *RE* for all crop types in all strata improved the precision of estimates. Tables 7.12 to 7.17 also prove that the *CV* for all crops considerably improved when the double sampling approach was applied. It is important to say that first, the relatively low spectral resolution of SPOT XS compared with Landsat TM associated with the extremely complicated environment of the study area affected the results. For example, high disagreement between the SPOT XS and field area measurements of olive and fruit trees was found in stratum two for certain sample units (see figure 7.2) which had a great influence on the regression analysis. These sample units are covered by *Tistacia Lintiscus* bushes that are spectrally similar to olive trees. Second, the difficulty of access to some samples reduced precision for some crops. Third, land use change from arable to olive trees in some plain areas occurred between the image acquisition date and the field sampling date and affected the correlation level between the field and the satellite data. Fourth, the difficulty of carrying out more intensive empirical field measurements resulted in a qualitative classification scheme rather than a quantitative one. Finally, because farmers do not keep records, information obtained from some of them may increased the difference between the two data sets.

9.3. Data Used for the Study

The SPOT HRV satellite data used in this study was acquired in 19, May 1994. The date of the image was suitable for the discrimination and identification of the major agricultural crop types in the study area. It was easy to discriminate cereal crops from other crop types because at this time of the year cereal crops would be in the yellowing stage. It was also easy to discriminate between the olive and fruit trees from other crops (cereals, horticulture, and citrus trees). The problem exists between olive trees and citrus trees on one hand and some areas covered with certain types of bushes and trees on the other hand. This spectral overlap can be addressed either by using intensive field radiometric and environmental measurements or by using sensors having better spectral resolution such as Landsat TM data. But the question which may a rise here: can the relatively high spectral resolution spectral of Landsat TM in these areas compensate for the better spatial resolution of SPOT HRV? The answer to this question is probably yes. As mentioned in chapter 5 and 6, olives especially in the uplands, exist in the form of large clusters and the field boundaries disappear under canopy. Therefore, the advantage of the higher spatial resolution of SPOT HRV XS does is not a huge advantage in these areas. This situation leads to the conclusion that SPOT HRV data are more suitable for the classification of the plain valuable agricultural lands characterised by small field size than the uplands characterised by surfaces with spectral similarity.

The Israeli aerial photographs used in the study were not ideal for training and testing data collection. They were acquired in autumn and winter where fields are either freshly sown or prepared for cultivation. This limitation particularly rose in the rain-fed plain areas which are cultivated by seasonal crops. However, these photographs were useful for training and testing the relatively constant crop types mainly citrus and olive trees. They were also used for mapping the boundaries of sample units in the plain agricultural areas because they show field boundaries very clearly.

The CORONA satellite photographs were useful in the sampling design of the field survey of the uplands. The large scale prints showed boundaries of olive and fruit clusters clearly. The digital data were used in Arcview GIS software for sample unit allocation, field boundary digitisation, crop type labelling and area measurement. These photographs can compensate for the lack of the Israeli aerial photographs in the upland areas where there has been very little land use change. However, the CORONA data of 1970 cannot be used efficiently in the plain agricultural land because of the rapid change of field boundaries in these areas. This rapid change in field boundaries is due to the fragmentation of land by the socio-economic system.

The 1: 50,000 scale Israeli topographic maps were useful for the geometric correction of the satellite images. Road junctions, wadis bending and crossings, and other clearly identified features on both images and the map were used (see chapter 5). Secondly, they were used as base maps in the stratified random sampling, and thirdly, they helped, in conjunction with the CORONA data, in selecting training data in some relatively static land cover types such as forests and built-up areas.

The field data were collected in two stages. The first stage was devoted for collecting training data for image classification and test data for image classification accuracy assessment. The second stage was devoted for the stratified random sampling where the collected data used for crop type area estimation. Because of Israeli security restrictions it was not possible to make in situ measurements, and so, the collected field data were qualitative. In other words, no measurements of crown closure, crop density or crop under canopy have been made, but ranks were given to crop status. For example, olive class was divided into three classes according to density (descriptive division) (see chapter 5). Lack of measurements for both stages had a great influence on regression analysis.

9.4. Recommendations for Future Studies

This study demonstrates the ability of satellite remote sensing to produce reliable agricultural maps and statistics for the WB. The overall accuracy of image classification of the study area (81%) shows that satellite remote sensing can be successfully used for agricultural studies over large areas. Remote sensing data when combined with limited field data produced more accurate crop area estimates.

Field survey in such a mountainous area, hot weather, and insecure conditions is very laborious, costly, time consuming, and dangerous. Therefore, the role of remote sensing in these complex environments can be a vital one.

Recommendations for future remote sensing studies can be derived from the results of this study:-

Results of image classification show that accuracy of some agricultural and non-agricultural classes (Olive Trees & Fruit Trees and Rough Grass & Bushes) is relatively low (It was 67% for olive and fruit trees and 71% for rough grass and bushes). Also citrus trees is overlapped with bushes. On the other hand, as the field data are combined with the satellite data, regression estimates are affected by both image classification accuracy and the field data accuracy as well. Classification accuracy and field data accuracy can be improved.

1. To improve accuracy of citrus trees, the plain lands which are mainly cultivated with seasonal crops and citrus trees can be separated from the other lands which are mainly dominated by olive trees and non-agricultural land cover using a GIS package.

Then classification of each part is carried out independently. By following this method, spectral overlap between citrus trees and the evergreen bushes is avoided.

2. To improve the classification accuracy of the olive trees, improved spectral resolution sensors are required. This could be achieved by using Landsat TM data to classify the uplands, because its better spectral resolution may compensate for the better spatial resolution of SPOT in areas which are characterised by large clusters of olives. SPOT HRV XS data will probably produce better classification results in areas characterised by small fields such as the plain lands of the study area. It would be useful to test this hypothesis with imagery for both sensors for the same time period.

3. Merging Landsat TM data with SPOT -PAN data. This process benefits from the high spatial resolution of SPOT-PAN and the high spectral resolution of Landsat TM. The spatial resolution of the Landsat TM imagery becomes 10 m instead of 30 m and at least 6 TM bands including the short infrared bands can be used for image classification and analysis.

4. For better, empirical, and more efficient classification scheme, radiometric and crop environmental measurements are vital. The radiometric measurements should be taken at the same date and time the image acquired. Field measurements such as crop density, crown closure, and land cover purity increase the precision of the classification scheme and give it a more environmental and morphological dimension which is necessary in remote sensing studies. These data can be integrated into a GIS package to maximise image analysis efficiency and accuracy of results.

5. To increase the accuracy of image classification and field area estimates it is important to have aerial photographs for the same year and season as the satellite image. This solves the problem of accessibility to some areas and compensates for the absence of agricultural records at the field level. Also, high resolution satellite data such as IKONOS may solve this problem.

this was mentioned several times in sect. 3.3 anyone who knows anything about RS & agric already knows this! This was also a recommendation of Shueb (1990) (see comment below)

6. Multi-season imagery may improve classification accuracy, and consequently improve crop area estimates. Multi-season imagery allows the exchange of spectral, spatial and informational data between the images. For example, images in the ripening stage of citrus may increase this crop spectral separability from other crops and land cover types (mainly horticulture and evergreen bushes) and improves its area estimation.

7. Farmers should be advised and trained to keep records of their work in the field. These records may include the crop type cultivated, the date of cultivation, the date of harvest, types of fertilisers they apply, amount of fertilisers, dates of irrigation, crop productivity and other relevant information. This type of information help the remote sensing analyst produce more accurate results.

one of the advantages of RS data is that such records should, in future, become less important, and that area estimations be done by means of a comb. of RS + fieldwork

Why test this methodology based on a RS image 4 years different + fieldwork when it is known that farmers have poor records of their crops? Also a recommendation of Shueb (90)

Anyway, this thesis seems to be a repetition of Shueb 1990. Different RS image, different study area. Same uni, same supervisor.

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